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Editorial

In this issue, we will focus wearable technology on two themes. One is sports and fitness, and the other one is how to provide special protection and mobility aid for vulnerable groups, such as infants, elderlies and disabled persons.

Two editor board members offered related articles for us. Prof. Paul D. Rosero-Montalvo from Salamanca University developed the embedded system inside the intelligent textile to realize the early warning and prevention (falls, burns and personal injuries) of accidents for infants in crawling stage. Meanwhile, Prof. Carlos Alberto Catalina Ortega from Burgos University developed advanced augmented reality (AR) technology and Internet services and mobile device interfaces specially designed for the elderly to provide autonomy and better quality of life in their daily activities.

Also, we collected some articles on wearable technology in sports and fitness, including related policies in different countries, competitive advantage of wearable technology in sports training, great potential of wearable skin-interfaced microfluidic systems and so on.

Editor-in-chief

Dr. Zhen Cao

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ORIGINAL RESEARCH ARTICLE

Study on wearable device users' willingness to continue using —ECM-IS based on the expansion model

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ABSTRACT

Based on the Expectation Confirmation Model of Information System(ECM-IS), three personal characteristic factors of self-efficacy, privacy concerns, and innovation as well as two external environmental factors of subjective reference and switching costs were introduced to construct a model of factors affecting users' continuance intention of wearable devices from the perspective of "technology-individual-environment". 356 valid samples were collected through the questionnaire for empirical analysis. The results of the study show that self-efficacy, switching costs, and perceived usefulness in the ECM-IS model have a significant effect on users' continuance intention at $p<0.001$ level while innovativeness and subjective references affect users' continuance intention at $p<0.05$, but privacy concerns have no effect on continuance intention.

Keywords: wearable devices; continuance intention; expectation confirmation model of information system (ECM-IS)

1. Introduction

With the strong promotion of information technology and Internet of things industry, wearable devices, as a new generation of portable electronic devices, have attracted extensive attention and are rapidly renovating consumer technology products. Wearable devices take intelligent hardware as the carrier, combined with application software and data interaction to realize the functions of business communication, health monitoring, leisure and entertainment. According to the report of Internet Data Center (IDC), the total sales volume of the global wearable device market in the third quarter of 2017 reached 26.3 million units, an increase of 7.5% over the same period of last year. Among them, Xiaomi, Fitbit and apple ranked among the top three in global market share respectively. Sutu Research Institute predicts that the market scale of wearable devices will reach 32 billion yuan in 2018 and will continue to expand.

At present, the research on wearable devices mainly focuses on design and function, and few scholars explore it from the user level. A few existing literatures only consider the initial acceptance and adoption behavior of users. For example, Yang et al. discussed the impact of perceived benefits and risks on the perceived value and use intention of wearable device users, and found that perceived usefulness and entertainment have a greater impact

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on perceived value than perceived risk[1]; Gu et al. discussed the initial trust of consumers in pervasive commerce from the perspective of wearable devices based on UTAUT 2 model, and stressed the need to focus on improving the entertainment, convenience and privacy of wearable commerce[2]; Wu Jiang et al. used meta-analysis to explore the impact of ten factors on wearable device users' attitude and adoption intention, and found that perceived usefulness had the most significant impact on users' adoption behavior[3]. Although the current wearable devices have a good prospect, there are still some problems such as serious homogenization, low user stickiness and high loss rate. According to Gartner's survey, although wearable devices initially attracted a large number of consumers due to their fashionable appearance and novel functions, about 1/3 of wearable device users will choose to give up after a period of time. Therefore, in today's highly competitive market environment, grasping the initial intention of users is only the first step to success. How to retain users and promote their sustainable use is the way to win for a long time.

Bhattacherjee proposed the famous information system continuous use model (ECM-IS)[4] on the basis of Expectation Confirmation Theory (ECT), which is used to explain the behavior of users who continue to use or give up using a certain information system. After reviewing the relevant literature, it is found that there are still many gaps in the research of applying ECM-IS model to the wearable field. In addition, the extended models of ECM-IS are mostly from the perspective of technical characteristics or a single perspective. With the socialization and application of wearable technology, internal personal factors and external environmental factors are also very important for emerging information technologies focusing on user experience such as intelligent wearable.

Therefore, according to the special situation of wearable devices, this paper expands the ECM-IS model, introduces self-efficacy, privacy concern and innovation to explore the user's perception of personal characteristics, subjective reference and transformation into the user's perception of external environmental factors, so as to adapt to the continuous use situation of wearable devices, and constructs the research model from the comprehensive perspective of "technology individual environment", explore what factors will affect the sustainable use intention of wearable device users, so as to provide sustainability suggestions for device providers in excavating product R & D and design priorities and improving operation and marketing strategies.

2. Literature review and research hypothesis

2.1. Technical characteristic factors in the context of wearable devices

The ECM model has been widely used in the field of marketing. The model shows that the continuous use intention of is users is determined by two post adoption variables, namely perceived usefulness and satisfaction, which in turn depend on the expected confirmation, as shown in **Figure 1.**

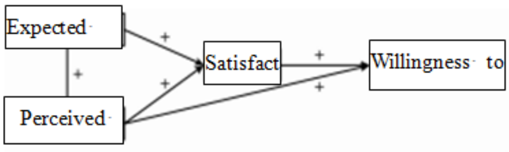

Figure 1. Information system continuous use model (ECM-IS).

The author believes that the relationship between expected confirmation and perceived usefulness, satisfaction and sustainability intention can be further applicable to the situation of sustainable use of wearable devices. Therefore, hypothesis H1: Users' expected confirmation of wearable devices is positively correlated with perceived usefulness. H2: Users' expectation confirmation of wearable devices is positively correlated with satisfaction. H3: Users' perceived usefulness of wearable devices is positively correlated with satisfaction. H4: Users' perceived usefulness of wearable devices is positively correlated with their willingness to continue using them. H5: Users' satisfaction with wearable devices is positively correlated with their willingness to continue using them.

After the ECM-IS model was proposed, scholars improved and expanded it in different situations, integrated it with other theoretical models or introduced different variables into the model to explore the continuous use intention of is users. At present, the expansion of ECM-IS model is mostly from the perspective of technical characteristics. For example, Larsen and others combine ECM-IS model and task technology matching theory (TTF) to explore the continuous use decision of college teachers on e-learning tools. The results show that the variables from ECM-IS and TTF can explain the continuous use intention of is users[5]; Cho conducted path analysis on the integration model of ECM-IS and TAM, and found that the continuous use intention of mobile health applications was positively correlated with perceived ease of use[6]; Taking health app as an example, Yin Meng and Li Qi verified the impact of system quality, information quality and service quality on continuous use intention through expected confirmation and perceived usefulness by integrating ECM-IS and is success model[7]. A few studies expand ECM-IS model from other perspectives. For example, Steelman & Soror explores the driving mechanism of mobile phone users' willingness to continue to use based on ECM-IS model and cognitive dissonance theory. The research results show that psychological states such as technology addiction and excessive technology pressure will affect user experience, and then affect post use feeling and decision-making at cognitive and emotional levels[8]; According to the characteristics of the elderly using the Internet, Liu Q and others added two factors of computer anxiety and physical function decline into the ECM is model. The results showed that the decline of physical function did not have an important impact on the continuous application of the Internet by the elderly[9].

Based on the existing research, it can be seen that the current expansion model of ECM-IS mainly focuses on the technical perspective or a single other perspective, and rarely involves two or more perspectives. With the social popularization and application of wearable devices and the continuous expansion of audience groups, users' willingness to continue to use will be affected by multi-dimensional factors, so it needs to be discussed from a more comprehensive perspective.

2.2. Personal characteristic factors in the context of wearable devices

Self-efficacy originates from social cognitive theory. It refers to an individual's belief in whether he is able to perform a specific task. It is an important basis for action. A prominent feature of wearable devices in the stage of rapid growth is the continuous influx of new functions. Although it is very attractive to users, users also need to have the corresponding ability to keep up with the pace of upgrading. HSU & Chiu applied the theory of planned behavior (TPB) to the context of is sustainable use and theoretically deduced the model of e-service sustainable use. The results show that users' willingness to continue to use is determined by Internet self-efficacy and satisfaction[10]. Cao et al. constructed the influencing factor model of customers' continuous use of self-service technology (SST) based on attribution theory and expectation inconsistency theory, and found that self-efficacy and satisfaction will significantly affect the willingness to continue to use SST[11]. Zhou took social commerce as the research background and established an empirical model based on content analysis. It was found that cognitive factors such as self-efficacy have a significant positive impact on user stickiness of social media[12]. According to the above research, the author believes that users perceived self-efficacy in the process of using wearable devices will positively affect their willingness to continue to use. Therefore, hypothesis H6: users' self-efficacy of wearable devices is positively correlated with their willingness to continue to use.

Paying attention to users' privacy and security is the basis for the success of emerging Internet technologies. Dong et al. found that privacy protection services have a significant impact on user satisfaction and continuous use intention of social interaction based on social networks[13]. Chen et al.

explored the influence path of cognitive and emotional factors on the willingness of social media service users to continue to use within the framework of "cognition emotion willingness". The results showed that the negative emotion brought by privacy risk had a stronger effect on the willingness to continue to use than the positive emotion[14]. In the context of wearable devices, while collecting the user's regular personal information, the device provider can also collect the wearer's action track information and vital sign data in real time, such as steps, mileage, calorie consumption, heart rate and sleep data. Although this brings great convenience to users, it will also cause users' concerns about personal privacy disclosure, which will affect their experience of wearable devices and their motivation to continue to use them. Therefore, this paper proposes the hypothesis H7: Users' privacy concerns about wearable devices are negatively related to their willingness to continue to use.

Innovation refers to people's willingness to adopt an innovative technology, which reflects the individual's interest in new things such as innovative products or services. In other words, individuals with a high level of innovation are more likely to become innovators or early users of new technologies. Previous empirical research results have confirmed the important role of innovation in new technology adoption and post adoption behavior. For example, Lassar et al. tested the impact of consumers' personality traits on the acceptance of online banking based on TAM model and innovation framework. The results confirmed that consumers' innovation has a significant positive impact on the use intention of online banking[15]; Lu conducted a survey among undergraduate and graduate students in American universities and found that among well-educated mobile e-commerce users, innovation at the level of information technology is a powerful factor affecting users' willingness to continue to use[16]; Lin & Filieri integrated the individual psychological structure into the TAM model and constructed the continuous use intention model of air passengers' online flight boarding service. The results showed that the innovation of Chinese airline passengers who have experienced online registration service can directly affect their continuous use intention[17]. Researchers in the field of is usually believe that users can continue to discover and use their new functions after adopting the system, which gives users the opportunity to demonstrate their innovation ability in their post adoption behavior. A typical intelligent wearable device is a new type of terminal hardware driven by mobile wearable technology, which has the characteristics of continuous innovation and upgrading at the technical and business levels. In view of the persistence and universality of innovation in trying and accepting a variety of innovative technologies[16], the sustainable use of wearable devices should be affected by user innovation. Therefore, this paper puts forward the hypothesis H8: the innovation of users is positively related to the continuous use intention of wearable devices.

2.3. External environmental factors in the context of wearable devices

Subjective reference is usually defined as the social pressure perceived by individuals to perform or not perform a certain behavior. It is related to the normative beliefs expected from others, also known as subjective norms. Subjective reference reflects the degree to which an individual's attitude, belief and behavior are influenced by others. Lee established a theoretical model for the "acceptance termination" phenomenon among e-learning users to explain and predict users' willingness to continue using e-learning system. The results show that the willingness to continue using e-learning system is significantly affected by subjective norms[18]. Chen et al. explored the mechanism of social factors on Web 2.0 users' satisfaction and willingness to continue to use. The results show that four social factors, including subjective reference, have a direct impact on willingness to continue to use[19]. Many users choose wearable devices because they see the use of their surrounding colleagues, friends or relatives and are recommended. In order to meet the expectations or recognition of the people around them, individuals are usually willing to follow their opinions. Therefore, the author puts forward the hypothesis that H9: subjective reference is positively correlated with users' willingness to continue to use wearable devices.

Conversion costs refer to the potential costs incurred by users in the process of switching from one service provider to another, including monetary and non-monetary costs (time and energy). For enterprises, the main function of switching cost is to cause customers' active or passive loyalty. Oyeniyi & Abiodun found that the increase of switching costs will increase users' dependence on service providers, which is an important reason for users' retention, according to a questionnaire survey of customers in the mobile communication industry [20]. Deng et al. constructed the influencing factor model of customer loyalty in the context of online shopping. The results show that the switching cost and satisfaction in the online environment significantly affect customer loyalty[21]. In the case of low conversion cost, users will have high conversion motivation due to low conversion barriers. When users' switching power is hindered by high switching cost, the switching cost will not only reduce the switching intention, but also cause users to stay in the hands of existing product or service providers, because changing providers will not benefit users. In the specific context of wearable devices, users' understanding of new devices, the search and evaluation costs to be paid in the conversion process, and the economic risks associated with trying new devices will affect their conversion intention. The higher the perceived transfer cost, the lower the conversion intention, and the stronger the continuous use intention of the original device. Therefore, this paper proposes the hypothesis that H10: conversion cost is positively correlated with users' willingness to continue to use wearable devices.

To sum up, this paper will expand the ECM-IS model from the perspectives of technical characteristics, personal characteristics and external environment to explore the influencing factors of wearable device users' willingness to continue to use. The research framework is shown in **Figure 2**.

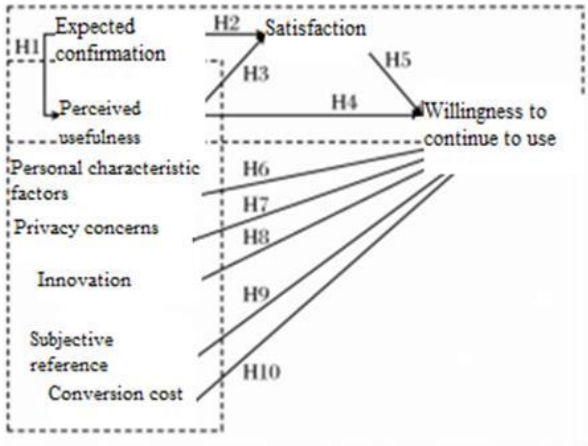

Figure 2. Sustainable use intention model of wearable device users.

3. Research design

This study uses the questionnaire to empirically test the wearable device user's continuous use intention model proposed above. The questionnaire is distributed in the form of a combination of online survey and offline distribution, and the target population is users who have used wearable devices. A screening item is set on the front page of the questionnaire. If participants have never used wearable devices, they will end the answer directly. This study finally collected 453 questionnaires, including 286 online questionnaires and 167 paper questionnaires. After deleting the abnormal answers by SPSS 22.0, the total number of valid questionnaires was 356, with an effective rate of 78.55%.

The questionnaire consists of two main parts. The first part is demographic issues, which aims to collect information on participants' gender, age, occupation and region. In the sample, there are 254 males, accounting for 71.35%, and 102 females, accounting for 28.65%; There are 11 people under the age of 18, accounting for 3.09%, 103 people from 18 to 24, accounting for 28.93%, 148 people from 25 to 30, accounting for 41.57%, 76 people from 31 to 40, accounting for 21.35%, and 18 people over 40, accounting for 5.06%; There are 162 students, accounting for 45.51%, 97 employees, accounting for 27.25%, 58 employees, accounting for 16.29%, 27 self-employed, accounting for 7.58%, and 12 employees in other occupations, accounting for 3.37%. There are 78 people in the first-tier cities, accounting for 21.91%. There are 121 people in second tier cities, accounting for 33.99%, and 157 people in third tier and below cities, accounting for 44.10%. According to the 2016 intelligent hardware industry insight report released by talking data, the proportion of men and women of wearable device users in 2016 was 75%: 25%. Young users under the age of 35 are the main user group of wearable devices, accounting for 76.5% of all age groups; The occupations with the highest proportion of users are college students and office workers. The proportion of users in first tier cities, second tier cities, third tier cities and below is 16.1%, 36.5%, 47.4%. Therefore, by comparing with the user portrait in the report, the sample data used in this study is in line with the user characteristics of China's current wearable device market.

The second part consists of the items of each variable in the research framework of this paper. The design of the topic draws lessons from the maturity scale widely adopted in the current foreign research, and makes targeted adjustments according to the recommendations of the expert group and the characteristics of wearable devices, so as to ensure the reliability and validity of the measurement results.

The final scale includes 9 variables and 30 items. Among them, expectation Confirmation (EC), perceived usefulness (PU), satisfaction (SA) and willingness to continue use (CI) refer to the scale of Bhattacherjee[4], self-efficacy (SE) and subjective reference (SN) refer to the scale of HSU & Chiu (2004)[10], privacy concern (PC) refer to the scale of son & Kim (2008)[22], innovation (in) refer to the scale of Lassar et al.[15], and switching cost (SC) refer to the scale of Jones et al.[23]. The option is scored with Likert 7 scale, reminding participants to answer according to their actual feelings. A score of 1~7 means from "very agree" to "very disagree".

4. Research results

4.1. Reliability and validity test

Firstly, this paper uses SPSS 22.0 to carry out KMO and Bartlett test on the data. The results show that the KMO value of the sample is 0.901, the chi square of Bartlett sphericity test is 4700.081, and the significance level is 0.000, indicating that this scale is suitable for factor analysis. Confirmatory factor analysis (CFA) can be used to test the reliability and validity of the scale. The results are shown in **Table 1** and **Table 2**.

Table 1. Analysis of reliability and convergent validity of measurement model

Factor	Item	Factor load	Cronbach's α	CR	AVE
EC	EC1	0.716	0.878	0.820	0.603
	EC2	0.802			
	EC3	0.808			
PU	PU1	0.750	0.868	0.862	0.610
	PU2	0.785			
	PU3	0.790			
	PU4	0.797			
SA	SA1	0.729	0.854	0.835	0.559
	SA2	0.762			
	SA3	0.729			
	SA4	0.770			
SE	SE1	0.802	0.856	0.822	0.606
	SE2	0.818			
	SE3	0.712			
PC	PC1	0.812	0.841	0.896	0.742
	PC2	0.899			
	PC3	0.871			
IN	IN1	0.797	0.812	0.889	0.727
	IN2	0.876			
	IN3	0.882			
SN	SN1	0.751	0.770	0.864	0.680
	SN2	0.864			
	SN3	0.854			
SC	SC1	0.813	0.756	0.846	0.647
	SC2	0.794			
	SC3	0.806			
CI	CI1	0.751	0.903	0.878	0.644
	CI2	0.840			
	CI3	0.794			
	CI4	0.822			

Table 2. Discriminant validity analysis of measurement model

Factor	EC	PU	SA	SE	PC	IN	SN	SC	CI
EC	0.777								
PU	0.642	0.781							
SA	0.585	0.574	0.748						
SE	0.328	0.317	0.321	0.778					
PC	-0.121	-0.163	-0.199	-0.153	0.861				
IN	0.234	0.286	0.290	0.257	-0.106	0.853			
SN	0.166	0.230	0.178	0.107	-0.048	0.244	0.825		
SC	0.235	0.216	0.280	0.225	-0.047	0.102	0.135	0.804	
CI	0.306	0.600	0.597	0.580	-0.205	0.353	0.335	0.556	0.809

4.2. Hypothesis test

Amos24 was used in this study 0 software to test the hypothesis of the model. The results of goodness of fit index are shown in **Table 3**, χ 2. RMSEA (root mean square of approximate error), CFI (Comparative fitting index), IFI (incremental fitting index), GFI (goodness of fit index), AGFI (adjusted goodness of fit index), NFI (benchmark fitting index), NNFI (non-standard fitting index) and SRMR (root mean square of standardized residual error) are all within the recommended value range, indicating that the fitting degree of the research model and sample data is good.

Table 3. Fitting index results of research model

Fitting index	χ^2/df	RMSEA	CFI	IFI	GFI	AGFI	NFI	NNFI
Recommended value	≤2	≤0.1	≥0.9	≥0.9	≥0.9	≥0.8	≥0.9	≥0.9
Model fitting value	1.731	0.045	0.972	0.972	0.923	0.899	0.937	0.967

The hypothesis test results of structural equation model are shown in **Table 4** and **Figure 3**. Among the 10 hypotheses, only one hypothesis is not supported, that is, the negative impact of privacy concerns on sustainable use intention is not significant. The innovation of the perspective of personal characteristics and the subjective reference of the perspective of external environment have a significant impact on the willingness to continue to use at the level of P less than 0.05, and the other paths are significant at the level of P less than 0.001. The variance explained by perceived usefulness, user satisfaction and continuous use intention were 44%, 40% and 54%, respectively.

Table 4. Hypothesis test results of research model

Hypothesis	route	Path coefficient	P value	conclusion
H1	Expected confirmation → perceived usefulness	0.645	***	support
H2	Expectation Confirmation → satisfaction	0.351	***	support
H3	Perceived usefulness → satisfaction	0.327	***	support
H4	Perceived usefulness → willingness to continue to use	0.461	***	support
H5	Satisfaction → willingness to continue to use	0.384	***	support
H6	Self-efficacy → willingness to continue to use	0.344	***	support
H7	Privacy concerns → willingness to continue to use	-0.080	0.113	I won't support it
H8	Innovation → willingness to continue to use	0.170	0.021	support
H9	Subjective reference → willingness to continue to use	0.164	0.032	support
H10	Conversion cost → willingness to continue to use	0.313	***	support

Note: ***, **, and * are significant at the levels of 0.001, 0.01 and 0.05 respectively

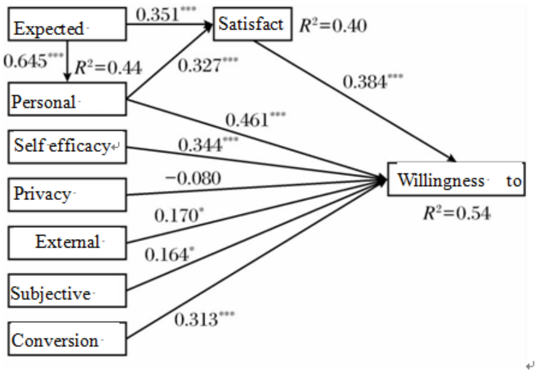

Figure 3. Analysis results of research model.

As shown in the chart, expected confirmation has a significant impact on perceived usefulness (0.645), expected confirmation (0.351) and perceived usefulness (0.327) have a positive impact on user satisfaction, and perceived usefulness (0.461) and user satisfaction (0.384) have a positive impact on users' willingness to continue to use; Users' self-efficacy (0.344), innovation (0.170), subjective reference (0.164) and conversion cost (0.313) significantly affect their willingness to continue to use; The impact of privacy concerns (-0.080) on continued use intention is not supported. In conclusion, perceived usefulness, self-efficacy and switching cost have the strongest positive impact on wearable device users' willingness to continue to use, followed by switching cost and innovation, and privacy concerns have no negative impact on wearable device users' willingness to continue to use.

5. Conclusions

On the basis of summarizing and sorting out the existing relevant literature at home and abroad, this paper establishes a research model for the sustainable use intention of wearable device users, expands the ECM-IS model from the comprehensive perspective of "technology personal environment", and explores the impact of technical characteristics, personal characteristics and external environmental factors on users' sustainable use intention to varying degrees. Through empirical test, all hypotheses except H7 are supported. The specific analysis of the research results is as follows.

(1) This study confirms the basic assumptions of ECM-IS model and shows that it is applicable in the context of wearable devices. Therefore, at the level of technical characteristics, efforts to improve users' useful perception of wearable devices can enhance their willingness to continue to use. This means that the developers and designers of wearable devices should focus on the practical value of the device, constantly optimize the functional design and operation interface, improve the quality of hardware and information system, make it meet the multi-directional needs of users, and finally retain users.

(2) The factors of personal characteristics and external environment are not often considered in the previous literature. From the perspective of personal characteristics, firstly, the results of this study show that users' perception of the ability to freely use wearable devices has a significant impact on their willingness to continue to use. Since the perceived self-efficacy of users will change with the accumulation of experience, device operators can try to enhance users' confidence in self-ability by means of easy to understand operation instructions, or use intuitive publicity means to enable users to obtain reliable information, so as to improve their sense of self-efficacy and the possibility of continuous use of wearable devices. Secondly, the relationship between privacy concerns and willingness to continue to use has not been confirmed. This may be because, on the one hand, the current privacy protection measures for wearable devices are relatively perfect, making users less worried about the leakage of private information; on the other hand, the purpose of tracking and collecting users' personal privacy by wearable devices is mostly to provide users with more accurate personalized services. The positive benefits obtained by users from wearable devices exceed the negative losses caused by submitting privacy information, so it has no negative impact on their willingness to continue to use. Thirdly, this paper confirms the positive impact of innovation on sustainable use intention. Equipment providers can adopt differentiated marketing methods according to users' innovation ability. Highly innovative individuals tend to have

strong curiosity about emerging technologies and new things, and will attract the attention of people around them when using wearable devices, which is conducive to promoting the promotion of wearable devices. Therefore, when carrying out marketing activities to such user groups, we should focus on the innovation of wearable technology. At the same time, when releasing new functions, we should pay attention to the guidance of individuals with high innovation, so as to drive individuals with relatively low innovation. Individuals with relatively low innovation tend to have low acceptance of new products and conservative ideas. Therefore, we should focus on the security measures of wearable devices to these users and reduce users' anxiety.

(3) From the perspective of external environment, the continuous use intention of wearable device users is directly affected by subjective reference. Wearable users will change their beliefs and behaviors according to the expectations of important people in the life circle or work circle. When users obey the opinions of others under pressure, it will directly affect their willingness to continue to use wearable devices. Therefore, it is suggested that operators adopt a variety of incentives to encourage them to share information about equipment with others, do a good job in word-of-mouth marketing and improve the reputation of enterprises. In addition, switching cost has a significant positive impact on users' retention intention. Therefore, enterprises should use resources to increase the conversion cost, make users feel that the conversion will face higher risks, and then become a barrier that prevents users from leaving.

Conflict of interest

The authors declare no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Design of a wearable upper limb rehabilitation robot and its motion simulation and dynamics analysis

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ABSTRACT

Objective: A new wearable upper limb rehabilitation robot is designed to address the disadvantages of the current desktop upper limb rehabilitation robot, which is bulky and inconvenient to move, and the rationality of the design is verified through the analysis of its motion characteristics and the calculation of joint moments. **Methods:** Firstly, according to the principle of modular design, the overall structure was designed. Secondly, the SOILDWORKS is used for three-dimensional modeling, and the SOILDWORKS Motion is used to simulate the elbow flexion/extension movement, shoulder flexion/extension movement and shoulder-elbow joint linkage movement of the robot. Finally, the dynamic equation of the system is established based on Lagrange method, and the change curve of the joint torque of the manipulator is calculated by MATLAB software. **Results:** The simulation results confirmed that the motion simulation curves of shoulder joint, elbow joint and wrist joint were smooth. The dynamic analysis confirmed that the joint torque variation curve was smooth and the maximum joint torque was less than the rated torque of the motor after deceleration. **Conclusion:** The design of wearable upper limb rehabilitation robot is reasonable, which lays a theoretical foundation for the subsequent research on upper limb rehabilitation robot.

Keywords: upper limb rehabilitation robot; kinematics; simulation; dynamics analysis; MATLAB

1. Introduction

Stroke is one of the major diseases threatening human health and safety. With the increasing aging, incidence rate of cerebrovascular accident or stroke secondary diseases is increasing. According to the Report on the Chinese Stroke Prevention (2015), about 15% of China's population over 40 years old are at high risk of stroke. After 55 years of age, the relative incidence rate of stroke increased 1 time[1] every 10 years. There are many sequelae after stroke. About 85% of stroke patients are accompanied by upper limb dysfunction in the early stage of onset[2], 55%–75% are still accompanied by upper limb dysfunction 3–6 months after onset[3,4], about 2/3 of

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stroke patients still regard the loss of upper limb function as the main problem 4 years after onset[5], and about 25% are still accompanied by severe paralysis of upper limb 5 years after stroke[6]. Therefore, it is particularly necessary to study the upper limb functional rehabilitation of stroke patients and its robot.

At present, most of the upper limb rehabilitation training equipment at home and abroad are desktop, such as the ARMin series exoskeleton upper limb rehabilitation robot[7,9] developed by the University of Zurich, Switzerland. Among them, ARMin II has 7 degrees of freedom[10], and ARMin III is the latest generation. ARMin III can assist patients with 3 degrees of freedom of shoulder joint, 1 degree of freedom of elbow joint, forward/backward rotation of the forearm, and wrist flexion/extension training, and the exchange function of left and right hands is added on the basis of Armin II[11]; CADEN-7 has been developed by the University of Washington in the United States, which uses rope for transmission to reduce the moment of inertia of the mechanism[12]. The Swiss company Hocoma has developed Armeo series upper limb rehabilitation training system, in which Armeo spring uses spring weight reduction mechanism to balance the weight of the arm, but it can only carry out active movement, which makes the application scope of the device small[13,14]. Armeo power has comprehensive functions, but due to the use of more motors, the shape is complex and huge[15]. Shanghai Jiao Tong University has developed a 6-DOF unpowered upper limb exoskeleton rehabilitation training equipment with gravity compensation function[16]. This upper limb rehabilitation training equipment have the problems of complex structure, huge volume and inconvenient movement. Therefore, this paper proposes the design of a wearable upper limb rehabilitation robot, which aims to design an upper limb rehabilitation training equipment with simple structure, lightweight and suitable for patients' home. At present, there are few mature products related to wearable upper limb rehabilitation robots in the market. Compared with the representative American emerging technology company Mypower 1000[17] and the University of Pennsylvania TitanArm[18] driven by ratchet and flexible cable. Their exoskeleton power is concentrated in the elbow joint, but the actual situation is that the shoulder and elbow joints of paralyzed patients have partial or total loss of motor function, Single joint drive cannot meet the needs of patients.

In view of the above problems, this paper adopts the modular design principle, through the reasonable choice of the degree of freedom of the manipulator and the selection of light materials, designs a new 4-DOF wearable upper limb exoskeleton rehabilitation robot with simple structure and light weight. In addition, this paper also establishes the theoretical basis for the motion simulation of human elbow/extension machine, and verifies the rationality of the motion of elbow/extension machine.

2. Overall mechanical structure

The mechanical structure of the wearable upper limb exoskeleton rehabilitation robot designed in this paper is based on the portable wearing design of the whole mechanism. On the premise of meeting the patients' normal wearing of the mechanism and considering the needs of patients' rehabilitation training, the mechanism is simplified as much as possible. Three degrees of freedom of shoulder joint and one degree of freedom of elbow joint are selected as the degrees of freedom of the manipulator from the seven degrees of freedom of human upper limb. Only one driving motor is installed at the shoulder joint and elbow joint, and light materials are selected to reduce the weight borne by the patient when wearing the mechanism and reduce the possible secondary injury to the patient's shoulder caused by the device. This design can not only ensure that patients can carry out passive training of shoulder and elbow joints when the muscle strength of upper limbs is relatively weak, but also add active training according to their own situation when patients recover to a certain extent. In the design, the modular design principle is adopted for the overall structure design, which can be divided into three modules, including shoulder module, shoulder module and elbow module. The whole mechanical mechanism is shown in **Figure 1** (3D modeling in SOLIDWORKS).

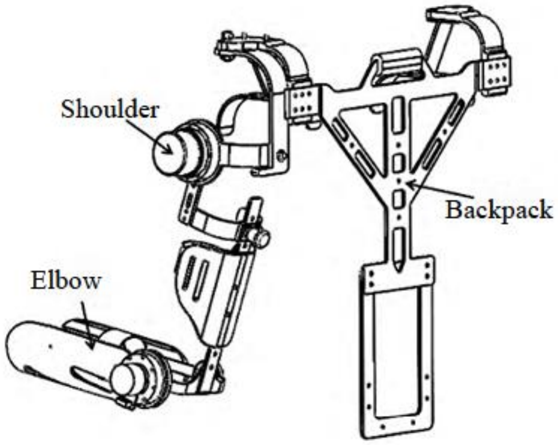

Figure 1. Overall structure of the wearable upper-limb rehabilitation robot.

The backpack module is mainly composed of back support frame and waist rod, which mainly plays the following roles:

(1) As an installation platform for installing motor drive, control board, battery and other hardware equipment; (2) As the mounting base connecting the shoulder module, it provides support for the shoulder module; (3) The mounting frame as a wearing mechanism is connected with a wearing mechanism for users to wear.

The shoulder module is composed of a shoulder back bracket, a shoulder blade frame and a shoulder motor base. The connection between the shoulder back bracket and the back support frame and between the shoulder back bracket and the shoulder blade frame provides two non-motor driven degrees of freedom: horizontal adduction/abduction and coronal adduction/abduction. A brushless DC motor and a harmonic reducer are installed on the shoulder motor base to form the shoulder power source to drive the shoulder joint to complete the forward flexion backward extension in the sagittal plane. Through this mechanism, the bionic restoration of three-dimensional spatial degrees of freedom of human shoulder joint (ball axis joint) is completed.

The elbow module is mainly composed of forearm support, elbow motor fixing ring, etc. a power source composed of DC brushless motor and harmonic reducer is installed to drive the elbow joint to flexion/extension movement. In addition, in order to reduce the power consumption of the motor driving mechanism and enhance the service life and endurance of the battery, a coil spring balance mechanism is designed at the elbow of the exoskeleton robot, and a tension spring balance mechanism is used at the shoulder mechanism. Through these balance mechanisms, the self-weight of the mechanical structure is balanced and the movement of the mechanism is smoother.

Therefore, the design of the wearable mechanism and the wearable upper limb of the patient is a key issue in the design of the wearable mechanism. The weight of the mechanism is evenly distributed in all parts of the body, and the back weight is arranged from top to bottom to maintain the stability of the center of gravity of the mechanism.

In order to adapt to the body size difference of different users and achieve better wearing effect, the overall mechanism is designed to adjust shoulder width, upper arm and forearm length, which can adapt to the average body size (18–60 years old) of 10%–99% of the human body in Human Dimensions of Chinese Adults (GB/T 10000–1988). IT meets the use needs of most people, and has good applicability.

3. Kinematics simulation of robot

In order to verify the effect of motor driven motion at each joint of the wearable upper limb exoskeleton rehabilitation robot, the established 3D mechanism model is analyzed in the motion simulation module motion of SOLIDWORKS. The motion analysis solver of motion adopts the solver of the mechanical system dynamics self analysis software ADAMS[19,20].

3.1. Kinematics simulation of elbow joint

In consideration of the requirements of rehabilitation training, the movement of the affected limb should be gentle and slow, and the movement process should be gentle (there should be no sudden change of movement, etc.) to prevent secondary injury. In the Motion simulation module of SOLIDWORKS, take the elbow joint as the coordinate origin, add a motor at the elbow joint, set the motor motion mode as oscillation, the oscillation frequency as 0.25 Hz, and set the maximum motion angle as 120° (i.e. the average speed of the elbow joint is 10 R/min and the motion cycle is 4 s). In motion, conduct a flexion / extension of the forearm in the sagittal plane driven by the motor for motion simulation. The flexion process is shown in **Figure 2** (the extension is the inverse process in the figure).

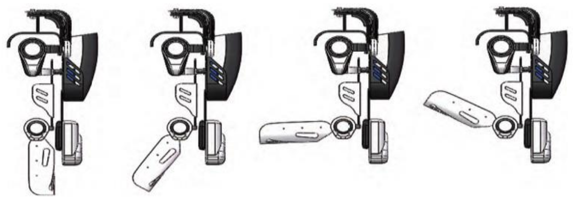

Figure 2. Motion simulation of flexion and extension in elbow joint.

In the process of forearm movement, the forearm can be simplified as a connecting rod rotating around the elbow joint, while the wrist joint (forearm support end) can be regarded as another end point of the simplified connecting rod, and its displacement data can reflect the overall situation of forearm movement (whether the displacement is smooth or not). After the motion simulation, the required angular displacement curve of elbow joint and linear displacement curve of wrist joint can be generated by using the “results and diagrams” in SOLIDWORKS Motion. The system will automatically generate the corresponding curve, and the user can modify and set the relevant attributes of the curve. It can also generate the corresponding Excel spreadsheet recording the relevant motion data in the whole motion process, and use these data to draw the curve through Excel. In this way, the specific value of each data point can be seen intuitively, and it is more convenient for users to edit and process the curve. Therefore, this paper uses this method to generate the angular displacement curve of elbow joint and the linear displacement curve of wrist joint in this motion cycle (**Figure 3**).

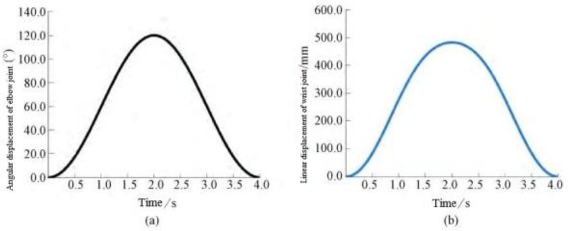

Figure 3. Angular displacement of elbow joint **(a)** and linear displacement of wrist joint **(b)**.

As shown in **Figure 3**, the change curve of angular displacement and linear displacement of the exoskeleton mechanism driven by the motor is smooth, indicating that the whole movement transition is smooth and close to the normal movement of human movement, which proves that the design of the exoskeleton elbow mechanism is reasonable and in line with the law of human movement, which can effectively assist the user in training and prevent secondary injury.

3.2. Kinematics simulation of shoulder joint

According to the established 3D model, the kinematics simulation analysis of the independent training process of the shoulder joint is carried out in the motion simulation module of SOLIDWORKS. The motion mode of the shoulder joint is set as oscillation, the oscillation frequency is 0.25 Hz, and the maximum motion angle is set as 90° (i.e. the average speed of the shoulder joint is 7.5 R/min and the motion cycle is 4 s). The motion simulation of the flexion/extension of the whole arm in the sagittal plane driven by the motor is carried out in motion. Its movement process is shown in **Figure 4**.

Figure 4. Motion simulation of flexion and extension in shoulder joint.

Considering that in the whole arm movement process, the elbow joint and wrist joint are the two most important joints of the upper limb except the shoulder joint (the simplified motion model of the human upper limb also simplifies the upper arm and forearm into two connecting rods and the two joints into hinges). The displacement of the two joints in a movement can approximately reflect the specific situation of an upper arm movement. Therefore, after the motion simulation analysis, use the “results and diagrams” in motion to generate an Excel spreadsheet that records the angular displacement data of shoulder joint and the linear displacement data of elbow joint and wrist joint in the whole motion process, and draw the angular displacement curve of shoulder joint and the linear displacement curve of elbow joint and wrist joint in this motion cycle through Excel (**Figure 5**).

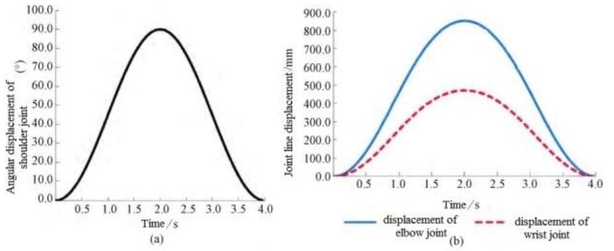

Figure 5. Angular displacement of shoulder joint (**a**) and linear displacement of elbow joint and wrist joint (**b**).

As shown in Figure 5, the angular displacement curve of the shoulder joint and the linear displacement curves of the elbow and wrist joints change smoothly during the whole arm flexion/extension movement of the exoskeleton shoulder mechanism driven by the motor. This indicates that the smooth movement speed and smooth movement curve during the whole arm movement are in line with the normal human movement pattern, which has good bionic properties and meets the relevant requirements for rehabilitation training.

3.3. Kinematics simulation of joint training of shoulder and elbow

The planned training modes of wearable upper limb exoskeleton rehabilitation robot include independent training of elbow joint, independent training of shoulder joint and joint training of shoulder and elbow joint. Considering this situation, after the motion simulation analysis of elbow independent training and shoulder joint independent training, the simulation analysis of shoulder and elbow joint linkage training mode is added to verify the motion effect of this training mode.

In the previously established model, the shoulder joint motion was set to oscillate with an oscillation frequency of 0.25 Hz, and the maximum angle of shoulder joint motion was 90° (i.e., the average rotational speed of the shoulder joint was 7.5 r/min, and the motion period was 4 s). The elbow joint motion was set to oscillate with an oscillation frequency of 0.25 Hz, and the maximum angle of elbow joint motion was 120° (i.e., the average rotational speed of the elbow joint was 10 r/min, and the motion period was 4 s). Run the shoulder elbow joint in the software environment, and conduct the shoulder elbow joint linkage training of flexion / extension in the sagittal plane. The movement process is shown in **Figure 6**.

Figure 6. Motion simulation of flexion and extension in shoulder-elbow.

The process of simulation results is analyzed and processed, and the position data of elbow and wrist in the whole simulation process are extracted. Through these position data, the displacement curves of wrist and elbow in a joint training of shoulder and elbow are generated (**Figure 7**).

The movement curves of the wrist and elbow joints of the shoulder-elbow linkage training show that the displacement curves of the elbow and wrist joints of the exoskeleton robot in the shoulder-elbow linkage training are gentle (the concave curve of the wrist joint is because the limit angle of the elbow joint is 120°, and the position of the elbow joint converges to the shoulder joint as the origin of the simulation system after exceeding 90°. The results show that it does not produce sudden changes in position that may cause secondary injury to the patient), which proves the reasonableness and safety of the mechanism.

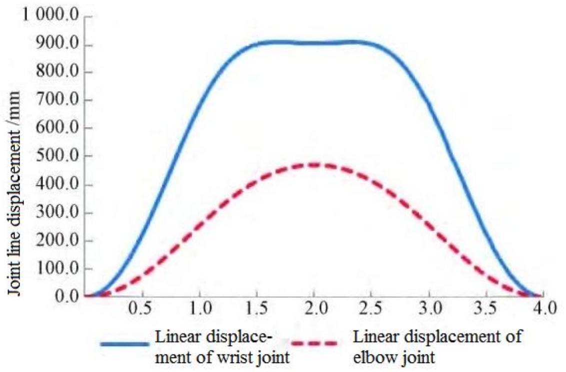

Figure 7. Linear displacement of wrist joint and elbow joint.

4. Dynamic analysis of robot

In order to verify whether the mechanical properties of the selected motor of the wearable upper limb exoskeleton robot can meet the requirements of shoulder elbow joint training, the motion of shoulder and elbow joints is analyzed and calculated.

Through the simplified analysis of the whole arm module driven by the two motors of the shoulder and elbow, it can be simplified into a two link mechanism with fixed base as shown in **Figure 8**, in which the upper arm is $l_1$and the forearm is l_2.

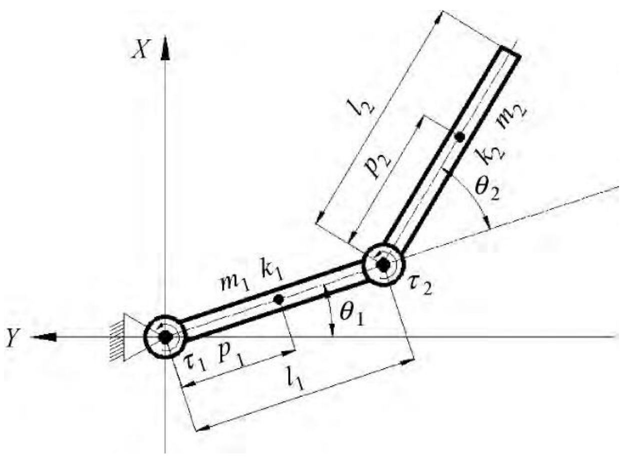

Figure 8. The robotic arm mechanism.

As shown in **Figure 8**, it is assumed that the joint variables of link 1 and link 2 are rotation angles θ_1 and θ_2, respectively. The corresponding torques of link 1 and link 2 are τ_1 and τ_2, respectively. The mass of the two links are m_1 and m_2, respectively. The lengths of the two links are l_1 and l_2, respectively. The centroids are k_1 and k_2, respectively. The distances between the centroid and the rotation center of the joint are p_1 and p_2, respectively. The rotational inertias of the two links around the centroid are I_{c1} and I_{c2}.

Select θ_1 and θ_2 as the generalized coordinates describing the position of the connecting rod, then the position coordinates k_1 of the centroid of rod 1 are:

$$x_1 = p_1 \sin\theta_1 \tag{1}$$

$$y_1 = -p_1 \cos\theta_1 \tag{2}$$

The position coordinates of the k_2 center of mass of rod 2 are:

$$x_2 = l_1 \sin\theta_1 + p_2 \sin(\theta_1 + \theta_2) \tag{3}$$

$$y_2 = -l_1 \cos\theta_1 - p_2 \cos(\theta_1 + \theta_2) \tag{4}$$

By deriving the time respectively, it is obtained that the velocity square of the k_1 center of mass of rod 1 is:

$$v_1^2 = \dot{x}_1^2 + \dot{y}_1^2 = \left(p_1\dot{\theta}_1\right)^2 \tag{5}$$

The velocity square of the k_2 center of mass of rod 2 is:

$$v_2^2 = \dot{x}_2^2 + \dot{y}_2^2 = l_1^2\dot{\theta}_1^2 + p_2^2\left(\dot{\theta}_1 + \dot{\theta}_2\right)^2 + 2l_1p_2\left(\dot{\theta}_1^2 + \dot{\theta}_1\dot{\theta}_2\right)\cos\theta_2 \tag{6}$$

The rotational angular speeds of the two connecting rods are:

$$w_1 = \dot{\theta}_1 \tag{7}$$

$$w_2 = \dot{\theta}_1 + \dot{\theta}_2 \tag{8}$$

Moreover, the plane motion kinetic energy of the rigid body can be expressed as the sum of the translational kinetic energy of the center of mass and the rotational kinetic energy around the center of mass. Therefore, the kinetic energy of the two rods can be obtained as follows:

$$E_{k1}=\frac{1}{2}m_1v_1^2+\frac{1}{2}I_{C1}W_1^2$$
$$=\frac{1}{2}\left(m_1p_1^2+\frac{1}{12}m_1l_1^2\right)\dot{\theta}_1^2 \quad (9)$$

$$E_{k2}=\frac{1}{2}m_2v_2^2+\frac{1}{2}I_{c2}w_2^2$$
$$=\frac{1}{2}m_2[l_1^2\dot{\theta}_2^1+p_2^2(\dot{\theta}_1+\dot{\theta}_2)^2+ 2l_1p_2(\dot{\theta}_2^1+\dot{\theta}_1\dot{\theta}_2)\cos\theta_2]+\frac{1}{2}I_{c2}(\dot{\theta}_1+\dot{\theta}_2)^2$$
$$=\frac{1}{2}[m_2(l_1^2+p_2^2+2l_1p_2\cos\theta_2)+I_{c2}]\dot{\theta}_1^2+\frac{1}{2}(m_2p_2^2+I_{c2})\dot{\theta}_2^2+(m_2p_2^2+m_2l_1p_2\cos\theta_2+I_{c2})\dot{\theta}_1\dot{\theta}_2 \quad (10)$$

Then the total kinetic energy of the system is:

$$E_k=E_{k1}+E_{k2}$$
$$=\frac{1}{2}[m_1p_1^2+I_{c1}+m_2(l_1^2+p_2^2+2l_1p_2\cos\theta_2) +2l_1p_2\cos\theta_2)+I_{c2}]\dot{\theta}_1^2+\frac{1}{2}(m_2p_2^2+I_{c2})\dot{\theta}_2^2 +(m_2p_2^2+m_2l_1p_2\cos\theta_2+I_{c2})\dot{\theta}_1\dot{\theta}_2 \quad (11)$$

Taking the coordinate origin fixed at the base as the potential energy zero point, the total potential energy of the simplified two link system is:

$$E_P=-m_1gp_1\cos\theta_1-m_2gl_1\cos\theta_1 -m_2gp_2\cos(\theta_1+\theta_2) \quad (12)$$

Establish the Lagrange function of the system:

$$L=E_k-E_p \quad (13)$$

According to Lagrange equation:

$$F_i=\frac{d}{dt}\frac{\partial L}{\partial\dot{q}_i}-\frac{\partial L}{\partial q_i}(i=1,2,3\cdots,n) \quad (14)$$

The moment of each joint is solved as follows.

$$\frac{\partial L}{\partial\dot{\theta}_1}=m_1p_1^2+I_{\mathrm{cl}}+m_2(l_1^2+ p_2^2+2l_2p_2\cos\theta_2)+I_{c2}]\dot{\theta}_1+ (m_2p_2^2+m_2l_1p_2\cos\theta_2+I_{c2})\dot{\theta}_2 \quad (15)$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial\dot{\theta}_1}\right)=[m_1p_1^2+I_{c1}+m_2(l_1^2+p_2^2+2l_1p_2 \cos\theta_2)+I_{c2}]\ddot{\theta}_1-(2m_2l_1p_2\sin\theta_2)\dot{\theta}_1\dot{\theta}_2 +m_2l_1p_2\cos\theta_2+I_{c2})\ddot{\theta}_2 \quad (16)$$

$$\frac{\partial L}{\partial\theta_1}=-m_1gp_1\sin\theta_1-m_2gl_1\sin\theta_1 -m_2gp_2\sin(\theta_1+\theta_2) \quad (17)$$

The joint torque of joint 1 can be obtained as follows:

$$\tau_1=\frac{d}{dt}\frac{\partial L}{\partial\dot{\theta}_1}-\frac{\partial L}{\partial\theta_1}$$
$$=[m_1p_1^2+m_2(l_1^2+p_2^2+2l_1p_2\cos\theta_2)+ I_{c1}+I_{c2}]\ddot{\theta}_1-(2m_2l_1p_2\sin\theta_2)\dot{\theta}_1\dot{\theta}_2+ (m_2p_2^2+m_2l_1p_2\cos\theta_2+I_{c2})\ddot{\theta}_2- (m_2l_1p_2\sin\theta_2)\dot{\theta}_2^2+(m_1p_1+m_2l_1)g\sin\theta_1 +m_2gp_2\sin(\theta_1+\theta_2) \quad (18)$$

By:

$$\frac{\partial L}{\partial\dot{\theta}_2}=(m_2p_2^2+I_{c2})\dot{\theta}_2+ (m_2p_2^2+m_2l_1p_2\cos\theta_2+I_{c2})\dot{\theta}_1 \quad (19)$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial\dot{\theta}_2}\right)=(m_2p_2^2+m_2l_1p_2\cos\theta_2+I_{22})\ddot{\theta}_1+ (m_2p_2^2+I_{c2})\ddot{\theta}_2-(m_2l_1p_2\sin\theta_2)\dot{\theta}_1\dot{\theta}_2 \quad (20)$$

$$\frac{\partial L}{\partial\theta_2}=-m_2l_1p_2(\dot{\theta}_1^2+\dot{\theta}_1\dot{\theta}_2)\sin\theta_2 -m_2gp_2\sin(\theta_1+\theta_2) \quad (21)$$

The joint torque of joint 2 can be obtained as follows:

$$\tau_2=\frac{\mathrm{d}}{\mathrm{dt}}\frac{\partial L}{\partial\dot{\theta}_2}-\frac{\partial L}{\partial\theta_2}$$
$$=(m_2p_2^2+m_2l_1p_2\cos\theta_2+I_{c2})\ddot{\theta}_1+ (m_2p_2^2+I_{c2})\ddot{\theta}_2+(m_2l_1p_2\sin\theta_2)\dot{\theta}_1^2+ m_2gp_2\sin(\theta_1+\theta_2) \quad (22)$$

In the SOLIDWORKS software environment, using the “quality attribute” function to analyze the simulation human wearable upper limb robot model, l_1=0.325 m, l_2=0.273 m, p_1=0.164 m, p_2=0.131 m, m_1=2.939 kg, m_2=2.112kg, g=9.8 m/s^2, I_{c1}=0.033 kg·m^2, I_{c2}=0.017 kg·m^2.

Bring the values into equations (18) and (22), and solve the two equations in the MATLAB software environment: Set the training time as 4 s and select the working state of two joints moving continuously for one cycle under the shoulder elbow linkage training mode as the analysis object.

After the solution, the results are processed, and the driving torque acting on the two joints in the whole process of shoulder elbow joint training can be obtained τ_1, τ_2 size change curve (**Figure 9**).

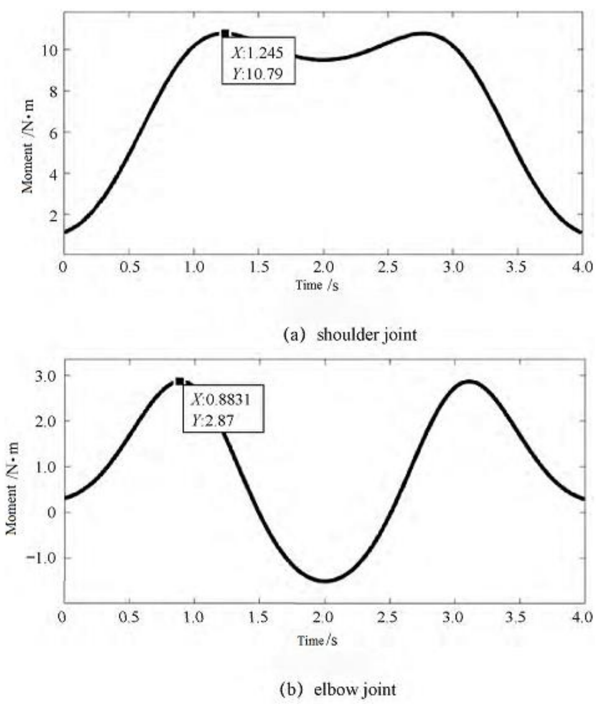

Figure 9. Torque curves of shoulder joint and elbow joint.

According to the calculation results:

(1) The maximum torque τ_1 of shoulder joint is 10.79 N·m<18 N·m (rated torque output by shoulder motor after reducer deceleration). (2) The maximum torque τ_2 of elbow joint is 2.87 N·m<7.8 N·m (rated torque of elbow motor after reducer deceleration).

Therefore, it can be seen that the motor selected on the two joints of the wearable upper limb rehabilitation robot is reasonable, and its mechanical properties can meet the ultimate mechanical requirements of the robot's shoulder and elbow joint training. In addition, it can be seen from the figure that the change curve of joint torque is also smooth, and there is no sudden change of joint torque, which can also ensure the safety of patients to a certain extent.

5. Discussion and conclusions

At present, most of the upper limb rehabilitation robots at home and abroad are complex desktop training equipment, which is expensive, and most of them need a large space for placement, which greatly restricts the possibility of upper limb rehabilitation training equipment entering the community or even the family. With the accelerating aging process and the increasing number of stroke patients with hemiplegia in China, the demand for rehabilitation robots will be greater and greater. The personalization, familization and popularization of rehabilitation medical products are the inevitable trend of future development. In this case, the wearable upper limb exoskeleton rehabilitation robot designed in this paper meets the needs of the current society. After completing the overall mechanical structure design of the wearable upper limb exoskeleton rehabilitation robot, the kinematics simulation of elbow flexion/extension movement, shoulder flexion/extension movement and shoulder elbow joint linkage is carried out in this paper. The simulation results confirm that the motion simulation curve is smooth. At the same time, the dynamic equation is established based on the Lagrange method. The joint torque change curve in the process of shoulder elbow joint linkage training meets the requirements of the optional motor, it is proved that the design of the wearable upper limb rehabilitation robot is reasonable, which lays a theoretical foundation for the follow-up research of upper limb rehabilitation robot.

The wearable upper limb rehabilitation robot designed in this paper adopts a novel knapsack mechanical structure design, which is simple and lightweight, and can be easily worn by patients. It changes the traditional physical therapy of upper limb rehabilitation and the fixed desktop training mode of upper limb robot, so that the rehabilitation training is no longer limited by the site, and has good clinical application and popularization. At the same time, because it can be carried with you, it can also assist the daily life of patients to a certain extent, so as to combine rehabilitation training with daily life assistance. This training mode is also a new trend of the development of rehabilitation training.

Conflict of interest

The authors declare no conflict of interest.

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Original Research Article

Study on research mode of smart safety outfits system for children

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ABSTRACT

According to the special characteristics of children's body and mind and the concept of human–computer interaction, the research and development model of children's intelligent safety clothing is explored and a A practical research model. Based on the multi–dimensional needs of consumers for children's clothing and the performance of smart components, we explore the combination of smart wearable equipment and children's safety clothing, and propose a design process architecture that takes into account function and aesthetics. Through the analysis of the connection technology between smart clothing and mobile terminals, we propose the idea from single interaction to multi–device co–connection, and establish a multi–interaction smart clothing based on the optimal allocation of energy and high. Through the analysis of the connection technology between smart clothing and mobile terminals, we propose the idea of moving from single interaction to multi–device co–connection, and establish the R&D process of multi–interaction smart wearable devices based on optimal energy allocation and efficient information transmission.

Keywords: childrens safety; smart clothing; multi–dimensional need analysis; intelligent interaction

1. Introduction

In recent years, there has been an upsurge of intelligent wearable devices in the field of industrial design. Intelligent wearable device[1] is the general name of wearable devices developed by applying wearable technology to intelligently design products that people wear and carry daily, such as various popular glasses, gloves, watches, clothes with intelligent concepts and functions. With the help of various intelligent devices, consumers have obtained unprecedented convenience in life and work. However, no intelligent wearable device can be omnipotent. At present, researchers mainly develop products that can solve specific problems for specific groups of people. Children's safety has always been the focus of the whole society, but the physiological weakness of children determines that any traditional safety equipment for mature limbs is difficult to meet the needs of children. How to provide proper supervision for children on the one hand and not affect the comfort necessary for children's healthy growth and daily life on the other hand is an important topic of children's safety clothing design. The upsurge of research and development of intel-

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ligent wearable devices provides a broader space for the design of children's safety clothing.

By analyzing and summarizing the research results of multi–dimensional requirements of man–machine interactive wearable equipment, the combination mode of intelligent wearable equipment and children's clothing, and the multi interaction between intelligent wearable equipment and mobile terminal, this paper attempts to put forward the system R&D mode of the combination of intelligent wearable equipment and children's safety clothing, hoping to provide practical and effective theoretical guidance for the design and production of children's safety clothing in the Internet era.

2. Key technologies and development status of intelligent wearable research

The development of intelligent wearable research is inseparable from the progress of fiber and material science. In recent years, various smart textile materials developed by new fibers through special weaving technology have become the main force in the field of intelligent wearable (especially in the field of intelligent clothing)[2]. Mondal's[3] uses phase change materials and microcapsule technology to produce intelligent textiles with heat storage and regulation performance, which can greatly improve the wearing comfort. The intelligent nano textiles developed by Coyle's and others[4] expand the functionality and potential of environment, clothing and fabrics. The smart textile developed through nanofibers has the functions of automatic cleaning, sensing, driving and communication, and the wearer can communicate with the surrounding environment in a harmless way; at the same time, the system can constantly update personal health status or resist environmental hazards. Shim BS et al.[5] used polyelectrolyte to coat carbon nanotube adult biological monitoring intelligent electronic yarn wear–resistant fabric. The combination of this material and intelligent wearable devices can be used for the monitoring of hemoglobin and the transmission of remote information. Lymberis A et al.[6] discovered the fibrous structure of intelligent fabrics and interactive textiles, which are used for sensing, driving, power generation, energy storage and interaction. Radetic M[7] proposed that silver nanoparticles and textile fibers are blended into textiles, and the current can be connected with wearable devices through specific fiber lines. Park S et al.[8] proposed a wearable biomedical system based on intelligent textile design to improve personal quality of life by enhancing the effect of real-time biomedical monitoring.

In addition to combining conductive elements with fibers and weaving them into intelligent textile materials, a more typical intelligent textile technology is to organically combine the formed clothing as a carrier with intelligent modules, cooperate with specific communication technologies, and establish the information exchange between the human body and the outside world, so as to realize the corresponding human auxiliary functions[9]. This kind of research mainly involves intelligent clothing technology. A complete intelligent clothing system usually includes three components: intelligent module (including intelligent sensing elements, signal transmission system, energy module, etc.), function carrier clothing and information processing module[10]. The intelligent module can be used to obtain human body data and transmit external signals to the human body to realize the two–way feedback between the human body and the external environment. It is the key module for intelligent clothing to perform its specific functions. Clothing is the carrier of intelligent wearable technology. Because of its inseparable relationship with human body, intelligent clothing has incomparable advantages in human machine interaction. Information processing terminal is the brain of intelligent clothing, which undertakes the task of collecting, analyzing and making decisions on the transmission data of intelligent originals.

In recent years, intelligent clothing technology has developed very rapidly. Park S et al.[11] proposed implanting micro monitoring equipment and sensors into ordinary shirts to make telemedicine monitoring possible. The research methods of wearable intelligent device[12] are discussed. Radetic M[13] proposed the design of wearable antenna to provide all-round monitoring and communication for the wearer. D-shirt sports wear[14] is a high-tech sportswear developed by French citizen sciences. Its fabric embedded sensor is connected with Bluetooth transceiver to track user activities and transmit the collected data to smart phones. After the transceiver is taken out, it can be washed and ironed. The quality of sportswear is no different from that of ordinary T-shirts. Many companies have launched smart clothing for the elderly, which combines smart phones, sensors and positioning elements to store and process information through wireless communication means (such as Bluetooth), so as to provide real-time security protection for the elderly[15]. Li H et al.[16] studied a wearable sensor of new intelligent clothing for human body temperature measurement. Intel has teamed up with clothing designer chromate to launch so-called “responsive clothing” that can be deformed according to users’ questions, adrenaline or stress levels[17]. Ohmatex, a Danish design company, has designed a smart sock that can detect leg edema and predict heart failure and epileptic aura in advance[18].

Because of their physical and mental particularity, children belong to relatively vulnerable groups and are important service objects of intelligent wearable devices. At present, the intelligent equipment for children seen in the market is mainly from the perspective of safety monitoring, such as smart schoolbags, shoes, foot rings, watches, telephones, urine humidity sensing shorts, infant vital signs monitoring underwear and pajamas with positioning function (i. e. anti-loss function)[19]. Other smart wearable devices focus on children’s psychological growth, such as storytelling T-shirts, luminous skirts, singing pajamas, etc.[20]. The successive emergence of all kinds of children’s wearable products reflects the care and attention of the whole society to children’s physical and mental health. However, most of the children’s wearable products currently on the market have single function and uneven quality[21]. Other slightly forward-looking products can not reflect their due value because the technology is not mature or cannot meet the actual needs of children. In addition, the market share of intelligent accessories far exceeds that of intelligent services pack.

This also reveals the technical bottleneck of today’s intelligent wearable products to some extent. Because, compared with intelligent accessories (such as watches, shoes and socks, accessories, etc.), the compatibility between technology and clothing needs to be considered in the development process of intelligent clothing. On the premise of meeting specific functions, it is necessary to ensure the basic wearing performance of clothing (which is difficult to achieve), which is particularly important for children’s intelligent clothing. Due to the immature physical and mental development of infants and young children, compared with adults, they have higher requirements for clothing comfort and safety, which undoubtedly increases the difficulty of intelligent clothing development. So far, there is no systematic and feasible research and development mode (or idea) in the field of children’s intelligent safety, which provides guidance for the good combination of intelligent wearable technology and children’s clothing safety research.

3. Research and development mode of smart clothing based on children’s safety

On the basis of extensive market research and in-depth analysis of previous and existing relevant research, this paper puts forward three main aspects involved in the research and development of children’s intelligent safety clothing, namely, the demand of children’s intelligent safety clothing, the combination mode of intelligent wearable components and children’s clothing, and the information interaction mode of intelligent children’s safety clothing.

3. 1. Demand for children’s intelligent safety clothing

The research and development of smart clothing is a typical human centered product design[22,23].

A very important link in its R&D process is to conduct in-depth investigation and analysis on the multi-dimensional needs of product users (i.e. smart clothing wearers), i.e. human factors. Only by accurately grasping the needs of users can we design and develop satisfactory products. The research and development of children's intelligent safety clothing needs to take into account the needs of users (children themselves), their guardians (parents) and the society for the wearability, functionality, safety, aesthetics, social acceptance and so on.

Specifically, as a special kind of functional clothing, intelligent clothing first needs to meet the designer's requirements for its preset functions, and ensure the stability of intelligent component installation, the convenience of interaction, the effectiveness of information transmission, the accuracy of data acquisition, the durability of energy consumption, etc. Secondly, due to the tightness of the combination of smart clothing and human body, the design of smart clothing also needs to meet the basic characteristics that it should have as clothing itself, such as comfort, aesthetics, safety, durability (such as washability)[24], and sometimes even consider the social acceptance of smart clothing and its use behavior.

The research and development of children's intelligent wearable products often starts from the perspective of safety monitoring. The so-called safety monitoring not only covers the monitoring of life safety, but also includes the attention to children's mental health and growth. The former includes various intelligent wearable products that help prevent children from getting lost, injured and ill, while the latter includes various products that bring psychological comfort and intellectual interest guidance to children. Therefore, based on the particularity of children's body and mind, the research and development of children's intelligent clothing should also consider a series of special requirements, such as the visualization of information interaction and the safety level of electronic components (higher than that of adults), in addition to meeting its functional and wearability requirements.

In terms of research methods, demand research is divided into two aspects: demand acquisition and demand analysis. In addition to literature study, the most commonly used methods to obtain needs are some psychological research methods, such as questionnaire, personal interview, expert discussion and so on. On this basis, demand analysis is to study the obtained qualitative or quantitative demand data through analysis and summary or data mining methods, and finally extract a series of research basis with guiding significance for follow-up work[25,26].

3. 2. Combination mode of intelligent wearable elements and children's clothing

Intelligent wearable devices can be divided into four categories according to the wearing mode: headwear, wristband, portable and wearing[27]. No matter what kind of device, the research goal is to improve the portability, wearability (to some extent, comfort) and wearing performance of the product on the premise of meeting the preset functions of components and according to the particularity of children's physiological, psychological and life situation.

Smart clothing belongs to category 4 of the above intelligent wearable devices, which is also a kind of intelligent wearable devices with higher difficulty in implementation. At present, most smart clothing is based on sensors. With the improvement of sensor integration, functionality and intelligence, the location of wearable components is not limited to a certain part of the human body, but is being laid out all over the body, making them have medical significance in addition to information interaction and communication, and even have the functions of data collection, monitoring and transmission of external environment, buildings and other data[28].

How to reasonably combine intelligent wearable components with clothing, so as to give full play to specific functions and make the wearer feel physically and mentally comfortable, is the key and difficulty of intelligent clothing research and development. This paper puts forward the research idea as shown in **Figure 1**. In short, the starting point of intelligent children's safety clothing research is to meet the multi– dimensional needs of children for clothing in specific safety situations. After analysis and summary, in addition to the function of the component itself, this study puts forward six indicators of the compatibility between intelligent components and children's safety clothing, namely, appearance acceptance, physiological fit, physiological harm, wearing comfort, obstruction to activities, and consideration of the safety and reliability of the component. Therefore, the key to the research and development of intelligent children's safety clothing is to select appropriate intelligent wearable components (function type, performance parameters, shape, size, etc.) according to the functions to be realized, that is, the research and development concept, reasonably transform the components if necessary, and then explore the specific combination parts and forms of the components and children's clothing.

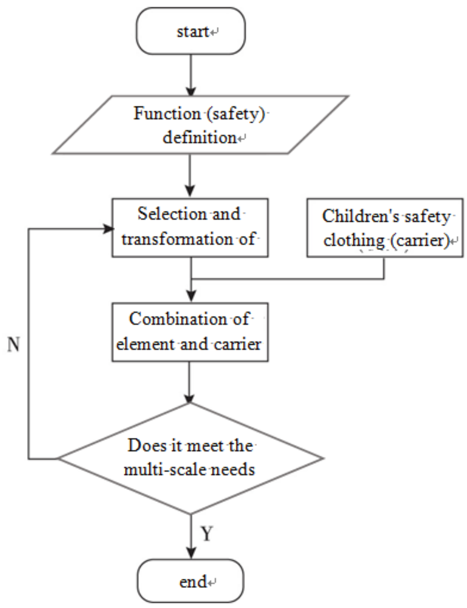

Figure 1. Basic process of the research on the combination of smart devices and children's safety clothing

Intelligent clothing system takes clothing as the carrier and intelligent wearable components as the function realization module. In order to organically combine functional modules with carriers, researchers need to apply multi–disciplinary knowledge such as clothing aesthetics, physiology, psychology, ergonomics, electronic informatics and so on.

The research on the combination of intelligent components and clothing is the central link of intelligent clothing design, which plays a connecting role in the whole research and development mode.

3. 3. Information interaction mode of intelligent children's safety clothing

With the popularity of mobile terminals such as smart phones and tablets (pads), most wearable smart devices rely on mobile terminals for data transmission and analysis. Sensor detection nodes and mobile terminals generally communicate data through short–range wireless transmission, such as low–power bluetooth, zigbee, WiFi, etc. The interaction mode between intelligent wearable devices and mobile terminals is usually single, that is, they only tend to establish a single connection between devices and mobile terminals, and the degree of information sharing is low (which directly leads to low information utilization), which affects the function maximization of intelligent products. Therefore, in order to better realize the efficiency of intelligent information processing and serve specific people (device wearers) to the greatest extent, it is necessary to conduct diversified research on the transmission and interaction modes of information between intelligent devices and between intelligent devices and mobile terminals, that is, the research on multi interaction. Therefore, this paper puts forward the research framework of intelligent clothing as shown in **Figure 2**.

In **Figure 2**, the whole framework consists of three parts: function end, analysis end and sharing end. The function end is the combination end of intelligent components and clothing.

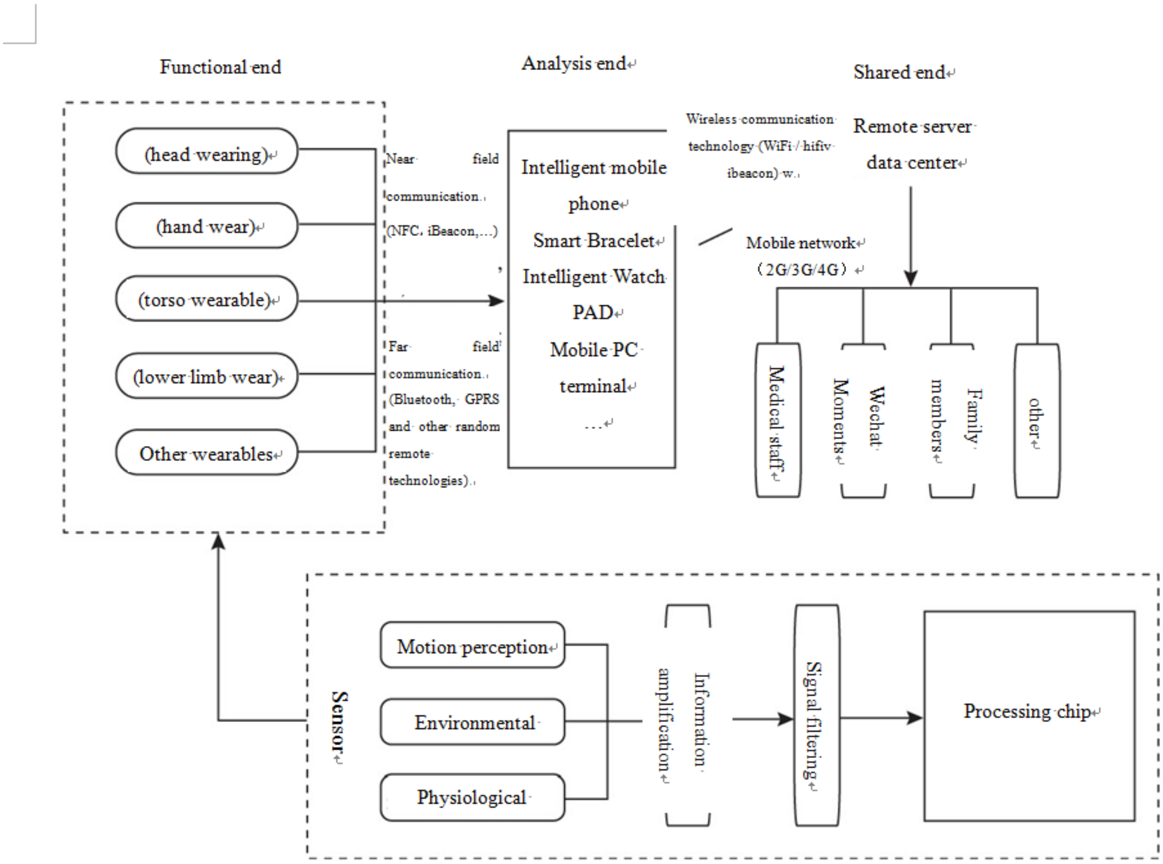

Figure 2. Framework of multi– interactive information sharing

It is the function realization unit of the whole intelligent clothing and is responsible for information detection and feedback. Among them, all kinds of sensors have become an important part of the functional end, and they are also one of the core components of the whole intelligent clothing system. The analysis terminal is the information terminal, which is the unit that reads and analyzes the data information transmitted by intelligent components. If the smart clothing system is regarded as the human nervous system, the functional end is the sensory organ (sensor, i.e. receptor), and the analysis end is the nerve center (brain). The information exchange between the functional end and the analysis end is realized through various wired and wireless communication technologies, such as the commonly used near-field (NFC, iBeacon technology, etc.) and far-field communication methods (Bluetooth, FM technology, etc.). Information is transmitted from intelligent components (sensors, etc.) to the analysis end through the communication network, just as sensory information is transmitted from the sensor to the brain through the sensory pathway. Common information terminals in the market include mobile phones, watches, bracelets, mobile PC terminals, tablet computers, etc. At present, most intelligent wearable devices are composed of function end and analysis end.

On this basis, this paper puts forward the third important module of intelligent clothing system, namely sharing end. Generally, the one-to-one (i.e. one functional end and one analytical end) information interaction mode leads to low information utilization. The shared end can be a remote server or a virtual data center. The role of the sharing end includes two aspects: a. By means of communication, multiple data terminals are interconnected to form a multi interactive network to maximize information exchange and improve information utilization. Specifically, the mobile terminal makes appropriate decisions and feedback on information through the role of internal decision–making modules (such as app applications with various functions installed in smart phones). The feedback information will be shared to the pre associated network community in the wireless network through the preset mode, that is, different types of mobile terminals, or shared by multiple devices to realize information sharing. Through the sharing end, the information obtained by smart devices can be easily shared with friends, family, medical institutions, etc. The significance of information sharing is not only to improve the utilization of information, but also to improve the controllability and security of intelligent clothing. b. The existence of sharing end also means that the analysis end of smart clothing can be expanded. The sharing network can not only share the information of the analysis end to different users, but also interconnect different intelligent systems to maximize the function of intelligent clothing. The data of different analysis ends are summarized in the remote data center through interactive technology to form a massive database. According to the principle of statistics, to a certain extent, the larger the sample size, the higher the accuracy and reliability of the analysis results. The expanded analysis end can improve the decision precision of the intelligent clothing system to a greater extent. In today's big data era, massive data storage and analysis technologies such as cloud computing are ideal means to establish the sharing end of intelligent clothing system[29,30].

The above framework is applicable to the research and development of different types of smart clothing and smart wearable devices. Based on the physical and mental particularity of the wearer, the R&D personnel should also consider the following factors in the design of intelligent interaction mode: a. Limited to children's poor situational judgment ability and perceptual expression ability, children's intelligent clothing should strengthen the design of auxiliary decision-making, real-time monitoring, automatic response and other functions. b. Smart clothing is usually equipped with various electronic components, which is easy to produce sound, light and electric pollution in the process of operation, thus causing harm to human body. Children are physically and mentally fragile and particularly vulnerable. Therefore, the research and development of children's intelligent clothing should put forward higher requirements for the safety of components, especially in the design of information interaction mode, the components with low power consumption and low radiation should be considered. c. According to children's psychological needs, smart clothing should follow the principles of simplicity, beauty and children's interest in the design of human "clothing" interaction mode and interaction interface.

3. 4. Construction of R&D mode of intelligent children's safety clothing

This paper puts forward the R&D mode of children's intelligent safety clothing as shown in **Figure 3**.

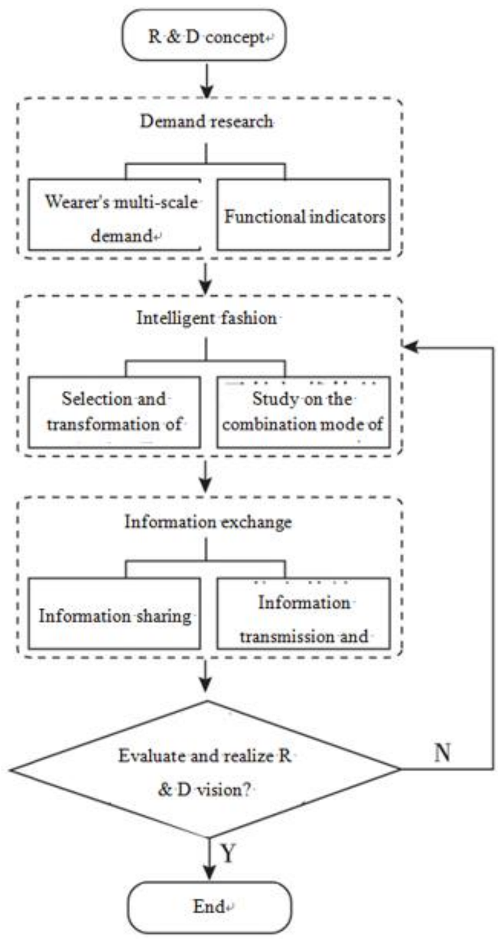

Figure 3. Research model of intelligent safety clothing for children

The pattern in **Figure 3** follows the basic principles of "needs determine design". Firstly, according to the functional requirements of smart children's clothing, comprehensively consider the multi-dimensional needs of children wearing smart safety clothing, that is, demand research. On the basis of demand analysis, formulate the technical (Design) indicators for the research and development of children's intelligent safety clothing, and explore the combination mode of intelligent components and children's clothing, that is, determine the specific design parameters such as the form and position of the combination of the two. Organically integrate functionality, design aesthetics and comfort, and design and develop smart clothes that meet children's physical and mental particularity and wearing needs. The third part of the research model involves the study of interaction mode. The intelligent components of children's clothing are interconnected with the analysis end of the intelligent clothing system through various communication technologies (near-field or long-distance transmission technology) to realize information interaction and complete the preset function. At the same time, set a sharing end for the smart clothing system, share the analysis end data to a wider community through the communication network, realize the common connection of different information terminals, improve the utilization rate of information, increase the controllability and security of the smart clothing system, and realize the common connection of different smart clothing systems. The establishment of massive information center and big data analysis means will greatly improve the decision-making effectiveness and functionality of intelligent clothing system.

The last link of the whole R&D model is very important, that is, to evaluate the efficiency of the children's intelligent safety clothing, and verify whether it meets the indicators and ideas formulated in the early stage of R&D. The evaluation link includes two parts: a. Functional evaluation of clothing. Researchers need to test and evaluate the functional indicators of products from an objective and mechanical point of view, that is, the test method is determined by the nature and function of each functional module of intelligent clothing system. If the preset function of the intelligent system is to detect the vital signs of the wearer, this evaluation link needs to evaluate the working state of each sensor (such as temperature, heartbeat, blood pressure sensor, etc.), the accuracy of the data at the analysis end, and the efficiency and accuracy of the information feedback system under the condition that the real person (or simulated real person) is dressed. b. Comfort evaluation. Smart clothing system takes clothing as the basic carrier, so it needs to meet the requirements of wearers for their physical and mental comfort. Sensory evaluation is a commonly used method for comfort evaluation[31,32]. Participants in sensory experiments usually include experts in textile (clothing) design and production, as well as ordinary wearers. The former evaluates the rationality of fashion design and production from a professional perspective (such as physiology, psychology and ergonomics). The latter evaluates the beauty and comfort of clothing from the perspective of their own needs. The research object in this paper is children, who usually do not have mature perceptual expression ability, so it is necessary to design a set of sensory experimental methods suitable for children. At the same time, according to the physical and mental particularity of children, it is also necessary to combine children's perception with parental intervention to obtain the wearer's perceptual evaluation of the beauty and comfort of clothing.

If the product meets the R&D concept, the R&D ends. If the product fails to pass the evaluation, the researcher must analyze the specific links and causes of the problem, and redesign the specific technical indicators of the problem until the indicators meet the requirements.

4. Conclusions

Based on the grasp of the development status and trend of intelligent wearable devices, this paper puts forward the general mode of children's intelligent safety clothing research and development. The whole model follows the basic concept of "demand determines design".

(1) Take the needs of smart clothing wearers (here children) as the driving force of R&D. Grasp the multi–dimensional needs of children's dressers and translate them into key technical parameters. (2) Design smart clothing. Select and reasonably transform the intelligent components according to the functional indicators, and explore the combination mode of components and carriers (i. e. safety clothing), so as to make the products have "functionality, beauty and comfort". (3) The information interaction mode of intelligent clothing system is designed. It includes one–to–one information interaction design (information transmission and analysis feedback) of function end (smart clothing) and analysis end, and multi device joint design to realize the multi interactive control of smart clothing system. On the basis of improving the controllability, security and utilization of information, the decision– making accuracy and efficiency of smart clothing system are improved through massive data storage and operation technology. (4) Verify the functionality and comfort of the smart clothing.

Conflict of interest

The authors declare no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

A method of attitude measurement and level assessment for skiers based on wearable inertial measurement

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ABSTRACT

Quantitative analysis of sports is an important development direction of scientific skiing training, and the digital expression of human movement patterns during skiing is the basis for scientific quantitative analysis. A human motion capture and attitude reconstruction system based on a wearable BSBD inertial measurement unit was designed and built, combined with the human multi-rigid body motion model to realize the human body reconstruction during the skiing, and applied to the auxiliary training of slewing movements in alpine skiing. At the same time, for the indoor training scene based on the multi-degree-of-freedom simulated ski training platform, a digital evaluation method suitable for ski slalom is proposed. The method uses motion capture system and posture reconstruction system to extract five kinds of sliding characteristic data of skiers, and realizes the evaluation of skiers' technical parameters through similarity measurement and linear fitting with high-level athletes' motion parameters, so as to assist scientific training. Finally, experiments are carried out on the indoor Olymp simulated ski training bench to verify the effectiveness of the method.

Keywords: motion capture; micro-inertial measurement unit; wearable sensor; assisted training

1. Introduction

When skiing, the ability to control body posture is a special specialty ability, which has an important impact on skiing performance. A motion capture and reconstruction system suitable for ski training can not only capture the body posture of skiers in real time, but also help ski trainers find the gap between themselves and high-level athletes with digital evaluation methods, find their own lack of action, correct the error of force, while popularizing skiing, increase the public's enthusiasm for skiing. In addition, a reliable motion capture and scoring system provides a powerful tool for the scientific training of ski trainers.

After decades of development, motion capture technology is mainly divided into two categories: video device-based motion capture and sensor-based motion capture. The motion capture system based on video equipment has high cost, low portability, and is susceptible to interference[1]. With the lower and lower cost of inertial sensors, sensor-based motion capture systems are gradually developed. At present, some companies in foreign markets have launched relatively mature motion capture products: Such as the MVN products

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launched by the Dutch company Xsens[2], the 3DSuit products launched by the American company Innalabs[3] and the Vicon Motion System launched by the British company Vicon. There is also a certain development of motion capture in China. For example, Noitom, developed and designed by the Dai Ruoli team launched by Beijing company Noi Teng[4] and MMocap developed by Professor Wu coming from Research Center of Sensor Networks and Applications of Chinese Academy of Sciences[5,8].

At present, motion capture systems are widely used in the field of sports training. Ghasemzadeh et al. applied the wearable posture detection device to golf training, and collected the rotation angle of the wrist during the golf swing[9]. Sharma et al. applied the wearable posture detection device to tennis, and analyzed the action standard of each stage[10]. Samir et al. installed a wearable detection device on the athlete's arm to identify whether the athlete is throwing in baseball or hitting in volleyball[11]. Chan et al. applied wearable posture detection equipment to dance training, which is convenient for teachers to guide students to improve their skills[12]. However, at present, there are few motions capture and reconstruction systems suitable for skiing, and there is a lack of quantitative analysis of skiing, which is an important development direction for scientific skiing training. The digital representation of movement patterns during human skiing is a key step in scientific quantitative analysis.

In this paper, a wearable motion capture and reconstruction system based on inertial sensors is designed for alpine skiing, which captures and reconstructs the motion data of 11 nodes of the human body in real time. The device can be used both outdoors and indoors. The device can be used both outdoors and indoors. At the same time, combined with the multi-rigid body motion model of the human body, the human body reconstruction during the skiing process is realized. Finally, in view of the lack of quantitative analysis and evaluation research on skiing, a digital evaluation method for slalom in alpine skiing is proposed, which can be used for ski trainers to analyze sliding characteristics and assist training.

2. Wearable human posture detection device

This motion capture and reconstruction system is an independent research and development system, and its work flow chart is shown in **Figure 1**.

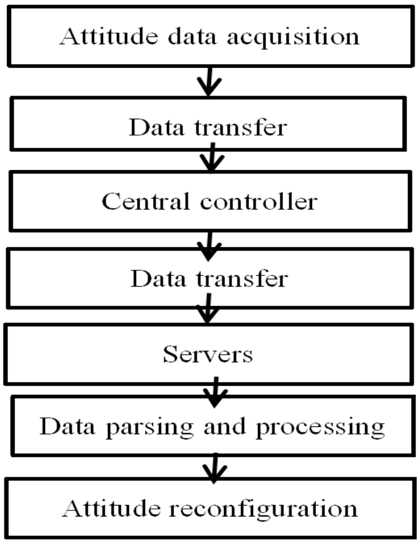

Figure 1. System flow chart.

The parameters of this motion capture and reconstruction system are shown in **Table 1**.

Table 1. Motion capture device parameters

Parameter Type	**Parameter**
number of nodes	11
Power supply	Wired connection / power bank
Supply voltage/V	3.3～5
Current/mA	<25
Size/cm	2.4×2.4×1
Output angle range/ (°)	±180
Attitude measurement stability/(°)	0.01
Data output frequency/Hz	120
Data transmission method	Wireless transmission

The 11 attitude acquisition modules are respectively worn on the 11 main nodes of the human body, and the wearing positions are shown in **Figure 2**. The hip also wears a central controller, which is responsible for receiving the posture data of 11 nodes and sending it to the server.

3. Human body modeling and pose reproduction

Human motion modeling based on inertial sensors is divided into skeleton model establishment and human kinematics model establishment. Due to the complex structure of the human body, the following modeling assumptions are made for the human body model:

Figure 2. Posture detection module wearing position.

(1) Ignore the influence of skin deformation on human movement. (2) The human skeleton is abstracted as a rigid body, and each joint defines the joint axis. (3) The joint coordinate system, the sensor coordinates system and the bone coordinate system are regarded as the same coordinate system.

Build a skeleton model containing 11 nodes and 5 parent-child inheritance relationship lines. The 5 parent-child relationship lines are:

(1) Pelvis—Chest cavity—Head. (2) Pelvis—Chest cavity—Left upper arm—Left forearm. (3) Pelvis—Chest cavity—Right upper arm—Right forearm. (4) Pelvis—Left thigh—Left calf. (5) Pelvis—Right thigh—Right calf.

The skeleton model is shown in **Figure 3**.

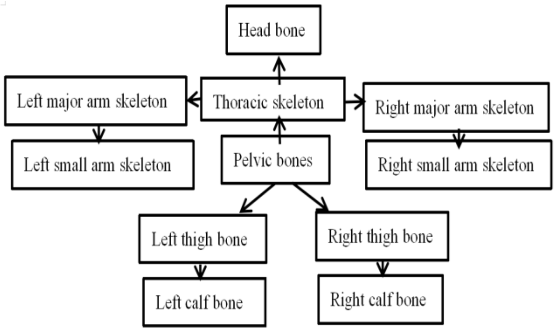

Figure 3. Skeletal model diagram.

Two coordinate systems are defined, namely the world coordinate system and the sensor coordinate system. In the world coordinate system, the X axis is the horizontal direction, the Y axis is the vertical direction, and the Z axis is vertical to the XY plane. For the Y axis, counterclockwise is positive and clockwise is negative.

After the initial posture of the human body is calibrated, the solution of the posture is mainly composed of the rotation matrix and the position matrix. The rotation matrix is expressed as:

$$R_x = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$R_y = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & \sin\beta \\ 0 & -\sin\beta & \cos\beta \end{bmatrix} \tag{2}$$

$$R_z = \begin{bmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3}$$

Among them, α, β, γ are respectively the rotation angles of the three-dimensional vector around the X, Y, and Z axes; R_x, R_y, and R_z are the rotation matrices obtained by rotating the three-dimensional vector around the X, Y, and Z axes, respectively. The total rotation matrix is expressed as:

$$R = R_x R_y R_z \tag{4}$$

The total rotation matrix is obtained from equations (1)–(4).

$$R = \begin{bmatrix} \cos\alpha\cos\gamma - \cos\beta\sin\alpha\sin\gamma & \sin\alpha\cos\gamma + \cos\beta\cos\alpha\sin\gamma & \sin\beta\sin\gamma \\ -\cos\alpha\sin\gamma - \cos\beta\sin\alpha\cos\gamma & -\sin\alpha\sin\gamma + \cos\beta\cos\alpha\cos\gamma & \sin\beta\cos\gamma \\ \sin\beta\sin\alpha & -\sin\beta\cos\alpha & \cos\beta \end{bmatrix} \quad (5)$$

When the attitude is translated, the position matrix P is expressed as:

$$P = [P_x \quad P_y \quad P_z]^T \quad (6)$$

Among them, P_x, P_y, P_z are the translations of the three-dimensional vector in the X, Y, and Z axes, respectively.

According to the actual motion of the posture, the transformation of the posture and position of the limb segment j in the joint j-1 coordinate system is represented by a homogeneous transformation matrix ${}^{j-1}_{j}\boldsymbol{T}$:

$${}^{j-1}_{j}T = \begin{bmatrix} {}^{j-1}_{j}R & {}^{j-1}_{j}P \\ 0 & 1 \end{bmatrix} \quad (7)$$

Among them, ${}^{j-1}_{j}\boldsymbol{T}$ is the rotation matrix of the limb segment j in the parent joint j-1 coordinate system; ${}^{j-1}_{j}\boldsymbol{T}$ is the position matrix of the limb segment j in the parent joint j-1 coordinate system.

Through the above analysis, it can be obtained that the homogeneous transformation matrix of joint system j in joint system i is:

$${}^{i}_{j}T = {}^{j-1}_{j}T\,{}^{j-2}_{j-1}T \cdots {}^{i}_{i-1}T \quad (8)$$

According to equation (8), the expression and conversion of the attitude in the specified coordinate system is completed.

In the specific implementation of human body motion 3D display, Unity 3D is selected as the development tool, and the motion reconstruction diagram based on inertial data is shown in **Figure 4**.

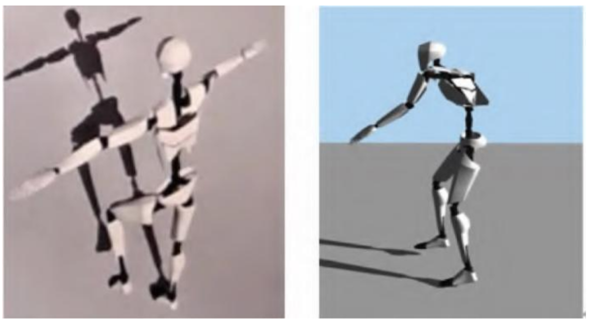

Figure 4. Motion reconstruction images based on internal data.

4. Ski aid training

The motion capture system described in this paper can be used not only in outdoor skiing environment, but also in indoor simulated ski training platform, providing skiers with analysis of key skiing techniques, and with digital scoring methods. The method can be used for the analysis of sliding characteristics and auxiliary training of ski trainers.

Taking an indoor simulated ski training platform as an example, this paper provides a digital ski level scoring method based on a motion capture system and suitable for slewing motion. The Olympic simulation ski training platform of SkyTech-Sport Company is used for the experiment, and its appearance is shown in **Figure 5**.

Figure 5. Top view of simulated ski training platform.

The trainer wears the motion capture system to perform rotary motion on the simulated ski training platform, and the motion capture system captures the trainer's posture and will be displayed in real time.

4.1. Analysis of key skiing technologies

In this paper, the process of the skier from the middle position of the simulated training platform to the leftmost end to the middle position to the rightmost end and then to the middle position is defined as a slewing movement, and the slewing speed is defined as:

$$v = \frac{R_1 + R_r}{t} \tag{9}$$

Among them, R_1 is the distance from the middle position of the simulated training platform to the leftmost position of the skier in a slewing movement; R_r is the distance from the middle position of the simulated training platform to the rightmost position of the skier in a slewing movement; t is the time required for the trainer to complete a slewing movement.

The three datum planes of the human body are sagittal plane, frontal plane and horizontal plane, as shown in **Figure 6**.

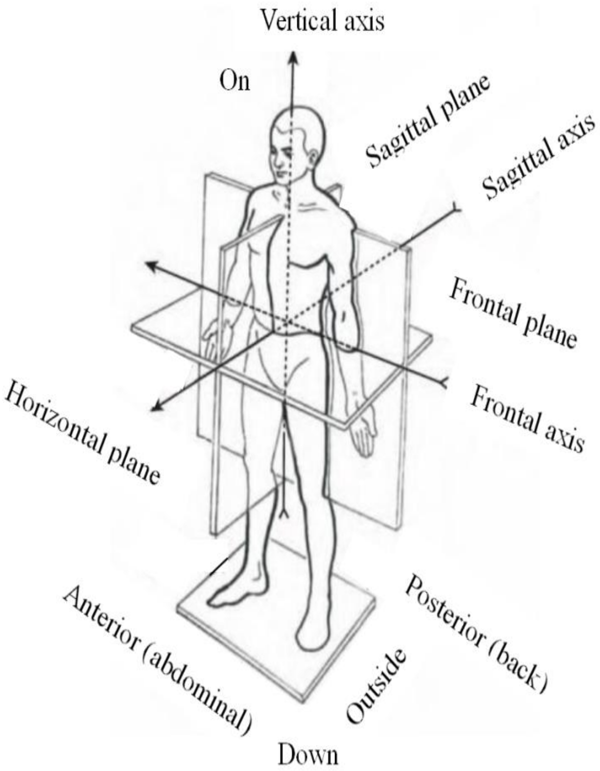

Figure 6. Human datum level.

In the experiment, the posture data of skiers with three levels of skiing, including ski instructors, intermediate skiers, and inexperienced skiers, were collected on the training platform, and the average speed of each slewing exercise was recorded.

Five characteristics that can reflect the physical fitness and skiing ability of skiers are extracted, as shown in **Table 2**.

Table 2. Table of ski features parameters

Number	Characteristic parameters	Corresponding physical fitness
1	Swing speed	Whole body coordination[13]
		Lower body Explosiveness[13]
		Knee extension[13]
2	Maximum inclination angle of the left swivel slide plate (vertical edge angle)	Lower body strength[14]
		Whole body coordination[14]
3	Maximum inclination angle of the right swivel slide plate (vertical edge angle)	Lower body strength[14]
		Whole body coordination[14]
4	Average angle between the back and the vertical axis in the sagittal plane	Upper body stability[15]
		Core power[15]
5	Maximum angle between the back and the vertical axis in the frontal plane	Upper body strength[16]
		Core power[16]

Among them, the angle between the back of the sagittal plane and the vertical axis is shown in **Figure 7.**

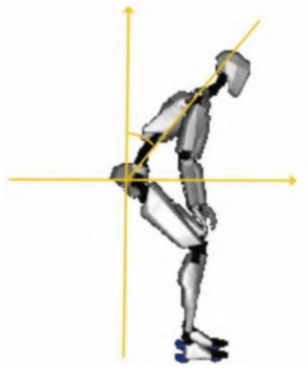

Figure 7. Angle between dorsal and vertical axis in sagittal plan.

The angle between the back of the frontal plane and the vertical axis is shown in **Figure 8.**

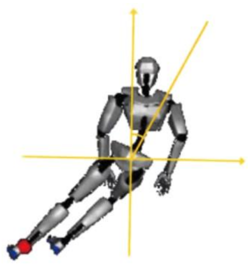

Figure 8. Angle between dorsal and vertical axis of coronal plane.

The maximum inclination angle of the skateboard, the angle between the back and the vertical axis on the sagittal plane, and the angle between the back and the vertical axis on the frontal plane are shown in **Figure 9.**

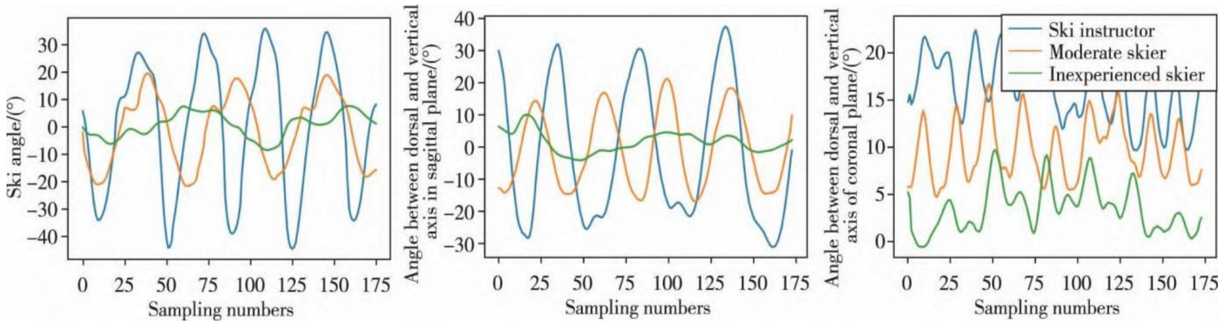

Figure 9. Skiing features of skiers at different levels.

From the data analysis, it can be seen that skiers with higher levels have better body coordination, greater explosive power of lower limbs, and greater range of motion of lower limbs, The higher the skier's level, the more stable the upper body is, the upper body leans forward and the center of gravity is pressed down, and the average angle between the back and the vertical axis on the sagittal plane is larger; The higher the skier's level, the greater the core strength of the body, the greater the left and right shaking of the upper body, and the greater the angle between the back and the vertical axis on the frontal surface.

4.2. Technologies ski level rating

This paper proposes a digital ski level scoring method suitable for slalom movements in alpine skiing.

Extract the five standard sliding features of ski instructors, and record them as y_1, y_2, y_3, y_4, and y_5 in the order of **Table 2**, and extract the sliding characteristics of any skier, and record them as x_1, x_2, x_3, x_4, x_5, the Euclidean distance method is

$$\boldsymbol{d}(\boldsymbol{X},\boldsymbol{Y}) = (\sum_{i=1}^{5}(\boldsymbol{x}_i - \boldsymbol{y}_i)^2)^{\frac{1}{2}} \quad (\mathbf{10})$$

According to the above similarity measurement results, the characteristics of the collected skiers are linearly fitted, in which the high-level coaches are scored 100 points, the intermediate-level skiers are 80 points, and the inexperienced skiers are 40 points. According to the fitting results, the final comprehensive scoring equation is obtained.

Taking the data collected in this experiment as an example, the fitting equation obtained according to the above evaluation method is:

$$S = -1.2d + 100 \quad (11)$$

Among them, S is the comprehensive score; d is the similarity measurement result.

According to this scoring method, every time the skier performs a slalom on the training platform, the system will give a real-time evaluation of the slalom. The higher the score, the closer the action is to the ski instructor.

In order to verify the feasibility of the scoring method, the experiment called 9 people to slide on the simulated training platform. Among them, 3 people were ski instructors, 3 people were intermediate level skiers, and 3 people were inexperienced skiers. Before skiing, 9 people were given subjective evaluations according to their skiing experience and level. The objective score is given by the scoring system when taxiing, as shown in **Table 3.**

It can be seen from **Table 3** that the system scoring results are all within the subjective scoring range, and the scoring method is feasible.

Table 3. Table of skiers' scores

Skater	Ski level	Subjective scoring	System Score
1	high level coach	90 ~100	96
2	high level coach	90 ~100	94
3	high level coach	90 ~100	96
4	Intermediate skiers	75~ 90	83
5	Intermediate skiers	75~ 90	80
6	Intermediate skiers	75~ 90	79
7	inexperienced skier	30~ 60	48
8	inexperienced skier	30~ 60	44
9	inexperienced skier	30~ 60	56

4.3. Ski training advice

For alpine ski trainers, this article makes the following recommendations: (1) For skiers with a slow average turning speed, strengthen knee extension exercises and lower body explosive power exercises. (2) For skiers with a small inclination angle and poor upper body stability, strengthening the muscle group strength training of the core (waist-pelvis-hip joint) can improve body stability and control through suspension training and Swiss ball training. (3) For skiers with a small range of upper limb movements during slewing, strengthen the strength exercises of the upper limbs and the waist and abdomen, and enhance the ability of the upper limbs to drive the movement of the lower limbs through exercises such as pull-ups and push-ups.

5. Conclusions

This paper designs and builds a motion capture and reconstruction system for alpine skiing. The main contributions and significance are as follows:

(1) Design and build a human motion capture and attitude reconstruction system based on wearable MEMS inertial measurement unit, and combining the multi-rigid body motion model of the human body, the human body reconstruction in the skiing process is realized, which provides a data basis for the in-depth analysis of the performance of alpine skiing. (2) Innovatively propose a quantitative extraction algorithm of key technical indicators for the analysis of the slewing action level in alpine skiing and a digital evaluation method based on key technical indicators to provide data support for scientific analysis of sports level and auxiliary guidance of sports training. In the future, on the basis of the motion capture system, data collection and processing technology can be further studied to deepen the refined training guidance of high-level players. (3) According to the different characteristics of ski trainers, put forward targeted training suggestions to help trainers improve their special abilities.

Conflict of interest

The authors declare no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Kinematic and kinetic analysis of transfemoral prosthesis

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ABSTRACT

The feasibility of using transfemoral prosthesis Otto bock with 3R80 knee and articulated ankle1C30 "Trias" was analyzed from the perspective of dynamics and clinic. The kinematic and kinetic study of gait were performed on 5 amputated volunteers and 5 controls using videography techniques and force platform. Kinetic asymmetry gait is one of the main causes of hip joint degeneration. Combining kinematic and kinetic variables, we can draw important conclusions related to the dynamic imbalance of the main causes of hip degenerative diseases through the clinical trials of radiography film and density measurement, which has become an important tool to evaluate the feasibility of prosthetic design.

Keywords: transfemoral prosthesis; kinetics; osteoporosis; osteoarthritis

1. Introduction

In patients with transfemoral amputation, the use of prosthetics will significantly change the biomechanics of their musculoskeletal system, consisting of its tendency during daily activities to recharge their intact limb, all of which can determine the occurrence of related diseases, such as knee and hip osteoarthritis of healthy limbs[1–5]. In most cases, insufficient mechanical stimulation associated with the bone remodeling process of amputated long bones can lead to osteoporosis and subsequent osteoporosis[3,4,6,7].

Scientific research in this field is increasingly related to the altruistic purpose of designing these devices[2, 8–13]. The ideal solution of this method is to study these design skills and methods. No wonder some researchers[5,14–17] have linked traditional terms such as comfort, mobility, mechanical strength and durability to comprehensive criteria to evaluate the suitability of prosthetic design. The authors believe that the functionality of lower limb prosthesis is usually related to the functional and well-being needs of amputees. This kind of well-being is mainly related to the gait pattern as close to the healthy limb as possible. with a minimal energy consumption and with the absence of disease in the residual joints caused by the prosthesis during the gait regimen.

In this study, we propose a method to evaluate

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OTTO BOCK transfemoral prosthesis, which combines kinematic and dynamic gait studies of amputated volunteers and control group; combined with clinical Radiography and density measurement, important conclusions related to prosthesis function were obtained. For this purpose, the temporal and spatial variables of gait, kinematic and kinetic patterns (moments, forces and joint energy consumption), limbs (amputated and non-amputated) and the same number of pattern subjects of 5 amputated patients were measured and deduced. Finally, these results are clinically treated by Radiography technology to find signs of limb osteoarthritis that may be related to amputation and ambulation of amputees[1,18], and densitometry, a technique that allows mineral density to be measured (Bone mineral density, BMD)[19].

2. Materials and methods

2.1. Subjects

In the two groups of subjects, the amputated volunteers and the control group were characterized by gait. The transfemoral amputated patients used Otto Bock prostheses, with keen modal 3R80 and flexible foot modal 1C30 "Trias", were 5 men with an average age of 32 ± 2 years, height of 1.75 ± 0.09 meters, weight 80 ± 10.97 kg. The control group consisted of five men whose age, weight, height and eating habits were similar to those of amputees. None of the subjects (patterns and amputees) had orthopaedic, neurological, cardiovascular or respiratory problems prior to the study. Before the test, all prostheses were thoroughly inspected, and the adjustment of each joint and the correct alignment of the prosthesis were checked. None of the subjects had any discomfort with their health and residual limbs, such as joint pain, motor stiffness, ligament instability, etc. The characteristics of volunteers are shown in **Table 1**.

2.2. Protocol

During the study, the subjects wore dark tight clothes and fixed reflective markers (0.02 m in diameter) affixed to the left and right iliac crest, greater trochanter, femoral epicondyle and lateral malleolus and L5-S1. For patients on the amputated side, according to Helen Hayes's labeling scheme[21,22] (see **Figure 1**), the reflection point of the preset area (center of gravity, joint or other signal to obtain the required characteristics) is estimated according to the corresponding position on the healthy limb. Each volunteer developed a walk of about 6 meters for the measurement, with a free cadence of 20 repetitions.

Table 1. Characteristics of the amputation volunteers included in the study

Volunteer	Age (years)	Amputation year	Daily use (hours)	Dimension (m)	Weight (kg)
1 (I)	28	8	10	1.72	80
2 (I)	32	14	8	1.79	82.5
3 (D)	30	14	10	1.83	72
4 (D)	47	16	6	1.73	81
5 (D)	65	15	8	1.78	87
Average value	58	13	7	1.77	80

I: Left leg amputated
D: Right leg amputated

Figure 1. Location of reflective markers for gait analysis based on Helen Hayes marking protocol[21,22].

2.3. Material

These studies were conducted at the Gait Analysis Laboratory at the University of Brasilia (UNB) (see **Figure 2a**). The gait cycle is recorded through the professional software package Qualisys Motion Capture System in Gothenburg, Sweden, and then the data is transmitted to the computer. The processing of mark identification gear is carried out through the Qualisys Track Manager package, QTM, Gothenburg, Sweden[23]. It is an analysis software tool for managing and reporting video data. Together with high-speed motion video, QTM provides an advanced and accurate solution for biomechanical motion analysis (**Figure 2b**).

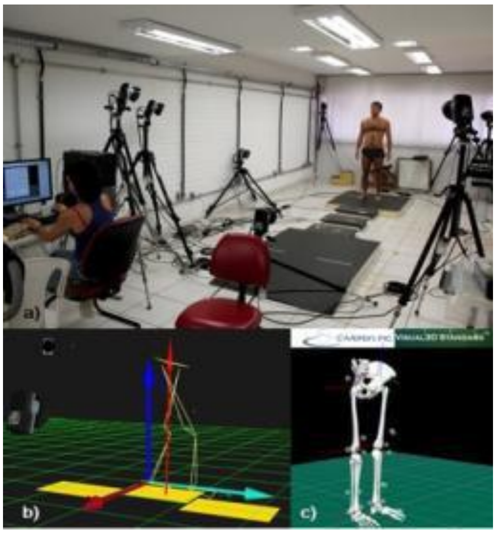


Figure 2. (a) Gait Analysis Laboratory at the University of Brasilia. **(b)** QTM software environment. **(c)** Conventional model of the lower limbs in visual 3D software (C-Motion).

After preprocessing, the data is exported to visual 3D v4 (C-Motion Inc., Germantown, MD, USA) for analysis and remaining gait processing. In visual3D, the traditional lower limb model is reconstructed (see **Figure 2c**), from which the reverse dynamics analysis is carried out to determine the angular displacements, torques and forces of the joints.

The data collections of amputees and healthy people were based on sagittal and frontal planes, which show the maximum displacement[24–26], as well as the values the components of the reaction force of the floor (vertical and anteroposterior) to facilitate the comparison between both limbs and the asymmetry of gait cycle.

2.4. Clinical trials of densitometry and radiograph

The bone densitometry results report provides the average bone mass values for each scan and measurement area, and uses digital and color images to link these average values with normal values based on the patient's age and gender. It is the main diagnostic tool for osteoporosis, so the risk of fracture can be determined.

Test results are usually reported as "T-scores".

The prevalence of osteoporosis and osteoporosis is estimated according to WHO classification. The test results are usually reported as "T-score" using the database referring to young people[27] (normal: T-score ≥1, bone mass reduction −1 to −2.5, and T score lower than −2.5 indicates osteoporosis.

According to clinical practice, the routine radiography examination was carried out for these cases, and all patients were examined. The technique used was to compare the anterior hip with the lateral femoral neck[28].

3. Results

3.1. Gait analysis

Table 2 shows the spatiotemporal variables generated by gait analysis of non-amputees and amputated subjects.

Table 2. Spatiotemporal variables of non-amputated and amputated subjects

Variable	Non-amputated subjects		Amputated objects			
			Complete state		Otto bock prosthesis	
	Average value	From	Average value	From	Average value	From
Operating speed (M/s)	1..177	0.319	0.986	0.281	0.986	0.272
Cycle length (m)	1.327	0.027	1.049	0.318	1.013	0.319
Step length (m)	0.670	0.023	0.579	0.021	0.653	0.039
Support time (s)	0.872	0.024	0.829	0.024	0.752	0.021
Rolling time (s)	0.455	0.022	0.418	0.013	0.501	0.012

From the spatiotemporal variables of the subject patterns of the two prosthesis types, it can be seen that there are significant differences in the spatiotemporal variables of the subject patterns of the two prosthesis types compared with the intact and amputated limbs of patients with transfemoral prosthesis. From the results obtained, it can be concluded that the speed and length of gait cycle of amputee subjects are lower than that of standard subjects. In this sense, the length of the steps is somewhat similar to the pattern.

Figure 3 summarizes the angular displacement of ankle, knee and hip joints, as well as the behavior of joint moments and energy consumption of two groups of subjects (patterns and amputees).

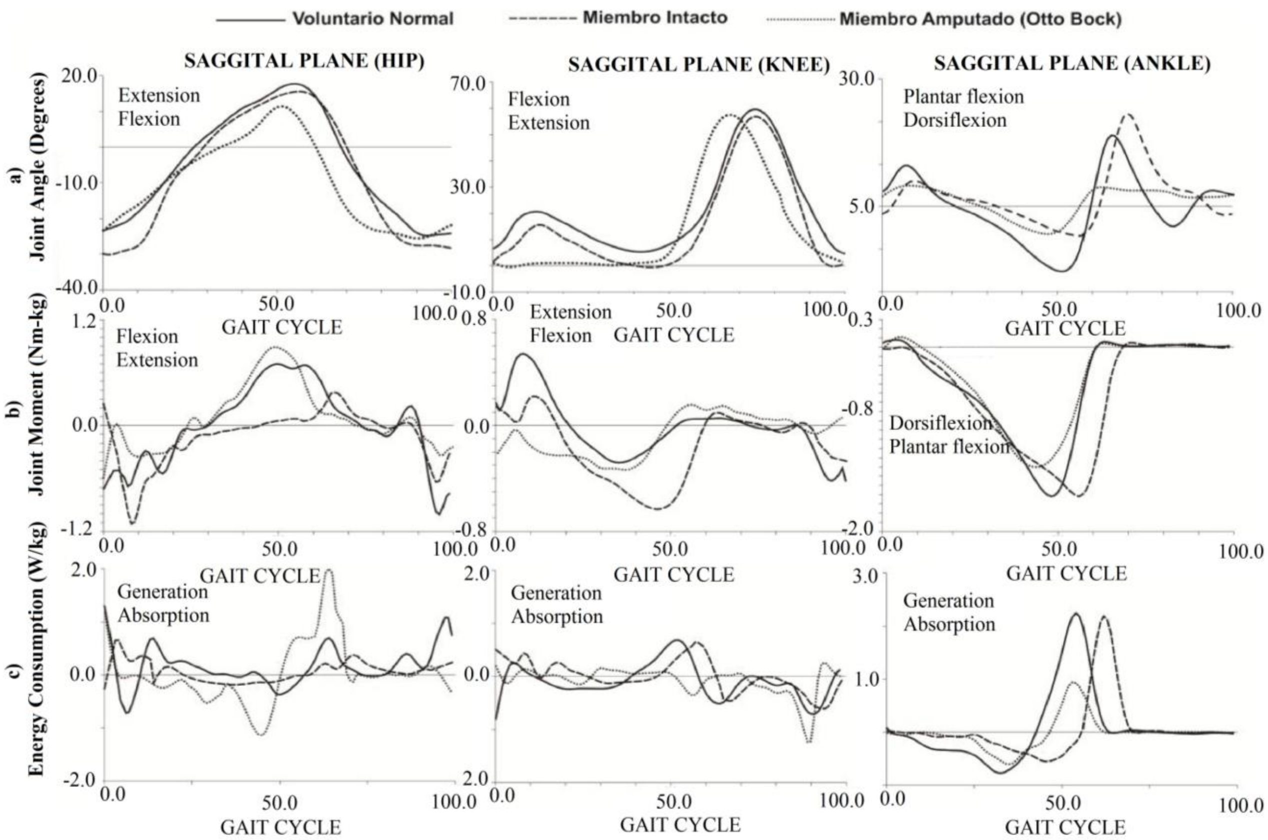


Figure 3. Angular and kinetic models for the standard subjects, intact and amputated limb of the transfemoral amputees. **(a)** Angular displacement of hip, knee and ankle. **(b)** Joint moments. **(c)** Energy expenditure.

The angular displacement of ankle joint has a pattern composed of an initial peak for normal people. In the standard subjects, the plantar flexion reaches about 10°, passing to dorsiflexion of about 15° at 53% of the cycle; finally, during the swing phase, the new plantar flexion of about 16° (68% of the gait cycle). In the intact limb of the amputee, the plantar bending is slightly smaller (5°), and then passes to dorsiflexion with a peak of about 7–8°, which has a certain delay compared with the control group. In the swing stage, there is a certain delay compared with the control group, experiencing a new plantar flexion, with a peak of 20° over 72% of the gait cycle.

In the amputated limb, the general spatiotemporal pattern includes a behavior of plantar flexion (≈ 5°) that is very similar to the that of the intact limb, and the posterior dorsiflexion also of the same amplitude as the intact limb, but that occurs only at 50% of the cycle, immediately transitioning to plantar flexion with a constant amplitude of only about 5° throughout the swing phase.

The angular displacement of the keen both for the standard subjects and for the intact limb of the amputees showed two important peaks. In pattern subjects, the first peak appeared in the support phase, accounting for 15% of the gait cycle, with an amplitude close to 20°, and the second peak appeared in the swing phase, accounting for 57°at 72% of the cycle. The intact limbs of amputees have similar behavior to some extent, with a certain delay and a slightly smaller amplitude.

However, the amputee's knee remained extended for almost the whole support phase, and then flexes at the same amplitude as the intact limb in the swing phase, but at 65% of the cycle, confirming that the amputee relied on the healthy limb for the longest time during walking. Without this slight knee flexion, dynamic shock increases.

As for the standard subject's hip joint, it showed initial flexion during the support of about 20°, and then extended for a long time for the rest of the support phase, with a peak extension of about 15°, and then was in a flexion state during the swing at the end of the cycle (80%). The amputee's intact limbs have similar behavior.

However, there are some differences in the behavior of the patterns and the healthy limbs of amputated hips. Although the initial flexion is no different from these, it maintains a longer support period during flexion and then extends to 8°. The time lag (top 10% of Health) confirms the argument that these patients rely on healthy limbs most of the time. The angular range of the displacement of the amputated hip joint relative to the healthy hip joint is significantly reduced, which is related to the temporary compensation mode due to the amputated valgus in the swing stage, so as to avoid rubbing the floor with the foot in the middle of the stage. The low angle motion of the hip joint is related to this and to the greater lateral swing of the trunk.

With regard to joint moment, for the ankle joints of standard subjects, they showed a small dorsiflexion moment at the beginning of support, which lasted for a short time, about 0.1 N.m/kg, and quickly transformed into a plantar flexion moment with a peak value of 1.6 N.m/kg (50% cycle), which gradually decreased to zero at 60% of the cycle.

The joint moment of healthy limbs of amputees showed a very similar pattern, except that the peak plantar moment with the same amplitude as that of standard subjects appeared at 60% of the cycle, that is, there was a certain delay compared with standard subjects. In contrast, the amplitude of the prosthetic limb was low (1.4 N.m/kg), with a delay of about 18% compared with the healthy limb.

The behavior pattern of knee moments showed that the extensor moment of the healthy subjects was 0.5 N.m/kg, which was slightly higher than that of amputated patients with intact limbs (0.2 N.m/kg), which showed a certain delay. The next peak, this time, was more pronounced for the amputated intact limb than for the control volunteers (0.65 N.m/kg and 0.2 N.m/kg, respectively). In both cases, the subsequent extended behavior has very similar behavior, gradually approaching zero.

However, the amputated limb shows a behavior different from the standard and intact limb, which is easy to understand from the angular displacement of the prosthetic knee joint. As observed, the flexor moment generated by knee hyperextension is logical, and then the flexor moment is increased to 0.3 N.m/kg, which is higher than that recorded by standard subjects, but much lower than that generated by the intact limb (0.653 N.m/kg), which is an important reason for the gait asymmetry of amputees.

With regard to the pattern of hip moment, the extensor moment was 0.3 N.m/kg in 16% of the cycle, then became the flexor moment with a peak of 0.7 N.m/kg (50% of the cycle), then gradually decreased, and the pattern was repeated at the next heel strike. At the beginning of the support, the intact limb has an extension peak of 1.2 N.m/kg, which gradually becomes a flexion moment at the end of the support phase (maintaining the extension for most of the support phase) with an amplitude peak of only 0.3 N.m/kg.

During heel support, the hip joint of the amputee is stable at about 0.3 N.m/kg, and is transformed into a flexor moment with a peak of 0.9 N.m/kg at the end of the support stage to gradually reduce.

The uneven kinematic and kinetic behaviors between the amputated and non-amputated limbs reflect the compensation process in the process of amputated walking, showing obvious asymmetry.

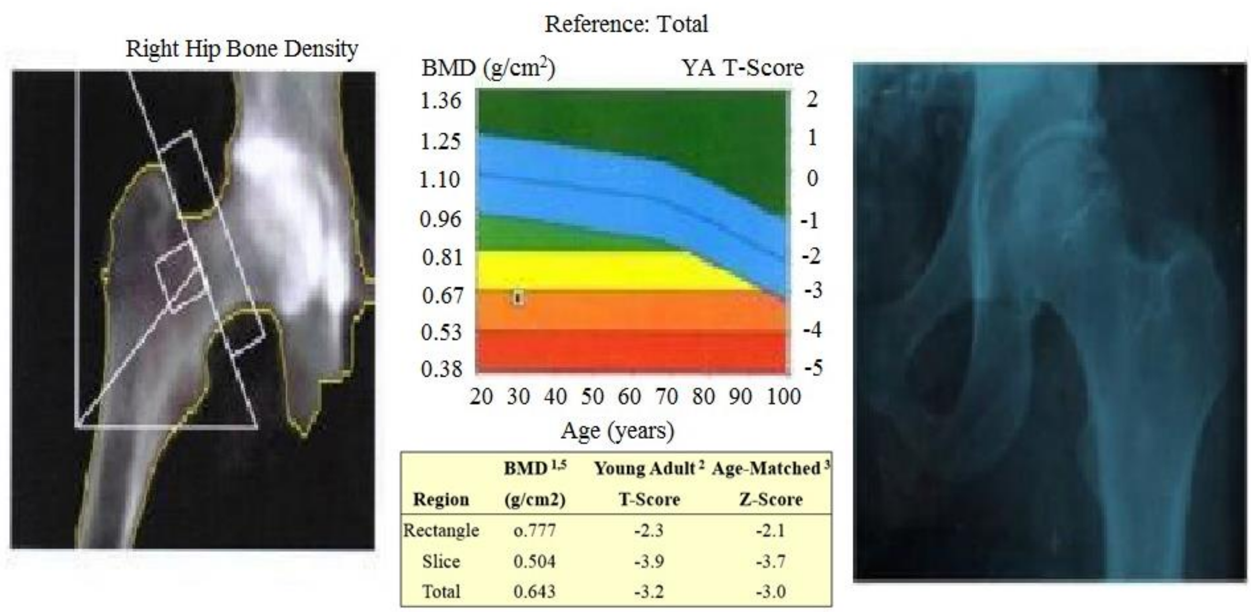
In terms of energy consumption, the results show that the mode of ankle joint is different in peak amplitude and development time, which is consistent with the above kinematic and dynamic behavior explained. The peak energy absorption of intact limbs of standard subjects and amputees corresponds to the value of 0.7 W/kg. The only difference is that the latter occurs in 50% of the cycle, that is, there is a certain delay compared with standard subjects. This behavior has similar characteristics at the end of support, because they produce a peak of 2.2 W/kg, and the delay of intact limbs of amputees is 10° (≈ 60% of the cycle). At the end of the support phase, the amputated ankle produces a peak of only 1W/kg, corresponding to the smallest plantar flexion.

For the knee joint, the resulting energy consumption showed a very similar pattern for the standard subject and the intact limb of the amputee with peak value very similar to heel shock and delayed -off for the intact limb in about 0.3 W/kg and 0.8 W/kg. For the amputated limb, when supporting, taking off and swinging, the power generation is low and the consumption is large.

As for the energy consumption of the hip joint, it is characterized in that the subjects control the two power generation peaks corresponding to heel support and take-off. For the intact limb of the amputee, during the heel support process, the peak is consistent with the pre-formed pattern of the subject within a certain period, and is delayed with the take-off of the foot. For the hip joint of amputated patients, the absorption and energy production levels are always much higher than those of standard subjects and intact limbs of amputated patients, with peaks of 1 and 2 W/kg.

3.2. Clinical study of bone mineral density measurement and radiography examination

The study was conducted in amputated volunteers (see **Figure 4**). Only 2 of them developed osteoporosis during amputation, and in no case did they find clear joint damaging osteoarthritis in healthy limbs.



Region	BMD [1,5] (g/cm2)	Young Adult [2] T-Score	Age-Matched [3] Z-Score
Rectangle	o.777	-2.3	-2.1
Slice	0.504	-3.9	-3.7
Total	0.643	-3.2	-3.0

Figure 4. (**a**) The density measurement of a 30-year-old and 14-year-old amputee showed that the amputee had obvious osteoporosis. (**b**) The radiography of the patient's non-amputated limb showed a significant lack of joint injury.

4. Discussion

The recording results of support and balance time show that during walking, amputee volunteers support their intact limbs longer than amputee volunteers, which has been reflected by other research work[9,12,13,29], and which is a clear sign of gait asymmetry and affects the pathological detection of amputee volunteers' intact limbs and stumps[4,6,30]

In general, all joints of the intact limbs of amputated volunteers describe trajectories similar to those of control volunteers, although at some peaks, the delay time is longer and the amplitude is lower, which has been reported by the authors[8,31,32] and other researchers[33–35].

The prosthetic knee remains extended throughout the support phase to bend during swing, but with10 degrees advance to the healthy one, which confirms the shortening of support time. Without this slight knee flexion, the dynamic shock increase.

As shown in the figure, the results of densitometry and radiography examination show that the asymmetry of transfemoral prosthesis is largely the cause of premature lesions in both limbs. However, in some amputated volunteers, the occurrence of osteoporosis and osteoarthritis depends on dynamic factors affecting the process of bone reconstruction, such as gait speed, step length, especially during support and swing time.

Although the literature[4,35] mentioned the presence of osteoarthritis in non-amputated limbs, no conclusion has been drawn in this study because the amputated patients studied did not have this pathology. A study involving more patients will help determine the extent to which the prosthesis is involved in these diseases.

5. Conclusions

The gait analysis of amputees showed that there were significant differences in gait patterns between healthy limbs and amputees compared with healthy patterns, and only prosthetic volunteers related to support and swing time had significant differences, which confirmed that amputees leans longer on healthy limbs than on the amputee during walking.

Gait research provides a very important detail for amputees using 3R80 knee joint, that is, the significant abduction of the amputated limb and the corresponding pelvic inclination.

The results of densitometry and radiography examination can determine the changes of mechanical stimulation in different areas of the two limbs and estimate the presence of osteoporotic areas in the absence of mechanical stimulation. However, in these dynamic stimuli, the effects of variables such as support and swing time and walking speed need to be considered. Combined with the methods used here, we can establish a standard of prosthetic function, which is considered to be a method of artificially designing close to healthy limb function without involving the occurrence of corresponding diseases.

Conflict of interest

The authors declare no conflict of interest.

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Original Research Article

Competitive advantage of wearable technology in sports training

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ABSTRACT

This document outlines wearable technology and the sources, related topics and authors of major publications on this subject in recent years. It is worth mentioning that wearable or wearable technology is also called "wearables" in English. It refers to theincorporationation of microprocessors, sensors and transducersthat we wear daily, which acts as a computer that always works with users, and can be used in a defined space for continuous interaction with users, wearable technology can be defined as an electronic device that can be embedded into human body to continuously obtain information. The purpose of this paper is to understand the development and current situation of this new technology, and apply it to new research findings and the development of wearable devices. The disciplinary connection between different knowledge fields provides a clear starting point for the development of research topics. In specific case of interest, the research focuses on the devices applied to sports, which are used to analyze the strength, flexibility and speed of athletes' lower limbs, and generate sports evidence related to numerical data, so as to further analyze, explain and produce conclusive results. Electronic engineering performs all data processing similar to electricity, thus defining a part of wearable design for adaptation during physical activity. In the field of programming, system engineering is very important for the data conversion of sensors and the representation of these data in a way that people can understand. This new technology allows the generation of a wide variety of data, but integrates multiple disciplines at the same time. With the understanding of sports, people will test the complex problems around the human body and how to correctly explain the results of clothing elements that can be designed technically.

***Keywords*:** Internet of Things; wearable; electronic devices; microprocessor; multitasking; smart watch; health monitoring wristband; wearable; wearable technology; GPS sneakers

1. Introduction

The technology in wearable components is gradually increasing, enabling us to take actions thatdecades ago or even in recent years could not have been imagined. Wearable devices are generated from these new technologies which are considered to be portable electronic devices embedded in some part of an individual's body. These devices have sensors that can calculate data, such as measure brain waves or the number of daily walks, a person's sleep. Wearable technology mainly focuses

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on monitoring a person's physical activity for medical care, but there are several wearable electronic devices with various functions on the market, some of these are: Pebble, Fixbit, Google for android wear, Jawbone. Among the different types of wearable devices that may exist, the most used are:

-Wearables for sports: They measure biological variables, most commonly heart rate and calories consumed.

-Wearables for health: They are the ones thatmonitor medical variables such as glucose, blood pressure and cholesterol.

-Wearables for daily use: They speed up daily activities, allowingvarious functions such as voioce recognition.

2. Current situation of wearable technology

The emergence of internet and the development of new technology make it possible for clothing elements to establish communication with public or private databases, which is an important way to establish man-machine relationship; allowing tohave different devices in our daily life to promote different tasks and improve the quality of life. Therefore, the Internet of Things (IoT) has consolidated the technological progress for the monitoring of micro-integrationwearable devices, miniaturized digital components that can be carried without being perceived, and at the same time contain communication interfaces.

The technology began with abacus rings made in China in the 17th century. In 1961, a group of MIT students built a computer inside a shoe in order to cheat in a roulette wheelinLas Vegas casinos. Followingto this appears Steve Mann, the predecessor of Google Glass. He is recognized as one of the leaders in the field of wearable computing[1].

At present, wearable devices can be found in different fields such as health, safety and sports in the global market. Google has launched a new innovative product on the market, called Google Glasses, which is controlled by voice commands and provides a screen that displays the information required by users. The tool also allows you to capture images and record video in high definition.

In the medical field, wearable elements with sensors are being developed to monitor the glucose level of diabetic patients and control diabetes by automatically injecting the required amount of insulin, so as to obtain the general health data of patients.

2.1. Projectionof wearable technology in Colombia

The internet and other information and communication technologies have contributed to social growth and connectivity between cites in the country. Although government agencies such as Colciencias try to promote the implementation of technology projects, the investment impact of encouraging researchers to develop projects that directly combine engineering and health is not extensive. However, the application of wearable technology in colombia has begun, as described in search on the Publinde platform[2]. The competition of large international research groups in providing wearable technology devices is obvious. This statement is based on relevant publications, and then the feasibility of putting the theoretical model into practice and commercialization. Some previous theoretical suggestions are now easily related to early entertainment applications, which are realized through bracelets or monitoringwatches called "smartwatch".

By searching on the Publindexplatform [2], with the search formula: Wearable Technology, the following is related publication:

Magazine: *Electronic Vision*, publication title: Wearable device with frozen gait of parkinson's disease in 2019. According to Publidex, in Colombia, the proportion of articles published under the concept of wearable technology is very low, because some categories are related to other similar search criteria and belong to the scope of engineering and health science keywords. Although the Publindex database does not provide information with bibliographic analyzer functions such as SCOPUS or Web of Science, it allows us to observe some topics related to the proposed topics, which focus on the regional background.

3. General query in database for wearable technology

Quering in SCOPUS[3,4] by searching for wearable and technology, we found that China and the United States are the countries that have most publishedon wearable technologies, followed by the United Kingdom, there have been a total of 28,874 articles related to this topic.

With regard to the number of publications and their publication dates, we can note that the number of publications increased between 2012 and 2014. As a background, it can also be said that this is the result of the rapid development of technology and the increasing number of researches.

Year↓	Documents ↑
2020	1622
2019	4295
2018	3997
2017	4224
2016	3250
2015	2760
2014	1067
2013	597
2012	409

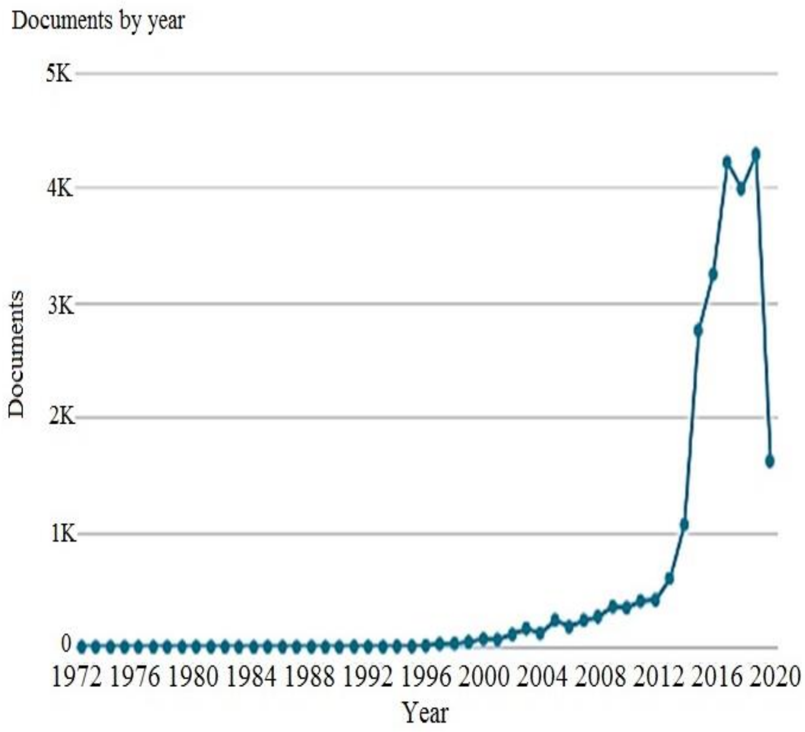

Figure 1. Matching search of wearable technology.

Source: SCOPUS

It can be seen from **Figure 2** that the relationship by the type of topics is also growing, that's to say that, if we talk about health technologies in 2011 and 2012, an ascending curve begins that identifies the starting point of the interest of researchers, for they show their results with the publication that relate each line and work theme. We can also discuss topics related to wearable technology, such as artificial intelligence and computing science applied for bioengineering.

From the author's relevant search, we can find that Wang ZL in China is the most published author on wearable technology, followed by BeniniL. From the origin of the authors in **Figure 3**, some of them are of oriental origin, which leaves a picture and imagination for the readers of this article, that is, where may be the largest production place of wearable technology now and in the future.

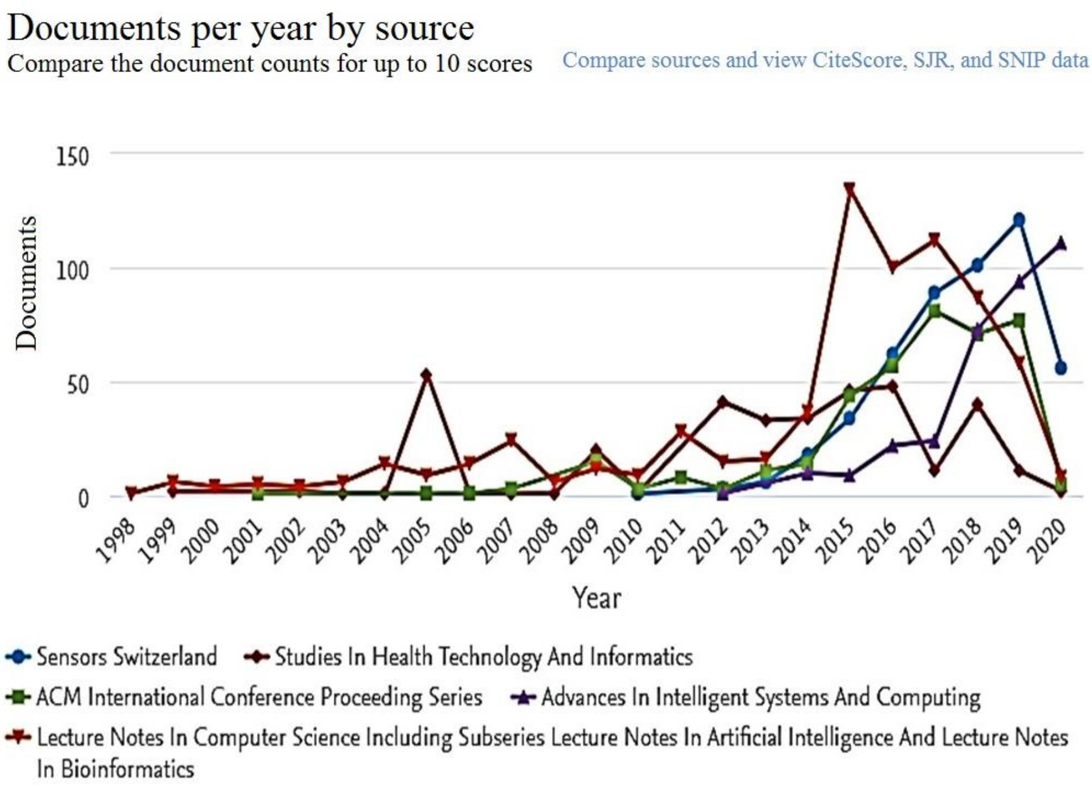

Figure 2. Documents by source and year.

Source: SCOPUUS

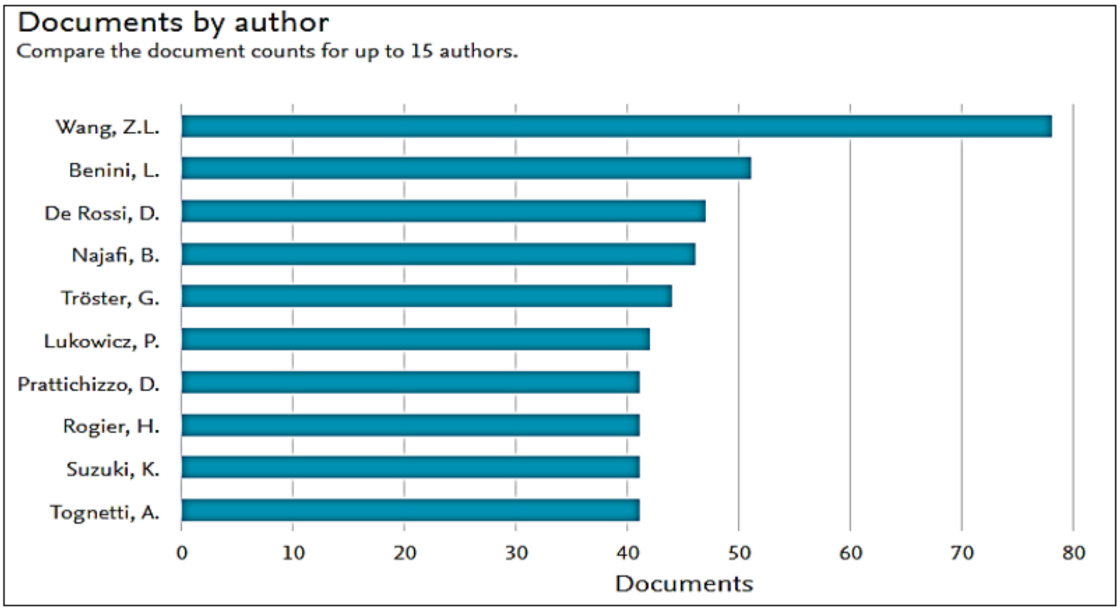

Figure 3. List of authors and number of publications.

Source: SCOPUS

4. Wearable technology and wearable devices

The concept of "wearable" can be translated into "wearable", "dressable" or "usable". That means you can wear it. Wearable technology is defined as an electronic device designed to be wearable as any supplementary element in clothing or accessories.

At present, the abbreviation WT is used for "Wearable Technology", and relevant devices WD is used for "Wearable Device"[5].

Wearable technology can perform various tasks performed by computers and mobile devices, but this technology is more complex because it uses sensors that can interact with users and their environment.

An important feature of wearable technology and wearable devices is their wireless connection ability, which enables users to always obtain real-time information.

The purpose of wearable technology is to access electronic devices in a stable, easy to access, transparent and innovative way in people's daily life.

4.1. Terms related to wear resistance technology

The following is a list of terms related to WT and WD and other terms that refer to other concepts.

- Tech togs: Refers to clothing elements with built-in technology, allowing connection.
- Fashionable technology: Technology of fashion, which is considered to be an element of technical clothing, but is more inclined to design and appearance.
- Fashion electronics: Electronics of fashion, which is similar to the above concept.
- Soft circuit: Refers to the use of soft materials, such as conductive fibers, using circuits and sensors as clothes.
- E-sewing: Electronic sewing, which refers to the concept similar to the above, that is, using conductive wire instead of textile thread to manufacture clothing.
- E-textile: Electronic clothing. This term refers to clothing with embedded electronic devices.
- Ubiquos computing: Ubiquitous computing, refers to the operation of executing wearable technology to obtain the basic functions of the computer, no matter where or when the computer is located.
- DIY wearables: Homemade devices. This term refers to devices specially designed to load them and perform functions during data collection, connection and other operations.

4.2. Wearable technology attributes

In his article[5] in 1997, Steve Mann proposed eight basic attributes that a specific device must have in order to be regarded as wearable technology:

- Constant: It may have some kind ofsleep mode, but the device must be awake.
- No restrication for the users: Users may be performing different activities, and the he himself should not interfere.
- They do not monopolize users' attention: Using it should not isolate users from the outside world.
- User observation: can be configured to generate notifications or alerts.
- User controllable: the user can fully control the equipment at any time.
- Pay attention to the environment: Environmently friendly.
- Communicating with others: It can be used as a medium of communication or expression at any time of need.
- Personnel: It can only be controlled by someone other than the owner. If the owner authorizes it, it must be inseparable from the body.

4.3. Advantages and disadvantages of wear-able technology

Wearable technology aims to make full use of all the advantages of technological progress in recent years.

- Wearable technology aims to improve the quality of life of anyone who decides to use it, because it is not only suitable for the consumer market, but also focuses on the fields of medical treatment and nutrition.
- Using wearable devices to store information, in addition to transmitting and processing information, it also allows to store local information or perform real-time synchronization on the network and other devices.
- Low radiation because these devices are characterized by very small size and produce less radiation than other portable devices.
- It has multiple application fields, because wearable technology uses the latest technological innovation, which helps it occupy a lot of space in the market and generate competition, thus contributing to the improvement of products.
- Multi-sensor devices, such as the well-known wearable technology, are also characterized by obtaining real-time data to produce continuous measurement of measured parameters.
- It is transparent to users. Because wearable technology has the great advantage of interaction between users and real-time environment, the system will act as a hands-free device.
- Compared with mobile phones or tablets, wearable devices have lower weight and have no weight problem.
- Combined with fashion, wearable technology is characterized by the combination of fabrics and fashion items designed for wearing, so that this technology can be combined with our clothes.
- Wearable devices with high configuration level have the advantage of high configurability, allowing users to change various parameters by enabling or disabling functions, so as to allow the presentation of data.
- The exclusion of technology and the ignorance of society about this new technology show the natural exclusion of change.
- Privacy, information that users don't know what they do with is unsafe.
- Due to technology dependence, users may refuse to use these devices for fear of technology addiction.
- Distrust. If you use any of these devices to provide users with incorrect or incomplete information, you will have distrust when you use the device again.
- Due to the lack of practicability, users may not see the functions of these devices because they find that this new technology has nothing to do with their daily life.
- Lack of consistency, if users intend to use this device occasionally, rather than as a necessary use in daily life, they will find how useless it is.
- High prices, the high prices of these devices, because of their innovation, make the public see that it is too expensive to reach their market consumption.
- Battery duration and charge, these devices show good charging duration, although they are small, and considering that they need a continuously activated interface.
- Due to the problem of heat dissipation, many devices are heated due to long-term use, which limits their durability and practicability.

4.4. Application of wearable technology

Accessories and complements: Watches, rings and bracelets that are activated by identifying fingerprints. These devices store information in people's daily life[6], as shown in **Figure 4**: Heart rate, mileage, sleep time, accelerometer and gyroscope information.

Figure 4. Accessories and complements.

Source: author

Safety: Wearable technology aims to greatly improve work safety. At present, a fire helmet is being designed to monitor oxygen level and temperature so that the users capable of withstanding in the event of a fire. In addition, it is equipped with GPS to locate users in the user's location.

Figure 5. Security.

Source. website: https://blue2310.tistory.com/1462

Textile industry: Clothes that can measure the baby's body temperature and send an emergency message when it exceeds normal body temperature. The utility model relates to a sportswear, which provides support for users to perform the appropriate movement for a certain sport

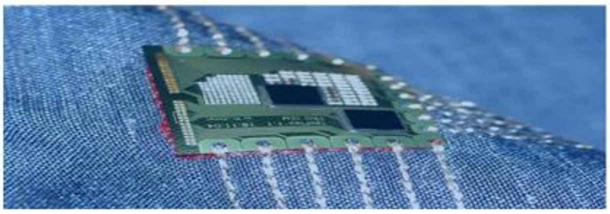

Figure 6. Textile industry.

Source: website. https://url2.cl/lfsnb

Fashion: Design clothes that can shrink or move to avoid users' replacement, so as to save time; discolored clothes, built-in energy-saving solar panels to ensure that smartphones will not run out of batteries.

Figure 7. Fashion.

Source: author

Drugs: Although more research is under way in this field and many devices have not been implemented, wearable technology has completely changed this field. For example, a sensor capable of controlling the glucose of diabetic patients has been developed so that the electronic distributor can inject the precise amount of insulin required by patients.

Figure 8. Drugs.

Source: https://www.dispositivoswearables.net/

5. Discussion

According to the number of papers published so far, it is worth noting that the publication rate of papers has increased since 2012, but the papers directly related to computer science, artificial intelligence and electronic progress reached the highest level in 2015. Since then, the number of publications has increased. In the past five years, the output has increased, showing an exponential curve in some cases, in 2019 and 2020. It has been published the most in recent years.

Through the investigation of the current situation of wearable technology in the world and considering the different applications provided by wearable technology, this is the starting point for starting the theme that has not been fully explored. Therefore, the theme is to implement devices oriented towards monitoring in the human body through wearable technology, which allow to understand the movement of lower limb joints, generate physical activity records, and analyze flexibility, strength and speed variables[8,9].

Through the exploration of this paper, the importance of the contribution of the field of health and engineering to the development of new equipment is explained. Based on this observation, the strategic need to combine three different knowledge sectors was identified, namely: System engineering, electronic engineering and sports[11]. Now the discipline of Santo Thomas University focuses on the research and development of new wearable technology devices.

6. Conclusions

The research carried out enables people to unknow and understand the progress made by wearable technology over time and its important applicability in the daily life of a new generation, so as to build a productive and integrated society. On the other hand, it was pointed out that despite the wide range of applications of these technologies, many innovations had not been carried out as expected due to the advantages and disadvantages of their implementation, but the implementation of these technologies was being sought to expand career and job opportunities and promote activities in the health sector.

The research scope of wearable technology is very wide, which has been proved by many publications in recent years. Most publications are interested in business trends, which open the door for research and publication in the field with more academic background and more in line with human life needs. If social methods can be adopted in this field, they can improve people's quality of life.

Physical culture and sports are the areas where wearable technologies are applied and used most. Despite this reality, there are still a large number of publications dealing with applications in use and commercial applications. The research group has a lot of room for work. They hope to continue to make new suggestions related to such technologies and establish new publications with different focuses on this subject.

Conflict of interest

The authors declare no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Application of embedded accident prevention system for infant crawling stage in intelligent textiles

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ABSTRACT

Infant crawling is a method to discover and learn its motor, cognitive, social and emotional functions. Therefore, infants face different risks, such as falls, burns and personal injuries. The most common is that the family is the place where the main event occurs. Therefore, the focus of this research is to develop the embedded system inside the intelligent textile to realize the early warning and prevention of accidents. The system is located in a clothing harness with a crawling knee pad connection including a magnetic sensor. These devices are responsible for detecting security tapes previously placed in the most dangerous location in the home. Therefore, the system gives an alarm with a response time of 7.6 seconds after activation.

Keywords: intelligent textile; magnetic sensor; Internet of Things; infant accidents; Arduino

1. Introduction

Crawling is the displacement of infants through quadruped postures[1]. This exercise enables infants to gain experience of motor maturity[1–3]. As a stage of exploring and learning spatial concepts, they cause changes in infants' perception, cognition, language, society and emotion[1]. In this way, infants can experience their own movement to begin independence[2]. According to García, et al., infants begin the crawling phase at 5 months, while Oldak-Kovalsky, et al.[4,5] takes 7 to 10 months as their initial phase. Therefore, from this stage, the possibility of accidents is greater[6].

The World Health Organization (WHO) defines an accident as: "Accidents, usually unfortunate or harmful, independent of human's will, are caused by external forces acting quickly, manifested as organ damage or mental disorder"[7,8]. According to Mizhquero and Minda[7,9], 54% of accidents of children under 5 years old occur at home. The most common accidents include drowning, falling, poisoning, burns, physical injury, ingestion of foreign bodies, toxic substances[7], etc. The kitchen, bathroom, bedroom, living room and garden are the most accident prone places[10,11].

In 2010, the Saint Vicente de Paul Hospital in Ibara, Ecuador recorded 5,166 family accidents, of

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which 494 involved children under the age of 5. Among them, 422 cases were aged between 1-4 years and 72 cases were aged between 0–1 years[7]. Documented care and hospitalization included fractures, falls, burns and poisoning, mainly men. These accidents are common among children because they are curious about the world around them. Therefore, risk prevention is very important to reduce such accidents.

Generally, there are various electronic security systems, which are mainly responsible for preventing or combating accidents such as home theft and fire, but it is not common to focus on protecting the safety of infants in the crawling stage, but there are various basic auxiliary devices on the market to help to take care of infants at home, including safety barriers, plug covers, sliding door guards, among other things, but in many cases, they are insufficient in the face of many dangers and lack other supplementary functions.

In view of the above, the purpose of this study is to provide input for the prevention and reduction of accidents of crawling infants, and it is suggested to develop an electronic security system on Arduino platform to warn the responsible person of infants by triggering an alarm reaching the mobile device. Similar work, Godoy, et al. and Rosero, et al.[12-14] provides electronic system solutions, but not for infants.

The second section introduces the methods and materials used in this study, and the third section introduces the results achieved. The fourth section analyzes and discusses the main contents. The fifth section puts forward the conclusions and suggestions of this study.

2. Materials and methods

This section describes the hardware and software resources used in this study and the corresponding process of designing and building a prototype safety system for preventing child accidents in the crawling stage.

These requirements are considered to ensure operation and efficiency in protecting the lives of young children, as follows: The response time for immediate reporting of hazards is very short; The coverage of the WiFi modem to be used; Proper power performance, beautiful, easy to place, does not interfere with the baby's motor activities, except as an independent and easy-to-use system.

2.1. Hardware components

All Smart clothing is a safety mechanism for children under 18 months of age and consists of the following components[11]:

—**Lilypad Arduino control board**: It maintains communication with sensors and usually undertakes the control of system functions.

—**Magnetic spring sensor**: It is connected to the control board and starts as soon as it detects the proximity of the tape that constitutes an obstacle to the exit to the dangerous area.

—**Magnetic tape**: It is coupled to magnetic spring sensors and has similar characteristics to magnets. It is very suitable for changing the state of the above sensors when approaching these tapes.

—**ESP8266 WiFi module**: Allow communication between the home wireless network and the Internet of Things platform, so as to give an alarm when the baby is in danger. It is configured as station mode, allowing communication with any device from the Internet.

—**IoT platform**: Receive and store information about all danger alarm messages provided by the communication block. The project cooperates with the open source thing speak platform[15], which not only analyzes and displays Arduino, rasperry and other components, but also promotes cloud storage.

—**IFTTT (If This Then That) notification platform:** It is installed on smart phones on Android and IOS operating systems, promotes communication with the Internet of Things platform according to received requests, and generates alarm notifications when necessary or dangerous.

—**System power supply**: It includes a rechargeable battery to provide power for the whole system. After proper design, it can provide system operation within 10 hours.

2.2. System programming

The control board programming uses Arduino's own IDE (English integrated development environment) and C language as the programming language. **Figure 1** shows the process of the control block performing different activities of system operation, starting with initialization variables, libraries, serial communication and ESP-01 module. If there is a connection error in the home WiFi network, the system will report the error by activating the buzzer. Otherwise, it will continue the process of sending notifications and initiating data to devices and applications that allow scanning the status of magnetic reed sensors to immediately detect proximity to tapes through the Internet of Things platform, thereby alerting parents or childcare workers to potential hazards.

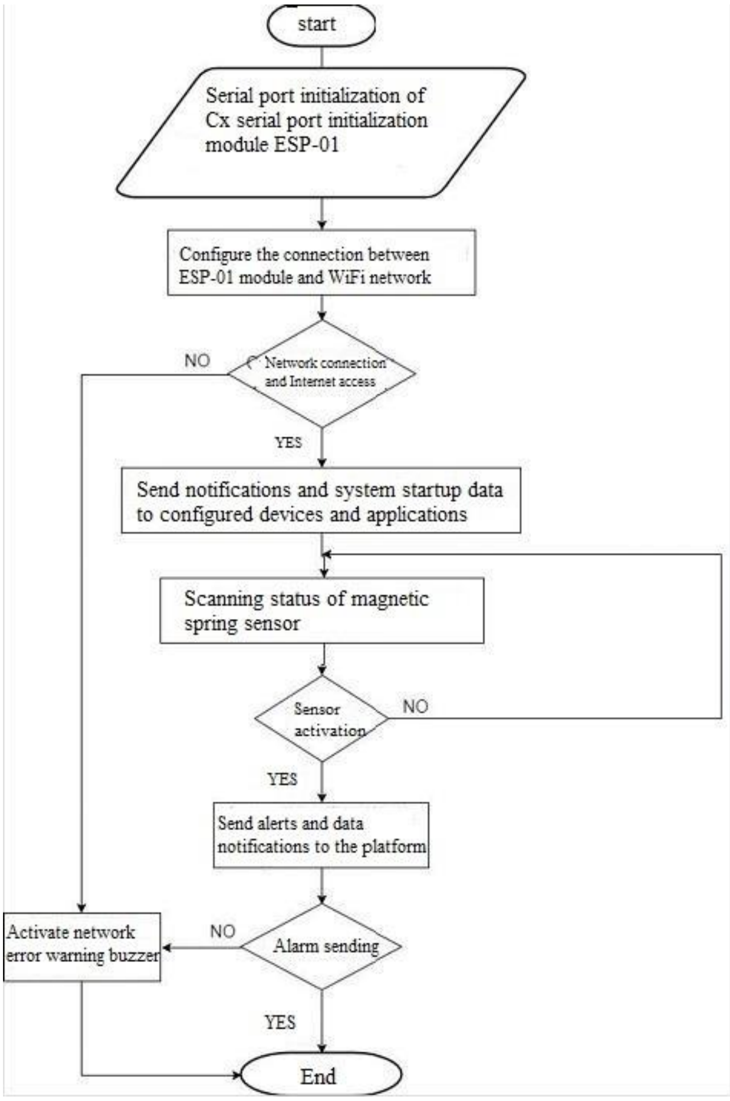

Figure 1. Process control board.

2.3. Construction of intelligent clothing

An important prerequisite for the proper operation of smart clothing is that the personnel responsible for crawling baby care determine the dangerous area, because it depends on the location of the tape. If the baby is close to the tape, the tape will produce activator when detected by the sensor. The sensor is part of the knee pad and is connected to the control board.

With regard to the communication of alarm prevention, the system uses WiFi module through serial communication with Arduino board to make the system part of home and internet wireless network, and stores data and alarms on the Internet of Things website, which interacts with the push notification application installed on smart phone. The construction process of smart clothing is described in detail below:

Complete system connection circuit

Figure 2 shows the electrical connection diagram of the control block, sensor, communication and power supply of the whole system.

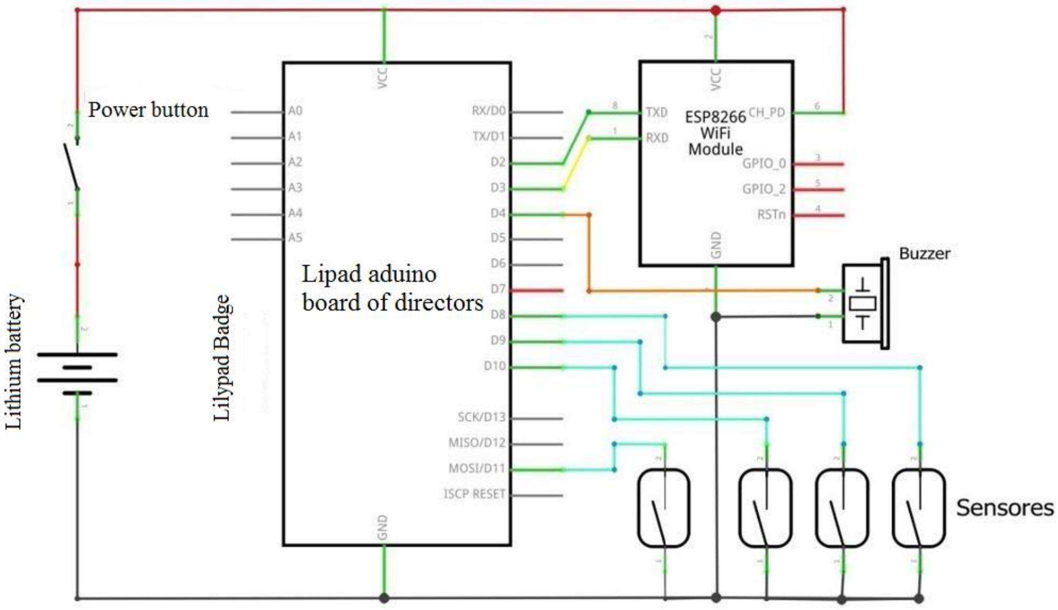

Figure 2. Schematic connection of hardware components.

Integrated WiFi module and power module

Initially, a badge was made with Eagle software, and its pin is similar to the LilyPad badge (**Figure 3**) to sew it on the fabric through wires. The components of the new board include: WiFi module, buzzer, micro USB connector for charging, jumper connecting battery, switch button, resistance, led charging indicator and rectifier diode of charging circuit. The needles to be stitched are: RX and TX of WiFi module, power supply (positive and negative) and pin of buzzer.

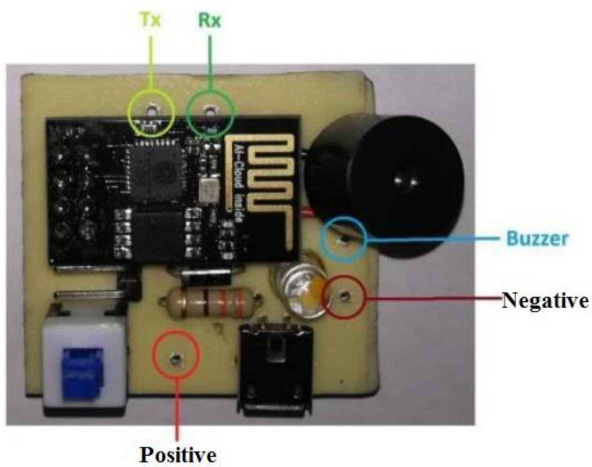

Figure 3. Integrated board of WiFi and power module.

Integrate components into fabric

All hardware (detachable parts) are made of conductive materials. The buttons are integrated into the garment nylon harness and extend the conductive wire to the crawling knee pad where the sensor is located, so as to trigger the alarm in case of danger. In addition, it has an additional pocket behind the removable part, that is, the back of the motherboard (LilyPad and WiFi module), as shown in **Figure 4**.

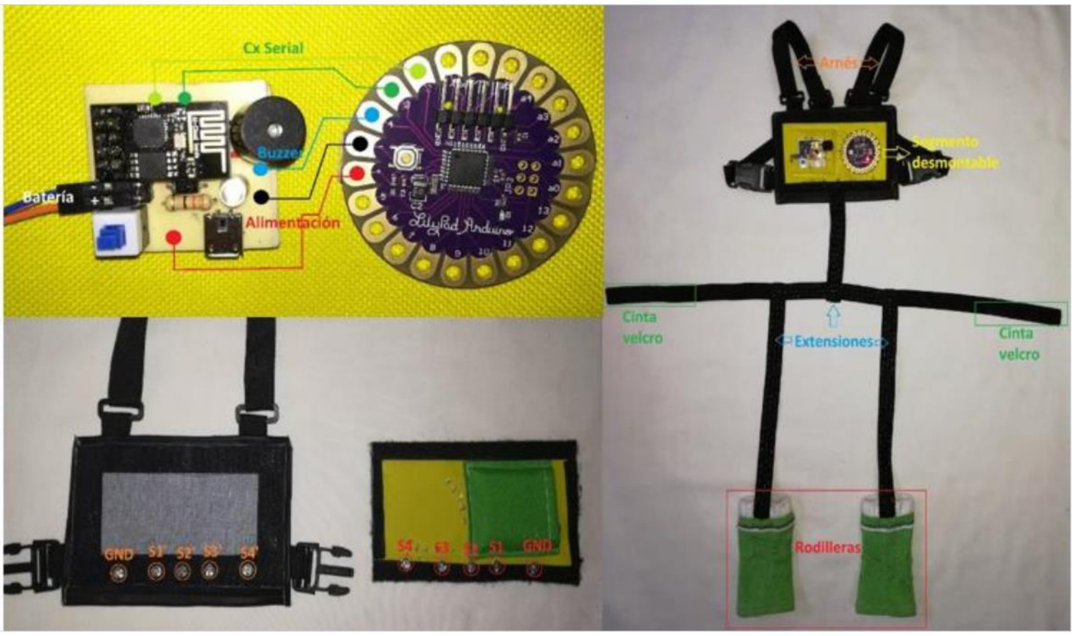

Figure 4. Integrate components into garment harness.

Sensor installation

Sensors fixed to knee pads with elastic features are placed in the lateral areas of the legs below the knee because these areas are close to the ground when the baby crawls, and this area helps to avoid damaging the sensor when the baby moves.

Tape installation

As mentioned above, the tape is placed near the dangerous area and kept at a careful distance so that the baby caregiver has time to respond and arrive at the scene. In order to determine the distance between the tape and the dangerous area, the data in the climbing Evaluation Dynamic Model were used to obtain the average climbing speed of infants aged 8 to 13 months, which is 0.21 m/s. In addition, the average time between triggering the sensor and establishing communication with the Internet of Things platform to send a notification is 7.36 seconds. According to these data, the safety distance is given by the principle of $x = v * t$, i.e. 1.54 m.

Optimized storage of data in Internet of Things network platform

The Internet of Things platform to use is thing speak, which needs to create an account on your official website to enable it. When working with the security system, the platform will receive data and store data when the sensor is started[16]. The data is sent to ESP-01 module (WiFi module) through HTTP request. The information to be received could be a value of 100 indicating that an alarm has been activated and a value of zero as well as the start of the system.

Notice

When the baby is close to the dangerous area, it is alerted through the caregiver's smartphone, which corresponds to the alarm mechanism. Applications used in mobile IFTTT work through links to the Internet of Things platform. To access IFTTT services, you need to register from an official page or even an application.

3. Result

The During the implementation, corresponding tests were carried out to verify its function, including the minimum safe distance for tape installation is 1.54 meters, away from the dangerous area.

The average system startup time of system startup test with network speed of 2Mbps is 18.7 seconds, and the estimated alarm notification time on tapes installed at different distances is 7.49 seconds: It is 4 meters away from the router (stairs), another 2 meters (bathroom), and the last 3 meters (kitchen). It is further away. It successfully attempts to send notifications at 13 meters in 6.8 to 7.8 seconds. The notification text sent when the sensor is activated is “alarm! Your child is in danger.”

The battery life is 12 hours and 10 minutes. It is recommended to charge the battery 1 hour before use.

The data is collected on the Thing Speak platform, the system sends a 0 (zero) when the system is started and 100 (one hundred) as an indicator that an alarm has been triggered which immediately communicates to the caregivers’ cell phone via the IFTTT platform.

4. Discussion

The intelligent system was evaluated in a controlled environment and then in the actual situation. The results showed that the average response time was 7.36 seconds within 1.54 meters from the dangerous area, which was initially considered prudent so that the baby caregiver could reach the scene and help the baby. It should be noted that the average response time of the system depends on the Internet connection speed, access point distance and wireless signal quality.

With regard to the possibility of affecting children’s daily and normal activities, a flexible system was considered in the construction process. The system consists of a standard seat belt that can be adjusted to the average weight of infants aged 6 to 18 months, minimizing the possibility of affecting children’s motor ability.

With the future work, it is expected that the system will be able to expand its coverage through machine to machine platform. In this way, the mobile communication antenna can be used more flexibly for communication.

5. Conclusions and recommendations

Crawling is one of the most important stages of infant development. It enables them to explore and develop the abilities of movement, balance and touch. Therefore, it is inevitable to restrict infants from using this movement mechanism between the ages of 8 and 13 months. However, there may be dangerous environments or places at home, such as stairs, bathrooms, kitchens, etc., which may become dangerous. Therefore, the purpose of this study is to help reduce the number of infant accidents by warning and reporting that minors are approaching an area defined as dangerous, and combining embedded systems with textiles with the help of software and hardware technical tools, Internet of Things and reporting platform.

Hardware and software components are selected from a set of similar tools, so the construction of the system needs to be evaluated and compared in advance to ensure the performance and efficiency of the system. However, for further work, it is recommended to optimize battery consumption and improve system response and communication time.

Conflict of interest

The authors declare no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Mobile assistive technology with augmented reality for the elderly

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ABSTRACT

Technology offers many possibilities, but older people often do not fully enjoy these opportunities and are frustrated or afraid of these new devices. This has led to their gradual isolation in a society where different forms of communication through the Internet and ICT are essential. In this article, we describe a study conducted during the anconeal project, which aims to provide technical solutions for the elderly to provide autonomy and better quality of life in their daily activities by integrating information and communication technologies. In order to achieve this goal, advanced augmented reality (RA) technology and Internet services and mobile device interfaces specially designed for the elderly have been developed. These technologies use the underlying structure of most home and geriatric care centers. We propose a prototype system composed of tablet computers and portable RA devices, and analyze the impact of society on user interaction, as well as the evaluation of acceptability and usability. The assessment was conducted through focus groups and individual pilot tests with 48 participants: The elderly, caregivers and experts. His comments concluded that older people have a strong interest and interest in RA based nursing information and communication technologies, especially those related to communication and autonomy.

Keywords: assisted living; augmented reality; information and communication technology; media literacy; cognitive stimulation; the elderly; learning

1. Introduction

Today, everyone agrees that we live in a developing society and rely more and more on new technologies to promote this change. This continuous change affects members of society because it involves the cost of adapting to all these new habits and practices (time, effort, etc.). In many ways, the growth rate and the breadth of this change have led to the widening gap between social members, which is difficult to adapt. Citizens aged 65 or over, that is, the elderly, suffer because of the inherent limitations of the aging process. Stereotypes that link age

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to resistance to change and inability to learn new strategies undermine their integration and quality of life in a growing digital society. This raises a serious social problem, exacerbated by the trend towards marketing to young audiences[1] or focusing on technically experienced users[2], and further exacerbated by increased social isolation due to age.

According to the 2014 report of Eurostat[3], the number of elderly people in the EU has accounted for 18.2% of the current population and is expected to increase to 31.3% within 20 years. In particular, Italy is the European country most affected by this problem: About 250,000 Italians are affected by Alzheimer's disease and a considerable number of dementia[4], which highlights the need for continuous assistance from nursing staff and ICT equipment to such patients.

Contrary to some common beliefs, older persons are aware of the importance and benefits of ICT, regardless of gender or level of learning, as shown by the studies of Agudo, Fombona and Pascual. It was noted that ICT was mainly used for social and entertainment, such as connecting with friends and family, or creating multimedia content. In particular, older people are easy to accept multimedia applications, such as video conferencing and online video, to supplement their daily activities.

A new method of providing multimedia and interactive assistive technology content is augmented reality (AR). This method includes superimposing animation or image on the image taken by digital camera. This technology is considered by educational researchers as a very powerful interactive tool[5] for visualizing complex structures[6], educational games[7] and design-based learning[8], thus improving students' learning motivation. Usually, these contents are provided through subscription stand-alone, tablet or mobile phone, and this function is integrated into some assistance systems[9]. However, these technologies are accepted, as shown by Hernández et al[10], this is not a simple usability or design issue: They should not be just tools to replace lost things, but tools for personal development.

An important observation in his work is that the conclusion is that the adaptation of ICT to older persons may be necessary, but this does not mean that it is a sufficient condition to ensure their use of technology. The device must be customizable, modular and scalable, especially for the elderly population with increasing individual differences.

Therefore, this flexibility to the personal needs of the elderly is an important part of the design of new technologies.

Computers and tablets require constant interaction and operation, which may not be enough to provide convenience for the elderly[11]. The six-sense project shows that using AR and a set of camcorders and picoprojectors, realistic visual tracks can be added to the user's environment, which is possible to interact with users. Advances in AR and simultaneous localization and mapping (SLAM) methods[12] eliminate the need to introduce AR markers and adapt the environment for their use.

The purpose of the Nacodeal project ((Natural Communication Device for Assisted Living) is to develop a new elderly care system aimed at promoting social integration through information and communication technologies. It provides a boot and communication service using two devices. The first is tablet computer, which contains a specially developed software to meet the needs and requirements of end users. It can be customized and accessed by different types of users. The second is a new type of Augmented Reality Technology[13]: A portable device with picoprojector and built-in camera, which uses the three-dimensional map of the environment to locate and locate users and truly project information (**Figure 1**).

Figure 1. Traditional AR (left) information is displayed on the

screen. In fact, on the website (right), information is projected and observed in the environment.

Using this technology, it is possible to create user-friendly guides, so that your users can perform their daily activities and access online services that are relevant to them. In order to meet these conditions, the following requirements are formulated:

• The system needs to determine the user location and equipment direction of AR in real time and automatically display the content.

• It must be suitable for care and rehabilitation centers without the need for complex infrastructure or expensive equipment.

• Users will interact with the system through a mobile interface (tablet) suitable for their cognitive level.

• It must be a bridge between ICT, end-users and their families and caregivers without changing their daily lives or reducing their mobility.

• You should change as few elements as possible.

These requirements cannot be achieved by WIFI or RFID triangulation because they cannot provide precise location and direction for portable devices, and the infrastructure required in this case is complex and expensive for most people.

• The visual slam/AR approach can meet these requirements by using components such as webcams and computers.

In order to assess the effectiveness of the proposed system, a study was conducted on voluntary older persons, caregivers and experts in Italian care centers to determine the benefits of social interaction and desirable features in terms of content, function and availability. The next section will outline the auxiliary system and its details in the verification process.

2. Design and verification methods

2.1. Auxiliary system

The system aims to take advantage of the resources available in most homes and public places: An open Internet access point. Its components are divided into two categories: Remote infrastructure, a web-based service used to manage the content of the display system; local infrastructure, a device installed in a medical center or home, and an interface device that interacts with end users (**Figure 2**).

Figure 2. Design the experiment assistant system.

The design of the system considers two main roles: Content creator and end user. The content creator is responsible for the creation and programming of multimedia content, which must be displayed by the auxiliary system. This person (or group of people) can be a caregiver, doctor, family member or behavioral specialist, and interacts with the system via a web interface accessible through a computer or smartphone. The end-user is the older person, who is provided with the content via the tablet and the portable AR device, called DC-PAR (device with a pico-projector for augmented reality) (**Figure 3**).

Figure 3. Interface devices: Tablet (left) and dcpar prototype (right).

A key concept of this design is that neither participant needs more knowledge than is required to use other common household appliances. Content creators must know how to navigate on ordinary websites, how to create or edit digital photos, presentations and movies, or at least how to play existing content. End-users only need to have a basic understanding of how to use the functions of tablets, and they can receive content through AR without professional knowledge. In addition, due to the capability of wireless devices, users should not stay in a fixed place because of the requirements of desktop computers. This allows you to complete your daily life with minimal interference.

• Web interface and database. The main purpose of the web interface is to make it easier for authorized content creators to include multimedia content and to determine where and under what conditions AR content should be displayed. This information will be stored in a remote database that will be accessed by local infrastructure components. Possible services include: Personal agenda and timetable; SMS, telephone, IP voice and online chat; newspapers and magazines; memory practice and treatment information; educational videos related to topics of interest (cooking, handicrafts, etc.); maps, including potentially dangerous advertising spots; content generated by family members: Videos, photos, or music.

Content creators can customize services according to users' needs and habits. In addition, each field and its related services are designed according to the user needs collected in the specific content analysis[14,15].

• Personal computer. The augmented reality PC is a dedicated server connected to a wireless connection point. As the processing center of the system, it is not affected by the weight, power consumption or ergonomics of handheld devices. AR PC automatically distributes video and audio content transmitted to tablets and dcpar in real time, and monitors the database at specific time intervals to collect planned changes. It is also responsible for implementing augmented reality algorithms, environment recognition and determining the direction of dcpar by processing the data transmitted by the camera. Other services, such as facial recognition or behavioral analysis, can be included as software updates to avoid hardware changes. The component is designed to be highly automated and, like any other household appliance, displays content when the power is turned on. In an environment with multiple end users, such as a nursing center, the system must be managed by an operator (such as a nurse or geriatrician).

• Tablet PC. This is a commercial tablet with intuitive software and guidance assistance system, which is built according to the guidance and treatment standards in reality to help people with cognitive problems. Treatment allows users to stimulate them throughout the day through a continuous flow of information related to their personal data, time and space. It helps older people establish coherent cognitive representations to better understand their surroundings and their role in them[16]. The software interface is designed to simplify users' navigation in services and applications and constantly stimulate users' memory. Tablets contain four main applications: Calendar, conversation, games and entertainment. Each area represents a specialized service that promotes brain activity during use and helps remember daily appointments and to-do items.

• DCPAR. The prototype is a portable device, including an integrated camera, a pico-projector and a transmitter. It is contained in a 10 × 14 × 3 cm shell with a belt at the neck. Although this is a specialized hardware, low-cost components are used to make it affordable. As a video input and output device, it transmits the environment displayed by the camera, processes AR by PC, and preprocesses the generated image. This allows the automatic display of multimedia prompts related to the website. For example, when the user approaches the stove, he will issue a warning of potential risks. More practical content can be programmed, such as arrow guidance mode, which can be adjusted in real time according to the user's position.

• Installation. The wireless access point and the AR PC use the network available at the installation site, and are placed in a position with good wireless coverage. In order to make the recognition and location algorithm of augmented reality work correctly, the three-dimensional map of the environment must be prepared in advance. This step is performed using specialized software[13], which runs on a laptop connected to a depth sensor (such as Microsoft Kinect), which scans the points of interest. The generated 3D map is stored in the database, and the content creator can configure the programming of RA according to the needs of users. According to the size of the scanning area, the scanning process shall not exceed two hours. Once completed, the attendance system can be used. Any significant changes in the environment, such as painting walls, moving or changing furniture, may require rescanning because the positioning system is based on visual reference.

2.2. User authentication

In order to correctly evaluate the proposed design, it is necessary to analyze its use in the elderly, identify defects and deficiencies according to the needs of the elderly, and determine its specific benefits to daily life. Most importantly, in this regard, one of the key contributions that needs to be analyzed is to reduce social isolation and improve socialization, integration and interaction with older persons affected by temporary memory loss. Taking these factors into account, the trial was conducted in group meetings and pilot individuals, nursing homes for the elderly and health centres in the province of Ancona, Italy.

The system verification phase with users is divided into two phases: A focus group composed of the elderly, nursing staff and experts (performance test phase 1) and a conversation with the pilot individual in the actual scene (performance test phase 2).

The first part of the test—A group meeting—attempts to understand the views of older people on the two components of the care system through a focus group at each facility. The purpose is to help older people access this new technology and help them understand the services and applications included. These meetings can explain the functions and characteristics of the equipment and collect preliminary opinions. An expert group was requested to assess these devices and their interaction with older persons. As a non-medical preventive measure, the system is not suitable for patients with serious cognitive problems. In addition, the clinical dementia score (CDR) scale[17] is used as a reference in the participant selection process. These tests were conducted for people with CDR 0 to CDR1 (**Table 1**).

Table 1. CDR scale and related cognitive status

CDR scale	Cognitive state	Definition
CDR 0	No cognitive impairment	Normal memory, no memory loss or slight and inconsistent forgetting. People are completely people-oriented and live independently. Able to maintain social relations, as well as intellectual interests and hobbies.
CDR 0.5	Suspicious cognitive impairment	Mild forgetting, partial retention events, but with good guidance ability. Slight difficulties in solving problems and social relations. Slightly affected and in need of help in family activities and personal care.
CDR 1	Mild cognitive impairment	Moderate memory loss, more sensitive to recent events and interfering with the development of daily activities. Moderate time orientation difficulties and certain geographical orientation obstacles. Unable to carry out daily activities independently. He needs help with dressing and personal hygiene.

Together with the focus groups, the experts assessed the impact of the devices on social interaction, and how each of the individual applications of the system offered autonomy, well-being and happiness. They also assessed which apps end users liked best and how the use of social networks generated new interest among older people. Finally, other aspects are evaluated, such as tablet availability and the functions required in dcpar. The first coordination group was established in chiaravalle, located in La Ginestra nursing home, with 12 participants, including the elderly, caregivers and experts. Seven volunteers participated as pilots and two volunteers as observers. The expert group consists of asylum coordinators, Alzheimer's specialists and operators responsible for recreational activities.

The second group is in Jesus, in Victor Emanuel II sanatorium. The group consists of a larger group of participants, most of whom are simple observers (4 pilots and 8 observers). The care coordinator, a member of the Alzheimer's Marche Association, a social health worker, two operators responsible for recreational activities and a family member of an elderly person assessed these devices and their use.

The third focus group is located in the Visintini care center in Falconara Marittima, which is dedicated to patients with Alzheimer's disease and Alzheimer's disease. The focus of this group was to assess the interaction of older people with more serious cognitive problems, which was significantly lower than that of the previous group. The team was supported by the day center coordinator, psychologists specializing in cognitive impairment and center volunteers.

The second test involved 13 pilots: 10 women and 3 men, with an average age of 80.3 years. Their physical and cognitive status varied: six of them were in wheelchairs due to physical pain or illness; There were 2 cases of mild cognitive impairment (CDR 0.5 and 1), and 5 cases of physical and mental health. All but three participants lived in the test facility: One lived in his own house, and two lived in the city center during the day, but returned to their families at night (**Tables 2 and 3**).

Table 2. Phase 1 performance test—Focus group sessions

	La ginestra	Emanuel	Visintini	Total
Install	Nursing center	Nursing center	Health center	
Total number of participants	12	18	5	35
-The elderly in the second test	7	4	2	13
-Observers	2	8	0	10
-Expert	3	5	2	10
-Technician/Researcher	0	1	1	2

Table 3. Phase 2 performance test—Pilot individuals and CDR status

	La ginestra	Emanuel	Visintini	Total
Main users involved	7	4	2	13
CDR 0	2	2	0	4
CDR 0.5	3	2	1	6
CDR 1	2	0	1	3

3. Results

3.1. End user response

Among the elderly who participated in the individual pill test, 30.8% completely relaxed during the test and 30.8% fully relaxed, which means that 61.6% had a positive opinion. The rest (30.4%) felt uncomfortable, although no one completely rejected the device. This response is considered normal because this target group is unfamiliar and has a certain degree of resistance to its use (**Figure 4**).

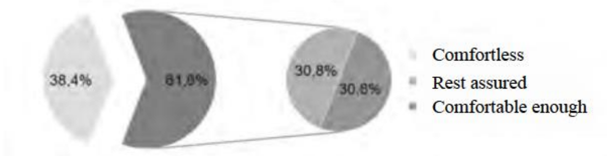

Figure 4. Focus group acceptance of equipment.

Most of the opinions collected after the tablet test were positive. Almost all the elderly interviewed felt ashamed and unsafe at first, followed by curiosity and enthusiasm. Older people believe that tablets are "a good tool to keep in touch with family and friends" and that having a "simple visit" can promote their "healthy and not lonely thoughts..." Many of them, after initial resistance and fear of novelty, learned to easily operate tablets and DCPAR. Once you understand its functions, you will show enthusiasm and willingness to learn more about the functions it contains. This gradual participation has led to positive cooperation, but it has also produced two key problems: The problem of equipment dependence and the treatment of negative reactions of the elderly, as well as the disappointment after the test. Experts believe that the problem of "addiction" is normal in this target group. They are usually lonely, have few social opportunities, or live in a monotonous life with few cognitive stimuli, so they appreciate any form of hint to exercise their memory.

• Tablet PC. According to the survey results, the favorite service for the elderly is photo library (46.2%), followed by video and television (23.1%). The proportion of phones and Mensa Jeria and music players is similar (15.4%). Participants are not interested in other applications. In fact, they mainly focus on content related to family and friends. Specifically, participants with cognitive problems felt that the agenda was too difficult to use.

Participants wanted to improve photo albums and music applications, especially in terms of music volume (hearing problems) and image size (vision problems). Tam Bién said they wanted more multimedia content and a more intuitive interface in their era (**Figure 5**).

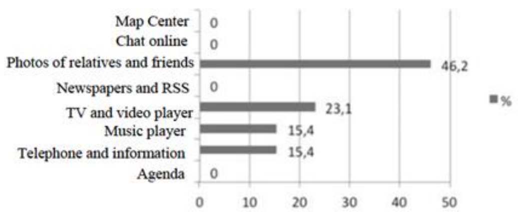

Figure 5. The preferred service among the services provided by tablets.

• DCPAR. In general, they find DCPAR bulky and sometimes difficult to correctly understand its purpose. Nevertheless, most of them can still use the functions of tablet and AR with a high degree of autonomy. In terms of its function, users are very satisfied with the ability to show pictures and films on topics of interest such as relatives or sports or religion. The responsiveness of the device is considered to be sufficient by properly adjusting the geometric environment of the projected image. Compared with the difficulties encountered on tablets, the most expected function of dcpar is that family members actively view the content they produce and use it as an agenda (**Figure 6**).

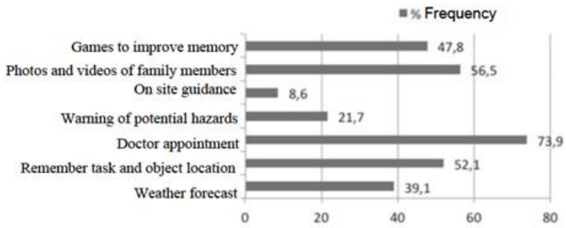

Figure 6. Function frequency requested by DCPAR user.

An important problem related to equipment ergonomics was found: The image quality was lower than expected due to the user's posture and the tilt of Pico projector. In addition, it is considered uncomfortable because it is worn around the neck and may increase the problems caused by osteoarthritis common in the elderly.

3.2. Caregiver response

Caregivers believe that the nursing system is a good support tool, but it is still too complex to be used independently by the elderly, especially if the elderly have any physical or cognitive problems. This view was supported by the subjects and their families, who suggested improving some user interface details, such as "keyboard size" and the full participation of caregivers, "they must play a central role in approaching the elderly and training in the use of new technologies". They also noted the addition of exercises to promote partnerships between places and images as a means of stimulating spatial perception in a facility or home environment, and introduced the possibility of video chat with friends and family.

Caregivers believe that the use of the proposed system may vary depending on the use environment. In the homes of the elderly, it helps to remember appointments and events, as a barrier warning system, as a reminder of the correct medication, as a television system with its own social network, and as a means of stimulating short-term memory and user interest. In a care center, the system is important to improve the relationship between users who use it as an entertainment device, remember daily plans and time and activities, and it can also help identify objects on the scene by associating the names of RA projections.

Nurses observed how users and nearby elderly people appreciated DCPAR images. It was also used as a tool to stimulate mobility in the elderly: Subjects were pushed to the room of the scene for investigation and often walked during the pilot test. Due to the perspective, it is difficult to be used for people with physical problems (such as the elderly in wheelchairs) and it is difficult to wear it for a long time. These are the weaknesses of the system. In addition, it is recommended to rearrange the help of caregivers or family members to manage appointments and user personal data in the online database.

Finally, caregivers have found that the best way to encourage the use of ICT equipment is to approach gradually at an early stage with the continuous help of "coaches" (such as caregivers or family members). This new technology approach requires the participation of people in the user's circle because they are more willing to cooperate with them than strangers. Another way to expose the elderly to the system may be through recreational activities, such as educational games. Experts involved in system validation believe that the elderly must participate from an early stage to avoid their tendency to isolate themselves. It may be an excellent tool for patients with Alzheimer's disease and contribute to non-drug treatment, although in this case, the user needs the support of the operator.

4. Conclusions

The analysis of users' needs and their acceptance of Pro technology solutions show how important it is for the elderly to keep in touch with others in order to actively stimulate their cognitive function and avoid social isolation. In the prototype verification phase, relational components have been carefully considered to understand the actual value of the technology under test and its ability to effectively affect the market. The results show that most elderly people want to participate in the digital process, but pay special attention to their prior knowledge and experience, which requires a deep understanding of their learning time. Most of the difficulties encountered are related to the level of internality and usability of the interface, rather than people's interest or understanding of ICT. This reinforces the view that "these older people need and desire to learn, and they see this moment in their lives, the moment when they are close to ICT.

Augmented reality technology provides automatic context detection and real environment information input, which plays an important role in the auxiliary system. Compared with tablet computers, the system can interact with users autonomously and provides the concept of "personal support" to help users complete tasks, rather than deviating from normal procedures when they want to enjoy the benefits of ICT. This feature may improve their mobility, and the information provided to the elderly who temporarily lose the memo will become an added value, or better "added" value, expressed in the most accessible channel for the target group: The link between experience and image. According to cognitive neuropsychologists, the matching of auditory or written images and information can promote and stimulate brain activity and help the elderly maintain good memory for as long as possible[16,18]. The analysis conducted in this study produced some valuable information, which is valuable for the design of AR devices for the elderly. Due to the participation of users and experts, the prototype is too large and cumbersome. The device should be designed in a more ergonomic way, and if it is expected to be used continuously and continuously in the user's life, it should have minimal difficulty in projecting the image into the field of view. In order to achieve this goal, the miniaturization and ergonomics of portable electronic devices should be further studied.

More tests are needed for older people living alone. Their needs and views may be very different from those of other people who often contact nursing staff, which is not included in our survey. At present, we are conducting research with volunteers in this situation to measure the possible impact of the proposed system.

It can be concluded that supportive technology solutions are a step towards the introduction of ICT to older persons and have a potentially beneficial impact on their lives. Tablets and depart have the potential to promote social interaction, virtually stimulate cognitive processes, and improve their self-sufficiency and quality of life. The system refuses to become a simple tool to compensate for the impact of information and communication technologies deemed unnecessary by older persons[10]. On the contrary, this technology has the potential to complement the current stage of personal growth, provide access to educational and entertainment content, and enable older persons to avoid the impact of social isolation by maintaining contact with family, friends and society. Future research will consider improving this technology to achieve the following objectives:

• Ensure that elderly people living alone can keep in touch with friends and family.

• Promote the autonomy of older persons through educational content and assistance.

• By implementing a special care center in the system to improve the sense of security and tranquility, the center can provide rapid care.

With the "increase" of the elderly, it is expected that the integration of AR technology into mobile devices will make their contact with ICT and digital tools more natural and pleasant.

Conflict of interest

The authors declare no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Research progress of wearable plantar pressure monitoring system

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ABSTRACT

In order to rapidly promote the application of wearable plantar pressure monitoring system, the physiological structure of human foot, the source of plantar pressure and exercise step frequency are introduced. Based on the current research status of wearable plantar pressure monitoring systems, the fabrication materials and response principles of the fabric sensor-based integrated pressure monitoring socks are explored, the principle of selecting the features of the wearable plantar pressure monitoring system and its application in the field of the pressure monitoring system is explained. The principle of selecting the features of wearable plantar pressure monitoring system and its application in fall detection, foot disease diagnosis, and plantar pressure database are explained. Finally, we discussed the problems in the industrialization of wearable plantar pressure monitoring system at this stage. The problems of poor material performance and short wireless transmission distance in the industrialization of wearable plantar pressure monitoring systems are discussed, and a better integrated system based on biomechanics, textile materials and electronic communication is proposed. A better application prospect based on the cross-fusion integration of biomechanics, textile materials and electronic communication is proposed.

Keywords: wearable; plantar pressure; pressure monitoring; flexible pressure sensors

1. Introduction

Plantar pressure refers to the human body standing or in motion, the body weight acting on the ground through the foot, the ground will simultaneously produce a force of equal size and opposite direction on the sole of the foot, this force can be used to assess the function and fatigue of the human lower limbs, often applied in medical diagnosis, foot disease assessment, disease severity determination and other fields[1–2]. Plantar pressure measurement systems such as pressure test plates and test benches, where the collected plantar pressure data are often used in motion measurements and disease diagnosis[3–4]. These traditional pressure measurement devices are large and inflexible and cannot meet the demand for real-time monitoring of plantar pressure. On the contrary, pressure monitoring socks and shoes are highly adaptable and have little space

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limitation, which can collect and analyze human plantar pressure information in real time and provide reliable data for gait research, footwear manufacturing, simulation robotics, and other fields. The development of such wearable plantar pressure monitoring systems covers several fields and requires research and analysis based on biomechanics, textiles, electronics, wireless transmission and other disciplines.

In this paper, we analyze the physiological structure of the human foot and the motion characteristics of the foot from the perspective of biomechanics, and explore the sensing elements and working principles related to plantar pressure monitoring socks and plantar pressure monitoring shoes. Finally, the research and application of wearable plantar pressure monitoring system is discussed, as well as the problems and development trend at this stage.

2. Human foot movement mechanics

2.1. Physiological structure of the human foot

The human foot consists of 28 bones with different functions, 33 joints, and more than 130 ligaments, muscle groups, and the nervous system, making it a complex and independent physiological system[5]. According to the structure and function, the bones can be divided into heel, tarsus, metatarsus, phalanges, and arch, as shown in **Figure 1**. The heel bone is large and is the main pressure-bearing bone in the human body; the tarsus is short and controls the turning and twisting of the foot; the metatarsus is the main pressure-bearing bone and absorbs and cushions the impact of the ground on the bottom of the foot during movement; and the toe bone is short and flexible and is the key to regulating the body’s balance[6]. The arch structure between the metatarsal and tarsal bones is the arch of the foot, which regulates body balance and has three major functions: cushioning, transition, and stirruping[7].

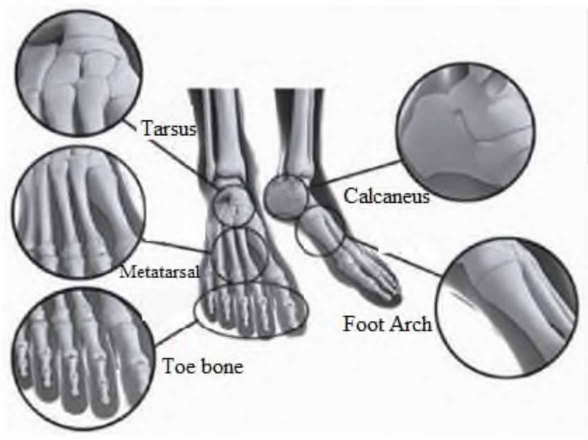

Figure 1. Skeletal structure of human feet.

2.2. Plantar pressure comes

From the perspective of biomechanics, the force situation and movement law of the organism under the action of external and internal muscle forces can be explored to better analyze the causes and mechanisms of human plantar pressure. When standing, in the vertical direction, the ground exerts an upward reaction force on the sole of the foot, at which time the plantar pressure is uniformly distributed on the sole of the foot, as shown in **Figure 2(a)**. When walking, the body naturally leans forward, the contact between the sole of the foot and the ground is periodic, in addition to the vertical reaction force, there is a horizontal force and friction, together to assist the body forward, at this time the peak plantar pressure is concentrated in the metatarsal region, as shown in **Figure 2(b)**. When running, the feet alternately land on the ground, the plantar and toe bone area when the sole of the foot touches the ground pressure is the largest, as shown in **Figure 2(c)**. Regardless of the movement state of the human body, by measuring and analyzing the magnitude and distribution characteristics of plantar pressure, the function of the skeletal and muscular groups of the lower limbs can be assessed for the purpose of preventing lower limb strain injury.

Figure 2. Analysis diagram of human foot of force from different motion state.

2.3. Foot movement gait analysis

Gait frequency is the number of circulatory exchanges between the left and right legs per unit of time, and is an important object of study in the field of bio motor mechanics, which affects the circulatory changes in plantar pressure. Jinman[8] pointed out that the frequency of human standing is 0 Hz, the frequency of natural walking is 1. 7 to 2. 0 Hz, and the ultimate gait frequency can reach 5.0 Hz. When a person walks, the ground reaction force compresses the plantar regularly, and the sensor of wearable pressure monitoring system can receive the cyclic stress of the plantar and output the pressure signal at a certain frequency. The resilience of the material can directly affect the accuracy of the pressure data, therefore, when developing the wearable pressure monitoring system, the matching between the response frequency of the material and the human step frequency must be considered to ensure that the monitoring system can accurately collect the plantar pressure signal and avoid the signal hysteresis phenomenon.

3. Wearable plantar pressure monitoring system

The early plantar pressure measurement method is the footprint method, i.e., a person stands on rubber, sand and other materials and leaves a footprint, and the plantar pressure information is analyzed by the morphological characteristics of the footprint[9]. Currently, pressure monitoring socks and pressure monitoring shoes have realized the collection, processing and wireless transmission of plantar pressure data. Their signal acquisition modules are all composed of pressure sensors, and the plantar pressure sensor is compressed by the foot when walking, so that the electrical signal is generated instantaneously, and the electrical signal rapidly decreases and tends to zero when the foot is raised. The electrical signal generated by the sensor is processed by noise reduction and other processes, and sent by the wireless transmission module to the terminal for visualization and numerical conversion processing[10].

The main difference between pressure monitoring socks and pressure monitoring shoes is that the former is knitted using a one-piece forming process in which conductive yarns are interwoven with ordinary yarns to form an intelligent wearable monitoring system containing several pressure sensor modules. In the latter, the flexible pressure sensors are placed directly into the insole, and the signal acquisition module and signal processing and output module are connected through thin wires to make an integrated intelligent monitoring system. The pressure monitoring sock has a high accuracy of measurement and can respond quickly to changes in plantar pressure due to its better wrapping of the foot, while the pressure monitoring shoe is more functional and can be loaded with subsequent data processing and output modules without affecting wearing comfort, while achieving efficient data acquisition and transmission.

3.1. Pressure monitoring socks

Pressure monitoring socks are wearable pressure monitoring systems with certain mechanical properties and pressure response performance by integrating pressure sensor modules made of conductive fibers or yarns into the characteristic locations of the socks, combined with signal processing technology and wireless transmission technology. The fabric sensor is the key part of the pressure monitoring sock, which is woven by conductive fibers or yarns according to certain laws, including knitted fabric sensor and woven fabric sensor. Its sensitivity is related to the type of conductive fibers, the compounding method and the structure of the fabric.

Conductive fibers for textiles

Conductive fibers are fibers with resistivity less than 1 × 107 Ω·cm under standard conditions (temperature of 20 ℃, relative humidity of 65%)[11]. According to the different conductive components, they can be divided into metal conductive fibers, carbon black conductive fibers and organic conductive fibers. Metal conductive fibers are made from metal directly drawn into fine wires or metal particles coated on the surface of polyester fibers, such as stainless-steel fibers, silver-plated fibers, etc. Drawing method of metal conductive fibers prepared by large mass, spinnability and poor dyeing; coating method to prepare the fiber softness, spinnability is good, but the coating fastness is poor, not resistant to friction and washing, so not widely used in the textile field[12]. Carbon black conductive fibers, including carbon fibers, carbon black coated fibers and carbon black composite fibers, have the advantages of high strength, good heat resistance, its electrical conductivity is better than stainless steel fibers, and can quickly dissipate the charge generated by mutual friction between yarns; however, due to its dark color, poor dispersion ability and other disadvantages, limiting its application in the field of textiles. Organic conductive fibers from conductive polymers directly spun into filaments or composite processing, common conductive polymers are polyacetylene, polyaniline, polypyrrole, etc. Conductive polymers are coated onto the surface of ordinary polyester fibers and made of composite conductive fibers with good electrical conductivity, excellent mechanical properties and stable chemical properties, which have good prospects for application in the field of functional textiles[13].

Fabric sensors

Fabric sensor is a sensing element that weaves conductive fibers directly into a knitted or woven fabric, using the resilience of the fabric to respond to cyclic stress in different parts of the foot. When it is subjected to plantar compression, the relative position of the yarn is shifted, causing a change in sensor resistance or capacitance as a response to external stresses. The signal processing module converts, reduces noise and amplifies the data collected by the sensor, and finally outputs the data to the PC for storage and display in combination with wireless transmission technology. Considering the conductive yarn as a wire, the conductive knitted fabric is like a complex parallel circuit, and when the coil in the fabric is deflected by the force, it causes a change in the resistance of the circuit, as shown in **Figure 3**[11]. Knitted fabric sensor resistance is calculated as:

$$R = \rho \frac{l}{A}$$

Where: R is the resistance of the conductive yarn, Ω; ρ is the resistivity of the conductive yarn (conductivity), Ω·m; l is the length of the conductive yarn, m; A is the cross-sectional area of the conductive yarn, m2. conductive yarn resistivity is certain, its resistance is proportional to its length, and its cross-sectional area is inversely proportional.

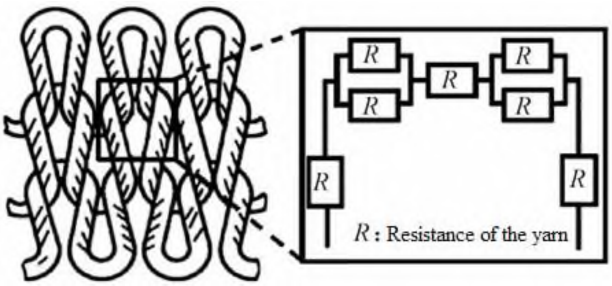

Figure 3. Equivalent circuit diagram of knitted fabric unit coil

The pressure response principle of the woven fabric sensor differs from that of the knitted fabric sensor in that it is based on the capacitor principle to respond to changes in external stress, as shown in **Figure 4**. In the woven fabric sensor, the 2 opposing electrodes are composed of yarn, and the dielectric tissue between the 2 electrodes is composed of an outer insulating coating. When the fabric sensor is compressed by an external force, the spacing and relative area of the 2 electrodes change, causing a change in capacitance. The calculation formula for the capacitance of this type of sensor is:

$$C = \varepsilon \frac{S}{d}$$

Where: C is the capacitance of the woven fabric sensor, F; ε is the dielectric constant of the dielectric tissue; S is the relative area between the 2 electrodes, m2; d is the distance between the 2 electrodes, m. When the dielectric constant of the dielectric tissue is certain, the capacitance of the woven fabric sensor is proportional to the relative area between the 2 electrodes and inversely proportional to the distance between the 2 electrodes.

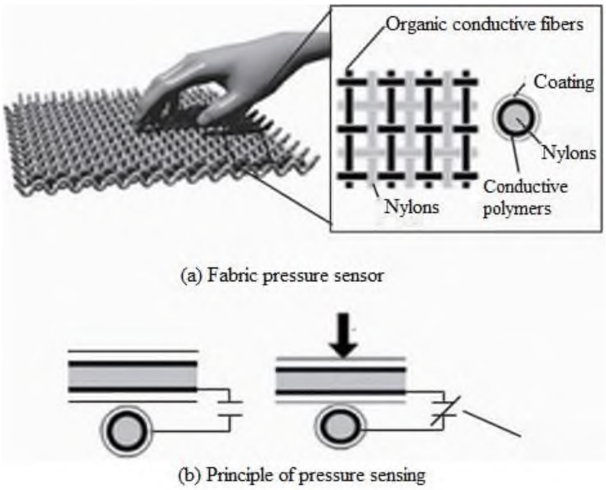

Figure 4. Schematic illustration of woven fabric pressure sensor.

Li et al.[14] prepared a pressure monitoring sock containing three knitted fabric sensors by one-piece forming process by using viscose conductive fibers containing stainless steel particles and nylon, and connected each sensor to the data processing equipment by conductive fibers. When the fabric sensor is subjected to a force, the fabric structure deflects and springs back, which in turn causes a change in the signal. On the contrary, woven fabric sensors have less resilience, are less sensitive than knitted fabric sensors, and suffer from signal hysteresis, making them unsuitable for application in pressure monitoring socks.

In addition, polymeric optical fibers can also be embedded into the characteristic parts of socks, combined with acceleration sensors to collect subjects' motion information and gait[15], as shown in **Figure 5**. Although the fiber optic sensor is small in mass and responsive, it is difficult to control the response to external environmental factors such as temperature, pressure, and magnetic field during human movement, so the fiber optic sensor is still difficult to control in practical applications.

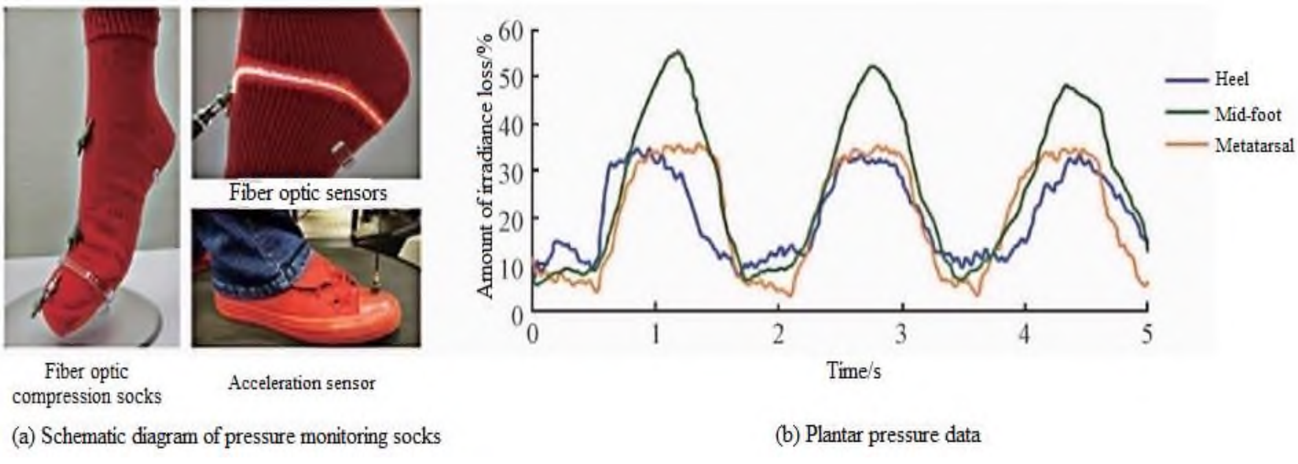

Figure 5. Pressure monitoring socks and pressure data.

3.2. Plantar pressure monitoring shoes

A plantar pressure monitoring shoe is a wearable monitoring system that integrates information acquisition module, signal processing and output module into the shoe body. It can rapidly collect and analyze the pressure data of human foot, and convert the pressure data into visual images or curves through the digital-to-analog conversion program, so as to analyze and evaluate the functions and force characteristics of human foot, and finally achieve the purpose of real-time collection and feedback of human gait information. The structure schematic and working principle of the foot pressure monitoring shoe are shown in **Figure 6**.

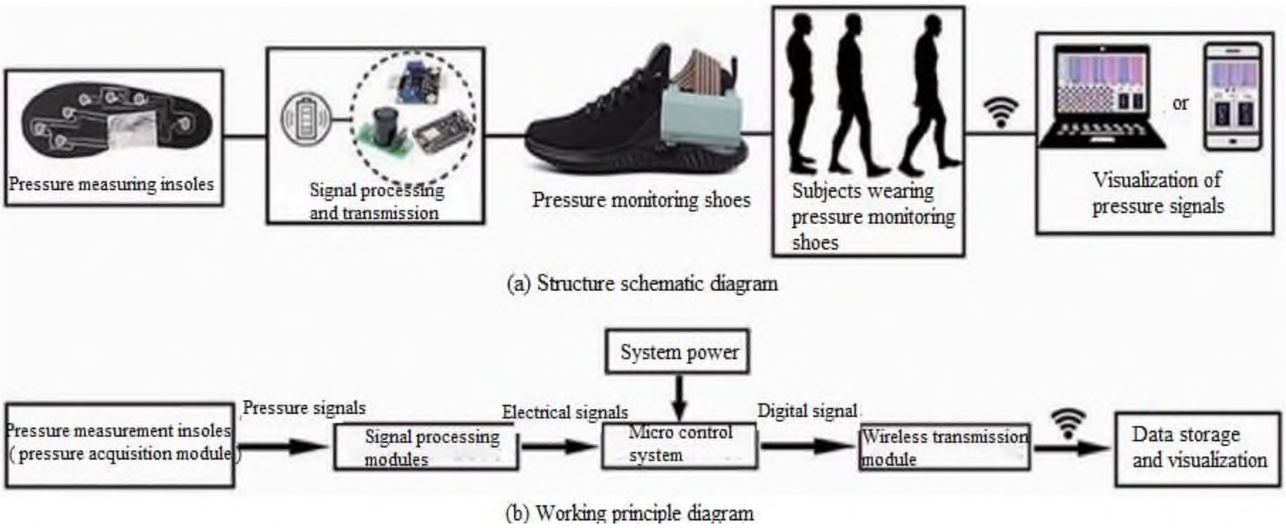

Figure 6. Structure diagram

Information acquisition module

The information acquisition module realizes the acquisition of human plantar pressure signal by embedding the flexible pressure sensor into the insole. It is the key part of the wearable plantar pressure measurement system, and the sensors used should have good flexibility, ductility, repeatability and stability, and should not hinder human movement. Commonly used sensors include piezo-resistive flexible sensors, capacitive flexible sensors, and piezoelectric flexible sensors, which convert pressure signals into output electrical signals according to certain mathematical laws in response to changes in plantar pressure[16], and the response principle of the sensors is shown in **Figure 7**.

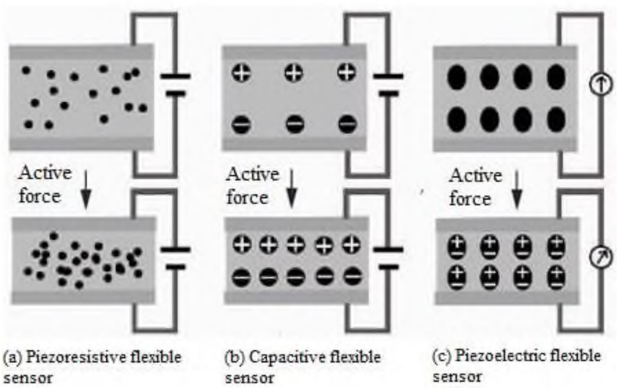

Figure 7. Schematic diagram of three flexible pressure sensors.

Piezo-resistive flexible sensors under force, the distance between the conductive particles in the elastic matrix becomes shorter and charge transfer occurs, causing a change in material resistance, the resistance changes with the magnitude of the external force[17]. The piezoresistive material used in piezoresistive flexible sensors can be fibers, yarns or fabrics, so this type of sensor can be widely used in the field of wearable technology. However, these sensors need to be used in combination with signal conversion circuits to convert resistance into voltage, so they require high data processing equipment and the circuit design of the system is more complex. The composition of capacitive flexible sensors is like that of woven fabric sensors, both containing two opposing electrodes and a dielectric layer, the electrodes can be yarn, fabric, metal sheet or conductive film. Capacitive flexible sensor response speed, high sensitivity, is widely used in clothing touch technology (fabric keyboard); when the finger in the "fabric keyboard" on the tap, slide, the fabric sensor will generate an electrical signal in response to the "touch command"[18]. Piezoelectric flexible sensors subjected to force deformation, will instantly generate an electrical charge in response to external stress, the typical piezoelectric material is polyvinylidene fluoride (PVDF), the PVDF piezoelectric sensor embedded in the insole, can respond to changes in human movement underfoot pressure[19]. The piezoelectric flexible sensor has high sensitivity and wide response range, and it is also widely used in the field of cardiopulmonary detection, but its charge is proportional to the sensing area, and when the area is small, the electrical signal is weak, and a circuit amplifier needs to be constructed to process it.

Signal processing and output module

The signal processing and output module is the key to obtain stable and accurate pressure digital signal for the plantar pressure monitoring system, which consists of three programs: signal processing, wireless transmission and data display.

The signal processing program includes signal conversion circuit, filter circuit and signal amplifier. Among them, the signal conversion circuit is applicable to the plantar pressure monitoring system of piezoresistive flexible sensor, which converts the resistance signal into voltage signal according to a certain law. The adjusted voltage signal is transmitted to the filter circuit, which suppresses the signal of high frequency by low-pass filtering and removes the noise and clutter in the data. The noise-reduced voltage signal is transmitted to the circuit amplifier with the purpose of amplifying the weak voltage signal in the same proportion according to a certain rule for subsequent analysis[20]. The multi-processed signal is transmitted to the microprocessor for numerical conversion, temporary storage and packing.

The wireless transmission procedure is implemented by wireless Bluetooth or Wi-Fi, and the wireless transmitting terminal sends the packaged data to the wireless receiving module of the host computer to complete the information transfer. The data received by the host computer is stored in a common database such as Microsoft Access or Microsoft SQL Server, and the data is uploaded and updated in real time through the wireless receiving module. Finally, the data display program visualizes the data stored in the database. Firstly, the data reading and writing program and the digital-to-analog conversion program are pre-designed in the LabVIEW platform, so that the data in the database can be transferred to the platform in real time[21]. Then the data is visualized by the digital-to-analog conversion program and presented in the form of graphs to achieve the purpose of real-time monitoring of plantar pressure.

However, there are still some problems in the actual use of pressure monitoring shoes at this stage, such as the small range of pressure that can be responded to and the short wireless transmission distance of data; at the same time, because the human body presents complexity in the process of movement, the sensing module is not yet able to collect the irregular movements of sudden changes in plantar pressure such as bouncing and dancing, so the improvement of the performance of the pressure acquisition module and the realization of remote transmission of data are problem that needs to be solved.

4. Selection of feature locations for foot pressure measurement

The pressure-bearing bones of the human foot vary under different sports conditions, therefore, when measuring plantar pressure, the plantar area should be divided to facilitate the selection of appropriate feature locations for the placement of pressure sensors. The number and location of sensors affect the accuracy of the data, such as the F-Scan and Pedar pressure test insoles, which have nearly 1,000 sensors embedded in each insole and collect accurate pressure data. However, when the number of sensors in a pressure monitoring system is too large, the system load is too high, leading to increased experimental costs and data redundancy. Therefore, it is important to explore the principles of selecting the location of plantar pressure features and using the least number of feature locations to obtain more comprehensive and accurate information.

In existing studies, the selection of plantar pressure feature locations is usually based on physiological anatomy or experimental experience, such as selecting multiple feature locations in the insole to place flexible pressure sensors, which are used to identify the human body for normal walking or weight loss walking; or dividing the plantar into several regions to investigate the gait characteristics of different people, such as patients with flat feet[22–23]. In daily life, foot movements are complex, and the changes of plantar pressure under different movements must be considered when exploring human gait information. Lin et al.[24] put on plantar pressure measurement shoes and used the "inverted pendulum model" (under standing conditions, the body swings back and forth to the limit position) to measure the distribution of plantar pressure in subjects, as shown in **Figure 8**. The experiments showed that the main pressure-bearing areas were the midfoot, metatarsal, and the limit areas (bunion and heel); secondly, mathematical statistics and superposition were performed to select the characteristic locations of plantar pressure in existing studies, and the five areas with the highest correlation were: the bunion, the first metatarsal, the fifth metatarsal, the lateral midfoot, and the heel. Therefore, when measuring plantar pressure distribution, the bunion, metatarsal, mid-lateral, and heel regions are set as the characteristic locations to ensure the accuracy of the data and to obtain effective gait information with fewer characteristic locations.

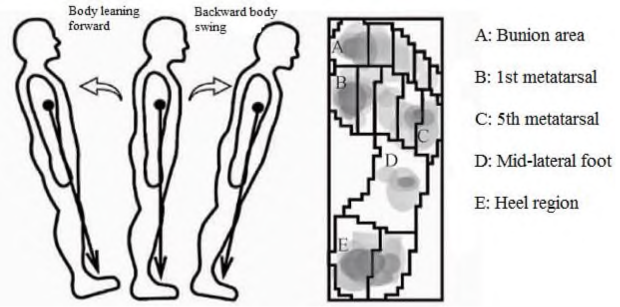

Figure 8. Selection method and superposition processing of feature position.

Currently, there are few studies on the selection of plantar pressure characteristics, and there are two main problems in these studies: (1) the distribution of plantar pressure in different postures when the subject is standing only, without considering the complexity of human motion; (2) in the "inverted pendulum model" experiment, the forward and backward tilting movements are difficult to reach the experimental results were not accurate enough.

5. Application of plantar pressure monitoring system

5.1. Fall detection system

A study showed that 30% of elderly people (65 years old and above) in the United States have one fall per year, and 11. 6% of the total accidents in Japan when elderly people are working in agriculture[25–26], therefore, monitoring the behavior of elderly people can provide timely rescue for fall accidents and effectively reduce the casualty rate. By integrating flexible pressure sensors, axial accelerometers and other components into the sports shoe body, a wearable fall monitoring system that monitors the subject's movement status in real time can be made. The monitoring system initiates an alarm when there is a sudden change in plantar pressure and acceleration, and if the wearer does not cancel the alarm within the specified time, the system will automatically request a third-party platform for timely rescue of the wearer[27]. Wearable monitoring system is a key research direction in the field of sports monitoring, but due to the complexity and variability of the wearing environment, the current functions such as wireless monitoring and data remote transmission can only be achieved in the laboratory with good results.

5.2. Diagnosis and treatment of foot disease

The prevalence of diabetes in the elderly continues to rise worldwide, with a prevalence of up to 20% in those aged 65–76 years or older, and 2011 data from the U.S. Department of Disease Control and Prevention show that about 8.3% of Americans have diabetes[28–29]. The plantar pressure distribution characteristics can effectively reflect the degree of foot ulcers in diabetic patients, and the use of pressure monitoring systems to determine the plantar pressure data of diabetic patients can provide scientific assessment of their stress conditions, which can provide reasonable treatment plans and take scientific and effective protective measures. The plantar pressure distribution characteristics of diabetic patients and healthy people when walking are different, and the main pressure-bearing area of the plantar of the former gradually shifts from the heel to the metatarsal, increasing the probability of ulcers in the metatarsal region[30]; therefore, pressure-relief insoles can be developed according to the plantar pressure characteristics of diabetic patients to reduce the peak pressure and the incidence of plantar ulcers[31].

5.3. Plantar pressure distribution characteristics database

Gait is an individual-specific behavior and a highly distinguishable biological characteristic[32], and its main parameter is the plantar pressure distribution characteristics, which can give feedback on the force characteristics and personalized features of the human foot[33]. A plantar pressure distribution characteristics database is a data processing method that collects a large amount of plantar pressure data, and stores and manages them. The wearable plantar pressure monitoring system can collect a large amount of plantar pressure information and establish a feature database to solve the problems of lack of pressure data, regional variability in pressure distribution features, and difficulties in sharing data resources. Gait feature recognition, as a biometric technology, can be applied in criminal investigation, where the unknown footprints are compared with the data in the database to analyze the individual characteristics of foot printers, which can improve the efficiency of investigation[34]. In addition, plantar pressure data can be applied in the research of human body posture correction[35], disease treatment[36–37], intelligent prosthesis[38], and other fields.

6. Conclusions

The wearable plantar pressure monitoring system is a fusion of plantar pressure measurement technology and textile and apparel field, which collects plantar pressure information through sensing elements and sends it to the host computer by combining signal processing technology and wireless transmission technology, and can provide real-time feedback on plantar pressure information. Therefore, wearable plantar pressure monitoring systems are widely used in human motion research, footwear manufacturing, intelligent robotics, disease monitoring and diagnosis. At the present stage, wearable plantar pressure monitoring system still has problems such as signal response lag, short material life, small pressure response range, and short wireless transmission distance, etc. Therefore, at this stage, the wearable plantar pressure monitoring system needs to be solved by enhancing the material performance and wireless transmission technology in order to promote its development in the direction of industrialization.

With the development of wearable technology, wearable pressure monitoring system can be applied not only in manufacturing and medical fields in the future, but also help the process of artificial intelligence and digitization of human body information, which has good application prospects.

Conflict of interest

The authors declare no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Wireless vibrotactile wireless optical device for motor activity assistance motor activities

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ABSTRACT

This article describes the research that leads to the development of a wireless optical device capable of generating vibrotactile mechanical stimuli at different points on the skin and at desired frequencies by means of sixteen actuators contained in a portable bracelet designed for any extremity of the human body. This prototype allows control over each actuator used as a stimulation point, actuated independently by wirelessly transmitted commands to a rechargeable stand-alone control system in the bracelet. Usability tests were carried out, with respect to tactile perception, which proved the correct functioning of the device. In perspective, the development, after a variety of validation tests with a large sample of patients with and without neuropathy, aims at creating a database to be used as set point values in front of these patients with the expectation that the system will also be used in patients with movement deficits, and employing tactile perception as a psychomotor stimulant in the execution of motor activities.

Keywords: motion deficit; tactile perception; tactile feedback.

1. Introduction

Owing A motor disability in a person can be caused by different reasons, mainly by accidents of different types or by diseases or neuronal lesions that, in one way or another, partially or totally paralyze the movement of the upper and lower extremities of the human body. When this type of disability arises, it is necessary to initiate a rehabilitation phase which requires different stages and methodologies with long assistance times, so that patients tend to abandon the procedures, leaving the recovery treatment unfinished.

In addition, there is a continuous worldwide growth in the number of patients in need of rehabilitation therapies, which has increased the pressure on

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health systems and, consequently, the reduction of time and resources available for treatment.

Regarding rehabilitation, it is often a tedious and lengthy process that can even last for months, even if several sessions are performed per week; it is carried out through recurrent visits to rehabilitation and physiotherapy centers at home, involving valuable human resources[1]. Under these considerations, it is essential to investigate more effective ways of performing therapies, so following a technological approach is very promising. In the above sense, technology and robotics currently offer users a multitude of advanced devices oriented to research, science, industry or entertainment, capable of simulating with great realism different haptic sensations (proprioceptive, tactile and vestibular). Such devices are characterized by providing physical contact between the computer and the user, as well as force and tactile feedback to the subject interacting with virtual or remote environments[2,3]. These advanced devices are able to make the user believe that they touch or collide with virtual, solid or deformable objects, they are also able to provide different haptic textures depending on the type of surface of the object (rough, smooth, frictionless, sticky, penetrable, among others).

On the other hand, research on the use of robotic and virtual reality technologies in patients with neuromotor deficits has been widespread in recent years[4,5]. Although the results reported in the literature seem promising, and their potential benefits extend to diverse patient populations, their application is strongly restricted to large-scale regional hospitals, but very limited to local physical therapy clinics, and they are practically unavailable for home training programs[6].

This has motivated the recent growth of virtual reality applied to serious video games for rehabilitation; such games have a potentially high impact due to their easy distribution, their applicability to a wider range of motor disabilities, and their potential for assigning "high-dose" and "high-intensity" training protocols[7,8]. However, despite the extraordinary technological improvements in this field, much research remains to be done. Among the problems to be addressed are: (a) the absence or limited possibility of sensorimotor feedback in the form of tactile contact; (b) limited interaction schemes, mainly oriented to very generic tasks involving reaching and hitting mobile virtual objects, which are still far from patients' real-life situations; (c) limited realism, generally focused only on visual aspects, but without convincing physical realism, which limits the possibility of assigning progressively more complex functional motor tasks requiring greater fine dexterity; (d) many systems are generic, but not focused on specific drugs; (e) poor understanding of the role in recovery of assigning different levels of therapy difficulty and especially how to assign the optimal dose, according to the clinical and personal conditions of the patients; (f) the reduced validation and extensive clinical evaluation in controlled studies of many systems; (g) the need to understand the relationship between the characteristics of these types of systems and their impact on patient recovery.

The use of virtual reality and mobile computing technologies in rehabilitation systems, affordable in local or home environments, is also currently feasible; however, such systems have the important limitation of lacking motor actuation and control capabilities because they are not integrated with any robotic system. In order to provide feedback to the patient on their performance/errors, it would be beneficial to provide haptic feedback in such virtual reality systems during training by introducing the sense of touch into the multisensory feedback loop and augmenting the visual and auditory channels[9]. Furthermore, having the tactile sensation of touching virtual objects-in addition to audio and vision-could play a major role in assisting in the process of relearning manual movement control skills in patients; Therefore, the integration of portable devices capable of providing haptic feedback is important, although this has received little attention from the scientific community - resulting in a precarious literature—but it has gradually begun to arouse more and more interest.

The paper is structured as follows: first, the materials and methods for the development of the wireless vibrotactile haptic feedback system (DRHVI) are established; then, the proposed DRHVI is described in detail; subsequently, the usability tests of the device in three types of experiments with a healthy person without motor disability or sensory deficit are exhibited; then, the results of the validation of the DRHVI are shown and discussed; and, finally, the conclusions of the research are shown.

2. Methodology and materials

In accordance with the above motivation, a DRHVI was developed that, when used together with complementary systems, could serve as a basis for future research in the area of assistance in the execution of motor rehabilitation activities. The DRHVI prototype is composed of three systems: mechanical, electronic and user interface. Six phases were established for its design and development: (a) characterization of the actuators; (b) selection of the electronic control device; (c) selection of the type of communication; (d) design of the power supply system; (e) integration of the system to perform sensory validation; (f) validation of the vibrotactile flow.

As a result, it was established that the hydraulic feedback system consists of sixteen vibrotactile actuators (minivibromotors), which can be driven randomly or precisely; also controlling the number of motors to be operated and their different frequencies independently.

The control is performed remotely with a system that establishes the communication through two Xbee modules, where one module works as a transmitter (Tx) connected to the central control equipment, equipped with a graphic user interface able to send commands wirelessly to the other receiver module (Rx), connected to a control system that interprets this command to generate PWM signals to the different actuators, regulating the vibration levels by increasing or decreasing the pulse width. Subsequently, all the elements that make up the system (actuators, communication devices, control and power supply) are coupled in a portable bracelet.

As a method of validation of the DRHVI, psychophysical and sensory usability tests were applied.

3. Development of wireless vibrotactile optical feedback system

For the purpose of the research, a profile of use was established in men and women between 16 and 65 years of age (age of labor productivity) belonging to any socioeconomic stratum, with a neuromotor disability (stroke) or musculoskeletal (rheumatism), or with sensory deficit due to neuropathy (diabetes), may present a transient disability condition that affects their quality of life due to the impossibility of performing daily life activities normally. This information suggested the definition of size, shape and frequency variables necessary for the design of the support structure at the interface of the device, in order to make it comfortable for the patient.

3.1. Device design features

To control the behavior of each of the actuators, a wireless communication and control device was designed (**Figure 1**), in which an Arduino NANO microcontroller was implemented as a base that allows the sixteen actuators to be operated simultaneously by means of PWM signals, while transmitting and receiving control commands wirelessly through an Xbee communication module.

The function of the Arduino Nano is to interpret the command received from the Xbee, a receiver that operates under the 802.15.4 specifications. This command contains the information of the motor to be activated, specifying motor number, vibration frequency and the time to be driven. The module allows point-to-point or point-to-multipoint data transmission with a speed of up to 250 Kbits/s and operates in the ISM (Industrial, Scientific and Medica) frequency band.

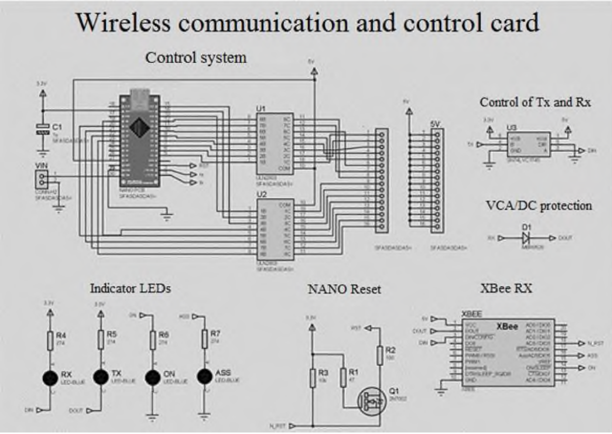

Figure 1. Schematic design of the coupling between the control system and the communication system made with Proteus 8.

Source: own elaboration.

Since two Xbee modules were used, one connected to the interface (Rx) and the other connected to the computer (Tx), it was possible to interact remotely with the actuators that generate optical sensations.

Then the double layer electronic board was obtained with the pads and metallized surfaces on which the components were mounted (**Figure 2**). This interface has a smaller size than expected, with a low power consumption that provides an optimal performance for the optical feedback system, its characteristics are specified in **Table 1**.

The power supply of the electronic board must be sufficient for it to perform its main functions efficiently, so a suitable power supply system was sought to provide energy for the continuous operation (several hours or days) of the wireless control system together with the vibrotactile actuators.

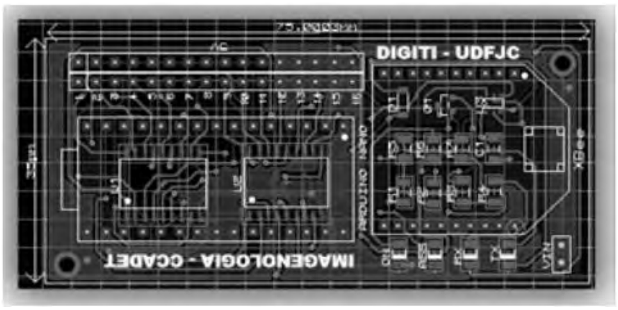

Figure 2. Printed circuit board design.
Source: own elaboration.

Table 1. Features of the wireless control system

Characteristics	Description
Speed	8 MHz
Flash	64Kb
Communication	Wireless connection XBee
Consumption	50 mA active status 2 mA inactive status
Size	7.5 cm x 3.5 cm x 1cm

Source: own elaboration.

After choosing the power supply system, all the systems were coupled and durability tests were carried out, in which satisfactory results were obtained, activating the sixteen actuators while transmitting control commands wirelessly, achieving a duration of more than two days of continuous use. The system is capable of lasting sixteen times longer if one optical actuator is activated at a time, and by not transmitting data wirelessly on a constant basis increases the power efficiency of the device; it is estimated that the device can have an average autonomy of four or five days. The final industrial design that connects the whole device consists of an insulating box containing the development board, a cylinder where the power supply system is fitted and a bracelet to hold the sixteen vibromotors and the points to be stimulated; these actuators were positioned equidistantly (2 cm) in two parallel columns, each one with eight vibromotors to cover a distance of 14 cm (**Figure 3**).

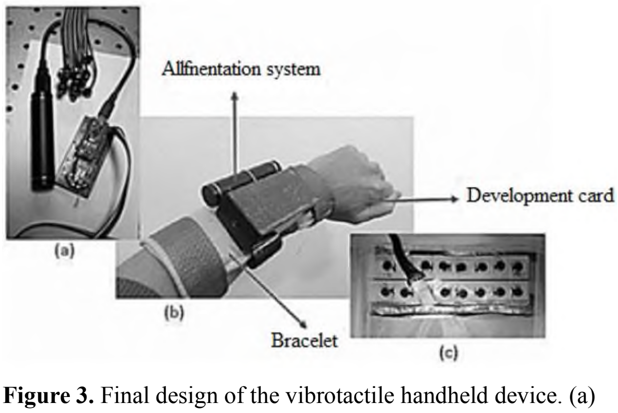

Figure 3. Final design of the vibrotactile handheld device. (a) Electronic control system; (b) final handheld interface mounted on an individual; (c) array of vibromotors of the device.

Source: own elaboration

Finally, to have complete control of the device and to be able to interact with the portable system, a graphic user interface was created that consists of two parts, the first is the control part that serves to characterize the actuators by sending commands through the Xbee module connected to the computer, it also allowed to generate haptic sensations in different points of the skin by selecting the vibromotors and the desired frequencies. The second part is a tool that allows to experiment the vibrotactile flow of a person, generating haptic sensations in a sequential and random way with different intensities, which can help to identify the discrimination capacity between different stimuli in a person.

4. Usability testing

Three types of experiments were performed with a healthy person without motor disability or sensory deficit, with the particular purpose of validating the vibrotactile flow provided by the device by means of feedbacks. The first experiment consisted of evaluating the threshold of cutaneous tactile perception with a series of vibrotactile stimuli applied with varying intensity; with this experiment the threshold frequency of perception of the people could be determined by repeating the experiment three times for each one and constructing the graph that allowed to demonstrate this frequency with variations in its voltage. With this method the device can be useful to evaluate the average sensitivity of a healthy person, or to generate a sensitivity map by zones in patients with tactile sensitivity problems.

The second experiment consisted of establishing the discrimination between two different stimuli, by limiting the distance at which two stimuli were activated at the same time and identifying when they felt like one, which could serve as another metric to evaluate sensory capacity in patients. The third experiment consisted of evaluating the usefulness of the instrument to adjust the localization capacity of variable vibrotactile stimuli that a person has this experiment allowed the validation of the vibrotactile flow by interacting with a virtual image and the device in question (**Figure 4**), the vibrotactile stimulus had to be located on a reference map, with and without the help of a visual reference.

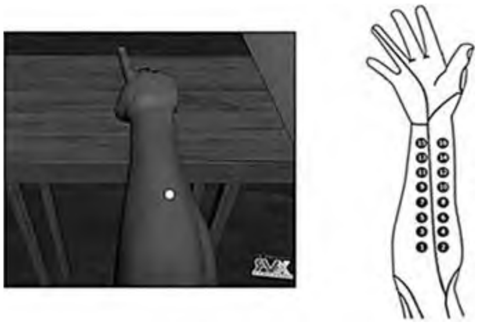

Figure 4. Experiment on stimulus localization. (a) Virtual image of visual reference of the stimulus; (b) localization map of the stimulus in different areas of the arm.
Source: own elaboration.

5. Results and discussion

In the case of the first experiment, the participant was able to detect up to a minimum average vibration of 30 Hz, which corresponds to normal skin detection frequencies. In the second experiment it was found that when the frequencies were higher than ten units (with respect to the level found in the first experiment) for the vibromotors that had a separation distance close to the average distance, only one type of stimulus was felt, so it was determined that it was not convenient to use frequencies higher than this; It was also found that in order to feel the stimulus at the point in question it is necessary to decrease the intensity levels provided to the device for its operation, since at very high frequencies and very short distances there is a perception of saturation in the stimulation provided.

For the third experiment, very interesting results were found. When vibrations were provided at nearby points and other vibration points were indicated in the virtual image, the person reported having a positive response (sensation of stimulation at the indicated point) when the stimulation was not performed at this point, but in a nearby area; This shows that in many occasions the person can be psychologically influenced to feel stimuli where they are not really being stimulated, this happens especially in people who are presenting a motor deficiency in their limbs.

In this case it is obtained that the localization errors were smaller when the participants had the visual aid, the error value was around one centimeter, which is the separation distance between each pair of motors. It is thought that it would be good to extend this test in the future with more people and testing higher intensity levels in order to investigate whether this is preserved or can change depending on the vibration levels. These tests resulted in the proper functioning of the feedback system, the validation of the vibrotactile flow and a final calibration of the actuators.

6. Conclusions

In this work we have presented the development of a portable optical device as a method of biofeedback in motor activity assistance and rehabilitation for patients with transient motor disability and, similarly, for early diagnosis of patients with neuropathy.

The validity of the system has been justified by controlled experiments to evaluate the vibrotactile flow, trying to discriminate or evaluate the possible influences of external factors such as the noise of the vibromotors or the use of sight as a distractor when receiving a tactile stimulus, for this purpose three experiments were conducted with a person without motor disability or neuropathy. When actuating the actuators at high frequencies 120 Hz, the ability to detect a specific point of vibration is lost, since the vibratory force is very high and makes us think that the element that generates it is larger than the area it occupies on the skin, This makes it inefficient for vibrotactile flow validations because it does not allow the discrimination of two or more close stimuli, likewise keeping it active for a long time can cause discomfort or injury to the skin due to the high temperature that the actuator takes with that pattern of operation.

Finally, this device can be integrated into virtual reality applications or training video games for the rehabilitation of human upper extremities. The device could allow to study the validity, efficacy and efficiency of this type of technology in the haptic sensory environment; in addition, it could have possible applications for sensory evaluation in the extremities of other types of patients with sensitivity problems (for example, in diabetics due to the development of neuropathies in their extremities). It is also considered that this device could be valuable as a preventive, diagnostic and monitoring tool in patients with other neuropathies.

Conflict of interest

The authors declare no conflict of interest.

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REVIEW ARTICLE

Application prospects for wearable body surface microfluidic system in sports

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ABSTRACT

The wearable body surface microfluidic system has great application potential in the field of sports. The use of the wearable body surface microfluidic system to monitor the physiological state of athletes can solve problems faced such as long inspection cycle in sports monitoring, difficulties in continuous monitoring, dependence on laboratory platforms, athlete resistance and other problems faced in technological integration to promote the development of the sports field. In recent years, the development of key technologies such as microfluidic chips and microneedle delivery provides an ideal solution for real-time monitoring and even immediate intervention of physiological states during exercise. This paper summarizes the latest research progress of wearable body surface microfluidic systems and focuses on eight wearable body surface microfluidic systems that may be applied in the field of sports, with their application prospects in sports analyzed and discussed. Finally, the application direction of the wearable body surface microfluidic system that may achieve breakthroughs is illustrated with the prospect demonstration of the future research and development direction of wearable sports equipment. This paper aims to focus on technical problems in the development of the sports field, provide multi-disciplinary solutions and advocate technology integration as well as provide scientific and technological assistance for the development of the sports field.

Keywords: wearable technology; microfluidics; microneedles; biochemical analysis; motion monitoring

1. Introduction

The use of wearable equipment for sports performance and physiological state monitoring plays a very good role in promoting the scientific training of athletes and the improvement of competition performance. Wearable equipment refers to a monitoring device that can be directly worn or attached to the body. Traditionally, wearable equipment is generally used for monitoring physical indicators such as heart rate and the number of steps. Smart bracelets and electronic timing vests are typical wearable equipment. With the gradual development of wearable devices, the monitoring of some physiological and biochemical indicators has also gradually developed into wearable devices. Today, a new generation of wearable devices is used to non-invasively monitor inorganic salts, metabolites, pH and other indicators in human sweat, and to analyze important

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information such as athletes' exercise energy consumption, exercise fatigue and sports nutrition supplement needs. The use of wearable equipment to monitor the kinematics[1], physiological[2] and biochemical[3] indicators of athletes has become the most commonly used method to evaluate their sports performance and motor function. However, existing devices are worn in limited positions[4] and as such, often limits the physical activity of the athlete due to volume[2], shape[5], weight[6], and wired data transmission[1,2]. Furthermore, even some tests can only be performed in laboratories[7]. As a result, this brings a lot of inconvenience to the assessment of sports performance testing, sports injuries and sports rehabilitation progress of athletes.

Wearable equipment developed in recent years combined with microfluidic chip technology[7,11] can achieve rapid, minimally invasive or non-invasive monitoring of body indicators. For example, the sweat analysis microfluidic system can non-invasively detect glucose in sweat[12], lactate[7,11,12], sodium ion[11,13], potassium ion[11], chloride[7,12,14], creatinine[10], urea concentration [10], sweat pH value[7,12], total sweat volume and sweat rate[7,12,13] while other indicators are monitored, with physiological and biochemical analyses carried out without collecting blood samples, thereby providing convenience to sports practitioners to obtain high-quality data, while facilitating their timely adjustment of athletes' exercise programs, and promote the implementation of scientific training. In addition, the development of microneedle delivery in recent years[15,18] has enabled us to attain real-time intervention of physiological states during exercise in the near future[16], that is, through microfluidics, micro-sensors, or solid-state micro-monitoring of the concentration of various substances in athletes' sweat or inter-tissue fluid, and through a closed-loop feedback mechanism, the use of soluble microneedles or hollow microneedles percutaneous injection of the required nutrients or therapeutic drugs. The development of this new sports medicine system will trigger a new round of technological revolution in the field of sports, and promote the development of sports with the help of technological integration.

The development of wearable body surface microfluidic systems can solve multiple challenges in traditional motion monitoring: (1) Long inspection cycle: Most of the traditional motion monitoring adopts the method of sampling and sending it to the laboratory for analysis during which the results in the long time intervals can easily cause data inaccuracy, such as evaporation of water from sweat during the sending process, causing the concentration of electrolytes in it to rise. On the contrary, wearable body surface microfluidic systems can complete the monitoring on the body surface[7,10,14] and can transmit the data through wireless means[7,13] to achieve real-time monitoring of data. (2) Continuous monitoring is difficult: Various physiological and biochemical indicators of the human body are often changing rapidly during exercise. However, traditional blood sample analysis is obtained in point-like discrete data with usually very long intervals between data points, so it is difficult to reflect the real state changes of athletes in real-time. The wearable surface microfluidic system can achieve continuous monitoring, such as the use of microfluidic chips[12] to monitor the concentration of lactate and glucose in sweat in real-time. (3) Dependence on laboratory platform: traditional analytical methods are concentrated in the laboratory[7], which usually requires expensive equipment and professional personnel to operate. With the use of body surface microfluidic system, not only that data acquisition can be performed in situ, but also the test results can be directly displayed on the mobile phone[7,12], thereby avoiding the dependence on the laboratory and do not require the user to master professional skills. (4) Athlete resistance: Traditional test methods often have problems such as discomfort, trauma, and restriction of physical activity, such as the lactate threshold test[19] which requires blood retrieval through fingertips. The use of wearable surface microfluidic devices[7,11,12] can analyze sweat in a non-invasive, comfortable, and unrestricted physical activity method, and achieve the required physiological state monitoring and analysis through the correspondence of its results to the concentration of lactate in the blood[12].

Based on the above advantages, there are many research works[6,11] demonstrating the great potential of wearable surface microfluidic systems (**Figure 1**). However, most microsystems were seen to be still in the small-scale testing stage with still many urgent problems remaining to be solved for commercial promotion. For example, some microfluidic systems are expensive to manufacture[7] and unable to be used repeatedly[7,10,20]. At the same time, there is also the need to collect a large amount of first-hand data, standardize evaluation standards and establish cloud databases. This paper summarizes the latest research progress in the field of body surface microfluidic systems in recent years, focuses on eight wearable surface microsystems that have been applied or may be applied in the sports field in the future, and are classified according to their main technical categories, covering the cutting-edge research results of microfluidic systems[10,11,20], hybrid microsystems[12] and microneedle delivery[15,18]. Finally, the direction of the most likely breakthrough progress of the microfluidic system in the sports field is illustrated along with the analysis of the application prospect and possibility of the microfluidic system in the sports monitoring and the prospect of the research direction of wearable sports equipment.

Figure 1. Recent featured research on wearable skin-interfaced microfluidic systems[6,11].

2. Wearable microfluidic system

The application of wearable body surface microfluidic systems in sports mainly focuses on sweat analysis[21]. Sweat is a body fluid secreted by the skin that is rich in electrolytes[22], small molecules[23], and proteins[7]. It does not only come from a wide range of sources and is convenient for collection and analysis, but sweat may also reflect the levels of various components in body fluids. Quantitative analysis of sweat on the body surface has a wide range of applications in the monitoring of physiological status (such as hydration status[7]) and the diagnosis of diseases (such as bladder fibrosis[7,14,24,25]). Sweat analysis based on microfluidics mainly uses the pressure generated by sweat glands[11] to push sweat into a series of pre-designed micro-channels and micro-chambers on the microfluidic chip and then through some color reactions[7,10,12,14,26] followed by image analysis [7,26] to measure the concentration of each substance in sweat.

In the field of sports, sweat analysis can be applied to monitor the physiological state of athletes[21]. During the training process, the measurement of lactate concentration in sweat can provide a basis for evaluating the training intensity of athletes[27] to formulate a more scientific training plan. In addition, the measurement of glucose concentration in sweat is helpful for us to accurately judge the energy consumption of athletes[28], which is also of great significance for guiding nutritional supplementation after training. The measurement and analysis of total sweat volume can be used to assess the physiological status of athletes, such as hydration status[7] and thermal regulation status[7], which is expected to provide data support for the formulation of individualized precise hydration strategies in sports. Therefore, through sweat analysis, sports training can be optimized, and ultimately the sports performance of the athlete can be improved.

To collect and analyze sweat during exercise, Choi et al.[11] developed a microfluidic system that can collect sweat on the body surface in time sequences (**Figure 2A. a**). Sweat first enters the microchannel from the sweat inlet in the center of the chip, follows through a serpentine channel connecting to 12 sweat reservoirs and is further injected into 12 sweat reservoirs in chronological order under the control of a series of valve structures (**Figure 2A. b**). The circular design of the chip is to be able to extract the sweat collected in the sweat reservoir by centrifugation (**Figure 2A. c**). Choi et al.[11] used this system to complete the time-sequence-based sweat collection and the concentration determination of lactic acid, sodium ions and potassium ions in sweat. Its test results can be used to assess exercise intensity and electrolyte balance in athletes. In addition, Reeder et al.[20] developed a microfluidic system for water movement monitoring (**Figure 2B. a**), which can collect human sweat in a water immersion environment for biochemical analysis and can also measure body surface temperature.

The wireframe illustration in **Figure 2B. a** shows the sweat inlet and outlet design: The sweat outlet is extremely small that can prevent water from entering during use to ensure accuracy of the test results; the dye or reactant is stored adjacent to the sweat inlet in the chamber comprising of red and blue dyes with different dissolution rates. Due to the dissolution of the blue dye, a clearly visible color gradient can be formed in the micro-channels, which cleverly visualizes the total sweat volume (**Figure 2B. b**). Total sweat loss can be quantified by observing the number of cells filled with sweat (1.5 μL volume per paperclip). Similarly, if the dye is replaced with a suspension of silver chloranilate, a corresponding color reaction will occur in the microchannel, and the sweat color of each unit is compared with the standard colorimetric card in the central sector of the chip, where then the concentration of chloride in sweat in the cell can be obtained (**Figure 2B. c**). This microfluidic system expands the scope of application of traditional wearable equipment and opens up a precedent for monitoring and analyzing the physiological state of sports in water or water sports.

The wearable body surface microfluidic system can not only be used for the determination of chloride concentration in sweat but also can integrate multiple chromogenic reactions on one chip to realize the simultaneous determination of multiple indicators.

Zhang et al.[10] developed a body surface microfluidic system that integrates water-repellent sweat collection and color reaction (**Figure 2C. a**). The system contains a serpentine channel for total sweat volume and perspiration control. Quantitative analysis was carried out through the micro-channel and the aforementioned micro-valve[11], where the sweat was also introduced into 3 consecutive chambers (3 chambers each for pH, creatinine and urea concentration measurement, 9 chambers in total) in chronological order. Thanks to the excellent waterproof function of the device, it can be used not only for sports athletes but also for infants, the elderly or sick people who cannot exercise vigorously.

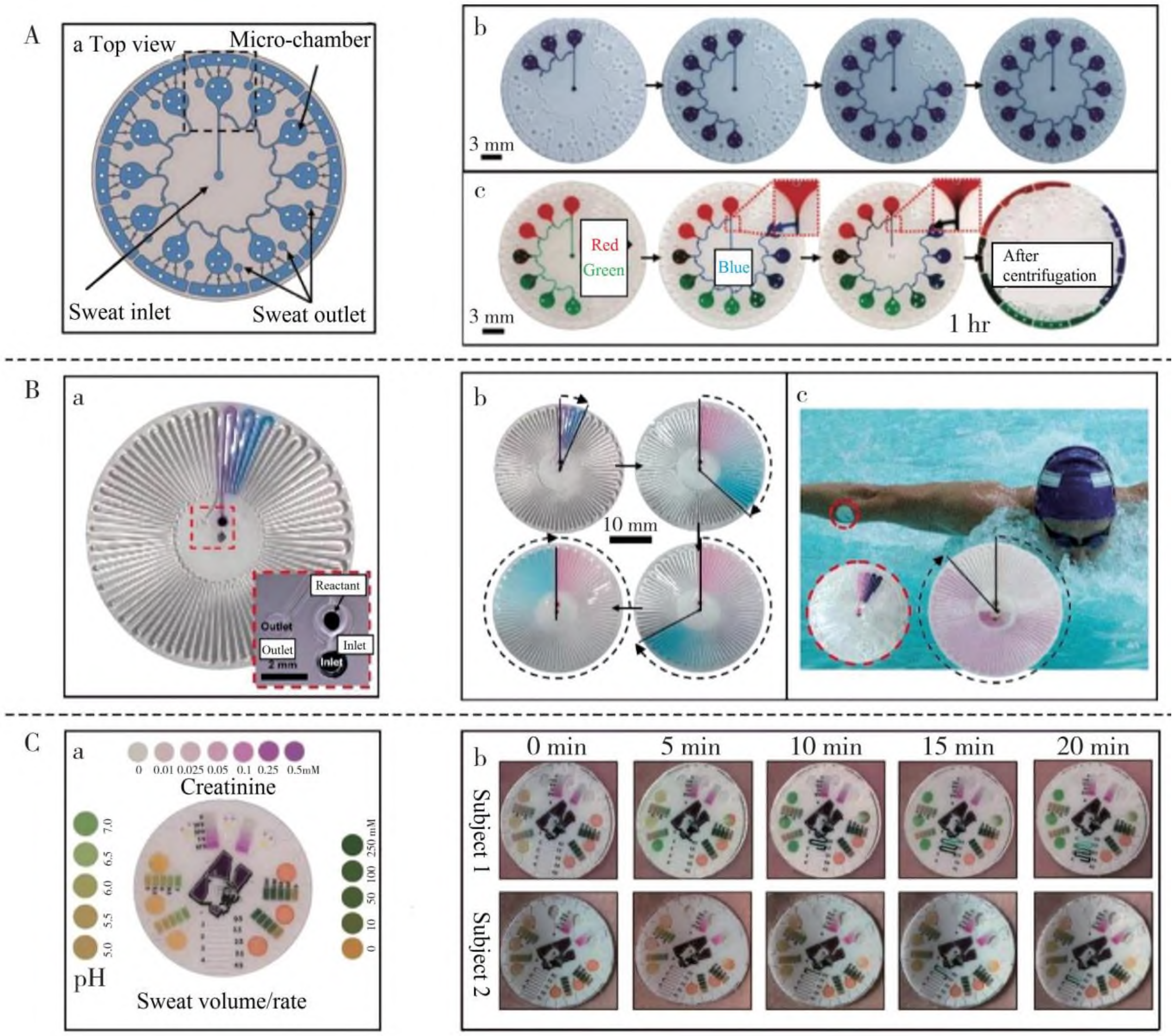

Figure 2. Wearable skin-interfaced microfluidic systems: **(A) a**. skin-mounted microfluidic systems for chrono-sampling of sweat; **(A**) **b**. pressure naturally induced by the sweat glands drives sweat through a microchannel to chrono-filling 12 micro-reservoirs under micro-valves' control; **(A) c**. the circular construction is beneficial to use centrifugation for extraction of sampled sweat[11]; **(B) a.** waterproof skin-interfaced microfluidic system for sweat analysis in aquatic settings (inset: microfluidic inlet and outlet ports); **(B**) **b.** a dye composed of blue and red water-soluble particles that dissolve at different rates results in a volume-dependent color gradient to visualize total sweat loss as the device fills with sweat; **(B) c.** a swimmer wearing a skin-interfaced microfluidic system that quantifies local sweat chloride concentration (inset: optical image of the waterproof microfluidic system)[20]; **(C) a.** skin-interfaced microfluidic system for colorimetric analysis of biomarkers in sweat; **(C) b.** a paper-based enzymatic or chemical assay for colorimetric analysis of creatinine and urea concentrations and pH[10].

The researchers attached the system to the subject's body surface and allow the system to undergo a hot water bath of 5–15 minutes (temperature: 38–42 °C). Thereafter, the results were then obtained through mobile phone image analysis: This system adopts the import and export mode from Reeder et al.[11] study, while the use of blue dye dissolved in sweat to visualize the total sweat volume and the method of the enzyme reaction and chemical reaction color development was based on the test paper used in the study by Koh et al.[7]. Through image analysis, creatinine, urea concentration, and pH in the subjects' sweat were quantified against standard color charts on the microfluidic chip (**Figure 5C. b**). Significance of this study: Firstly, it expands the applicability of the microfluidic system for surface sweat analysis; secondly, the sweat analysis results of this system can be used to evaluate the user's renal function (when kidney function is abnormal, especially when glomerular filtration function is abnormal, the concentration of creatinine and urea in blood and sweat will increase, and pH value will also be affected).

3. Wearable hybrid micro-system

In recent years, some scholars have proposed the concept of a hybrid system, which refers to the combination of two quantitative analysis systems; microfluidics and micro-sensors and exert their respective advantages. Bandodkar et al.[12] developed a hybrid microsystem that can simultaneously perform electrochemical, chromogenic, and volumetric quantitative analysis of sweat. The system consists of a disposable microfluidic subsystem (**Figure 3A. a**) and a near field communication (NFC) subsystem (**Figure 3A. b**). In the microfluidic subsystem, one ring-shaped channel with soluble blue dye produces the visualization and quantification of total sweat volume and sweat rate, while two channels connected with six color reaction chambers combined with micro-valves were used to introduce sweat into the reaction chamber in chronological order (a standard colorimetric card is attached to the side of the chamber) to produce the quantitative analysis of the color reaction of pH value and chloride concentration. Additionally, two slightly larger sweat inlets were used to embed micro-sensors to achieve real-time monitoring of glucose and lactic acid concentrations. The NFC subsystem is tightly coupled with the microfluidic subsystem through a magnetic force, which not only provides enough magnetism to keep it from falling off during vigorous exercise but also makes it easy to remove for next use, saving testing costs. **Figure 3A.c** shows the process of sweat analysis by the system. The results of the color reaction can be obtained through mobile phone image analysis, and the power supply and data transmission of the electrochemical analysis was completed through the NFC subsystem connected to external devices (**Figure 3A. d**). The experimenters also conducted the analysis on the trend variation of glucose and lactate concentrations in sweat obtained by micro-sensor analysis (represented by the black dashed line in the figure), and the variation trend of glucose and lactate concentrations in the blood obtained by the blood test (represented by the red dashed line in the figure). For comparison (**Figure 3B**), it was found that the data were close in most cases with the results consistent with previous studies[16,25,28,29], demonstrating the feasibility of sweat analysis to obtain semi-quantitative data and its application prospect in non-invasive exercise monitoring and analysis.

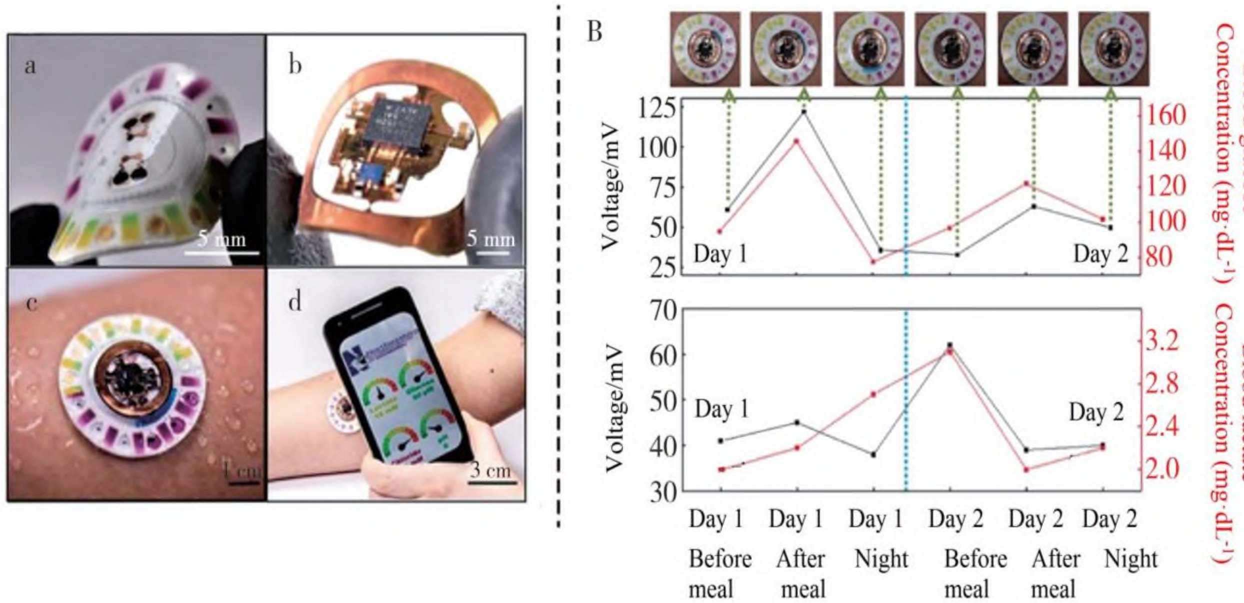

Figure 3. Hybrid microsystem integrating microfluidics and micro-sensors: human trials that compare concentrations of glucose and lactate in sweat and blood; **(A) a.** microfluidic subsystem with embedded sensors' anodes and cathodes; **(A) b.** NFC subsystem; **(A) c.** hybrid microsystem for electrochemical, colorimetric and volumetric analysis during sweating; **(A) d.** wireless power supply and data transmission via external devices; **(B)** correlation of data acquired from glucose and lactate sweat sensors (black line) with that acquired from blood glucose and lactate meters (red line), respectively[12].

In summary, the wearable body surface microfluidic system provides a platform for accurate quantification and real-time monitoring of sweat analysis, and at the same time, it can achieve targeted physiological and biochemical analysis through technology accumulation and the combination of micro-sensors and other technologies. This system not only can be used for the formulation of traditional energy supply schemes for athletes in sports and to promote the innovation of sports technology analysis methods but also to provide scientific and technological assistance for real-time physiological state monitoring of diseased populations in formulating and implementing sports rehabilitation plans. Taken together, these applications demonstrate that microfluidic technology has broad development space and huge market potential in the field of sports.

4. Wearable microneedle system

Traditional drug delivery methods are mainly subcutaneous[30] and intravenous injections[31]. Meanwhile, blood tests have become common means of physical condition detection[32], disease diagnosis[33], and even athlete motor function monitoring[19].

At present, invasive detection methods such as blood drawing not only require professional personnel to operate[30], but the athletes also experience pain, discomfort or fear of needles[30,31,34]. Therefore, achieving efficient drug delivery or painless body fluid collection has become a hot research topic. The development of wearable microneedle chips provides new solutions for sports replenishment, motion monitoring in diseased populations and sports injury treatment. Accurate, efficient, and safe physiological condition monitoring and drug delivery can be achieved through wearable microfluidic chips combined with microneedle arrays or micro-sensors[30,36].

Figure 4A shows the principle of microneedle delivery: the length of the microneedle is generally less than 1 mm, and its needle accurately penetrates the epidermis without touching the blood vessels and nerves at the base of the dermis so that exogenous substances can be introduced into the dermis layer by passive diffusion and other methods without pain[31]. **Figure 4A** also shows four typical microneedles[30]: (1) Solid microneedles, which can be used to penetrate the stratum corneum of the skin and form microporous channels to increase the permeability of the skin for subsequent transdermal drug delivery. (2) Coated microneedles, when attached to the body surface, the drug coating on the surface of the microneedles can quickly dissolve into the interstitial fluid. (3) Dissolvable microneedles, the needles are usually encapsulated with drugs and can be completely dissolved in the interstitial fluid of the skin, which can be used for sustained drug release[17]. (4) Hollow microneedles, the tube in the center of the microneedle can be used to continuously inject exogenous substances into the dermis layer. This kind of microneedle usually controls the injection dose per unit time through pressure and can freely achieve fast or slow drug delivery. The above microneedle systems have been widely used in biomedicine and other fields, such as drug delivery[30], interstitial fluid extraction[31,37], disease diagnosis and treatment[16], medical cosmetology[39] and so on. The following summarizes the micro-needling technology that is expected to be applied in the field of sports.

Gowers et al.[15] developed a microneedle array-based sensor for antibiotic concentration monitoring (**Figure 4B**). **Figure 4C** shows the cross-sectional view of each coating on the surface of the microneedle array, the real image of the chip, and the local electron scanning microscope image of the microneedle array.

Its working principle is as follows: the hydrolysis of the antibiotic β-lactam by the β-lactam enzyme plated on the surface of the electrode will produce a change in the pH value of the interstitial fluid. The researchers thus established the correlation between the antibiotic concentration and the pH value, and the pH value is linearly related to the electrical potential in the sensor circuit[15].

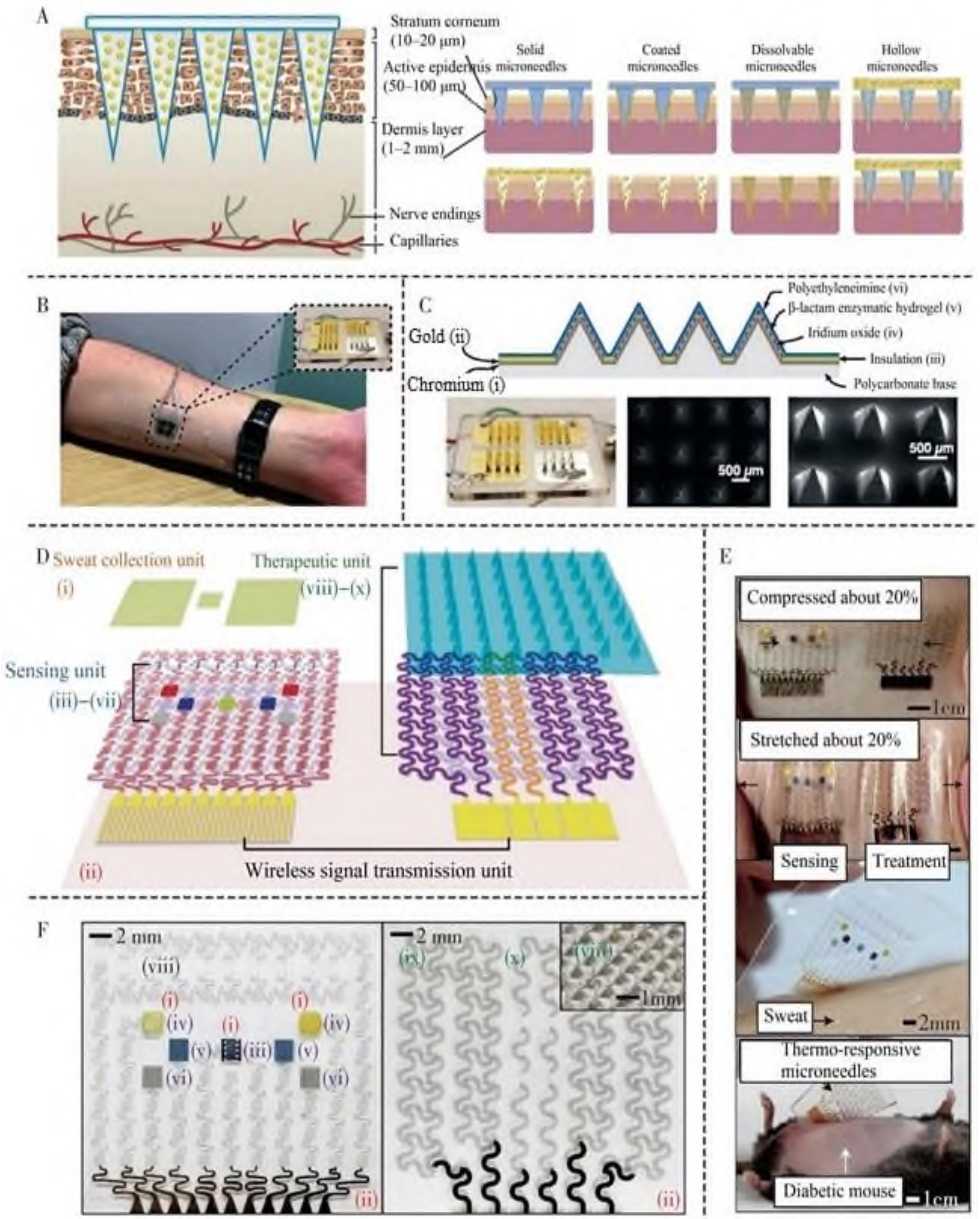

Figure 4. Working principle and application of microneedles: **(A)** common working principle of microneedles for drug delivery and four types of microneedles[30,31]; **(B)** Microneedle-based sensor for continuous monitoring antibiotic concentrations; **(C)** schematic cross-section of working electrode showing each layer, optical image of the microneedles patch, and the scanned electronic microscopy (SEM) image of the microneedle array[15]; **(D)** schematic diagram of the graphene-based electrochemical system with thermo-responsive microneedles; **(E)** the skin-interfaced system with thermo-responsive microneedles under mechanical deformations, electrochemical sensor array on the human skin with perspiration and therapeutic microneedle array laminated on the skin near the abdomen of the diabetic mouse; **(F)** the image of the chip with thermo-responsive microneedles (inset: bioresorbable microneedle array)[16].

To put it in another way, the researchers established the correlation between the concentration of interstitial fluid substances and electrical signals through the combination of microneedle arrays and electrochemical sensors to monitor the changes in the concentration of interstitial fluid substances in real-time through electrical signals and in doing so enable timely delivery of drugs to reduce their side effects[40].

In 2016, Lee et al.[16] unified sweat analysis, micro-sensors, and dissolvable microneedles into a graphene-based electrochemical microsystem (**Figure 4D**), enabling sweat-based diabetes monitoring and feedback-based accurate drug delivery. **Figure 4E** shows its ability to resist deformation during exercise and the sweat analysis module: the micro-sensor is connected to a portable electrochemical analyzer that powers the micro-sensor, transmits data to a smartphone via Bluetooth. It was verified that the system can efficiently deliver the hypoglycemic drug metformin into mice and rapidly reduce the blood glucose level of mice. **Figure 4F** is the physical image of the chip. The microneedles dissolve when the temperature exceeds 41–42 °C. In vitro experiments have shown that the microneedles can release the drug only when the temperature exceeds the thermal response temperature, with precise and controllable drug release being well achieved.

Dissolvable microneedles can be used for precise drug delivery based on thermal response and for the slow release of drugs to achieve long-term therapeutic effects. Li et al.[17] developed a sustained-release effervescent microneedle chip, using the effervescent substrate encapsulated citric acid and sodium bicarbonate (**Figure 5A**). When the microneedle is pierced into the skin, the polyvinylpyrrolidone (PVP) in the effervescent rapidly dissolves in the interstitial fluid, while sodium bicarbonate, citric acid and interstitial fluid react to produce carbon dioxide, resulting in effervescent substrate rupture, achieving rapid separation of microneedle needles and chip substrates (separation efficiency up to 96% ±4%). As shown in **Figure 5B**, the microneedles encapsulated with purple-red fluorescent dyes were pierced into the porcine skin, and the microneedles were left in the porcine skin for sustained drug release. The study also tested the sustained-release process of effervescent microneedle chips loaded with contraceptives (LNG). The results showed that the effervescent microneedle chip that was attached to the mouse body surface for only 1 minute was able to leave the microneedle needle in the mouse skin and slowly release the drug for up to 2 months so that the concentration of LNG in its interstitial fluid was higher than the concentration of human treatment level for more than 1 month. Additionally, there was no erythema, edema or other skin irritation observed and histological analysis also confirmed its good biocompatibility.

Compared with keeping the drug in the body for slow release, Di et al.[18] developed a stretch-induced drug delivery microneedle chip that can be attached to the joint and store a drug in a microgel chamber on the chip, which releases and delivers the drug into the skin when needed. **Figure 5C** shows the principle of drug storage and release: the microgel drug compartment is used to load the polymer nano-drug particles and bind them to the stretchable elastic membrane. When the elastic membrane is deformed by the joint movement, the microgel drug cartridge releases the nano-drug particles into the microgel matrix, which is then injected into the skin on the joint surface by the microneedle array on the chip (**Figure 5D**). The microneedle system is expected to be applied to long-distance events, such as marathons, where anti-inflammatory drugs[18] can be delivered into interstitial fluid on the surface of the joint body by using traction caused by joint movement during exercise, alleviating joint inflammation in athletes in long-distance sports.

In summary, the wearable microneedle system can achieve painless, minimally invasive and precise transdermal drug delivery. It can also be combined with microfluidics and micro-sensor technology to achieve individualized closed-loop feedback therapy, which enables it to have broad prospects in the field of sports and health. The system can monitor the sports performance of athletes, treat sports injuries and provide nutritional supplements in sports and also facilitate the exercise intervention made by sports coaches and researchers in the field on disease populations (such as hypertension, diabetes, arteriosclerosis patients). It has greatly promoted the integration of scientific training and physical medicine, thus providing technical support for Healthy China 2030.

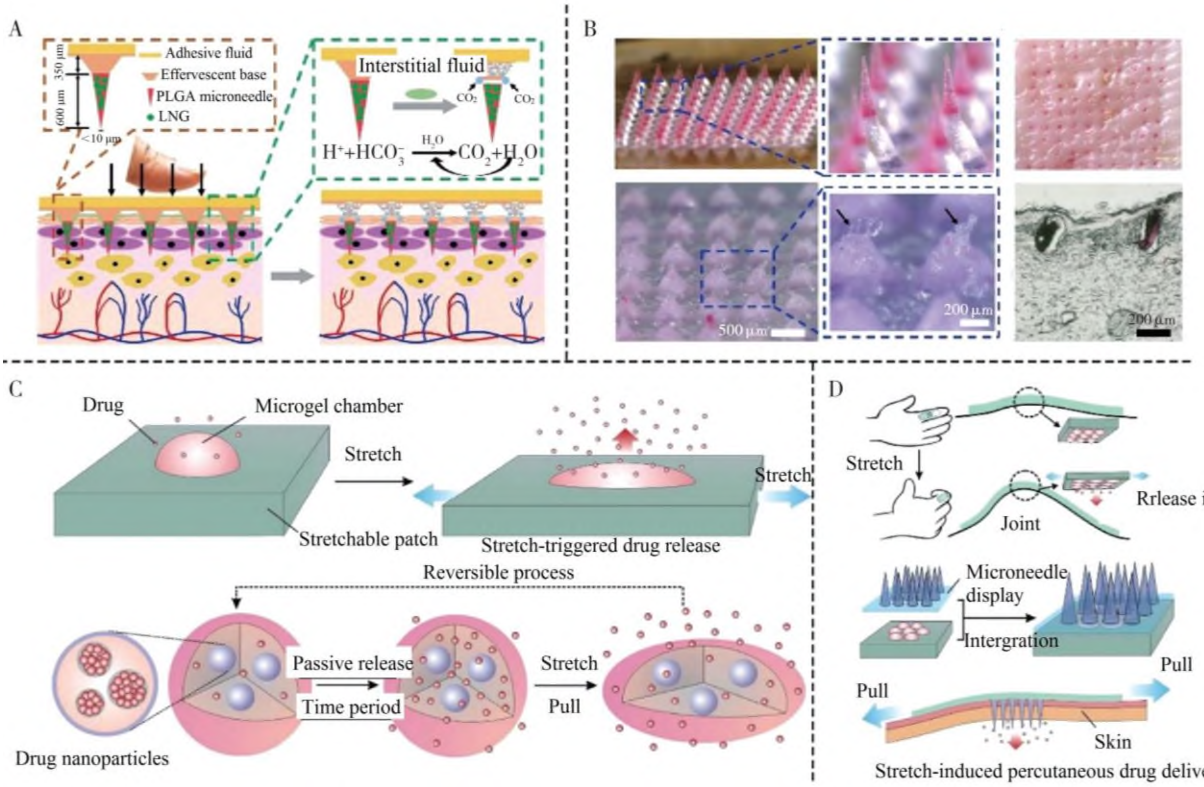

Figure 5. Two long-acting microneedle patches and their working principle: **(A)** schematic drawings of the process of microneedle patch application to the skin to rapidly deliver microneedle tips into the skin by the fast dissolution of the effervescent backing; **(B)** images of an effervescent microneedle patch with microneedle tips containing red fluorescent dye (Nile red) and photos took after microneedle tips separated from the effervescent patches; representative bright-field microscopy images of porcine skin after microneedle patch insertion and microneedle tip detachment in porcine skin and a corresponding image of a histological section of porcine skin (bright-field)[17]; **(C)** stretch-triggered drug delivery microneedle patch and its working principle of drug storage and release; **(D)** stretching of the patch induced by joint movements promotes the drug release and diffuse into the microneedle for transcutaneous drug delivery[18].

5. Conclusions

The wearable body surface microfluidic system combines the principles of physiological and biochemical analysis, with its in situ, real-time, non-invasive and other characteristics to continuously collect and analyze various indicators of the human body and monitor the health status of sports athletes. Coupled with the promotion of 5G and the widespread establishment of big data processing capabilities, a new generation of microfluidic systems supported by cloud databases is expected to achieve accurate quantitative analysis based on big data.

With the increasing demands of athletes' kinesiology monitoring, scientific training, and exercise intervention for diseased populations, the application of wearable body surface microfluidic systems in sports in the future is expected to achieve breakthroughs in the following aspects. (1) Sweat analysis: The wearable microfluidic chip can accurately measure the concentration of glucose, lactate, sodium ions and potassium ions in sweat, which can be used to judge the training intensity, exercise energy consumption, hydration state and thermal regulation state of athletes. The microfluidic chip on the body surface interacts with the mobile phone to display information such as the intensity of the exercise in real-time and give scientific nutritional supplement suggestions after the exercise.

In addition, with the help of the corresponding relationship between the concentration of substances in sweat and the concentration of substances in the blood, we can also establish the connection between sweat analysis results and clinical blood analysis data. Sweat analysis microfluidic chip gradually replaces blood sample detection and achieve true non-invasive exercise monitoring and analysis. (2) Exercise intervention for the diseased population: the wearable microfluidic system can also achieve real-time monitoring of the physiological indicators of the diseased population while being able to be combined with the microneedle chip to enable drug delivery. It is expected that microfluidic chips can be developed further for people with hypertension, diabetes, hypoglycemia and other populations in the future so that they can exercise more scientifically and safely. At the same time, the system may also be used to predict exercise-induced coma and falls, thereby helping to promote a healthy China. (3) Minimally invasive and precise drug delivery: the combination of micro-sensors and dissolvable microneedles can monitor the concentration of substances in sweat and interstitial fluid, thereby enabling precise, painless, and portable drug delivery in an individualized manner. By developing such microneedle chips, we can deliver a wide variety of drugs, not just diabetes and anti-inflammatory drugs. The new microneedle chip developed in the future is expected to solve the problems of needle fear, repeated injection, and adverse reactions caused by the traditional drug delivery injection process. In addition, such microfluidic and microneedle products are small in size, which is convenient for storage, transportation, and distribution, and reduces circulation costs. Athletes or users only need to put them in their pockets or backpacks before exercising, and they can be attached to the body surface when they need to be used, which provides great convenience to users and facilitates promotion and use.

At the same time, there are still some constraints and difficulties in the application of microfluidic technology in sports, such as: (1) To complete a series of complex fluid manipulation and biochemical reactions on a microfluidic chip, professional designers and chip processing equipment are required. (2) Microfluidic chips are still in the stage of small-scale application testing in the field of sports and are gradually being industrialized and commercialized. Physiological and biochemical researchers also lack opportunities to collaborate with medical engineering researchers. (3) At this stage, the performance of wearable body surface microfluidic systems is increasingly getting better with the test data is getting more and more accurate. However, the golden standard for sweat analysis has not yet been established.

In summary, wearable microfluidic systems have broad application space in the field of sports, whether it is in kinesiology monitoring, exercise training effect evaluation, or intervention in drug delivery, in which all of them provide new possibilities. In the future, the research and development of wearable sports equipment, especially in combination with microfluidic technology, will introduce a multi-index, non-invasive or minimally invasive, real-time data analysis, cloud database support, feedback drug delivery and high-speed wireless data transmission functions. The wearable body surface microsystem provides strong scientific and technological support for preparing for the Olympic Games and a healthy China.

Conflict of interest

The authors declare no conflict of interest.

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REVIEW ARTICLE

"Internet +" helps research on fitness for all

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ABSTRACT

Using the literature method and the logical analysis method, the study of "Internet +" to help the national fitness is conducted. The value of "Internet +" in helping national fitness: helping the government to reform the national fitness sector in terms of "decentralization, management and service"; helping the national fitness service to match supply and demand accurately; helping the national fitness sector to develop intelligently. The existing dilemmas: the popularity of "Internet +" national fitness integration is not high, the platform construction is insufficient, and the supervision ability is not strong. Accordingly, the development path of "Internet +" to help national fitness is proposed: based on the integration and popularization, to enhance the ability of the masses to apply online fitness; platform construction as the core, to strengthen the governance capacity of national fitness; innovation–driven focus, to promote the intelligent empowerment of national fitness; rule of law construction as a guarantee, to enhance the ability of national fitness network supervision.

Keywords: mass sports; national fitness; Internet +; smart sports

1. Introduction

State Council Unveils Internet + Action Plan to Fuel Growth states that "the integration and development of the Internet with various fields has broad prospects and unlimited potential, and has become an unstoppable trend of the times. Accelerating the development of "Internet +" is conducive to reshaping the innovation system, stimulating innovation vitality, fostering new business models and innovating public service models". With the rapid spread of network information technology, the development of national fitness has been given more possibilities. *The Opinions of the General Office of the State Council on Strengthening the Construction of National Fitness Facilities and Developing Mass Sports* proposes to promote "Internet + Fitness" and makes specific requirements for building an Internet platform to improve the intelligence, information and digitization of public services for national fitness. Through literature combing, it is found that promoting "Internet +" to help the development of national fitness has become a general consensus among scholars[1–3], and scholars have already ex-

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plained the specific functions of "Internet +" in the development of national fitness in terms of data governance, public service supply, fitness industry development, and fitness application empowerment [4–7]. "However, the existing research still lacks a systematic overview of the significance of the value of "Internet +" in the development of national fitness. However, the existing research still lacks a systematic overview of the significance of "Internet +" in helping national fitness. These are undoubtedly important issues that need to be clarified in the current development of national fitness. The value and significance of "Internet +" in helping the whole nation to get fit

2. The value and significance of "Internet +"

2.1. Helping the government in the field of national fitness "put, management, service" reform

At present, it is difficult to meet the growing fitness needs of the people by relying solely on a single government entity to manage national fitness and provide mass fitness services[8]. The government, market and society should give full play to the resource endowment and governance advantages of multiple actors[9,10]. However, if traditional offline governance channels are used alone, multiple subjects cannot converge in real time, and information transfer and subject interaction are limited by "time and space", making it difficult to give full play to collaborative governance capabilities.

The "Internet +" platform can expand the governance field of national fitness to online, and all subjects can access the platform through computers, mobile phones and other Internet terminals, and carry out multiple consultations, requests, approvals and decisions, information release and feedback at any time, aggregating the input of national fitness elements and improving the practical effect of collaborative governance. Take the abolition of the approval of commercial mass sports events as an example, the decentralization of the event has greatly activated the vitality of private organizers, but the organization of sports events often requires the coordination and cooperation of many departments, such as security, fire fighting and medical care, and the market and social organizers often face many practical difficulties in mobilizing the assistance of various departments[11]. In addition, the increase in the number, diversification and distribution of tournament organizers has made it more difficult for government departments to supervise them after decentralization[12]. By relying on the "Internet +" platform, the organizers can submit their requests online and realize the filing, verification and approval of multiple departments "simultaneously", and the guidance and services of government departments can be directly delivered to the organizers through the online platform, thus improving the quality and efficiency of government services. This will improve the quality and efficiency of government services.

In order to deal with the supervision after the decentralization, the State General Administration of Sports proposed in the measures for the management of Sports Events to give full play to the function of "Internet + Supervision", accelerate the sharing and unified application of supervisory information from all relevant departments, at all levels and in all fields, and realize comprehensive supervision, intelligent supervision and dynamic supervision. With the deepening of the "decentralization, management and service" reform, sports administrative departments to speed up the transformation of their functions, in giving society and the market more space to participate in governance, but also on the decentralization of services and supervision put forward new requirements. The application of "Internet +" technology can help government departments to effectively play their regulatory and service functions after the decentralization of government at the operational level.

2.2. Helping to match supply and demand for national fitness services with precision

From the demand side, "Internet +" can break the information barrier of mass fitness and improve the matching degree between the access of mass services and their own needs. Before the advent of the "Internet +" era, access to fitness information for the masses was very limited and inefficient. Through the "Internet +" technology, fitness equipment, fitness training, fitness venues and other types of services and products can be aggregated in a unified platform, integrating the introduction of merchants, products and services, user reviews and other information, so that the fitness public can choose according to their actual needs. With just a mobile phone, people can retrieve and understand the service information they need at any time, and complete various operations such as screening, booking, payment and evaluation, realizing the "efficiency" of fitness service acquisition and avoiding "blindness".

From the supply side, "Internet +" can promote the accurate identification of fitness needs. On the one hand, the application of big data, cloud computing and other internet technologies can provide scientific information support for the decision making and execution of national fitness service providers. For example, in 2016, the Suzhou Sports Bureau took a pulse on the fitness demands of the elderly through the "Su Titong" big data platform and made targeted adjustments when formulating the government's purchase service plan for the next cycle. 21.8%. On the other hand, "Internet +" technology can change the traditional "top–down, one–way" service supply model, which ignores the needs of the subject, and avoid a mismatch between supply and demand. For example, Shanghai's Internet–based "community sports distribution" system makes various fitness services available to the community in the form of online menus, which are then distributed by the city's community sports association, truly handing over the choice of services to the public and realizing the precise delivery of public services for national fitness. Relying on "Internet +" technology, national fitness government decision–making and service provision can be based on an accurate grasp of the needs of the masses, optimize resource allocation, make the limited available resources play the maximum integration benefit, and better meet the diversified and refined fitness needs of the people.

2.3. Contributing to the development of intelligence in the field of fitness for all

While there is widespread consensus on the health–promoting benefits of physical activity, the lack of scientific exercise not only leads to reduced fitness benefits, but may also have a negative impact on physical health[13]. In addition, the rapid development of urbanisation has weakened interpersonal ties in modern communities[14], making it difficult to fully exploit the 'social function' of fitness. The development and application of "Internet +" technology can help promote the intelligent development of the national fitness sector, broaden the social field of mass fitness, and improve the safety and effectiveness of mass fitness.

With the promotion of "Internet +" technology, fitness APPs such as Keep, Goudong, FitTime, and Yueting Circle have emerged, allowing users to access fitness courses and guidance online according to their own fitness needs and facilities, thus promoting the further improvement of scientific fitness guidance. In addition, fitness apps such as Goudong and Yueting Circle have broken through the spatial field of fitness interaction through the construction of an "Internet +" fitness platform. Users can not only exchange fitness tips and participate in sports topic discussions online, but can also discover nearby fitness partners and find fitness organizations. In addition, sharing their fitness news through social platforms such as Weibo, WeChat's moment of friends and QQ space has become a way of life for more and more fitness participants, who will be further motivated to work out during the interaction process such as likes and comments, and their personal fitness behaviour will also be consolidated into a huge social fitness network under the aggregation of "Internet +", resulting in a positive fitness demonstration effect. The Internet has also created a huge social fitness network, creating a positive fitness demonstration effect.

Currently, many wearable smart products already have eSIM (virtual smart card, meaning that the traditional SIM card is directly embedded into the device chip, so that the device can independently access the network) function, which can get rid of the mobile phone and Wi-Fi network, access various fitness apps anytime and anywhere, record and analyse fitness data in various fitness scenarios, and obtain corresponding fitness courses and online guidance from fitness experts. Based on this, the GoMore Ai coaching system, jointly developed by the National Institute of Physical Fitness and the company, has been installed in some of the wearable products. The system is able to recommend the right exercise intensity for exercisers based on data such as individual heart rate, weight and past exercise records, as well as real–time monitoring of physical condition during exercise, issuing guidance through voice, allowing exercisers to exercise at a better pace and giving appropriate recovery advice after exercise. It also gives advice on how to recover after exercise. Under the "Internet +" technology, smart wearable devices have gradually become the terminal interface of the masses' smart fitness. Modern technologies such as the Internet of Things, AI, Big Data and fitness experts can break the barriers between time, space, things and people in the past, and monitor the exercise track, exercise intensity, physiological indicators and other information for the exercise individual. On the basis of the data, we can provide individualized and scientific fitness guidance services for individuals.

3. The existing dilemma of "Internet +" to help national fitness

3.1. Low penetration of integration

With the latest development and application of contemporary science and technology, "Internet +" technology has made breakthroughs and has an all–round impact on various fields of social life[14]. However, at present, the popularity of "Internet +" national fitness integration is low, which hinders the full application of "Internet +" technology in national fitness. However, at present, the penetration of the integration of "Internet +" into national fitness is relatively low, which hinders the full application of "Internet +" technology in national fitness.

Firstly, uneven and insufficient access to the Internet for the masses has led to a weak foundation for the integration of "Internet +" national fitness. Statistics from the 46th Statistical Report on the Development of the Internet in China show that as of September 2020, China's Internet penetration rate was 67% and the number of non–Internet users was still as large as 463 million, with a large difference between urban and rural Internet penetration rates, at 76.4% and 52.3% respectively. In a field study, it was found that because cadres and people in some areas do not know how to use computers, network information equipment has been shelved in rural neighbourhood committees for a long time, and the network platform that could have promoted the development of rural sports has created an unbridgeable gap with the masses[15]. An important significance of the "Internet +" to promote mass fitness is to effectively aggregate all kinds of human, material and information resources for national fitness and connect them to the fitness public. Therefore, Internet users are the physical unit and basic unit of "Internet +" to promote national fitness, and the current scale of nearly 500 million non–Internet users indicates that the foundation of integration of "Internet +" national fitness has not yet been firmly established.

Secondly, there is a general lack of mass application of "Internet +" national fitness. Smart wearable devices and sports apps have become important tools and support for "Internet +" national fitness, and their functions such as sports guidance, sports socialization, sports analysis, vital sign detection, emergency call and accurate positioning are of great significance to ensure the effectiveness and safety of fitness participation of people of all ages. According to the analysis data of IDC and Guanyan Tianxia Information Consulting Company, the total number of wearable devices shipped in China from 2015 to 2019 is 292.85 million units, and the user scale of sports app is about 165 million by the fourth quarter of 2019. For China's total population of over 1.4 billion and the number of over 900 million internet users, the penetration rate of smart wearable and sports apps is still at a low level. In terms of economic threshold, many smart wearable devices have already entered the 100 yuan price range, and many fitness app services are free of charge, so the economic cost is not the main factor preventing the popularity of "Internet +" national fitness applications. Combined with the demographic data in the above survey, the 20–39 age group accounts for 76% of the total number of people who follow wearable smart devices, while the 18–39 age group accounts for 85.9% of the total number of people who follow sports apps. It can be seen that the lack of attention and awareness of "Internet +" fitness applications among the middle–aged and elderly groups is the main reason why fitness apps and smart wearable devices have not been widely popularized, which has restricted the widespread and integrated promotion of "Internet +" fitness for all.

3.2. Inadequate platform building

With the advent of the "Internet +" era, many regions have strengthened the construction of national fitness information technology, and a number of local national fitness information service platforms, such as "Meng Xiangdong", "Su Titong" and "Soprts Jia", have been launched one after another, playing an important role in integrating national fitness resources, strengthening the collaborative governance of national fitness and connecting to the masses' fitness needs. However, in general, the platform construction of "Internet +" national fitness still needs to be further strengthened.

Firstly, the construction and use of national fitness information service platforms still needs to be strengthened. At present, there are still relatively few regions that have built national fitness information service platforms, and some of the platforms are not sufficiently developed and maintained, so it is difficult for them to play their proper role continuously. The reason for this is that the construction of a national fitness information service platform requires professional technical talents, and a lot of time, financial and material resources are needed for platform construction, resource integration, publicity and promotion, and maintenance and operation, so the cost of platform construction and operation is too high for many regions.

Secondly, the function of the "Internet +" government affairs platform to help national fitness is not sufficiently explored. A review of the official websites of regional sports departments reveals that the application of the Internet platform in many regions remains at the level of "vertical and single inefficient use" such as the publication of sports policy documents, event notices and tender announcements. In a social survey, 960 people had faced problems with damaged public sports equipment, of which 406 did not report the problem, 182 did not know how to report the problem because they lacked a channel to do so, and 554 did, but 217 of them did not receive timely repairs after reporting the problem[6]. It is clear that the "Internet +" government platform can achieve a lot. The "Internet +" government affairs platform can collect opinions, give feedback on problems, and supervise the implementation of multiple functions that have not yet been widely and effectively used in the actual work of national fitness. Improving the ability of government departments to use the "Internet +" platform is the first and foremost task to achieve "Internet +" empowered governance of national fitness.

3.3. Inadequate regulatory capacity

The construction of the "Internet +" platform has brought new opportunities for the transformation and upgrading of market players, as well as a new experience of efficient and convenient fitness consumption for people. However, due to the lack of supervisory capacity of "Internet +" national fitness, the phenomenon of network "misconduct" in the field of national fitness is common, which has a bad impact on the personal rights and interests of consumers and the benign development of national fitness that cannot be ignored.

Firstly, the network platform provides a channel for the circulation of inferior products in the market. CCTV once reported on the quality sampling of household treadmills, among the 9 batches of samples sampled from the online sales platform, only 1 batch was qualified, with a failure rate of 88.9%, while 5 out of 21 batches of samples sampled offline were unqualified, with a failure rate of only 23.8%. The "strange" phenomenon of the same brand of products in the offline distribution channel passing the sampling test but the network sales channel failing the sampling test. Due to the virtual and non–experiential characteristics of the network trading process, product descriptions, user reviews and other information to become a key reference for consumers to choose the transaction, but the falsification of information by unscrupulous businesses, information distortion phenomenon is endless, seriously affecting the choice of the masses fitness consumption judgment. In addition, the difficulty and cost of returning and exchanging fitness equipment, and the difficulty of finding many quality problems with safety hazards in short–term use, has further increased the difficulty of consumer protection, making the network platform the main circulation channel for poor fitness products.

Secondly, network capital operation has given rise to financial risks. While the "Internet +" has brought development opportunities for the fitness industry, it has also provided an easy breeding ground for financial risks. For example, the "Health Cat" app, which started as an O2O teaching service for personal trainers in the fitness industry and was motivated to "support retired athletes and college sports graduates to start innovative businesses", grew rapidly after it was launched in 2015 and has established strategic partnerships with many government departments, banks and universities. The app was launched in 2015 and grew rapidly, establishing strategic partnerships with government departments, banks, universities and more than 250,000 users, but eventually became a "Ponzi scheme" involving a total amount of RMB 8.27 billion. The fundamental objective of an enterprise is to maximum economic benefits, but if it improperly profits against the laws of economic development, it will not only harm the rights and interests of the public, but also sow huge hidden dangers for its own development. Due to the lack of regulation of network behaviour, the "Guangzhou Elephant Health Technology Co Ltd", which does not have any financial license, is driven by the drive of capital for profit, in the "name" of fitness services and the "reality" of illegal fund raising. "The "Internet +" fitness industry has a regulatory gap.

4. The development path of "Internet +" to help national fitness

The "Internet +" has the practical function of helping to reform the government's "decentralization, management and service" in the field of national fitness, improving the matching of supply and demand for national fitness, and promoting the intelligent supply of national fitness, which is important for building a higher level of public service system for national fitness and meeting the people's. This is an important strategic value in building a higher level of public service system for national fitness and meeting the growing and diversified fitness needs of the people. At present, due to the unbalanced and insufficient integration and popularization of "Internet +", the scope of "Internet +" to help the development of national fitness is limited; "Internet +". The lack of construction of platforms for national fitness has affected the actual effect of improving the governance capacity of national fitness, the lack of supervisory capacity of "Internet +" national fitness has made misconduct of national fitness supply subjects common, endangering the rights and interests of the masses in fitness and negatively affecting the benign development of national fitness.

It can be seen that the path of promoting "Internet +" to help national fitness must focus on two basic points, one is around the value and meaning of "Internet +" to help national fitness, and the other is to crack the "Internet +" existing dilemma. The second is to crack the existing dilemma of "Internet +" to help national fitness. The relationship between the two is that the value and meaning is the result to be achieved by promoting "Internet +" to help the national fitness, and cracking the dilemma is the process needed to achieve this result, that is, the actual dilemma of "Internet +" to help the national fitness should be the focus of breaking. In other words, we should focus on solving the practical dilemmas of "Internet +" for national fitness, and propose specific and operable development paths to promote the strategic value of "Internet +" for national fitness.

4.1. Promoting the use of online fitness for the masses based on integration and popularization

The first is to give full play to the practical value of the "Internet +" to promote fitness for all. Firstly, it is necessary to open up the connection channels between the people and other subjects, so that more people can access the Internet and weave the "Internet +" national fitness integration network covering both urban and rural areas and sharing the whole area. According to the survey data of the China Internet Network Information Center, the most important reason for non–Internet users not to access the Internet is "not knowing the computer/Internet", accounting for 48.9 percent; cultural restrictions are the next most important reason, accounting for 18.2 percent, and the lack of equipment ranks third, accounting for 14.8 percent. Therefore, the popularization of the Internet should focus on enhancing the cultural knowledge and digital technology usage skills of non–Internet users, giving full play to the propaganda role of grassroots governance units such as communities and villages, and making the general public aware of the Internet, understand the Internet and master the basic methods of Internet usage through organizing public service lectures, distributing learning and propaganda materials, and organizing learning and training. At the same time, it is necessary to further strengthen the construction of network infrastructure, especially to expeditiously make up for the shortcomings of broadband network construction in the vast number of rural and central and western regions, and to support telecommunication enterprises to actively assume social responsibility and carry out free broadband speed–up and price reduction activities in areas with lower income levels, so as to realize that people in all regions can "use the Internet, have access to the Internet and can afford to use it". To further increase China's Internet penetration rate and lay a solid integration foundation for "Internet +" national fitness.

Secondly, we should further improve the level of awareness and application of the "Internet +" national fitness among the people, especially the middle–aged and elderly groups. On the basis of the widespread popularity of the Internet, more intelligent and user–friendly products and services will be developed to meet the fitness needs of various groups of people in different scenarios, to enhance the applicability and convenience of "Internet +" national fitness, and to reduce the learning and usage costs of the masses. The "Internet + Fitness Guidance Guide" will be compiled in terms of the integration carrier, main functions, routine operations and precautions of "Internet +" fitness for all, and will be popularized by social sports organizations, social sports instructors and sports associations. Focusing on two aspects: lowering the threshold of product application and improving the ability of the masses to use it, so that the results of the integration of "Internet +" national fitness development can benefit the masses.

4.2. Platform building as the core to strengthen the governance capacity of national fitness

The "Internet +" platform has become an important engine to promote the modernization of the national fitness governance system and governance capacity, but the "engine kinetic energy" still needs to be further activated.

The first is to standardize the operation of the platform and activate the "Internet +" government platform's function of national fitness governance.

At present, all regional government websites have been opened, and the national integrated government platform has basically taken shape, but the level of development varies from region to region, so the concept of "people–centred" construction should be adhered to, the threshold of platform operation should be lowered, and the ease of use of the user port should be optimized. On the basis of the traditional functions of publishing sports policy documents, event notices and tender notices, the platform should also set up consultation, reservation, suggestion, complaint and evaluation sections to build an interactive bridge between social subjects, market subjects, individual people and government departments, and to realize the online integration of multiple functions such as the collection of opinions, feedback on problems, implementation supervision and democratic evaluation of national fitness. According to the actual characteristics of the various levels and types of national fitness government projects, guidance standards for platform construction are promulgated, with standards peddling as a grip to ensure the full play of the governance functions of the platform in each region. Establish a top–down vertical supervision system and a mass feedback mechanism for democratic evaluation to guarantee the standardized operation of the platform.

Secondly, the construction of a national fitness information service platform will lead the way in enhancing the capacity of national fitness information services. At present, there is a large gap in the development capacity of national fitness information in various regions of China. It is difficult to establish and operate regional national fitness information service platforms in most regions because it will cost a lot of human and material resources, and the functional requirements of national fitness information services are basically the same for most regions. Therefore, we can focus on relying on the national fitness information service platform developed by the State General Administration of Sports to enhance the capacity of national fitness information services in each region. It is suggested that in this platform, administrative regions are used as the basis for division, accessing the sports administrative departments of all regions in the country, giving corresponding platform authority, and building a top–down national fitness network governance system and resource aggregation system. It is recommended that administrative regions at or above the county level integrate their national fitness service resources into the platform and build an information service platform that integrates multi–functional functions such as venue inquiry and booking, activity competition registration, information release and problem feedback, so that people in all regions can obtain convenient and accessible fitness services through the platform.

Thirdly, the construction of a big data platform is used to promote scientific governance of national fitness. In the context of the "Internet +" era, the collection and application of big data is an important basis for improving the decision–making level of national fitness governance. Although regional big data platforms have been built in Zhejiang, Sichuan and Hebei, and enterprises such as Jingdong and Alibaba have also established their own big data centers, the data barriers between regions, industries and levels still. However, data barriers between regions, industries and levels still exist. Under the coordination and unification of the central government, a cross–regional and cross–sectional big data sharing platform should be established in conjunction with the construction of a national fitness information platform, so as to provide data support for researching and judging the influencing factors and changing trends in the development of mass fitness, serve the scientific governance of national fitness, and promote the accurate matching of national fitness service supply with mass fitness demand.

4.3. Focusing on innovation drive to promote smart empowerment of national fitness

With the advent of the "Internet +" era, the rapid development of modern information technology such as big data, cloud computing and 5G, and the increasing degree of social information, national fitness has been given more possibilities. We should make full use of the technological changes brought about by the "Internet +" to promote the transformation of national fitness from a crude development model that relies on resource input to an intensive development model that is led by science and technology and driven by innovation, so as to achieve intelligent empowerment of national fitness.

Firstly, strengthen the research of key application technologies and products in the field of "Internet +" national fitness. Relying on the "Internet +" platform, we will narrow the time and space restrictions on cross–domain scientific research cooperation, establish a global platform for recruiting and cooperating with professionals in sports scientific research, information technology and medical rehabilitation, and boldly explore the construction of composite scientific research teams. Strengthen the construction of the main research force of sports science and technology, rely on universities and research institutes to create a group of key laboratories for national fitness, supporting the construction of scientific training and support mechanisms and performance evaluation mechanisms. Make use of the advantages of data storage, analysis and transmission on the "Internet +" platform to implement collaborative innovation, promote the open sharing and efficient use of scientific research data, scientific and educational resources and experimental resources, etc., implement the declaration of the list of scientific and technological projects for national fitness and the inclusion of scientific and technological achievements in the database, and mobilize the sports administrative departments of provinces, autonomous regions and municipalities to participate in scientific and technological assistance for national fitness The government has also implemented the declaration of the list of scientific and technological projects and the database of scientific and technological achievements, and mobilized the sports administrative departments of provinces, autonomous regions and municipalities to participate in the work of science and technology for national fitness.

Secondly, promote the rapid transformation of scientific and technological achievements in the field of "Internet +" national fitness. Strengthen the cooperation between scientific research institutions and sports enterprises to achieve the iterative upgrading of intelligent fitness products. Establish a smart fitness guidance system and exercise risk warning system with the "Internet +" platform as the hub, Ai technology, exercise monitoring technology and fitness and medical experts as the fusion, and smartphones and smart wearable devices as the port, and create a non–medical health intervention system suitable for community residents' scientific fitness and chronic disease prevention and control requirements.

4.4. Building the rule of law as a guarantee to enhance the regulatory capacity of the national fitness network

The virtual, dynamic, cross–regional and other characteristics increase the difficulty of regulation of the Internet, but the Internet is never a place outside the law, relying on the "Internet +" to promote the healthy, healthy and sustainable development of national fitness, must firmly establish the concept of national fitness rule of law, strengthen the legal system construction.

Firstly, strengthen the legislation in related fields. At present, the legislation in the field of sports in China is relatively lagging behind, and there is a lack of legislation in the field of "Internet +" sports. In the face of new situations, new contradictions and new problems in the field of national fitness, such as network trade, network rights, network capital operation and network data management, relevant departments should quickly follow up and clarify the actual problems and areas where the law is lagging behind the reality. The problem and the area of belonging, multi–departmental joint cooperation, strengthen the legislation, to achieve "Internet +" to help the development of national fitness has a law to follow.

Secondly, the legal system should be made more popular. Governments at all levels should improve the way they teach the legal system and use the cases that have already occurred as a wake–up call to raise the awareness of the "bottom line" of market players in the production of fitness products and the supply of fitness services, so as to reduce the incidence of illegal misconduct; through forms that are popular with the public, the legal system should be integrated into the daily life of the public, so that in a subtle way.

Thirdly, strengthen the government's law enforcement capacity. In the face of the increasingly complex and diverse "misconduct" in the field of national fitness, the government, as the main body of law enforcement, must keep pace with the times and improve its own law enforcement capabilities. With the help of the "Internet +" government platform, a special window for reporting violations in the field of national fitness has been opened to support the processing mechanism and give play to the role of supervision by the people. The government should make full use of artificial intelligence, big data, cloud computing and other modern information technology to monitor network data and information in real time, establish a screening mechanism for abnormal data and information, improve the identification and governance of illegal acts such as selling substandard fitness products on the Internet platform, using asymmetric information on the Internet to mislead the fitness public, and illegally collecting funds through the "Internet + fitness" model.

Conflict of interest

The authors declare no conflict of interest.

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