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REVIEW ARTICLE

Development trend of agriculture UAV technology based on patent analysis

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ABSTRACT

In recent years, global patent applications of agricultural UAV technology have continued to grow at a high speed every year. In the global ranking of applicants, the top 10 are all Chinese applicants, with Chinese companies and universities far ahead. The patents applied are mainly for operation management, which is closely connected with the application scenarios of agricultural UAVs. In order to study the development trend of agricultural UAV technology, patent applications after 2009 in the field of agricultural UAV technology were analyzed. Characteristics of patent activities of agricultural UAV technology were revealed from perspectives of overall trend, geographical distribution, main competitors, and technical composition, and the development trend of agricultural UAV technology was revealed from a patent perspective. The results showed that agricultural UAV technology was in a stage of technological development, and prospects were promising. In the next few years, the number of patent applications related to agricultural UAV technology and the number of applicants will still maintain a high growth trend. Overseas deployment and raising awareness of patent protection have become the focus. The study results could provide references for the development of the agricultural UAV industry.

Keywords: agricultural UAV; patent technology; patent analysis

1. Introduction

The demand for agricultural aviation in modern agriculture is increasing day by day, especially in the micro and small agricultural drone industry for agricultural plant protection, which is developing rapidly in my country. Agricultural drones can provide convenient, intelligent, and reliable agricultural plant protection solutions, with good operation quality, low cost, and strong adaptability, and the operation efficiency can be increased by 60 to 90 times compared with manual operations. Therefore, in the industrial drone market, It occupies an extremely important industrial position with commercial value[1].

From the perspective of use, agricultural drones can be mainly divided into three types.

One is plant protection drones, which are used for plant protection. The protection method is mainly to achieve pesticide spraying through ground remote-controlled aircraft[1–3]. The main advantages are that the spraying operation efficiency is high, the long-distance remote control operation avoids the danger of pesticide poisoning, and the low-altitude operation makes the droplets sprayed from the sprayer be accelerated by the downward airflow of the rotor to form an aerosol flow, which increases the penetration of the liquid droplets on the crops. Therefore, the control effect is better than traditional spraying, and it can also reduce the pollution caused by the penetration of pesticides into the soil[4,5].

The second is the farmland monitoring drone, which is used to obtain farmland information and usually carries a variety of task loads. Non-contact monitoring equipment such as imaging spectrometers can obtain remote sensing digital information about farmland and crops and then obtain information such as crop growth and farmland environment through data processing and analysis[6].

Farmland monitoring UAV can accurately and real-time monitor crop growth parameters, such as vegetation cover, leaf area index, plant height and the correlation between these parameters and yield. It is helpful for the decision of crop growth, such as the diagnosis of crop nutrition status and soil moisture information in the field. It also has high accuracy in the monitoring of pests and diseases. It can also quickly obtain spatial location information of farmland, crops and soil information at different stages, divide land use types, locate farmland boundaries and infrastructure, and measure planting area[7,8]. Compared with traditional field positioning monitoring, agricultural UAV monitoring has the characteristics of fast information collection and high spatial coverage[9,10].

The third is the seeding and fertilization UAV, which is used for seeding, fertilization and application of medicine. During operation, the air flow from the propeller of the UAV is used to blow the plants open, and the fertilizer liquid squirted from the spraying device is evenly sprayed onto the crop leaves under the action of the air flow, which has the characteristics of accurate fertilization, high operating efficiency and conducive to large-scale production[11,12].

In the global rapid development of high and new technology, patent applications, under the situation of sustained and rapid growth, in view of the field of agricultural technology, this paper retrieves 2009–2019, an application for a patent for all agricultural unmanned aerial vehicles (UAV), the agricultural technology in the global patent application, patent application situation in our country, the main applicant and technology constitute the content such as macro statistics and quantitative analysis, it is concluded that the overall situation and development in the field of technology.

2. Data sources and data description

The patent literature data used is mainly from the Incopat Science and Technology Innovation Information Platform, the China Patent Literature Database of the State Intellectual Property Office (CNPAT), and the Patent Literature Database of the European Patent Office (EPODOC). The search deadline for the China Patent Database and the global patent database is September 2019. Focusing on the application of UAV technology in the agricultural industry, the research boundary determined is the agricultural UAV technology closely related to the agricultural operation scene, without involving the general technology in the field of UAV technology.

3. Patent situation analysis

3.1. Patent application trends

As of the search date, there were 4483 agricultural UAV patent applications worldwide, and the trend of global and Chinese agricultural UAV patent applications is shown in **Figure 1**. As can be seen from **Figure 1**, the overall number of agricultural UAV applications in the past 10 years showed an upward trend. Before 2012, the annual number of patent applications was less than 100, mainly overseas patent applications. The number of applications began to exceed 100 in 2013 and showed a rapid growth trend in 2016. Since 2013, China's patent applications in this field have been growing rapidly, and in 2016, they began to show explosive growth, with China coming from behind to lead the rapid growth of global filings.
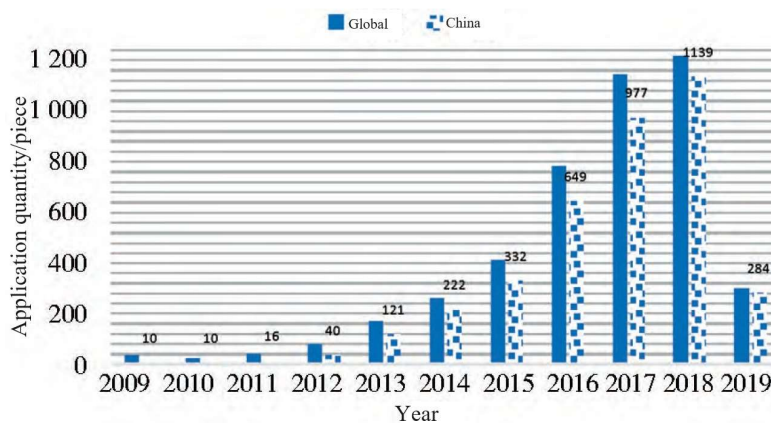

Figure 1. Global/Chinese agricultural UAV patent application trend.

3.2. Geographical distribution of patent applications

The global distribution of agricultural UAV patent countries/organizations is shown in **Figure 2**. It can be seen that the sales volume of China's agricultural UAV industry has occupied a large market share in the global agricultural UAV market in recent years[13,14].
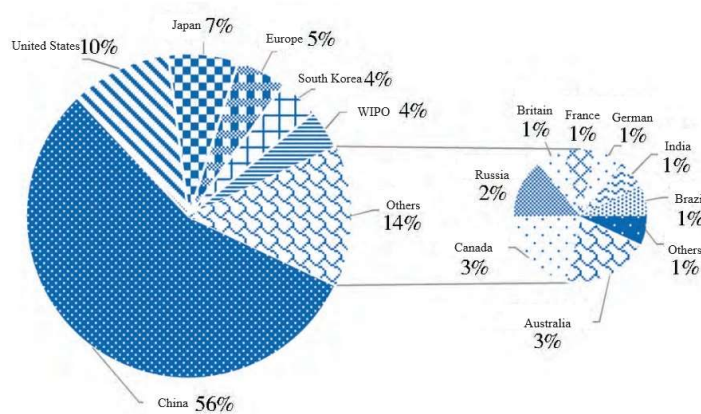

Figure 2. Distribution of patent countries/organizations for agricultural UAV.

In terms of the number of patent applications, from the perspective of global patent distribution, in the field of agricultural UAV technology, China's patent applications account for 56% of the total number of global patent applications by country, making it the main applicant country in this field. Second, the United States

accounted for 10% of global patent filings, while Japan accounted for 7% of global patent filings. In terms of regional applications, European patents accounted for 5% of the total number of EP patents filed in the EPO, excluding the number of individual applications filed in European countries. From the perspective of global application scope, China, the United States, Japan, and Europe are all key countries or regions in the field of agricultural UAV. Since 2013, the number of applications in China has been continuously rising, far surpassing those in the United States and Japan. This indicates that the domestic applicant has actively arranged agricultural UAVs in China, invested relatively high research and development efforts in this field, and has certain competitiveness and innovation ability.

3.3. Main patent applicants

The top 10 applicants for agricultural UAV technology patent applications are all Chinese applicants, led by enterprises and universities. The ranking of global patent applicants is shown in **Figure 3**. Yamaha Engine Corp. and Aero Vironment, Inc. of the United States, which are established agricultural UAV companies in Japan, have about 30 applications. In addition, international traditional agricultural machinery manufacturers such as Kubota, Iseki Agricultural Machinery, and Deere have a small number of patents in the field of agricultural drones. From the composition of applicants, the main force engaged in the research, development, and innovation of agricultural UAVs are traditional industrial or consumer UAVs manufacturers, and traditional agricultural machinery manufacturers do not participate much. Of the top 10 applicants, three are universities and research institutes, with South China Agricultural University in second place, Zhejiang University in fifth place, and Nanjing Institute of Agricultural Mechanization in 10th place. Jifei Technology (390 applications), South China Agricultural University (205 applications), and DJI Innovation (147 applications) were the top three applicants.
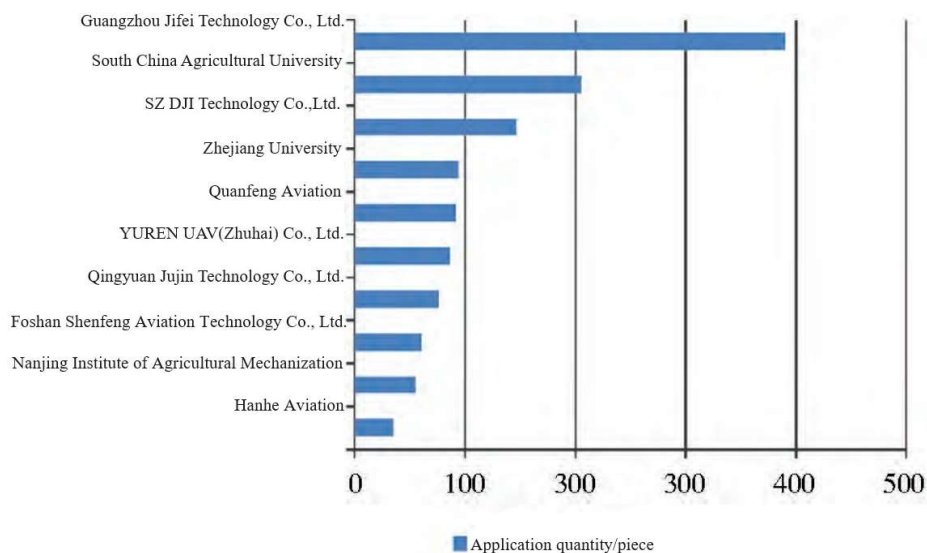

Figure 3. Ranking of global patent applicants.

Jifei Technology Co., Ltd. (Guangzhou Jifei Technology Co., Ltd.) was established in 2007, focusing on the R&D and manufacturing of civil agricultural UAVs and flight control systems, and is a leading agricultural UAVs R&D enterprise in China[15]. Jifei Technology released the first-generation P20 UAV system for plant protection and agriculture in 2015 and the P20 2017 UAV system for plant protection and agriculture in 2016. In 2017, three new plant protection agricultural UAV systems (P10 2018, P20 2018, and P30 2018) and the Jifei Geographic intelligent surveying and mapping agricultural UAV C2000 were released. In 2018, the P

Series 2019 plant protection agricultural UAV system and the xmission multi-functional agricultural UAV system were released. In terms of market share, according to statistics, as of 30 November 2018, the number of plant protection agricultural UAVs operated by Jifei Technology worldwide was 21,731. As of 21 September 2019, the global cumulative operating area of the plant protection UAV of Jifei Technology has exceeded 2 000 hm^2, saving 4.29 million tons of water for agricultural spraying and reducing the abuse of 18.6 million tons of pesticides and fertilizers.

South China Agricultural University has a "national aviation technology applying pesticide precision agriculture international joint research center", the research center, is the Ministry of Science and Technology of national research center for domestic pesticide applying typical food crops, cash crops in aviation plant protection, the United States department of agriculture agricultural research service agency aviation technology center (USDA-ARS-AATRU), the University of Queensland's Pesticide Application and Safety Center and other foreign advanced agricultural aviation application technology research institutions, around precision agricultural aviation, jointly carry out agricultural aviation remote sensing, aviation precision variable spray and other related technology and equipment innovation research key technologies and common problems, promote precision agricultural aviation technology. South China agricultural university depends on research center in precision agriculture airline, air spray technology and aviation research and development application of remote sensing technology, agricultural drones air distribution of spray droplets deposition, agricultural conditions of low altitude remote sensing information acquisition and parsing, agricultural drones intelligent control system, agricultural precision applying pesticide, key components, control technology and control equipment, and agricultural unmanned aerial vehicle (UAV). Many patents have been produced for key technologies, such as performance testing platforms.

Dji Innovation (Shenzhen DJI Innovation Technology Co., Ltd.) was founded in 2006 and is the world's leading unmanned aerial vehicle control system and agricultural UAV solution developer and manufacturer. In December 2015, DJI launched an intelligent agricultural UAV for agricultural spraying prevention, the DJI MG-1 Agricultural Plant Protection Machine, which marked DJI Innovation's official entry into the field of agricultural UAV[16].

In general, in the field of agricultural UAV technology, universities and research institutes are important forces that cannot be ignored in the development of agricultural UAV technology. Effective cooperation between industry, universities, and research institutes will accelerate China's technological development in the field of agricultural UAVs and effectively enhance and promote China's agricultural UAVs market share in the world.

3.4. Composition of patented technology

Agricultural UAV technology can be divided into UAV application technology in various scenes of modern agriculture and UAV performance improvement technology to adapt to agricultural application scenarios. Therefore, agricultural UAV technology is divided into technology components, as shown in **Figure 4**.

According to the trend of applications over the years in **Figure 4**, the branch of operation management (2212 cases) has the largest number of patent documents, accounting for about 50% of the total number of agricultural UAV patent documents. Due to the fact that many technical schemes protected by agricultural UAV patents are not the improvement of agricultural UAV systems themselves, but the technological innovation of agricultural UAV operation behaviors focused on agricultural application scenarios, such as spraying pesticide, powder, and seed on farmland[2–4]. Therefore, the patent of application type such as

operation management accounts for a large proportion, which is also corresponding to the application of agricultural UAV mainly in plant protection operation, farmland monitoring, sowing, and fertilization[17–19].
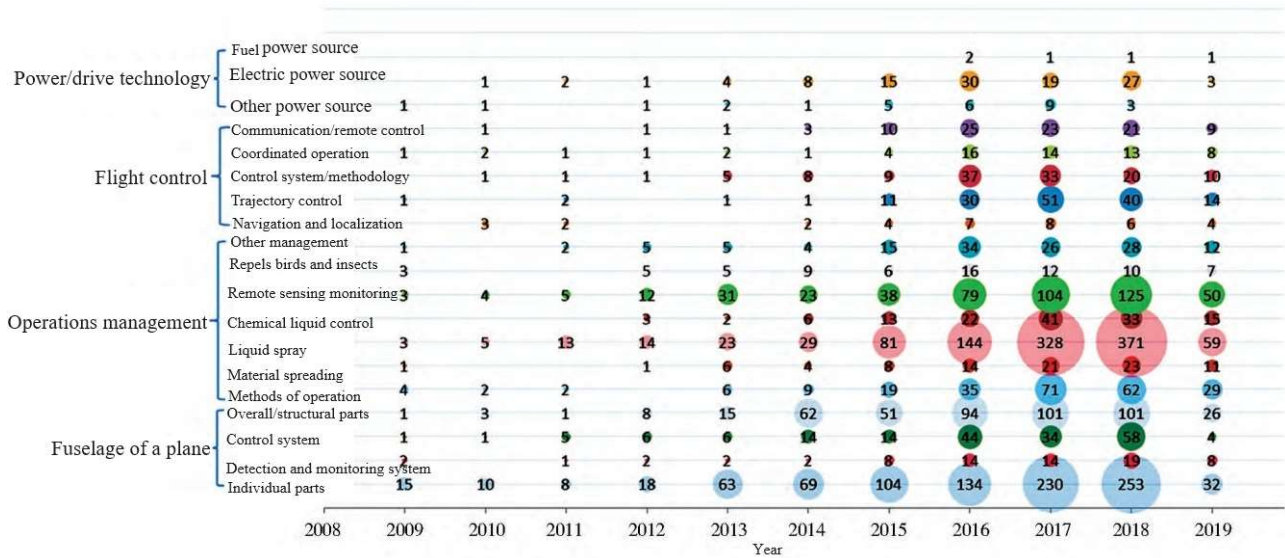
Category	Subcategory	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Power/drive technology	Fuel power source									2	1	1	1
	Electric power source	1	2	1	4	8	15			30	19	27	3
	Other power source	1	1		1	2	1	5	6	9	3		
Flight control	Communication/remote control	1		1	1	3	10	25	23	21	9		
	Coordinated operation	1	2	1	1	2	1	4	16	14	13	8	
	Control system/methodology	1	1	1	5	8	9	37	33	20	10		
	Trajectory control	1	2		1	1	11	30	51	40	14		
	Navigation and localization	3	2		2	4	7	8	6	4			
Operations management	Other management	1	2	5	5	4	15	34	26	28	12		
	Repels birds and insects	3		5	5	9	6	16	12	10	7		
	Remote sensing monitoring	3	4	5	12	31	23	38	79	104	125	50	
	Chemical liquid control			3	2	6	13	22	41	33	13		
	Liquid spray	3	5	13	14	23	29	81	144	328	371	59	
	Material spreading	1		1	6	4	8	14	21	23	11		
	Methods of operation	4	2	2	6	9	19	35	71	62	29		
Fuselage of a plane	Overall/structural parts	1	3	1	8	15	62	51	94	101	101	26	
	Control system	1	1	5	6	6	14	18	44	44	58	4	
	Detection and monitoring system	2	1	2	2	2	8	14	14	19	8		
	Individual parts	15	10	8	18	63	69	104	134	230	253	32	

Figure 4. Application trend of agricultural UAV technologies.

Secondly, 1658 patents in the direction of the body accounted for a large proportion, accounting for 37% of the total application volume of agricultural UAVs, among which the main contribution came from Chinese applicants for Chinese patents. The patent system in our country started in 1985. In our country, the applicant for a patent is still in its primary stage and involves the structure of the patent writing classes, usually from the protection products through the writing of the overall structure, making the patent application in agricultural unmanned aerial vehicle (UAV). The connection between the body and the body parts of the patent application amount is much more.

Flight control technology and power/drive technology had fewer patent applications, accounting for 10% and 3%, respectively. Both technologies are basic supporting technologies of UAV technology, and relatively few patents focus on agricultural scenarios for technological improvement in patent applications[20]. The patent application of flight control technology mainly focuses on the direction of trajectory control and control system control methods[6]. Trajectory control mainly includes path/route planning technology and UAV obstacle avoidance technology[21,22]. The patent layout in these two directions has increased significantly since 2016, and it is expected that there will still be a large space for development in the future. (Since it takes at least 18 months for a patent to be filed to be published, the data coverage of patent applications in 2018 and 2019 is not complete.). For the control system control method of flight control, there are many patents that apply artificial intelligence technology to UAVs, which is used to accurately identify the data information of the operation scene and then provide route planning and decision for the flight of the UAV based on the rules of an expert system. Artificial intelligence, machine learning, deep learning, and other technologies are integrated with UAV technology in agricultural scenarios, which further improves the automation and intelligence level of agricultural UAV flight control. Power/drive technology, the power system to change or improve the performance of affected by application scenario change, is not big, so for unmanned aerial vehicle (UAV) in agricultural scenarios of power/drive system improvement is unusual. According to unmanned aerial vehicle (UAV) power source, power/drive technology mainly includes fuel/gas drive, electric drive, such as solar power, and hybrid drive. Among them are electric and fuel-driven, and domestic applications tend to favor

battery-driven air weight and lightweight design.

3.5. Analysis of representative patents of technological development

The innovative technologies of agricultural UAVs in application scenarios such as plant protection operations, farmland monitoring operations, and sowing and pollination operations were analyzed by combining representative patents in each technology branch. Based on a comprehensive consideration of application date, citation frequency, family status, and technical content, the representative patent diagram shown in **Figure 5** is determined to reflect the research hotspots and trends in this technical field.

Figure 5. Representative patents of different technology components.

From the perspective of the application years of representative patents, more technical achievements were

made from 2015 to 2017, focusing on the fields of job management technology and body improvement technology. In the field of operation management technology, the most important patents are in the fields of remote sensing monitoring and subdivision technology, followed by the patents on plant protection operation methods related to spraying and application. Among them, in the field monitoring operation direction, low-profile multi-band hyperspectral imaging for Machine Vision proposed by DJI in 2017 (CN110476118A), provides a hyperspectral imaging system that can be used in machine vision systems. This imaging system has higher spatial resolution because it can use all sensor pixels of the camera when filtering images in different spectral bands and, at the same time, provides better spectral resolution than a traditional RGB camera system[23]. In 2017, DJI Innovation also proposed the output image generation method, equipment, and UAV (CN109076173A), which focuses on protecting how to improve the accuracy of UAV images[24]. In addition, the highest temperature point tracking method, device, and UAV (CN109154815A), the infrared camera on the UAV can sense the thermodynamic temperature of each object in the picture captured by the UAV, realizing the tracking and shooting of the highest temperature point so that the highest temperature point is located in the target position of the image[25].

The above three patents were all filed in 2017, and the technical solutions protected by these patents correspond well to the P4 Multispectral UAV released by DJI in September 2019. This UAV is the first by DJI to integrate the multi-spectral imaging system into the UAV platform to accurately collect multi-spectral data. Compared with visible-light imaging, multispectral imaging can provide more accurate directional information and help farmers and agricultural technicians understand the growth status and health of plants.

Harris Aerial is a commercial UAV manufacturer in the United States. In 2018, it launched the Carrier H4 HY-BRID, a hybrid UAV. The main features of the UAV are as follows: first, it is equipped with a battery, gasoline generator, and cylinder to achieve a long range of hybrid UAV. Second, the propeller can be folded, and the volume can be reduced by 50% after folding, which is convenient to carry, collect, and store and saves transportation costs[8,26]. Among them, the folding heavy Aerial UAV (US10266245) applied by Harris Aerial in 2016 is a collapsible structure to protect the propeller[27]. In addition, Harris Aerial's 2017 application for a modular sprayer system for heavy aerial vehicles (US10478841), listed in **Figure 5**, provides a liquid storage tank, its structural and connection relationship with the mounting unit and pump assembly, and includes a level sensor for determining the liquid level in the liquid storage tank[28]. US10478841 also protects the content of UAV communication, which is related to the communication standard (ETSI_TS 23 502, ETSI_TS 23 288) and becomes a standard essential patent. Standard essential patents are included in international standards, national standards, and industry standards, and in the implementation of standards, they must use a patent. That is to say, when the organization for standardization sets certain standards, some or all of the draft standard because there are no other technical or commercial alternatives, inevitably involves a patent or patent application, that is generally considered to be the standard essential patents have higher value. The number of standards, necessary patents in the field of agricultural drones is extremely rare.

From the perspective of representative patent applicants, the patent layout of traditional agricultural machinery manufacturers in the field of agricultural UAV still focuses on the field application research of UAV. For example, the aerial spreading device applied by Yanma in 2015 has a patent layout in China, and the patent is cited by DJI Innovation, Inseki Agricultural Machinery, and other companies. The patent provides an aerial spreading device capable of matching the amount of spreading with crop growth and yield deviations for efficient spreading. Deere also filed a patent in 2015 for the use of drone technology for yield estimation. Its agricultural drone technology is not available in China, but farm machinery giants Kesneholland and Agco have also cited the patent.

From the perspective of the patent layout, plant operation and farmland monitoring operation are hot spots in current research and development. Participating in the main body of research and development is given priority by unmanned aircraft manufacturers, agricultural machinery manufacturers, and domestic manufacturers to fly and Dji Innovation science and technology. The two have a more international patent layout, which is mainly focused on Europe, the United States, Japan, and South Korea. The risk of repeated research and development is high, and the difficulty of technological innovation is relatively large. The types of subjects involved in the R&D of flight control technology and power drive technology are relatively unconcentrated, including traditional aircraft manufacturers, communication manufacturers, and some exploratory aviation companies, such as Google, which successively applied for two articles (US9957037, US9518873) in 2013 and 2014 for patents related to UAV technology integrated with solar cells and have a technical layout in China[29,30]. The R&D personnel can comprehensively consider the terrain, environment, and other factors in agricultural scenarios to strengthen the patent layout in the direction of power systems and flight control[31].

4. Conclusion

In general, agricultural UAV technology is in a period of technological development with promising prospects. In the next few years, the number of patent applications and applicants related to agricultural UAV technology will continue to maintain a high growth trend. Through the above patent information, the development of agricultural UAV technology is revealed, which provides the basis for the technical development of scientific and technical personnel. Based on the above analysis, three suggestions are put forward for the patent layout of agricultural UAV technology.

1) Strengthen the layout of overseas patents in the field of agricultural UAVs and improve the bidding ability of products in overseas markets. According to Blueweave Consulting, the global agricultural UAV market size is expected to grow from USD 1.1 billion in 2019 to USD 4.7 billion by the end of 2026, growing at a rapid CAGR (compound annual growth) of 31.3% over the forecast period from 2019 to 2026. The compound annual growth rate (compound annual growth rate) Technological innovation, patent protection of innovative technology, and market competitiveness of innovative technology products are closely related. In the environment of the booming agricultural UAV market, our agricultural UAV enterprises should strengthen the application of domestic invention patents in order to pursue a long-term technical protection period. At the same time, the application and layout of international patents should be strengthened to lay a solid foundation of intellectual property rights for agricultural UAVs to go abroad and improve the bidding ability of agricultural UAVs in overseas markets.

2) Improve patent writing skills and strengthen awareness of the layout of patent claims. XAG and DJI are the two leading companies in domestic plant protection drones. In terms of the number of patents for agricultural drones, XAG has more applications than DJI. The main reason is that XAG is a Agricultural drones are the main business, and DJI only started its agricultural drone deployment in 2015, and a large number of its patents are concentrated in the field of consumer drones. The technical operations of the two companies in patent drafting are worth learning (please refer to CN110382356A, CN209626259U and CN209080184U and other patents)[32–34]. In terms of claim protection, the general technology and general components of UAVs will be protected. However, the protection subject matter will usually be protected by an independent claim for the application of UAVs in agriculture. At the same time, in the embodiments of the specification, the description of the application scenario in agriculture not only ensures the scope of patent protection, but also realizes the concreteness of the technology in the

application scenario. This way of drafting and laying out claims is extremely helpful for the interpretation of claims during the patent invalidation stage and for the comparison and alignment of patents and infringing products in patent infringement litigation.

3) While strengthening awareness of patent protection, we will also improve our ability to use patents in the market. The acquisition of patent rights enables the rights holder to have exclusivity and proprietary rights over his patented technology, and he will naturally have the ability to proactively assert his own rights. Since 2015, there has been a boom in the field of consumer drones. Waves of patent battles. According to incomplete statistics, DJI has sued a number of drone companies including Shenzhen Daotong, Foshan Dark Horse, Guangzhou Walkera, YUNEEC Haoxiang and Beijing Zero Degree over issues related to patent infringement. XAG also has a number of patents involved in patent infringement litigation. At present, there is no large-scale intellectual property competition in the field of agricultural UAVs. However, as the agricultural UAV market develops and market competition intensifies, patent wars in the field of agricultural UAVs are about to break out.

Conflict of interest

The authors declare no conflict of interest.

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