DEVELOPMENT TREND OF AGRICULTURAL DRONES BASED ON PATENT RESEARCH

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Abstract. Technical and technological advancement is essential for sustainable agriculture. The future of the agricultural sector depends directly on continuous development, which can stimulate greater competitiveness, economic revitalization, increased investment, creation of additional jobs, and development of new machinery and technologies with higher productivity, ultimately contributing to economic growth. At the same time, innovation is costly and requires substantial investment. To manage these costs effectively, it should be accompanied by inventive activity that leads to the creation of intellectual property, more specifically industrial property. Industrial property is not an end in itself but rather a market instrument that enables the recovery of investments made in the development of new technologies and technical solutions. This research focuses on inventive activity in the rapidly developing field of agricultural unmanned aerial vehicles (UAVs), or drones, as an innovative element of precision agriculture. The study is based on patent data obtained from the Espacenet patent database. An analysis of the subject area was conducted to identify development trends in agricultural drones and to determine the current directions of research and development in this field. During the study, patent holders and the countries in which the first patent applications were filed were identified. This made it possible to identify key patent markets and to provide an illustrative profile of selected applicants active in the sector.

Keywords: agricultural engineering, drones, intellectual property, smart agriculture, unmanned aerial vehicle.

Introduction

Since the beginning of this century, agriculture, particularly agricultural machinery and technology, have undergone rapid changes and development [1; 2]. A scheme describing the stages of agricultural development presented in [3] clearly highlights the characteristics of present day and future agriculture. The agricultural revolution known as Agriculture 4.0 is characterized by technologies such as artificial intelligence (AI), the Internet of Things (IoT), machine learning (ML), 5G, and cloud computing, while Agriculture 5.0 is associated with robotics, unmanned aerial vehicles, and big data analytics. These developments have been discussed in greater detail in the relevant literature [4-8].

This study focuses on drones, or remotely controlled unmanned aerial vehicles (UAVs). The first drones began to appear on the market approximately fifteen years ago [9]. At about the same time, technical solutions related to unmanned aerial vehicles began to be legally registered through patent and utility model applications. In this study, utility model applications are treated together with patents as industrial property documents; depending on the jurisdiction, a utility model is usually granted through a simpler procedure and may be issued without substantive examination. These intellectual property documents provide a valuable source of information for analysing technological developments in this field. In recent years, drone technology has developed most rapidly in the military sector, largely driven by armed conflicts, including the war in Ukraine. At the same time, drones have increasingly been adopted in agriculture, where they contribute to improving the efficiency of traditional farming practices and reducing negative environmental impacts. As a result, drones have become an important technological component of modern agriculture.

Agricultural drones, i.e. UAVs used in agriculture, can be classified according to several criteria [10; 11].

1. Field of application: crop monitoring, soil sampling, precision spraying, livestock tracking, and other agricultural data-acquisition or field-intervention tasks.
2. Wing configuration: fixed wing drones; hybrid fixed wing drones combining features of fixed wing aircraft and multirotor drones; single rotor helicopters; multirotor drones (e.g. quadcopters, octocopters, and dodecacopters); and foldable wing drones.
3. Payload capacity: micro drones (< 5 kg), light drones (5-50 kg), medium drones (50-200 kg), heavy drones (200-2000 kg), and very heavy drones (> 2000 kg).

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4. Flight range: short range drones, medium range drones (up to 200 km), and long range drones (up to 22,000 km).

Patent data have previously been used to analyse development trends in agriculture and agricultural machinery. Reviews of patent trends in agricultural machinery [12] have shown that the number of patents in this field increased steadily between 2010 and 2017. This trend is particularly evident in areas such as data collection, monitoring technologies, and process automation. Cano et al. [13] examined trends in agricultural technologies based on the United States patents without referring to individual patent documents. Their study identified eight key categories of precision agriculture, including Automation, Control and Robotics; Computing and Cloud Technology; Data Acquisition and Communication; Artificial Intelligence; and Manufacturing Technologies and Equipment. However, drone technology was not considered as a separate category. Nevertheless, all the areas analysed in [13] are directly related to drone technologies.

The aim of the present study was to investigate and analyse the development trends and potential of agricultural unmanned aerial vehicles (UAVs), or drones, as a rapidly evolving field and an innovative element of precision agriculture. In addition, the study aims to assess their impact through inventive activity and to provide an applicant-level profile of selected developers active in this field. The novelty of the study lies in the patent-based separation of agricultural drone development by time period, application field, country, and applicant. This approach makes it possible to distinguish agricultural drone innovation from the broader drone patent landscape and to identify the main directions of inventive activity in this sector.

Materials and methods

Patent analysis methodology. Novel technical solutions are legally protected through patents. Patent information is available in several databases, including Google Patents, Espacenet, the European Patent Register, Patentscope, and Intellectual Property Resources, among others. In the present study, the Espacenet database was used, as it is also employed by the national patent office during the patent examination process.

Keyword-based searches are commonly used in patent analysis. A particular feature of the present study is that the terms drone and unmanned aerial vehicle refer to the same object. In patent documentation, terminology is generally required to remain consistent throughout a document, meaning that the same technical term is used consistently within a patent. As a result, it is unlikely that the terms drone and unmanned aerial vehicle would be used interchangeably within a single patent document. Therefore, in order to obtain an accurate picture of patent activity in this field, patents referring to drones and unmanned aerial vehicles were combined in the analysis. The Espacenet database also allows Boolean searches. For the general drone dataset, the following search logic was used: drone OR “unmanned aerial vehicle”. For the agricultural-drone subset, the Boolean query was: (drone OR “unmanned aerial vehicle”) AND (agricultural OR spraying OR “precision spraying” OR “crop monitoring” OR “soil sampling” OR “livestock tracking”).

For the agricultural-drone subset, an additional keyword filter was applied to the general drone/UAV dataset. The agricultural keywords agricultural, spraying, precision spraying, crop monitoring, soil sampling, and livestock tracking were searched in the patent title or abstract. Patent documents were included when the title or abstract combined drone/UAV terminology with at least one agricultural keyword or otherwise explicitly described an agricultural function. Patent documents were excluded when the title or abstract referred only to military, recreational, delivery, communication, or other non-agricultural functions and did not indicate an agricultural application. Therefore, the agricultural-drone dataset was isolated from the broader drone/UAV patent pool by keyword filtering of titles and abstracts, followed by exclusion of documents without an identifiable agricultural function.

Inventive activity by year was determined by filtering the search results by patent publication year. Country-level results were determined by filtering the document number field using the two-letter country code. Applicant-level results were obtained by filtering the selected dataset by company or applicant name in the applicant field.

In addition to the patent database analysis, the company-level discussion considered the list of companies reported in the market overview [14]. This list was used as an illustrative set of market-relevant companies rather than as a comprehensive ranking of all agricultural drone patent holders. Therefore, the applicant-level results should be interpreted as selected applicant profiles, not as a complete global ranking of agricultural drone patent holders. The companies considered include well-known drone companies from different countries: SZ DJI Technology (China); AeroVironment (USA); XAG Co., Ltd. (China); Parrot Drone SAS (France); Kespry Inc. (USA); Sentera (USA); Dedrone (USA); Yamaha Motor Co., Ltd. (Japan); AgEagle Aerial Systems Inc. (USA); and Draganfly Inc. (Canada).

Results and discussion

Patent trends. According to the Espacenet database, more than 100,000 patent documents related to drones and unmanned aerial vehicles have been registered, distributed across many countries (Fig. 1). The distribution of these patents by country shows a clear concentration of inventive activity in a limited number of technologically advanced countries.

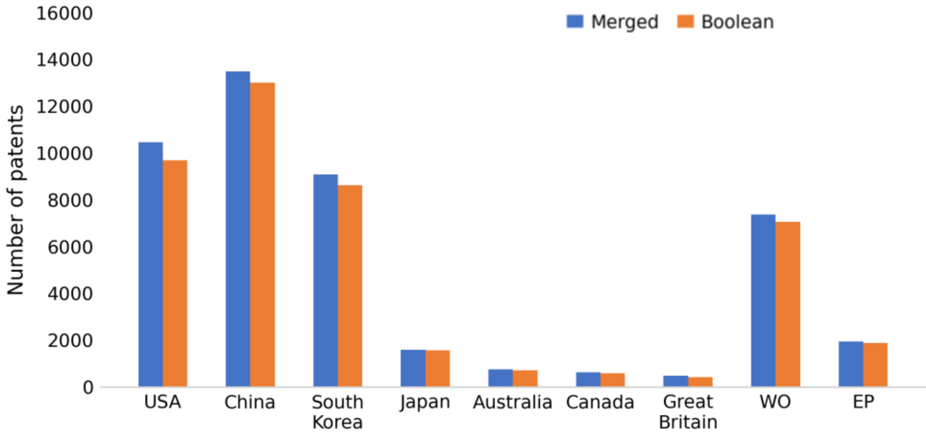

Fig. 1. **Number of registered drone and unmanned aerial vehicle patents by country (Espacenet database, as of 30 April 2026):** WO – World Intellectual Property Organization (WIPO); EP – European Patent Office (EPO)

As shown in Fig. 1, the largest numbers of patent registrations are associated with the United States (10458), China (13476), and South Korea (9086). A considerably smaller but still significant number of patents has been registered in Japan (1590). In addition, a large number of international patent applications have been filed through the World Intellectual Property Organization (WO, 7362) and the European Patent Office (EP, 1932). Other countries with notable numbers of registered patents include Canada (628), Australia (745), the United Kingdom (473), and Russia (236). Smaller numbers of patents have been registered in Spain (90), France (51), Ukraine (47), Bulgaria (44), Germany (41), and Poland (33). It should be noted that the analysed patent documents cover a broad range of drone technologies, including agricultural drones, military drones, recreational drones, and other types of unmanned aerial vehicles. Fig. 1 also compares the merged search results with the Boolean query results. For the countries shown in the Fig., the difference between the two approaches ranged from approximately 1.0% to 7.4%, indicating that both approaches produced broadly similar country-level distributions.

Based on the conducted patent analysis, the development of agricultural drones and unmanned aerial vehicles can be divided into three distinct periods: (1) 2011-2015 – early stage of development , (2) 2016-2020 – period of rapid development, (3) 2021-2025 – stage characterized by the emergence of new applications.

The main characteristics of these periods are briefly described below.

Period 1 (2011-2015): first agricultural drones began to emerge

The development of agricultural monitoring and observation drones was at an early stage, and the overall number of patent applications remained relatively low compared with subsequent periods. Early technical solutions primarily addressed basic functionalities, including aerial imaging and the processing of collected data (images and videos) for crop growth assessment. Technological development at this stage was led mainly by developers from South Korea, the United States, Japan, and several European countries, whereas China, which later became a major contributor, was not yet significantly represented. These early patents established the technological foundation for the subsequent development and wider adoption of drones in agriculture, particularly in relation to data acquisition and aerial imaging.

The main technological directions during this period can be summarized as follows:

- *Mapping and photogrammetry*. Drones were used to capture aerial images of agricultural fields and to generate orthophotos and three dimensional models, which supported the planning of land improvement and agricultural operations.
- *Multispectral remote sensing*. Infrared and multispectral cameras began to be mounted on drones in order to estimate vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), which are used to assess crop health.
- *Initial development of flight platforms*. Technological development focused on improving flight stability and extending flight duration, enabling drones to cover larger agricultural areas. In terms of sensors, most systems relied on existing camera technologies for RGB image acquisition.
- *Early data processing approaches*. Data analysis was still performed mainly in ground based environments, with drones functioning primarily as data collection platforms. However, patents began to appear describing systems that enabled communication between drones and cloud based platforms or other machines, allowing faster data processing. For example, early solutions were patented in which drones transmitted images to crop yield forecasting applications, where the data were integrated with weather and soil information to produce more accurate predictions.

Period 2 (2016-2020): rapid development and diversification of drone technologies

The period from 2016 to 2020 marked a turning point in the development and patenting of agricultural drones. From 2016 onwards, the number of patent applications increased significantly. This growth was driven primarily by South Korea and China. While China's contribution during the 2011-2015 period was relatively modest, the number of patent applications originating from China increased sharply after 2016, making China the leading country in this technological field. During 2016-2020, thousands of new patent applications related to agricultural drones were filed worldwide, several times more than in the previous period. China played a dominant role, accounting for approximately 56% of all patents in this field by the end of the period. The United States ranked second, followed by South Korea, Japan, and several European countries, which together accounted for the remaining approximately 44% of patents.

The main technological directions during this period included the following.

- *Crop protection and precision spraying*. A large share of patents focused on spraying systems integrated with sensors and cameras, enabling drones to adjust spraying operations according to crop conditions. Combined monitoring and intervention systems became increasingly common.
- *Multispectral and hyperspectral sensing*. Drones were equipped with improved sensors, including hyperspectral cameras for vegetation analysis and thermal cameras for assessing water stress.
- *Artificial intelligence and data analytics*. The use of artificial intelligence increased significantly, with patents describing automated image recognition and decision support systems capable of generating dynamic fertilization or spraying plans based on drone collected data.
- *Vertical take-off and landing platforms*. The development of vertical take off and landing (VTOL) drones, including multirotor configurations capable of performing one or several functions autonomously, became more widespread (for example US2019197908 A1).
- *Emergence of new applications*. Novel applications included drone based pollination systems and biological pest control solutions in which drones distribute beneficial insects (for example US11957096 B2; US11952118 B2).

Several patents during this period focused specifically on agricultural monitoring drones.

- *Real time crop condition assessment*. For example, system for plant health diagnostics using drone imagery, where a drone equipped with a spectrometer analyses leaf spectral characteristics to detect nutrient deficiencies (US9377404 B2).
- *Soil monitoring drones*. From 2016 onwards, several patents addressed the use of drones for mapping soil properties. One example is the South Korean patent KR101845395B1, which describes a drone equipped with a drilling probe capable of briefly penetrating the soil during flight in order to collect small soil samples or measure soil moisture. Such solutions aim to obtain soil data without requiring manual sampling at each location, although they present significant technical challenges related to flight stability and probe operation.

Period 3 (2021-2025): emergence of new applications and integration of advanced digital technologies

During this period, the annual number of patent applications remained at a high level. For example, nearly 500 patent applications related to agricultural drones were filed worldwide in 2022 alone. Although the growth continued at the beginning of the period, it gradually stabilized in the middle and slowed slightly toward the end. It is estimated that approximately 3000 new patents were filed between 2021 and 2025, of which around 2000 were related to monitoring and surveillance applications.

The main technological directions during this period include the following.

- *Artificial intelligence and autonomous decision making*. The role of artificial intelligence has increased significantly. Patents describe drone systems capable of independently collecting and analysing data and performing actions based on the results. Swarm based solutions have also been patented, in which multiple drones communicate with each other and distribute tasks autonomously. For example, Aerobotics patented a method for counting fruit from drone imagery using artificial intelligence to accurately predict crop yields (US20240116630A1). Advances in machine vision have also enabled automatic identification of weeds among crops and the detection of crop growth stages.
- *Sensor integration and smart monitoring networks*. Increasing numbers of patents address the integration of aerial and ground based sensors. The University of California patented a system in which a drone uses machine learning to determine optimal flight paths and positions for deploying soil sensors in agricultural fields (WO2025015035A1). The US company Groundworx patented portable wireless soil sensors that can be relocated without excavation (US20240168001A1).
- *Real time monitoring platforms and digital twins*. Many recent patents describe cloud based platforms where drones transmit data in real time and where the collected information is integrated into digital models of farms. Digital twin solutions have been patented in which continuously updated virtual representations of fields are created based on data from drones, agricultural machinery, and weather sensors. These digital twins allow simulations to be performed before implementation, for example, testing different irrigation regimes in a virtual environment.
- *Integration with precision agriculture systems*. Drones were increasingly integrated into broader agricultural ecosystems together with tractors, harvesters, stationary sensors, and software platforms, forming part of integrated farm management systems (EP4302590 A1, US11957096 B2; US20260010979 A1; US20260013429 A1).
- *New applications and equipment*. The application areas of drones have expanded further. The University of Arizona patented an autonomous drone system for plant pollination, where the drone uses machine vision to detect flowers and applies pollen in controlled quantities (US11957096B2). The Swedish company AirForestry patented drones capable of autonomous thinning and extraction of trees in forest environments (US11993407B2). DroneSeed Co. patented a drone based seeding system that disperses seed containing capsules from the air (US11985914B2).
- *Safety*, *regulation*, *and operational usability*. As drone use has expanded rapidly, patents increasingly address safety and operational reliability. These include systems for automatic landing and docking stations where drones recharge autonomously and transmit data to cloud platforms (EP3406408B1), as well as improved obstacle detection and navigation systems (DJI

patent US20220004201A1). Some patents also describe secure group control of multiple drones to prevent mid air collisions.

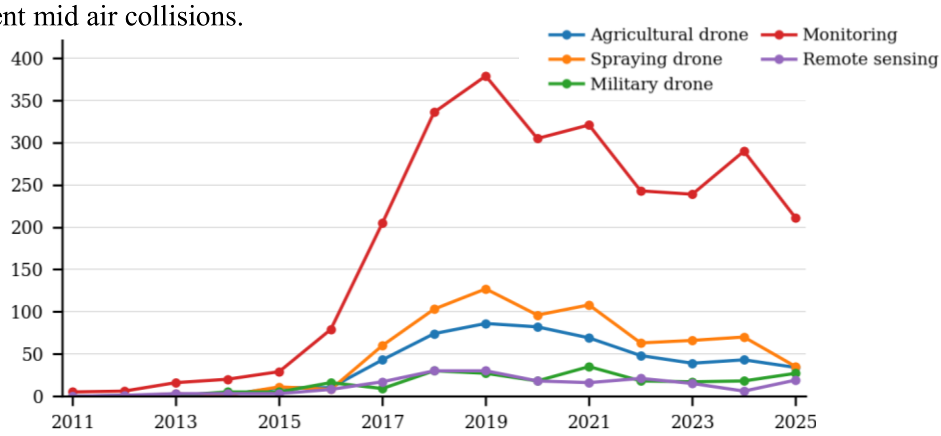

Fig. 2. **Distribution of drone patents by field of application**

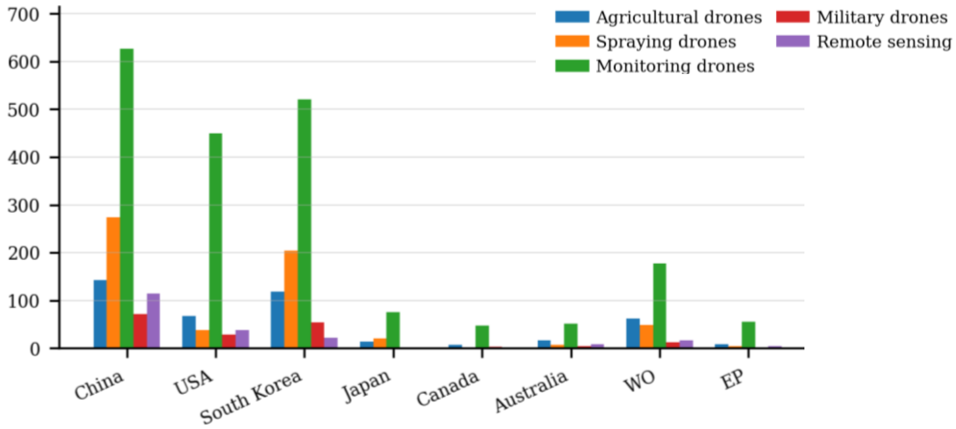

Fig. 3. **Number of drone patents by field of application by country**

Fig. 2 separately presents inventive activity over time for agricultural drones, spraying drones, monitoring drones, remote-sensing drones, and military drones. The fastest growth in patenting related to agricultural drones occurred in 2016-2020, when monitoring and spraying applications increased sharply. Military drones are included only as a comparative technological context, not as part of the agricultural-drone dataset. The connection between military and agricultural drones lies in shared enabling technologies such as airframes, batteries, imaging sensors, navigation, communication systems, and autonomous control. These technologies may be transferred or adapted from military to agricultural applications, for example in monitoring, remote sensing, route planning, and precision spraying. The data should therefore be interpreted as evidence of related technological dynamics rather than direct dependence.

Fig. 3 presents patent activity by application field and country. China, South Korea, and the United States have the highest numbers in most categories. Monitoring drones form the largest group across the leading countries, while spraying drones are especially visible in China and South Korea. Remote-sensing and military-drone categories are smaller but illustrate the broader technological environment in which agricultural UAVs develop.

Among the selected applicants analysed in the Espacenet dataset, SZ DJI Technology Co., Ltd. (China) had the largest patent portfolio, with 3905 patent documents. Other prominent applicants in this illustrative applicant-profile analysis included TopXGun (China; 267 patents), XAG (China; 116 patents), Parrot Drone SAS (France; 268 patents), and AeroVironment (USA; 235 patents). Universities also contributed to drone development; for example, the Nanjing University of Technology was associated with 188 patent documents. These Fig.s should be interpreted as an applicant-profile analysis based on the selected Espacenet search rather than as a complete global ranking of all agricultural drone developers.

Conclusions

This patent-based study analysed the development of agricultural drones during 2011-2025 using a systematic search of the Espacenet database. The results show a clear development trajectory across three periods. Between 2011 and 2015, relatively few patent applications were identified and the technological focus was on fundamental functions such as photogrammetry and multispectral remote sensing. Innovation during this stage was led primarily by the United States, Japan, and European countries. The period 2016-2020 marked a turning point. This stage was characterized by a sharp increase in patent registration activity, largely driven by China, which reached a 56% share of patents in this field. Technological progress included the adoption of hyperspectral cameras, the integration of artificial intelligence, and the development of precision spraying systems. Development of agricultural drones in the period 2021-2025 emphasized autonomous systems, coordinated unmanned solutions (aerial and ground), and digital twin technologies. During this period, patent registration slowed down somewhat. Overall, the agricultural drone sector has undergone rapid and structured growth, with China assuming a leading position. The technology has evolved into commercially viable and integrated systems, and current trends indicate further progress toward increased autonomy and system integration.

Author contributions

Conceptualization, J.O.; methodology, J.O., O.L. and Y.I.; formal analysis, Y.I. and O.L.; investigation, J.O., O.L. and Y.I.; writing – original draft preparation, J.O.; writing – review and editing, O.L. and Y.I.; project administration, J.O. All authors have read and agreed to the published version of the manuscript.

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