



# Global Unmanned Aerial Vehicle Utilization Research Trends

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## ABSTRACT

The rapid development of technologies in unmanned aerial vehicles (UAVs) has led to their use in various areas. UAVs are mainly used for commercial purposes, but their utilization is increasingly important in other areas because their operation cost is less than satellites and aerial imaging. The utilization of UAVs in the environment/ecology area is relatively new. Therefore, identifying the trends of UAV-related spatial information is significant in basic research for UAV utilization. This study quantitatively identified domestic and international research trends related to UAV utilization and analyzed research areas. An attempt was also made to identify upcoming UAV-related topics in the environment/ecology research field using text mining to analyze the bibliographic information of global research literature. Domestic UAV-related studies were classified into seven clusters where basic research on “UAV technology/industry trends” was abundant, and studies on data collection and analysis through UAV remote sensing technology have increased since 2015. Eight clusters were identified for international studies where the most active research area international was “remote sensing technology/data analysis”. In addition, Canopy, Classification, Forest, Leaf Area Index, Normalized Difference Vegetation Index, Temperature, Tree, and Atmosphere appeared as the main keywords related to environment and ecology. The appearance frequencies and association strengths were high because the advancement in UAV optical sensor technology and the rapid development of image processing technology enabled the acquisition of data that could not be obtained from existing spatial information. They are recognized as future research topics as related domestic studies have begun corresponding to international research.

**Keywords:** Data mining, Literature analysis, Remote sensing, Research trends, Unmanned aerial vehicle

## Introduction

As technologies in unmanned aerial vehicles (UAVs) have attracted attention as the growth engine of the fourth industrial era, related technologies are being rap-


idly developed and social interest is increasing. With the recent expansion of UAV applications, research papers on each topic have been published through various international journals. It is not easy, however, to identify UAV application research trends in specific areas.

In recent years, the applicability of informetric analysis methods to research the knowledge and attributes recorded in media, such as papers, by applying mathematical and statistical methods to the bibliographic information of literature has increased. The analysis of the research contents and topics of such academic papers is useful in

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revealing the interdisciplinarity of academic areas (Lee & Kwak 2011). It is also significant as basic research that can objectively identify the performance of each detailed research area and present the future research direction.

As such, an attempt was made to objectively evaluate the status of domestic research by identifying active research topics in the ecological environment research area through the analysis of domestic and international UAV research trends. This study was conducted for two purposes.

First, UAV-related research areas were subdivided, and the research status of the environment/ecology area was quantitatively identified among them. Second, research topics that have recently attracted attention were presented by analyzing UAV research trends for 20 years. Third, UAV technologies that are applicable to the environment/ecology research area in the future were identified.

### Materials and Methods

#### Theoretical considerations

Among big data analysis methods, the text mining technique derives formalized information from a large amount of non-formalized text data and constructs it in the form of new information, such as visualization and digitization. It can effectively extract and utilize meaningful information desired by the research when applied to text-based data, such as research literature. Therefore, this study attempted to quantitatively identify research trends using text mining and co-word analysis as research literature analysis methods. Visualization of Similarities (VOSviewer; Centre for Science and Technology Studies, Leiden University, Leiden, The Netherlands) is an analysis tool frequently used by many researchers for the analysis of bibliometric data, such as recent collaborative relationships between publications, journals, or researchers, and citation relationships between scientific terms (Heersmink et al., 2011; van Eck & Waltman, 2010; Waltman et al., 2010).

VOSviewer can create a two-dimensional (2D) map from

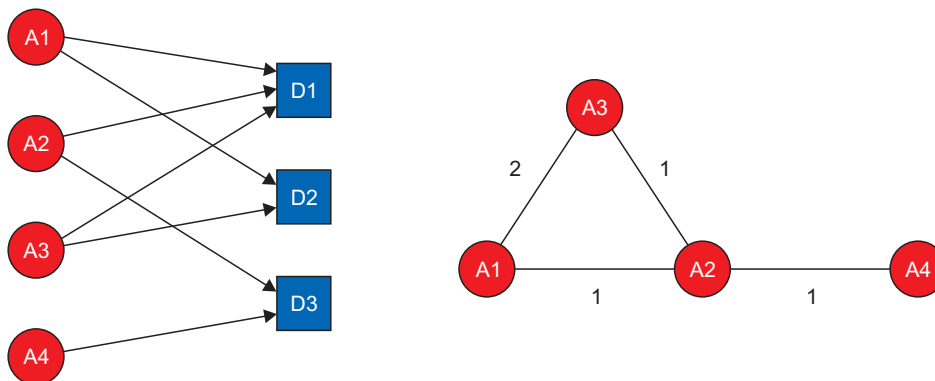
network data, such as co-word and proximity matrices, and perform data clustering using its own clustering algorithm (Choi et al., 2011). It also includes an algorithm that identifies only the noun phrases from a text document after classifying and tagging the phrases in each sentence into verbs, adjectives, and nouns, thereby enabling analysis using the relevance score specified by the researcher. These functions extract words related to a specific research topic from the collected paper data and classify them into similar topics, and then analyze research trends by identifying the appearance frequency and association strength of each word.

The analysis principle of VOSviewer is to create an intuitive network map using nodes, appearance frequency, and association strength based on the number of edges, which can be explained in a conceptual analysis diagram (Fig. 1). For example, when A1 to A4 are assumed as authors or words and D1 to D3 as documents, A1 and A3 have a connection strength of 2 because both of them were used in two documents (D1 and D2).

This relationship analysis is mainly conducted in three steps. In the first step, a co-occurrence matrix is created for words that constitute the literature, and similarities between categories are calculated based on the matrix. The similarities are calculated using the association strength method in equation 1, one of the similarity calculation methods.

$$\text{Association strength} = \frac{mC_{ij}}{K_iK_j} \quad (1)$$

where  $C_{ij}$  is the number of simultaneous occurrences between items (words or papers)  $i$  and  $j$ .  $K_j$  and  $K_i$  are the total number of occurrences of  $i$  and  $j$ , respectively, and  $m$  is the population parameter. In the second step, a 2D map is created based on the similarities calculated in the first step. Items with high similarities are close, but those with low similarities are distant. In the third step, each parameter is clustered. Depending on the occurrence frequency, the graph is enlarged if the density of the parameters is



**Fig. 1.** Authorship links between four authors and three documents (left), co-authorship network constructed using full counting (right) (Source: van Eck, N.J., and Waltman, L., 2018).

high and reduced if it is low. In this study, keywords for each main research area were extracted to examine their association strengths and changes from the past to the present were investigated for the analysis of UAV-related research trends.

### Data collection

In this study, the Web of Science Database (DB) by Thomson Reuters was utilized to identify domestic and international UAV-related research trends. DBs for collecting paper information are also available for Scopus and ScienceDirect. The Web of Science not only has a separate DB to search for journals registered in South Korea but it also makes it possible to collect a large amount of data on quality papers, such as the Science Citation Index Expanded (SCIE) and Social Sciences Citation Index (SSCI). In addition, data processing is easy because domestic and international data can be provided in the same format during the collection of bibliographic information.

Papers from 1997 to 2017 that used “UAV” in the title or as a keyword were targeted. Citation indices were limited to SCI, SCIE, SSCI, and KCI, excluding articles, reports, and theses. The collected papers were classified by title, year, abstract, and journal name. Data that could cause errors in analysis, such as papers without an English abstract or unrelated to the topic, were removed. Consequently, 745 domestic papers published since 2002 and 3,858 international papers published since 1997 were collected.

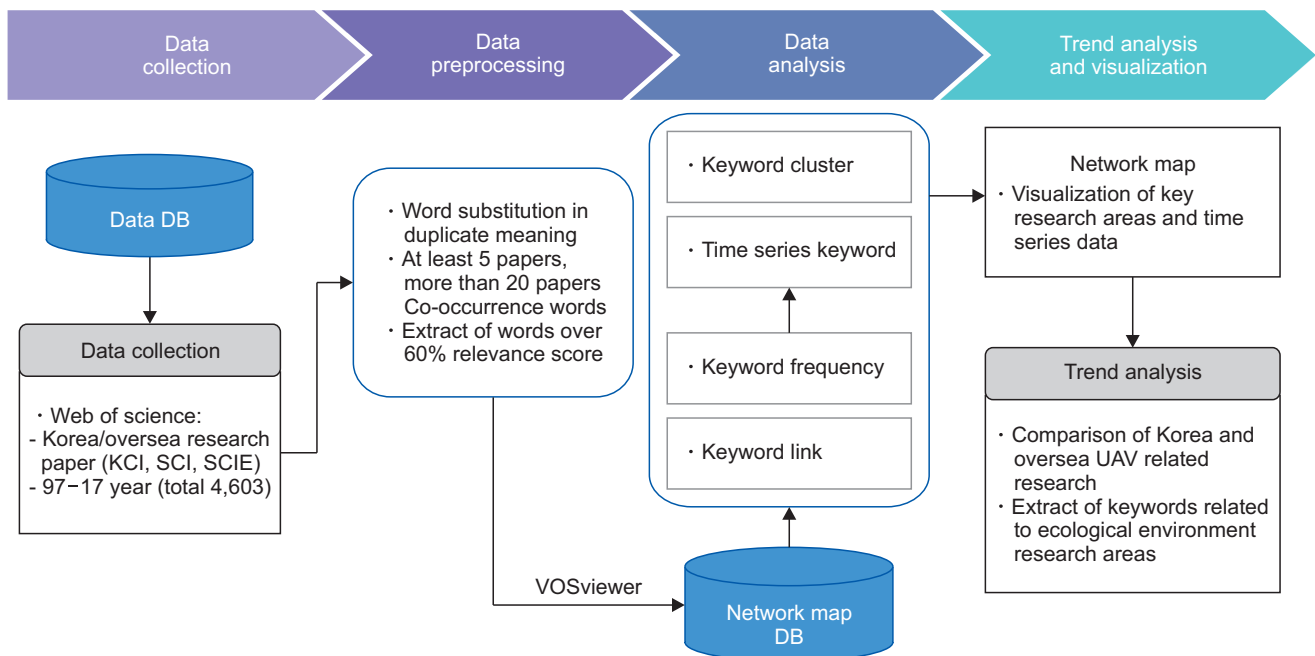
### Keyword extraction

The process of extracting keywords and phrases through VOSviewer was performed using the following criteria. First, words with similar meanings were excluded or replaced with identical words for analysis (e.g., UAV, UAS, Smart UAV, and Unmanned aerial vehicle). Second, words or phrases that appeared in at least three papers were selected. Third, for general words and postpositions that cannot be determined as keywords among the words with high appearance frequency, only the words that corresponded to the top 60% of the keyword relevance scores were extracted using the basic values (van Eck & Waltman, 2014) of the function provided by VOSviewer (Fig. 2).

## Results and Discussion

### Preprocessing results

To identify UAV-related research topics, the co-occurrence frequencies of the words and phrases used in abstracts were analyzed. There were 13,359 occurrences extracted for domestic papers and 73,628 for international papers. Among them, words with similar meanings (e.g., unmanned, unmanned aircraft, aviation, and UAV) were excluded. Considering the size of the collected literature, the words that appeared in at least 10 domestic papers or 20 international papers were extracted in the first step. In the second step, a network map was created by setting Resolution to 1.5 and Min Cluster size to 5 in the clustering option for the visualization of the words that



**Fig. 2.** Text mining analysis process. DB, database; KCI, Korea Citation Index; SCI, Science Citation Index; SCIE, Science Citation Index Expanded; UAV, unmanned aerial vehicle.

corresponded to the top 60% (VOSviewer setting), which acquired the relevance score as a keyword. A time-series network map to identify the time-series flow for research areas was created using the time information for the occurrence of the main keywords. The data before 2013 were excluded from the map because they did not meet the minimum criterion of the co-occurrence frequency.

**UAV-related research trends**

A total of 3,858 international papers from 1997 to 2017 were collected, and 745 domestic papers from 2002 to 2017 were collected (Table 1). In international countries, the number of papers increased by 7 per year from 1997 to 2008 and sharply increased by 89.8 per year from 2009 to 2017. In South Korea, the number of papers increased by 4 per year until 2013 and by 19.9 per year from 2014 to 2017 (Fig. 3). This appears to be because of the rapid growth of the private drone industry market, and the application range of drones expanded due to the improvement of hardware performance, miniaturization of related imaging devices, and the development of sensor technologies for drones. Considering the time at which the number of papers began to rapidly increase, there was a time difference of approximately five years between South Korea and international countries.

**Research area classification results**

The analysis results revealed that there were 173 main keywords for domestic papers and 477 for international

papers. When clustering was performed based on this, domestic UAV-related studies could be classified into seven key areas compared to eight areas for international studies. In addition, a time-series network map was created based on the keyword appearance time to identify changes in the time series for each research area.

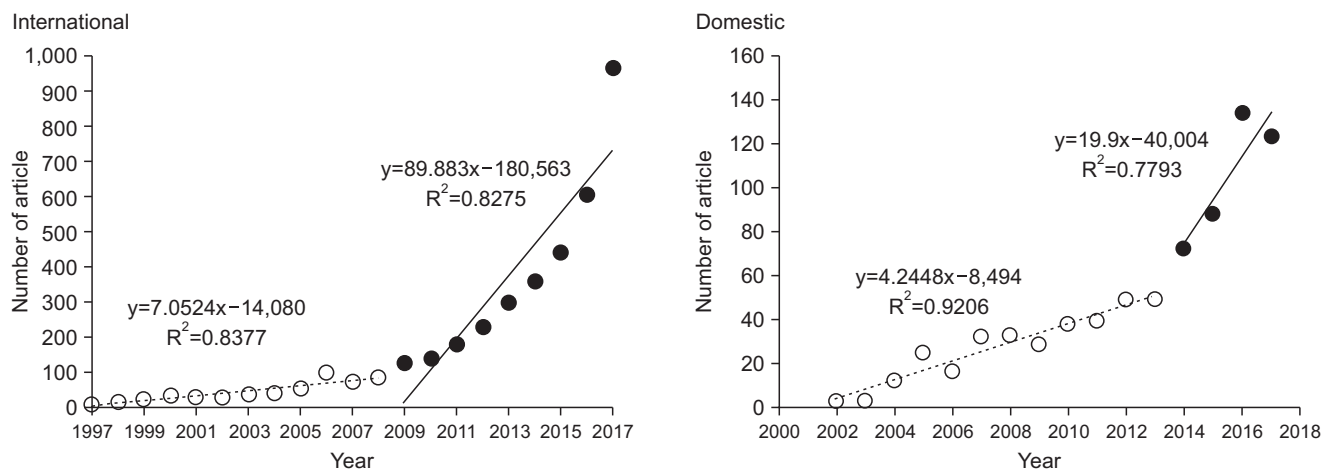
As for international studies, 99 co-words were derived in Cluster1, a research area related to “remote sensing/data analysis”. The cluster represented the largest proportion in the entire research area. The word that appeared most frequently was “monitoring”, and the cluster was highly associated with “tree”, “plant”, “vegetation”, and “species” (Fig. 4).

Research on UAV remote sensing is similar to research that uses satellites and aerial imaging in terms of methodologies, but this study was conducted with a focus on the characteristics of UAV images that can acquire more precise spatial information than the existing data. The publication of related research literature has shown an increase since 2014, and research has been conducted most actively along with the Cluster4 area (Fig. 5).

In Cluster2, a research area related to “mission performance”, 77 co-words were derived and the word that most frequently appeared was “simulation”. This cluster was highly associated with “path”, “constraint”, “obstacle”, and “collision”. As UAV is a research area on flight paths, control, obstacles, and collisions for performing UAV missions, it was dominated by experimental studies using software and hardware. Considering the publication time

**Table 1.** Yearly number of domestic and international papers

	97	98	99	20	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	Total
Domestic	-	-	-	-	-	3	3	12	25	16	32	33	29	38	39	49	49	72	88	134	123	745
International	8	14	21	31	27	29	37	38	51	95	72	84	127	141	182	229	300	362	440	605	965	3,858



**Fig. 3.** Increase in the number of articles per year.



**Table 2.** Clustering classification filed with keyword of international papers

Cluster	Classification filed	Top 20% frequent words
1	Remote sensing/ data analysis (99 words)	Monitoring Imagery Tree Classification Coefficient Correlation temperature satellite High Value Remote sensing plant Crop Vegetation Forest Vegetation index NDVI Assessment Observation Index Object High resolution species
2	Perform mission (77 words)	Simulation constraint Path Target Function Scenario Optimization Team Search Surveillance operator Obstacle Behavior Formation Node Robot Guidance Communication Path planning formulation
3	Flight control (76 words)	Rotorcraft autopilot Flight control system Helicopter Fault detection hardware Actuator Loop simulation controller design control system simulation study subsystem control law Proof, control respect stabilization control input control algorithm

research was most active around 2010 but has been decreasing.

Cluster6 is a research area related to the “UAV technology/industry trend”. Thirty-five co-words derived and the word that most frequently appeared was “tool”. This cluster was highly associated with “year”, “precision”, “variety”, and “opportunity”. It was dominated by studies with

**Table 2.** Continued

Cluster	Classification filed	Top 20% frequent words
4	Collecting data/ process (76 words)	Image Accuracy Map, mapping surface Quality Survey Site photogrammetry point cloud Low cost Case study dataset Uav image Sfm Acquisition volume Density Lidar Aerial image
5	Airframe performance (69 words)	Design Aircraft Angle Degree Concept Wing Landing Flight test unmanned Air vehicle Equation Power Force Modeling Energy Load Endurance
6	UAV Technology/ industry trend (35 words)	Tool Year Precision Drone Variety Uav platform, uas opportunity unmanned aerial system decade overview
7	Navigation/ location-based technology (31 words)	Position experimental Result vision Velocity Navigation Gps Localization Noise Global positioning System
8	Radio wave/ radar (13 words)	Pattern Processing Imaging band antenna

NDVI, Normalized Difference Vegetation Index.

a focus on the precision and various applications of the data acquired by UAVs.

Cluster7 is a research area related to “navigation/location-based technology”. Thirty-one co-words were derived



**Table 3.** Clustering classification filed with keywords of domestic studies

Cluster No.	Classification filed	Top 20% frequent words
1	UAV technology/ industry trend (40 words)	Aircraft Requirement Industry Safety Korea Law Trend Regulation
2	Utilization/data acquisition (35 words)	Image Accuracy Field Error Survey Map Possibility
3	Airframe performance (28 words)	Performance Design Control Simulation Controller Stability
4	Flight performance (23 words)	Test Power Configuration Wing Hale Shape
5	Remote sensing/ data analysis (21 words)	Monitoring Estimation Coefficient Growth Imagery
6	Reconnaissance technology/ navigation (15 words)	Algorithm Mission Surveillance Path Reconnaissance
7	Navigation/location- based technology (11 words)	Signal Navigation Flight path

UAV, unmanned aerial vehicle.

mance". Twenty-three co-words were derived and the word that most frequently appeared was "test". The words that showed a high association were "power", "configuration", "wing", "hale", and "shape". This cluster was dominated by test studies on wings, batteries, and airframe geometry, which are related to endurance.

In Cluster5, a research area related to "remote sensing/data analysis", 21 co-words were derived. The word that most frequently appeared was "monitoring" as in Clus-

ter1 of the international studies where the corresponding studies were similar. The words that exhibited a high association included "estimation", "coefficient", "imagery", "height", "classification", and "NDVI". This cluster was dominated by papers on vegetation. Such papers have increased since 2015.

Cluster6 is a research area related to "reconnaissance technology". Fifteen co-words were derived and the word that most frequently appeared was "algorithm". The words that exhibited a high association were "mission", "surveillance", and "reconnaissance". Studies on reconnaissance and surveillance using UAVs correspond to this cluster. In this research area, which is distinguished from the international analysis results, the contents of the research papers were mainly published for military purposes, but most of the research results focused on technology trends and utilization. Therefore, this cluster is determined to be similar to Cluster1.

Cluster7 is a research area related to "navigation/location-based technology". Eleven co-words were derived and the word that most frequently appeared was "signal". The words that showed a high association were "navigation", "flight path", and "ground control system". Studies related to location-based technology and the accuracy of the UAV route correspond to this cluster. This cluster exhibited a low association with other research areas and was observed in limited time periods.

When the domestic and international research trend analysis results were summarized, it was found that they were generally clustered into areas with similar meanings, but the year the keywords appeared differed, which indicated research topics, association strength between words, and diversity. For example, basic studies on UAV technology trends and utilization were abundant in South Korea, but studies on data collection and analysis through UAV remote sensing technology were most abundant in international countries.

Fig. 8 compares changes in main domestic and international research areas for 17 y between the two periods. The main international research areas between 2000 and 2013 were found to be "mission performance", "airframe performance", and "location-based technology". After 2014, research areas related to "remote sensing/data analysis", "data collection/processing", and "UAV technology/industry trend" sharply increased. This change appears to be the result of the stabilization of UAV-related basic technologies and the gradual increase in demand for application areas. On the other hand, the main domestic research area between 2000 and 2013 was found to be "airframe performance", and other studies were not significant. Since 2014, research has been actively conducted in all areas and a tendency to follow the international research areas was observed. Research is expected to be expanded in various areas in the future even though the

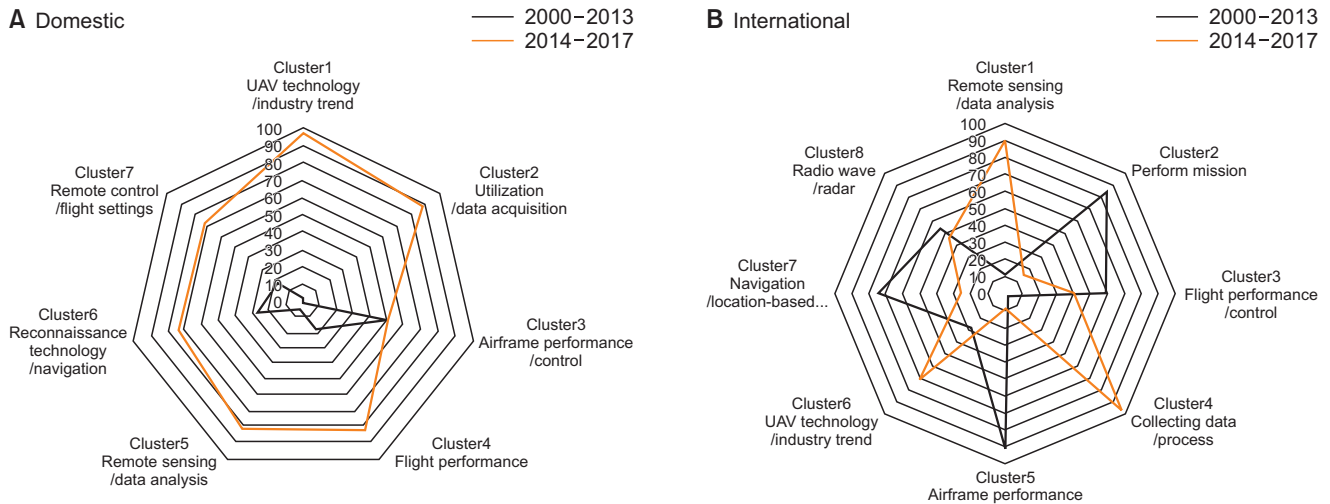


Fig. 8. Percentage increase and decrease by research area for 2000–2017 years. UAV, unmanned aerial vehicle.

Table 4. Key words of environment and ecology

Country	No.	Label	Cluster	Total link strength	Occurrences
International	1	Monitoring	1	3,447	292
	2	Height		2,460	187
	3	Classification		1,715	134
	4	Temperature		1,210	109
	5	Tree		1,444	109
	6	Plant		1,307	93
	7	Crop		1,416	92
	8	Species		1,175	89
	9	Vegetation		1,223	83
	10	Forest		1,065	79
	11	NDVI		699	45
Domestic	1	Monitoring	5	246	33
	2	Classification		138	20
	3	Height		148	16
	4	Temperature		93	16
	5	NDVI		131	13

NDVI, Normalized Difference Vegetation Index.

research area related to “remote sensing/data analysis” shows a time difference of approximately three to four years.

**Ecological environment research area derivation using UAVs**

The research area related to the ecological environment is included in “remote sensing/data analysis”, which corresponds to Cluster1 for international studies and Cluster5 for domestic studies. The words that appeared were

“monitoring”, “plant”, “crop”, “classification”, “forest”, “temperature”, “tree”, “species”, “Normalized Difference Vegetation Index (NDVI)”, and “Leaf Area Index (LAI)”, which were mostly associated with plant ecology (Table 4). These words became the keywords of research topics that attracted attention recently because the advancement in UAV optical sensor technology and the development of image processing technology made it possible to acquire data that could not be obtained from the existing spatial information. The fact that related domestic papers have

recently increased in a similar manner to international research trends indicates the recognition of the importance for future research in this area.

In conclusion, UAVs have attracted attention as the key industry of the fourth industrial revolution era because they integrate innovative technologies, such as aviation, information communication, sensors, and software, and can be combined with various areas. Despite this potential, research that utilizes the data acquired through UAV systems is in the preliminary stage. In particular, studies on spatial information acquisition and analysis methods in the ecological environment area are extremely insufficient. This study examined domestic and international research trends using the text mining analysis method and found that active attempts have been made to apply various research methodologies to UAVs. For example, the shape of the canopy gap was identified through ultra-high-resolution UAV images to analyze species diversity for forest vegetation, and such images were used to collect time-series vegetation index data for research on phenology. Moreover, the ground surface temperature images of vegetation distribution areas were acquired for their wide utilization in ecosystem research, such as habitat environment analysis.

The keywords that appeared in such domestic and international research literature were “monitoring”, “classification”, “height”, “temperature”, and “NDVI”. Among them, “monitoring” exhibited the highest appearance frequency. This is because it was used as a gerund along with subwords. For example, it was used as keywords that represent research topics, such as “plant monitoring” and “tree monitoring”. “Classification” is a word that appeared in studies related to the extraction of ground surface information, such as land cover and vegetation classification, using matching images. “Height” was found in studies that utilized tree height information to identify the growth status in relation to farmlands or crop cultivation. “Temperature” is a keyword in studies that analyzed the habitat environments of animals and plants or identified individuals through precise ground surface temperature image data. NDVI is the vegetation information utilized in various research types, such as forests and farmlands, and

it most frequently appeared in studies that used near-infrared cameras.

While research has been conducted on various topics internationally, UAV-related domestic research is in the early stage. Although preliminary studies were conducted at different target sites on different topics, studies that were examined in terms of accuracy verification and utilization based on the field data are insufficient.

Therefore, to increase UAV utilization in the ecological environment area, it is necessary to increase the accuracy of testing and calibration methods considering various factors that affect homogeneous data acquisition, such as weather, airframe performance, and image processing methods, in processes from data acquisition to the derivation of results. Follow-up research on this topic will increase UAV utilization in the ecological environment area.

### Conflict of Interest

The authors declare that they have no competing interests.

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