

REVIEW ARTICLE

Overview of smart masks and research on new technology

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ABSTRACT

The smart mask is a new type of mask with active air supply and breathing. It adopts an external electric fan-forced air supply system, which can effectively reduce the user's breathing load and achieve the purpose of improving comfort and user experience. However, in the current market, the function of smart masks is relatively simple with weak practicability and limited application. Based on these situations and in the research of a large number of smart masks and other types of masks, their application scenarios, advantages and disadvantages of the current technologies used in smart masks are analysed and compared to demonstrate their advantages in comfort and functionality. In terms of application prospects, new technologies can be integrated into the research and development of smart masks, providing new ideas for the research and development of new masks, which is crucial to the future market development of smart wearable products.

Keywords: smart mask; motor wind wheel; sensor; fit; functionality; wearable technology

1. Introduction

Portable active air supply type smart mask, its interior is designed with a motor wind wheel, which can effectively solve the shortcomings of insufficient air supply of ordinary masks, especially when compared with ordinary protective masks. Smart masks have better facial fit and a more obvious filter effect. At present, there is only one type of mask design on the market. Apart from special industry, personnel being unable to find suitable masks in the mask market, ordinary consumers to find masks suitable for daily wear in the market also face the difficulty. The multi-functional air supply and exhaust smart mask not only improves the wearing

comfort of the user, but also protects special types of work according to the user's environment and external climate. Smart masks will become one of the main development trends of the mask market in the future^[1].

2. The origin of smart masks

At the beginning of the 20th century, masks became a necessity for public life. In 2013, the northern regions of China PM2.5 air hazards have become serious, and hence masks have become more popular and functional due to frequent haze weather. Over time, masks no longer simply play a role in preventing dust and air pollution. In addition

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to medical masks, activated carbon masks, air filter masks, etc.^[2] are also relatively common in life, and smart masks are also appeared owing to smog. Due to the shortage of masks during the epidemic, smart masks are becoming increasingly popular.

2.1. Analysis and comparison of smart masks and ordinary masks

Masks can be divided into three types from the perspective of users: Civilian masks, medical masks and industrial protective masks. These three types of masks are also different from each other due to different implementation standards. Among them, civilian masks are further divided into cotton masks, decorative masks and thermal masks. Medical masks are divided into medical protective masks, medical

surgical masks and general medical masks. Industrial protective masks are a branch of industrial protective facemasks. According to the protection level, they can be divided into 90 (90% protective power), 95 (95% protective power), etc. According to the classification of protective objects, they can be divided into dustproof and oil fume proof. Aside from the above three types of masks, smart masks as a new contemporary product, have gradually entered the public eye. The following is an analysis and comparison of smart masks and other masks from three aspects: Functional advantages and disadvantages, specifications, and application scenarios. First of all, it is necessary to clarify the specifications and standards of the above three types of masks, see **Table 1**.

Table 1. Comparison of specifications and standards of three types of masks

Type	Area	Executive standard	Filtering efficiency %		
			Low-level standard	Intermediate standard	Advanced standard
Daily protection masks	CHN	GB/T 32610—2016 <i>Technical Specifications for Daily Protective Masks</i>	Level III \geq 90.00	Level II \geq 95.00	Level I \geq 99.00
		TAJ1001—2015 <i>PM2.5 Protective Masks</i>	Level 2 F90 \geq 90.00	Level 1 F95 \geq 99.00	Level 1 F95 \geq 99.00
		YY 0469—2011 <i>Medical Surgical Masks</i>	BEF \geq 95.00	BEF \geq 95.00	BEF \geq 95.00
Medical and healthcare masks	CHN	YY/T 0969—2013 <i>Disposable Medical Masks</i>	BEF \geq 95.00	BEF \geq 95.00	BEF \geq 95.00
		GB 19083—2010 <i>Technical Requirements for Medical Protective Masks</i>	Level I \geq 95.00	Level II \geq 99.00	Level III \geq 99.97
		EU EN14683—2014	TYPE I BEF \geq 95.00	TYPE II BEF \geq 98.00	TYPE III BEF \geq 98.00
Labour insurance masks	US	ASTM F2100—2004	BEF \geq 95.00	BEF \geq 98.00	BEF \geq 98.00
	CHN	GB 2626—2006 <i>Respiratory Protective Equipment Self-priming Filter Anti-particulate Respirator</i>	KN90, KP90 \geq 90.00	KN95, KP95 \geq 95.00	KN100, KP100 \geq 99.97
	EU	EN149: 2001+A1—2009	FFP1 \geq 80.00	FFP2 \geq 94.00	FFP3 \geq 99.00
	US	NIOSH Standards (Title 42 CFR Part 84)	N90, P90 \geq 90.00	N95, P95 \geq 95.00	N100, P100 \geq 99.97

Function advantages and disadvantages

PM2.5 masks can deeply filter and block smog, effectively filter bacteria and viruses, car exhaust, second-hand smoke, formaldehyde, air pollution poisonous gases, etc. However, due to the large breathing resistance of PM2.5 masks, it is not suitable for people with heart or respiratory difficulties (such as asthma and emphysema), pregnant women, etc. Meanwhile, medical surgical masks can prevent the spread of blood, body fluids and splashes during invasive operations, and have strong resistance to bacteria and viruses. However, the filtration efficiency of particles is limited, and most of them are rectangular designs that do not provide the same tight-fitting to the face as that of medical protective masks.

Compared with ordinary masks, smart masks have the advantage of reducing breathing resistance, effectively preventing suffocation, greatly reducing the user's breathing load and are more suitable for people with poor lung capacity such as the elderly and children. However, smart masks are not suitable for use in high-risk environments such as hospitals. Smart masks are powered by electric motors and used for a short time after each charge, which will bring restrictions and inconvenience.

Specifications

The group standard of *PM2.5 Protective Masks* (TAJ1001-2015) was implemented on March 1, 2016, and is the first group standard for PM2.5 protective masks in China^[3]. Before the introduction of this standard, most protective mask products implemented *Respiratory Protective Equipment Self-priming Filter Type Anti-particulate Respirator*,

GB 2626-2006 standard or individual enterprise standards, with some implemented the American NIOSH standard and the European FFP standard. However, these standards are industrial mask standards. In fact, for civilian anti-fog products, these standards are not very applicable and thus, there is the TAJ 1001-2015 group standard^[4].

On December 31, 2011, National Food and Medical Products Administration issued the YY0469-2011 *Medical Surgical Masks*^[5] YY 0469-2011 is an industry-standard for the pharmaceutical industry and it is also a mandatory standard^[6]. The standard clearly stipulates the technical requirements, test methods, signs and instructions for use of medical surgical masks, as well as packaging, transportation and storage requirements.

The safety items of smart masks are tested according to *Safety of Household and Similar Electrical Appliances Part 1: General Requirements*^[7] GB 4706.1-2005, while the performance of smart masks is tested according to *Electric Anti-haze Masks*^[8] T/CAQI 63-2019. This standard provides a method for the testing of electric anti-haze masks. The standard mainly emphasizes the main performance indicators such as material, structural design, protective effect, internal quality, air supply volume, noise and microbial filtration efficiency, anti-allergen, antibacterial and mildew resistance. At present, there is no standard for smart masks, and the relevant standards are only in the tests.

Application Scenarios

The application scenarios of different masks are different and the comparison of application scenarios of several types of masks is shown in **Table 2**.

Table 2. Application scenarios of several masks

Type of mask	Particle type	Application scenarios
Smart mask	Smog, pollen, industrial powder, etc.	Haze weather and suitable for people with poor lung capacity
PM2.5 mask	Smog, viruses, bacteria, dust mites, pollen, etc.	Widely used in the medical and health industry, public places
Medical surgical mask	Bacteria, viruses, blood, body fluids and splashes, etc.	Generally used in medical clinics, laboratories

Medical protective mask	Particles in the air, blocking droplets, blood, body fluids, secretions, etc.	For preventing respiratory infections
Activated carbon mask	Organic gases, acid volatiles, pesticides, SO ₂ , Cl ₂ and other irritating gases	For anti-virus, deodorization

2.2. Advantages of smart masks under the epidemic

Under the COVID-19 epidemic, with the comprehensive promotion of resumption of work and production, the daily demand for masks in the country is expected to reach 530 million with strong market demand^[9]. However, in the process of wearing masks, people will experience poor breathing and discomfort^[10]. During the epidemic, medical staffs wear medical surgical masks for long periods, which lead to prolonged pressure on the skin and hinders the evaporation of water vapour, thereby causing device-related pressure injury^[11], which endangers the health of medical staff to a certain extent. The emergence of new smart masks with active air supply has improved user experience.

Most of the smart masks use silicone or latex materials in the parts, which come into contact with the face^[12]. They have strong deformation adaptability and strong recoverability, which can meet the airtight requirements of different facial features and give the wearer a sense of comfort. In addition, some smart masks use adjustable ear straps and adjustable nose clips in the design^[13], where users can make appropriate adjustments according to their face shape to reduce the pressure on the bridge of the nose and ears.

Additionally, a smart mask with an active air supply appeared on the market. It adopts 5 layers of composite filters to achieve a 99% high-efficiency filtration effect with excellent air permeability. The air outlet of the main unit is designed according to fluid mechanics. Fresh air is circulated and supplied to both sides and then enters the nasal cavity after the wind is moderated. The flexible gill valve and exhaust valve are closed when inhaling and opened, when exhaling to discharge turbid air and condensed

water, increasing air permeability and making breathing smoother. Meanwhile, the folded cavity of the silicone mask allows water vapour to flow out along the inner wall of the cavity, preventing water vapour from flowing to the face and causing discomfort. There are also smart masks with various functions such as making calls and listening to music. To improve the quality of people's calls when wearing masks, a high pickup microphone and high-quality headphones are embedded outside the mask. In addition, the main control board STM32, battery, Bluetooth, wireless charging ring, temperature and humidity measuring instrument are installed inside the mask, while an OLED display is installed on the wall of the mask to display real-time data. A dust-measuring instrument is also hung on the same side, which provides the monitoring of the environment and the transmission of data, allowing users to have a better experience.

3. Analysis of the current situation and functional design of smart masks

3.1. Status of relevant patents

By retrieving keywords such as smart masks, the research situation of patents related to smart masks in the CNKI database was counted, as shown in **Figure 1**. As can be seen from **Figure 1**, the first patents related to smart masks were issued in 2001, and in the following 13 years, only a few patents were issued. However, the number of related patents has increased sharply since 2014, which shows that due to the haze weather, smart masks have received widespread attention while a sharp falling number was seen in 2019. It is speculated that the current domestic smart mask field may be in a bottleneck period. In short, the distribution of patents related to smart masks shows an overall growth trend.

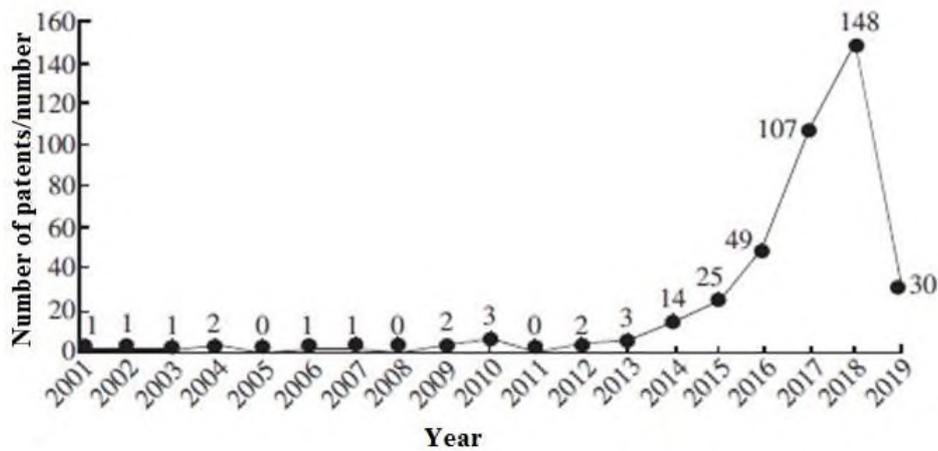


Figure 1. Number of patents related to smart masks in CNKI database.

Selected main patents retrieved from CNKI along with compared main functions and features is shown in Table 3. It can be seen that there are many

types of patents for smart masks in China and the functions are relatively complete.

Table 3. Comparison of related patents of several smart masks

Patent name	Application time	Main features
Hidden detachable smart mask	Jan. 30, 2018	The hidden detached smart mask is composed of a mask, a host and a trachea. The main unit is placed on the inside of the jacket, does not appear when wearing the mask, and the air temperature can be adjusted.
Intelligent anti-smog mask for traffic police	Apr. 28, 2018	An electric exhaust structure and a Bluetooth communication module for Bluetooth speaker communication are set on the anti-fog mask to make breathing smooth where traffic police can conduct effective traffic command without taking off the mask.
Solar smart mask	Aug. 30, 2018	The mask includes the mask body, the fresh air module and the solar module. The battery of the fresh air module is charged through the solar module to improve the battery life.
A type of smart mask	Nov. 26, 2018	The mask includes a mask body, controller, temperature and humidity sensors. There are LED lights at the front of the body and a processing module at the lower end, which can heat and humidify the air and serve as a night warning.
Smart mask	Dec. 17, 2018	The smart mask includes a front cover, a filter body frame and a silicone mask. There is a sound-absorbing structure, which can effectively reduce noise and improve the overall comfort of the smart mask.

3.2. Current situation of commercialized smart masks

Generally, the smart masks sold on the market are roughly divided into three types: Fan-type masks, masks with external air purifiers and masks

with built-in air purifiers. The three brands of electric masks are listed, as shown in Figure 2. The comparative analysis of smart masks and ordinary masks is shown in Table 4.



Figure 2. An example of an electric smart mask.

Table 4. Comparison of smart masks and ordinary masks

Mask Category	Function	Applicable Scope	Degree of comfort
Fan type mask	Anti-haze and sterilisation	High dust concentration	Easy to adjust and comfortable
External air purifier type mask	Anti-haze and deodorization, effectively purify toxic substances	High dust concentration	The quality is heavy and wears on the ear, not easy to wear for a long period.
Built-in air purifier type mask	Anti-haze and deodorization, effectively purify toxic substances	High dust concentration	General comfort, inconvenient to wear for a long period
Ordinary mask	Anti-haze, dust-proof	Low dust concentration	Average comfort, poor breathing, not suitable for long-term wear

Compared with ordinary masks, the biggest advantage of smart masks is that they reduce the breathing resistance and can effectively prevent suffocation. Taking the familiar N95 mask as an example, the N95 mask with a valve produces filtering protection by controlling one-way air intake. It works, but if you wear it for a long time, you will feel a sense of suffocation, which is not good for breathing.

3.3. Design elements and functionality of smart masks

Design

a. Material and shell

The whole smart mask uses healthy and harmless materials and does not produce toxic and harmful substances. Meanwhile, the tightness of the mask and the face directly affects the protection effect^[14].

Most smart masks use silicone or latex materials^[15], which can satisfy both airtight conditions and comfort. To adapt to the face shapes of different people, an adjustable ear strap design has appeared on the market. The material of the ear buckle part can be made of food-grade silicone, which is non-toxic, odourless, environmentally friendly, soft, elastic, non-cracking, and has a long life with high tear strength.

b. Filter element

The 4–5 layer filter design can make the filtration effect reach 95%–99%^[16], mainly using sterilisation paper, activated carbon, HEPA filter and non-woven fabric. Sterilisation paper can sterilise and prevent bacteria from growing on the surface of filter paper while activated carbon can absorb and eliminate various odour molecules in the air as well as absorb formaldehyde, ammonia, benzene and other harmful gas molecules. The HEPA filter used is

PM2.5, which is a good medium for effective filtering of smoke, dust, bacteria and other pollutions. The non-woven fabrics can inhibit the growth of bacteria and protect the filter paper.

c. Electric air supply device

According to the design principle of fluid mechanics, the main air outlet should avoid problems such as facial spasms caused by wind directly hitting the human skin while the flexible air discharge gill valve and exhaust valve increase air permeability to reduce the feeling of dampness to make breathing easier^[17].

Additional functions

On February 19, 2020, according to foreign media reports, the United States Patent and Trademark Office granted Xiaomi a patent for a smart mask. The smart mask features an embedded computing unit that includes a processor, a memory module, a battery, and a connector. In addition to filtering the air, this smart mask can also calculate the intake of pollutants and record the total wearing time of the mask. The smart mask compares this data with the filtration efficiency of the mask air filter and estimates the air quality the user is breathing in the user's environment and can even help the user determine changes in lung capacity. Finally, the onboard processor will initiate a wireless connection with other devices (such as smart phones) to send data about the air the user is breathing to an App. After sharing the data with the device, the smart mask can request air quality data from the central server to inform the user of the air quality of the city in real-time.

From the breakthrough of Xiaomi smart masks in digital science and Bluetooth devices, we can see the application of high-tech technology and the development of other functions in the current smart masks. In addition, many patents have made progress in other functions, such as temperature and humidity sensors, solar cells, and communication equipment^[18]. This has greatly promoted the development of smart mask functions. It is believed that

smart masks will be more diversified and intelligent in the future.

3.4. The main factors restricting the market popularisation of smart masks

Firstly, the price is expensive. The average price of smart masks on the market is 200–300 yuan, some of which are even more expensive. Apart from that, the most critical part inside the smart mask is the filter element, which needs to be replaced regularly. Hence, the long-term purchase of the filter element alone will also be an additional expense. Secondly, in the large quality of the mask, due to the presence of multiple components such as motors and batteries, which make the mask relatively heavy. As such, the long-term wearing of the mask will have adverse effects on the head. Thirdly, the battery life is short, where the current average battery life of smart masks is observed to be mostly 4–6 hours, which can't satisfy long-term travel. Fourthly, the motor and fan will generate noise, which makes people feel anxious. Fifthly, the air intake of human breathing is non-linear such as the gap between walking and running. It is very large, and the instantaneous air intake of some electric air supply masks is insufficient, which makes this type of smart mask only suitable for use when walking or light exercise.

4. Function development and new technology application

The development prospects of smart masks are huge. In future research and production, people will no longer be satisfied with the single function of active air supply of smart masks but put forward higher requirements for the versatility and practicability of smart masks. Therefore, we need to develop and perform research towards the trend of multi-functional smart masks according to different application scenarios, user groups, etc., combined with new technologies in the digital age.

4.1. Flexible wearable electronic devices

Flexible wearable electronic devices have the characteristics of thinness, low energy consumption, good biocompatibility, and tuneable mechanical properties. In addition, small size, bendability, and portability are also the reasons why the products are favoured.

Flexible wearable electronic devices are one of the main forms of flexible electronics. Based on flexible materials, combined with micro-nano processing and integration technology, we designed and manufactured products that possess functions such as logic amplification, filtering, data storage, signal inversion, digital computing, and sensing. Flexible functional materials have unique physical and chemical properties such as light, electricity, magnetism, heat, and force, which can be widely used in intelligent electronic systems such as flexible display, data encryption, and wearable perception. Therefore, the application of flexible electronics in electrically driven masks can greatly improve the experience of using masks and enhance the practicability of electrically driven masks. Using microelectronic printing technology, the various printed components are combined to obtain the electric device required for the electric drive mask, which can reduce the volume of the mask and realize portability.

4.2. Bluetooth module

Bluetooth technology is an open global standard for wireless data and voice communication. It is based on low-cost short-range wireless communication and provides a communication technology with special connections for the communication environment of fixed and mobile devices^[19]. The survey shows that answering the phone or listening to music while wearing a mask has a certain impact, whether it is a Bluetooth headset or a wired headset, they all have their disadvantages. Based on Bluetooth technology, a high pickup microphone and high-quality earphones are embedded on the outside of the mask, allowing users to enjoy high-quality music and calls. For example, the low-cost and cost-effective BEKEN BK8000L chip is used to provide higher-quality music and compatibility for

the Bluetooth module of the smart mask. Using Bluetooth 5.0, the low-power mode will not have a great impact on sound quality^[20] and can greatly increase battery life^[21].

4.3. Detection sensor

Detection of PM2.5

PM2.5 air quality detector refers to a special detection instrument specially used to measure the value of PM2.5 in the air. It is suitable for the measurement of public places, atmospheric environment and indoor air, and can also be used for the evaluation and analysis of the purification efficiency of air purifiers. The PM2.5 air quality detector can monitor the concentration of PM2.5 particulate matter in the air in real-time, digitise it, and display the dynamic curve of the concentration on the digital display.

In order to make people understand the surrounding environment more clearly in haze weather, the value changes of PM2.5 are monitored in real-time using sensors added to the masks which are connected to the Internet^[22] or mobile phone software, so that people can use it no matter where they are. The mobile phone can check and understand the changes in the air quality at any time. According to the current technology, mobile phone software based on Java programming language is designed^[23] to combine with the haze detector and GPRS module data transmission of the atmospheric haze monitoring system^[24] as well as an intelligent wireless communication and detection function within built-in masks. The chip finally transmits the real-time monitoring of the local haze situation to the mobile phone software. The terminal records and analyses the acquired data, integrates the data and displays it to the user, and can generate a smog map, while providing a variety of personalized health services for mask wearers, playing a role in smog monitoring and responding to bad weather in advance.

Detection of the breathing signal

The respiratory rate can reflect the health status

of the human body^[25], so the detection of human respiration is not only applicable to the medical industry, but also of great significance to the health of the general population. In recent years, increasingly more wearable devices have emerged on the market with gradual improvement in the comfort of the devices^[26]. Their applications in the field of biomedicine have also become more and more extensive. The detection of breathing signals is embedded in the mask to monitor human respiration.

There are many different methods for detecting respiratory signals in the current literature. The main methods of wearable respiratory monitoring include nasal airflow method, electrical impedance plethysmography technology and induction plethysmography technology^[27]. The breath detection element uses a semiconductor thermistor^[28] as a sensitive element and uses the principle of detecting the airflow temperature differences between exhalation and inhalation to produce data analysis^[29]. To directly monitor the amplitude and frequency of people's breathing activities, the fibre rapid condensation and evaporation system^[30], as well as the fibre micro-conduction technology, are used^[31]. Additionally, remote monitoring can also be achieved, which is of great significance for reducing the risk of infection among medical staff.

5. Conclusions

At present, the research on smart masks shows great potential. This paper sorts out the research and development status of smart masks and discusses the feasibility of new technologies in the design and development of smart masks. Currently, high-tech textiles have become a competitive point in the international textile market and also as a new growth point for the textile industry to improve economic benefits. In this context, there is a huge market space for the research and development of smart masks^[32]. The research and development of mask performance for the epidemic are one of the hot spots in the current market. Therefore, the development of smart masks will tend to be digital and multi-functional, which is more in line with the

needs of different users.

In the international market, functional textiles are widely used. Whether in daily life, industrial production, or military equipment, the usage has been greatly increased in recent years and the prospects for high value-added textiles are bright^[33]. As a part of that, the development prospect of smart masks is self-evident. In the future research and development of smart masks, there are two main aspects: Firstly, many applications of smart masks in medical treatment, in complex medical environments or how to prevent the spread of viruses are a major problem in the design and development of smart masks; secondly, how to correctly and appropriately integrate new scientific and technological elements into the research and development of smart masks so that the protective performance and versatility of smart masks can be improved, and the usability needs of consumers can be met from many aspects. The research and development of smart masks increase the added value of mask products, can arouse people's interest, promote consumption, and help to promote the development and revitalization of the textile industry^[34]. At the same time, with the mutual penetration of various disciplines, the performance of functional textiles has been continuously optimised and gradually tends to be multifunctional^[35]. Therefore, in the future development of the industry, researchers are required to grasp the basic needs of the public, so that smart masks can truly serve users.

Conflict of interest

The authors declare no conflict of interest.

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