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Application of Internet of Things (IoT) in Agriculture: A Review

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***Abstract*—The Internet of Things (IoT) is a revolutionary technology that offers effective and dependable solutions for upgrading several areas. Agriculture is unquestionably the most significant provider of income and livelihood in the countries like India, particularly in rural areas. Solutions based on the Internet of Things (IoT) are being devised to autonomously manage and monitor crops with minimum human assistance and intervention. IoT smart farming solutions are made to assist in crop field monitoring and irrigation system automation using sensors. This paper reviews a wide range of IoT-related technologies in agriculture and describes the critical components of IoT-based smart agriculture. Investigators, researchers, and agri-scientists worldwide have been looking into technological solutions to improve agricultural productivity in a way that complements current amenities by deploying the Internet of Things (IoT) technology and data collected through proximity sensing, environment monitoring, can be analyzed for precision farming including historical meteorology, soil reports, and pest and crop disease detection. It can be deployed with other state-of-the-art technologies for in-depth field analysis of crop monitoring and field surveys. This paper discusses a thorough overview of cutting-edge IoT technologies for smart agriculture, and analysis is done using bibliometric analysis to get various insights. Moreover, this paper presents an overview of how the Internet of Things (IoT) solutions can transform the farming profession and assist farmers in controlling and managing their fields and processes more effectively while increasing their incomes and contributing to the rural economy.**

***Index Terms*—Internet of Things (IoT), Precision Farming, Smart Agriculture, Sensors, Bibliometric Analysis, Agritech.**

I. Introduction

The Internet of Things, or IoT, describes the shared network of connected gadgets and devices and the technology that enables the interaction among sensors, devices, and the cloud. The Internet of Things (IoT) has caused a revolution in practically every industry across the world. IoT technology and sensors detect, gather, store, and transfer data to various components in an intelligent agricultural application. The smart agriculture revolution refers to the application, integration, and deployment of cutting-edge technology in agriculture, such as the Internet of Things (IoT) and Artificial Intelligence, to enhance and increase agricultural yield quantity and quality. IoT technology allow farmers to observe and control their farms remotely, while large-scale agriculture farms can be accurately monitored. Intelligent agricultural modelling systems are significant aspects of modern agriculture that assist researchers in completing agriculture experiments, real-time crop growth, and yield prediction at a low cost and efficiency. The projection of gain yield plays a vital part in sustainable development as an important way of formulating agricultural policy, ensuring food safety, and maintaining social stability.

II. Need of deploying IoT in Agriculture

The global population is expected to reach 9 billion by 2050, increasing the demand for food by 70 percent. This rise is projected primarily for emerging nations, where agriculture is a critical component of the economy and growth. Around 75 percent of the world's poor live in rural regions and rely on agriculture. Thus increasing agricultural output is critical to reducing poverty and ensuring food security. In the case of our country this year, India ranks 101st out of 116 nations on the Global Hunger Index (GHI). It was rated 94th out of 107 countries last year. It is now one of the 31 nations where severe hunger has been documented. The growing human population and need for food, challenges the planet's sustainability and future. To meet this issue, novel technologies like the Internet of Things (IoT) must be deployed in agricultural settings.

III. Related Woks

The focus of the study is to explore how IoT technologies can be used in agriculture and farmers at the ground level can exploit and use them to increase production, yield, and profits. Researchers of this paper [13] explored the application of IoT technology in agriculture and chose mobile wireless communication technologies to accomplish greenhouse-site monitoring. The crucial parameters like temperature, humidity, and soil moisture data are gathered in real-time. The agricultural production process is communicated via M2M-enabled wireless networks (machine to machine) platform for assistance. SMS (Short Messaging Service) is used in the industrial environment, and WAP (wireless application protocol) service for the terminal to grasp the information and direct the processes. A centralized monitoring system that combines internet and wireless communications is presented. At the same time, an information management system is created with system administration in mind. The system's

Table I.

Study	Year	Author	Research Theme	Findings
[1]	2022	Abhineet Anand, Alok Misra et. al.	Applications Of Internet of Things(IoT) in Agriculture: The Need and Implementation	The authors of the paper look into how IoT-based farming operations can be coupled with other critical technologies, such as cloud computing, big data, analytics, and security concerns in IoT agriculture. They took an example of wheat cultivation and showed factors responsible for increasing its production.
[2]	2021	Yang Lu, Jia An, Shukai Shi	Research on Smart Agriculture IoT System Based Heterogeneous Networking Technology	The study explores how to combine intelligent agriculture with IoT technology in China effectively. It proposes a method for building an intelligent IoT-based monitoring system using wireless transmission, systems data flow, and sensing technologies.
[3]	2020	Yash Bhojwani, Rishab Singh et. al.	Crop Selection and IoT Based Monitoring System for Precision Agriculture	They developed a prototype that monitors environmental factors affecting crop growth, such as temperature, humidity, soil moisture, etc. Farmers can make accurate and reliable decisions with the help of visualised data for their crops.
[4]	2020	Abhishek Srivastava, Ravi Kumar et. al.	Monitoring of Soil Parameters and Controlling of Soil Moisture through IoT based Smart Agriculture	Researchers in the paper aimed to remotely monitor the field and conserve water. A hardware and software setup monitors important soil parameters from a remote location and controls soil moisture content automatically.
[5]	2020	Sriveni Namani, Bilal Gonen	Smart Agriculture Based on IoT and Cloud Computing	The authors of the paper explore using drones for crop management, where real-time data from cameras along with IoT and cloud computing technologies aid in developing sustainable precision farming.
[6]	2020	Alexandre Heideker, Dener Ottolini et. al.	IoT-based Measurement for Smart Agriculture	The authors of the paper stated that deploying an IoT architecture for collecting soil, climate, and weather forecast data in an agricultural area and transmitting information from various sensors and IoT devices using technologies such as LoRaWAN and Wi-Fi.
[7]	2019	Sudhir K. Routray, Abhishek Javali et. al.	Internet of Things Based Precision Agriculture for Developing Countries	Researchers in the paper presented the most recent frameworks of smart farming, which rely heavily on sensor-based technologies, and demonstrated how they facilitate optimal resource management in agricultural activities for developing countries.
[8]	2018	G. Sushanth, S. Sujatha	IoT Based Smart Agriculture System	The focus of the paper is to design a system that can monitor temperature, humidity, moisture, and even the motions of animals that may destroy crops in agricultural fields using sensors and an Arduino board, and it also sends an SMS notification to the farmer.
[9]	2018	Dweepayan Mishra,Arzeena Khan Rajeev Tiwari, Shuchi Upadhay	Automated Irrigation System-IoT Based Approach	The authors of the paper present an automated water system using Arduino and moisture sensors, and a Wi-Fi module for the terrain that will reduce manual labour while optimising water usage and increasing crop yields. As a result, irrigation-based actions require no human intervention to start the water pump and can irrigate the field with less water.
[10]	2018	RajinderKumar M. Math, Nagaraj V. Dharwadkar	IoT Based Low-cost Weather Station and Monitoring System for Precision Agriculture in India	Researchers in the paper present an IoT-based real-time local weather station for smart farming, which would allow farmers to automate their agricultural practises like irrigation, use of fertilizer, and harvesting at the appropriate time, enabling them to use agricultural resources more efficiently and at the right time for the crops. They showed this by developing a prototype for it.
[11]	2017	Apeksha Thorat, Sangeeta Kumari, Nandakishor D. Valakunde	An IoT Based Smart Solution for Leaf Disease Detection	The study includes leaf disease detection and server-based remote monitoring of humidity, temperature, soil moisture, etc., and sensors are interfaced with RasPi. Instantaneous statuses of a farm affecting the crops, such as humidity, temperature, and moisture, are sent to farmers via Wi-Fi.
[12]	2016	Prof. K. A. Patil, Prof. N. R. Kale	A Model for Smart Agriculture Using IoT	The study explores sensor technology and wireless network integration of IoT technology in an agricultural setting. The primary goal is to collect real-time data from the agricultural production environment to provide easy access to agricultural facilities, such as alerts via Short Messaging Service (SMS) and advice on weather patterns, crops, etc.

data collection provides agricultural research and management facilities. Based on the findings of the research, the greenhouse monitoring system based on IoT technology offers high precision in monitoring and controlling the overall operations. The interface is user-friendly and operates online, which offers real-time monitoring, and it also has the following characteristics: it runs independently, has high performance, and is easy to maintain.

Authors of this paper [14] discussed the issues and constraints that must be addressed promptly in smart agriculture, which are related to hardware and devices, networking and communication, infrastructure, signal interference, data security, and organizational obstacles. Several problems are associated with smart and intelligent agricultural technology and application adoption at the ground level.

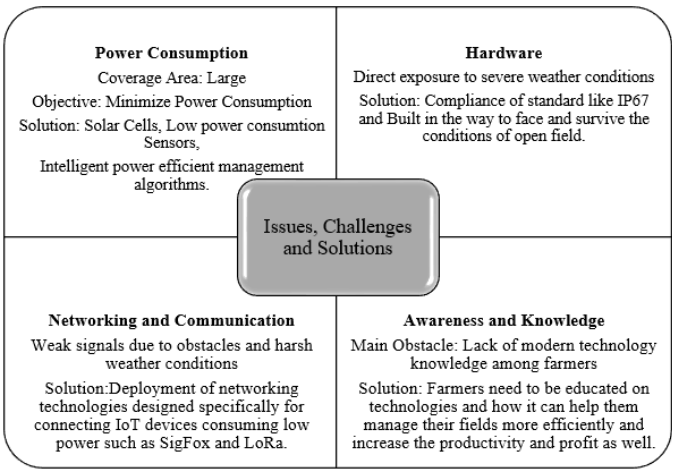

Fig. 1: Issues and Challenges

The researchers of paper [15] developed the prototype for sensing all of the relevant parameters from the agricultural field and then making the necessary choice to operate the actuator. These agricultural characteristics are temperature, relative humidity, soil moisture and light intensity. Based on the data collected from the sensor, a corresponding action is executed; for example, an irrigation valve is triggered based on soil moisture values, and a fogger valve (for releasing water droplets) is activated based on relative humidity (RH) values and so on. They proposed the creation of a sensor node capable of detecting all of these parameters and generating actuation signals for all of the actuators.

Researchers of this paper [16] tried to address an issue by leveraging IoT and automation, which can administer the majority of agriculture activities and allow farmers to strategize which crops to produce based on market demand instead of spending the majority of their time on crop upkeep and production. The study aimed to automate maintenance, insecticide and pesticide control, water management, and crop monitoring.

Similarly, sensor data can be used to forecast and optimize choices for numerous agriculture areas. IoT-based techniques can be deployed for several agricultural domains such as a) soil monitoring, b) irrigation management, c) crop management, d) predicting of weather, e) plant growth and yield management, as well as f) livestock management etc.

IV. Case Studies

Numerous beneficial IoT applications in agriculture have been employed worldwide for smart agriculture, like increasing crop production and yield and automating the various operations of farms. Some examples are illustrated in the diagram.

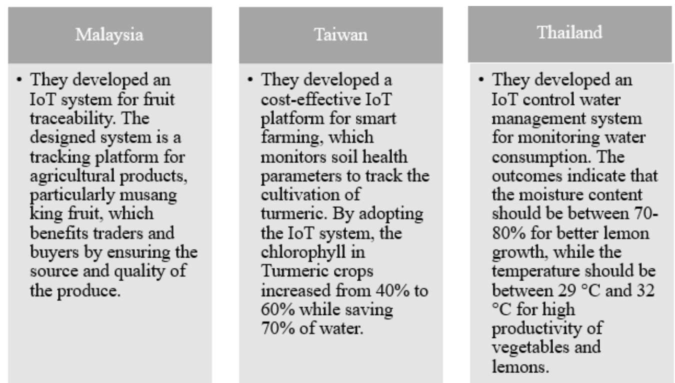

Fig. 2: Case Studies

V. Methodology

A. Bibliometric Analysis

We found 154 articles on Internet of things based agriculture using data mining using the Scopus repository. We generated data visualizations to highlight the nations, institutions, and organizations spearheading IoT-based scientific research in agriculture. An exhaustive search is performed online using the database of Scopus. The search terms were Internet of Things, agriculture, IoT, etc. The search and analysis were conducted in a specific timeframe to eliminate bias induced by daily database changes. Only original papers and reviews published in English were included in this study, and the search yielded 154 items that fulfilled the inclusion criteria.

Search Query:

(TITLE-ABS-KEY (internet AND of AND things AND in AND agriculture) AND TITLE-ABS-KEY ("iot") AND TITLE-ABS-KEY ("iot in agriculture"))

Fig. 3: Search Query

Data Analysis: We used Biblioshiny to conduct relevant bibliometric and visual analyses via an interactive online interface, significantly decreasing information input intensity and usage threshold, and VoSviewer, a framework for creating and displaying bibliometric networks. These relationships can be built via citation, co-citation, bibliographic coupling, or co-authorship relationships and comprise journals, researchers, or individual articles. Bibliometrics combines two significant procedures: performance analysis and science mapping. Several approaches are used in bibliometric performance analysis (for example, word frequency analysis, citation analysis, and country publications analysis). Instead, the authors' indexed keyword and country map collaboration analyses were carried out using the VOSviewer application. Another fundamental method of bibliometrics is science mapping, a spatial description of how various scientific players are connected. In this study, we employed the VOSviewer software to analyze keyword co-occurrence. It is chosen for its potential to ensure improved performance in the building and display of co-occurrence networks of the essential phrases derived from metadata. It can display even vast networks in a more straightforward way using maps. As a result, it has been frequently used in the bibliometric literature evaluation of the investigated topic. A sample of 154 documents is located using this latest search technique in the Scopus database (search data: April 2023). Based on our Query, we got 154 results and then exported them in CSV and BibTex format for analysis.

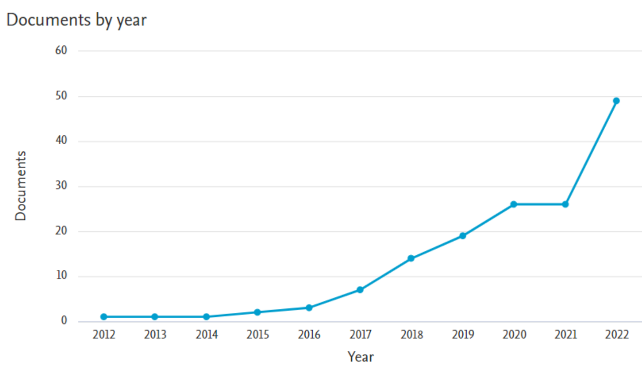

Fig. 4: Documents by Year

The Fig.4 depicts the annual trend in document publication from 2012 to 2022. The literature output appears to have been relatively low in the initial years (2012-2016), with an average of less than one paper per year. Following 2016, there has been an increase in interest in this domain. Finally, the trend has accelerated dramatically from 2017 to the present times.

Frequency of IoT applications in Papers:

Applications	Mentioned in Papers
Crop Monitoring	27
Water Monitoring	18
Precision Farming	25
Livestock Monitoring	6
Agricultural Robot	30
Soil Moisture	30
Irrigation	42

Fig. 5: Frequency of IoT applications in Papers

The Fig.5 gives insights into the application of IoT technologies' occurrence in the documents published. It is visible that irrigation, soil moisture, agricultural robots, and crop monitoring are the most talked about and researched fields in the papers and there is a vast scope for innovation in these domains.

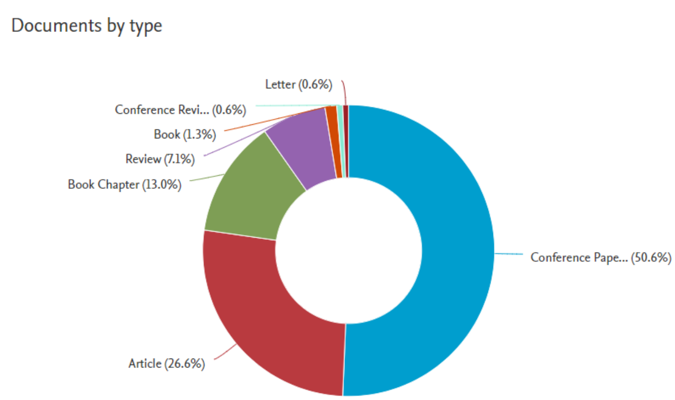

Fig. 6: Documents by Type

This Fig.6 is about the publication type like in Articles, Conferences, Book Chapter, Reviews, etc.

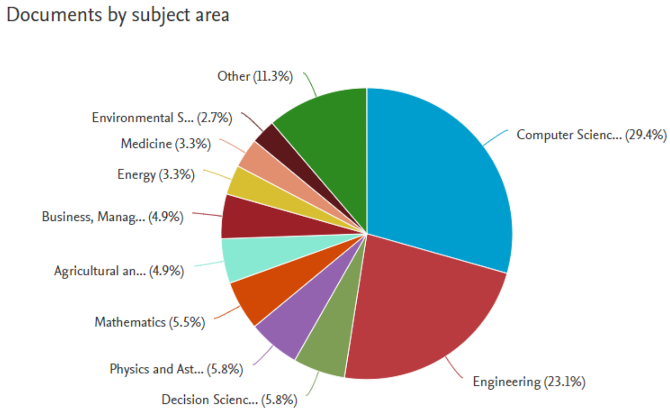

Fig. 7: Documents by Subject Area

Based on our query, the Fig.7 shows that the published documents fall into different subject areas like Computer Science, Engineering, Environmental Sciences, Business Management, Energy, etc. And it is pretty visible that work is happening at the intersection of Computer Science, Engineering and Technology and Business Management.

Thematic Map:

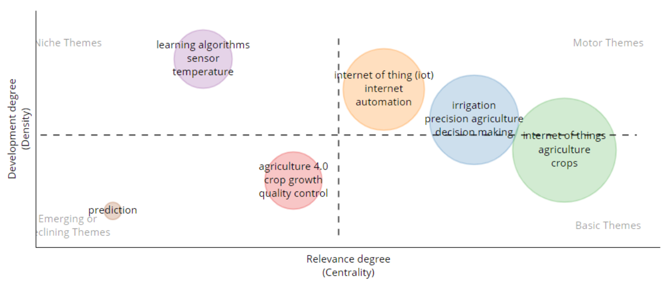

Fig. 8: Thematic Map

The thematic map defines the conceptual structure of the matter, including a word co-occurrence network analysis to determine what research communicates about in an area, as well as important topics and trends. The Fig.8 demonstrates a thematic map based on Density (y-axis) and Centrality (x-axis). The degree of interaction among networks is measured by centrality, whereas Density, on the other hand, measures the network's intrinsic strength. The diagram is broken into four sections. Themes that occur in the lower-left corner are either developing or waning. These fresh concepts may develop to improve or disappear from the research field. The fundamental or transversal themes are those that appear in the lowest right corner of the thematic map. These topics have a low density but a high centrality. Much study has been conducted on these topics. The upper left section has a high density but a low centrality; these themes are well-developed yet separated. The upper right corner denotes high Density and centrality. So, based on the Fig. 8, i.e. thematic map exhibits the prominent themes of IoT-based Agriculture, and we can infer that automation and precision agriculture are the motor themes. At the same time, sensors, learning algorithms and temperature monitoring are the Niche themes in the available literature analysis.

Trend Topics:

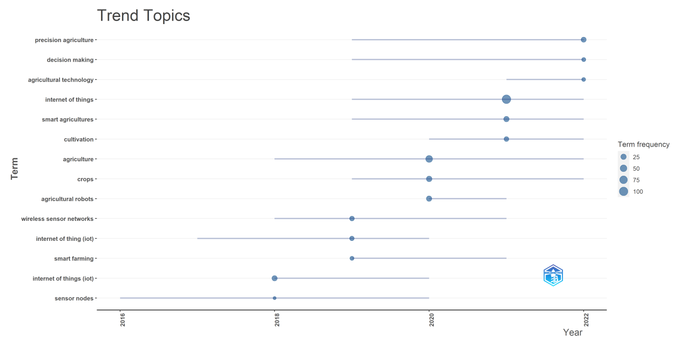

Fig. 9: Trend Topics

From the Fig.9, we get the insights into trending topics in IoT-based agriculture, and it is found that Agricultural technology, Agricultural Robots, the Internet of Things, precision agriculture and sensor are trendy terms, and we can see the direction of research is going in these domains.

Word Growth:

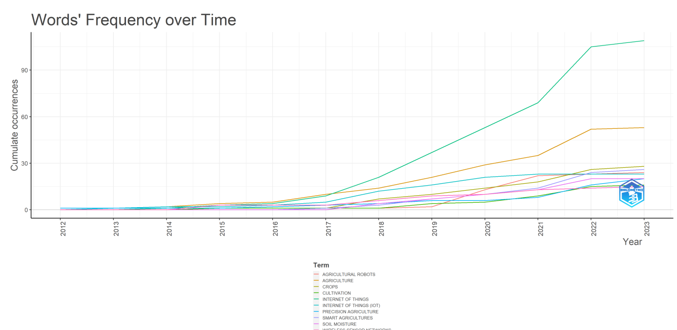

Fig. 10: Word Growth

The Fig.10 is about cumulative occurrences of the word and its growth with time. And we can infer from this figure that technology-related words are gaining popularity in smart farming, and their usage is increasing exponentially, like agricultural robots, IoT, wireless sensor networks, etc.

Word Cloud:

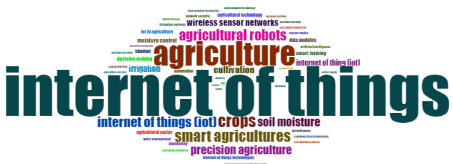

Fig. 11: Word Cloud

The Fig.11 depicts a word cloud generated using keyword inclusion. Words that often appear in the literature are more significant in size. Smart agriculture, soil moisture, agriculture robots, and irrigation appear most frequently in the literature, so these are the most important terms used in the sources.

Most Global Cited Documents:

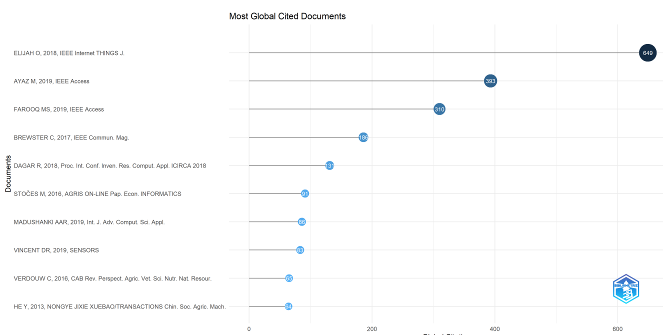

Fig. 12: Most Global Cited Documents

The Fig.12 shows that “IEEE Access” is the most relevant source of literature related to IoT-based Agriculture.

Most Relevant Words:

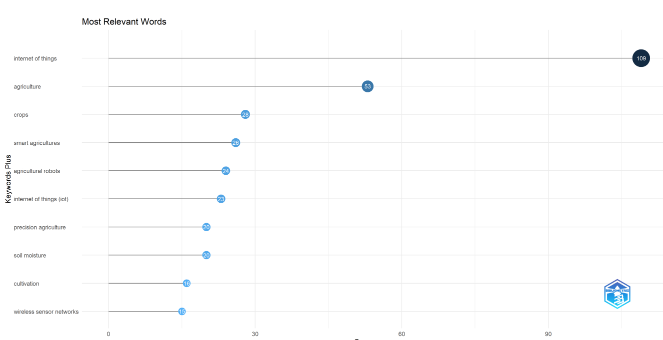

Fig. 13: Most Relevant Words

From the Fig.13 we observe that for IoT-based agriculture query, smart agriculture, agriculture robots, soil moisture and wireless sensor networks were the most relevant and frequent keywords.

Co-occurrence Map:

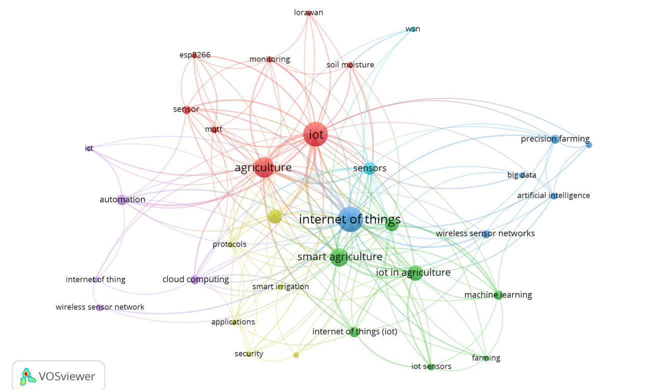

Fig. 14: Co-occurance Map

A co-occurrence network is a text-analysis approach with a graphic representation of probable links between distinct concepts. It gives us essential information for mapping and comprehending the relationships in the core document sets. The result of the keywords co-occurrence map shows that the IoT-based research in agriculture is mainly concentrated on smart irrigation, sensors, big data, wireless sensor networks, protocols, artificial intelligence and cloud computing.

Cluster Analysis and Multiple Correspondence Analysis:

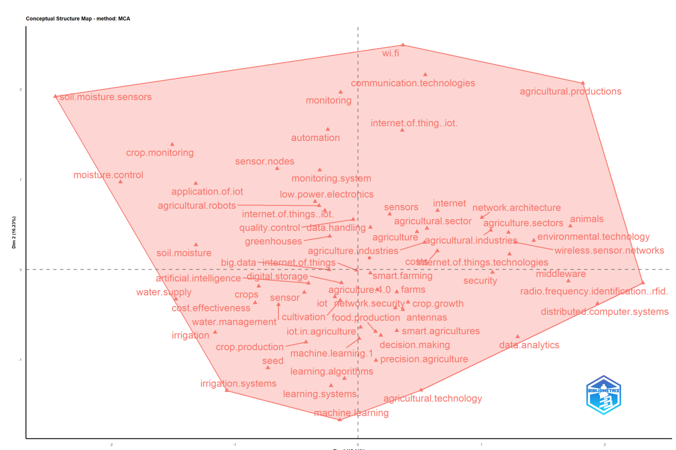

Fig. 15: Conceptual Structure Map

We examined the conceptual structure maps using factorial analysis and multiple correspondence analysis (MCA) for high-frequency keywords, which compresses large amounts of data with multiple variables into a low-dimensional space to create an intuitive two-dimensional graph that uses plane distance to represent keyword similarity. We observed many relationships between keywords, synonyms, and ideas that revolve around the Internet of Things and agriculture. A big cluster appears in the above image of factorial analysis and conceptual structure map, containing references to smart farming, sensors, precision agriculture, crop monitoring and many other variables.

VI. Conclusion

In this paper, we have presented a comprehensive survey on the state-of-the-art technologies for IoT in agriculture. This survey and bibliometric analysis are expected to give precious knowledge to researchers, agriculture scientists, and policymakers involved in the IoT field and technological innovations in agriculture. To that end, we discuss several IoT use cases and applications in the agricultural sector involving crop monitoring, automated irrigation, drone imagery, etc. We comprehensively overviewed current and ongoing advances in IoT agricultural applications, devices/sensors, communication protocols, and various innovative technologies. The objective of employing IoT technology in farming is to ensure that resources are used as efficiently as possible in order to increase agricultural yields and lower operating expenses. Implementing Internet of Things (IoT) technology can make the agricultural sector more productive, and it can be employed for a variety of agricultural applications for the betterment of farmers and society. Furthermore, integrating IoT-based farm systems with key technologies such as artificial intelligence, cloud computing, and big data analytics can significantly impact the ground level and increase crop productivity manifold. Subsequently, there is a need to develop a comprehensive IoT framework for agriculture domain bringing and integrating all the relevant technologies to improve the quantity and quality of production and yield, conserve resources such as electricity and water, and produce economically viable crops that cost less and enhance more profit, as farmers play a significant role in GDP in countries like India.

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