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Artificial intelligence in agriculture: Application trend analysis using a statistical approach

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ABSTRACT

To ensure food security and sustained production of crops, the traditional practices of agriculture should be replaced by modern artifacts. Artificial intelligence provides advanced methods and procedures that support domain-specific problem-solving and agricultural decision-making. They have immense successful applications for devising suitable solutions in agriculture. Several literature surveys have been reported worldwide regarding the applications of different artificial intelligence techniques in agriculture. However, none of them presented a complete scenario in a single nutshell. Moreover, a traditional and descriptive way of literature review with a limited number of papers is not sufficiently adequate to recognize the application trajectory of various artificial intelligence techniques in agriculture. Only a statistical study can emphasize the advancements and new frontiers of future applications prevailing in the field, compare the various aspects of different techniques and suggest the best one for a particular problem. Trend analysis provides a predictive guideline for forecasting any technique or approach prospect. However, no statistical study or application trend analysis of prevalent artificial intelligence techniques in the major subdomains of agriculture has been reported. This paper presents a statistical study to cover all multidimensional aspects of applications of various artificial intelligence techniques in agriculture concisely, based on a large number of articles published during the last three and a half decades.

Keywords: Artificial intelligence, Agriculture, Application trend analysis, Statistical study.

1. INTRODUCTION

Agriculture is one of the prime resources of human sustenance. According to the world bank, it employs almost 26.85% of the entire human population worldwide and is a source of raw materials for numerous allied industries (Employment in agriculture, 2020). Agriculture and allied sectors are among the key areas contributing to 6.40% of the global Gross Domestic Product (GDP) (Countries by GDP Sector Composition, 2020). Alexandratos and Bruinsma (2012) estimated that the agriculture sector would have to feed a population of about 9 billion by 2050. The demand for agricultural products is gradually increasing to meet consumer needs, whereas the land under cultivation is approaching its limit. Traditional practices should be replaced by modern tools and technologies to boost production and meet the massive demand.

The agriculture sector faces significant challenges like the infestation of insect pests and diseases, improper irrigation practices, poor selection of crops, indiscriminate use of fertilizers, the decline of soil fertility, etc. All these problems lead to huge crop and revenue losses for marginal farmers. Mitigating these issues demands proper experts' knowledge and judgment, which is very scarce and costly in poor or developing nations. In most cases, these problems go unnoticed or are taken care of by a rural farmer without sufficient technical knowledge. As a result, the quantity and quality of production are remarkably affected.

Artificial intelligence (AI) is a branch of computer science capable of mimicking human knowledge for better decision-making. Artificial intelligence has had immense applications in various sectors for precise decision-making due to its capability to replicate subtle features of human cognition, including medical diagnosis, social sciences, defense, aeronautics, and many more. AI uses a non-algorithmic approach which makes it closer to the human way of thinking and inferring. It uses heuristics, inferencing from a set of rules, pattern matching, and machine learning. Numerous literatures have been published to describe the concept, architecture, and algorithm of various AI techniques. These techniques pave the way for modeling the problems in the agriculture domain for devising suitable solutions. Popular artificial intelligent techniques, such as expert systems (ES), fuzzy systems (FS), artificial neural networks (ANN), machine vision systems, hybrid systems, etc., are being deployed in various subdomains of agriculture for their betterment. Some modern AI approaches use real-time data collected through sensors and drones to provide a farmer with quick and robust site-specific solutions. Since 1985, the use of such technologies, in turn, has boosted agricultural productivity in all respect.

Numerous research papers have been published worldwide, and several literature reviews have been conducted on applying AI techniques in various problem domains of agriculture (Liu et al., 2015; Nema et al., 2017; Patrício and Rieder, 2018; Chlingaryan et al., 2018; Golhani et al., 2018; Ding et al., 2018; Iqbal et al., 2018; Kamilaris and Prenafeta-Boldú, 2018; Liakos et al., 2018; Bannerjee et al., 2018; Wang et al., 2019; Koirala et al., 2019; Jha et al., 2019; Eli-Chukwu, 2019; Tripathi and Maktedar, 2020; Talaviya et al., 2020; Ramesh et al., 2020; Misra et al., 2020). However, these reviews were conducted on a very limited number of papers, and none of them presented a complete scenario of applications of the prevalent AI techniques in all major subdomains of agriculture, in a nutshell.

On the other hand, compared to a mere literature review, trend analysis is a more efficient way to project the trajectory of development and application of a technique. It emphasizes the advancements and new frontiers of future applications prevailing in the field. It helps to compare the various aspects of different approaches and determine the suitable one for a particular problem. Trend analysis is a predictive guideline for forecasting the prospect of any technology or approach. However, no such statistical study or application trend analysis of popular and prevalent AI techniques in the major subdomains of agriculture has been reported so far.

Vazquez et al. (2021) reported a scientometric analysis of research papers on the application of AI in agriculture but from a different angle of view. They studied the distribution of papers based on the year of publications, the country and the affiliating institutes, the journals where published, the authors of the papers, and the number of citations. They did not emphasize projecting the past, present, and future scenarios of applying various AI techniques in agriculture.

This paper presents a statistical study on 713 articles to answer the following research questions: How is the application trend of a specific AI technique in various subdomains? How is the application trend of different AI techniques in a specific major subdomain? What is the chronological trend of applications of these popular AI techniques in agriculture?

2. LITERATURE REVIEW

Several literature reviews were published regarding the application of AI techniques in agriculture. A summary of some relevant and latest contributions is presented in Table 1. Each of the previous review papers provided valuable information regarding applying different AI techniques to solve various problems in agriculture. Some of these studies analyzed the pros and cons of the applied AI techniques and provided comparative studies. However, these surveys were conducted with a few numbers of papers on limited subdomains, and they provided textural descriptions of the applications of various AI techniques without presenting any statistical findings or application trend analysis.

3. METHODOLOGY

This paper aims to present a statistical study and trend analysis of five popular AI techniques applied in agriculture. The collection, evaluation, and selection of contributory research papers relevant to the scope of the present study were performed using an explicit and systematic method of literature analysis as suggested by Kitchenham and Charters (2007). Three factors were considered to search out the most relevant and significant works reported regarding the applications of AI techniques in agriculture; the AI techniques applied, the availability of the publications, and the repute of the journal where the research articles were published.

In the first step, the relevant papers were collected from five reputed indexing databases such as Google Scholar, Web of Science, Scopus, Crossref, and Microsoft Academic. These five global online repositories have been considered as they have high acceptability in the scientific community and global outreach. The papers were retrieved using 'Publish or Perish' (PoP) software, Version-7, (https://harzing.com/resources/publish-or-perish). The search keywords containing the name of the AI techniques and the term Agric* concatenated by the AND operator were used (e.g., "Fuzzy system AND Agric*"). The resultant

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Table 1. Summary of the various literature reviews

Sources	Applied AI techniques	Application subdomains	Number of the papers considered in the review
Liu et al. (2015)	Artificial neural network Machine vision systems	Quality control	61
Nema et al. (2017)	Artificial neural network	Irrigation management	16
Patrícioa and Rieder (2018)	Artificial neural network Machine vision systems Fuzzy system	Disease management, Quality control, Phenology	26
Chlingaryana et al. (2018)	Artificial neural network Machine vision systems	Yield prediction	17
Golhani et al. (2018)	Artificial neural network	Disease management	7
Ding et al. (2018)	Hybrid systems	Irrigation management, Farm management, Food processing	48
Iqbal et al. (2018)	Artificial neural network Machine vision systems Fuzzy logic system Hybrid systems	Disease management, Species identification	83
Kamilaris and Prenafeta-Boldú (2018)	Machine vision systems	Disease management, Species identification, Yield prediction, Miscellaneous domains	40
Liakos et al. (2018)	Artificial neural network Machine vision systems Fuzzy logic system Expert systems Hybrid systems	Yield prediction, Disease management, Weed control, Quality control, Species recognition	31
Bannerjee et al. (2018)	Artificial neural network Machine vision systems Fuzzy logic system Expert systems Hybrid systems	General crop management, Pest management, Disease management, Quality control, Weed control, Soil and irrigation management, Yield prediction	100
Wang et al. (2019)	Artificial neural network Machine vision systems Hybrid systems	Weed control	67
Koirala et al. (2019)	Machine vision systems	Yield prediction	12
Jha et al. (2019)	Artificial neural network Machine vision systems Fuzzy logic system Expert systems	Crop diseases, Storage management, Pesticide control, Weed control, Irrigation management	10
Eli-Chukwu (2019)	Artificial neural network Machine vision systems Fuzzy logic system Expert systems Hybrid systems	Soil management, General Crop management, Disease management, Weed control	49
Tripathi and Maktedar (2020)	Artificial neural network Machine vision systems Hybrid systems	Disease management Quality control	28
Talaviya et al. (2020)	Artificial neural network Machine vision systems Fuzzy logic system	Irrigation management, Weed control, Yield prediction	34
Ramesh et al. (2020)	Machine vision systems Fuzzy logic system Expert systems Hybrid systems	Species recognition, Irrigation management, Yield prediction, Miscellaneous domains	Not specified
Misra et al. (2020)	Machine vision systems	Weed control, General crop management	Not specified

concatenated string comprised of the regular expression Agric* and the name of the AI technique retrieved the relevant articles for this study. A total of 5845 papers were searched out. Of these 5845 publications, 3030 were selected based on the relevancy, quality (citation score) of the papers, and reputation of the journals. The details of the article, such as paper title, authors, year of publication, journal name, application subdomain, AI techniques used, etc., were well documented. After removing redundant entities, 713 relevant papers were downloaded for this study covering 1985 to February 2020.

Finally, 713 papers were checked individually and grouped into categories based on different subdomains, applied AI techniques, and year of publication. Detailed references of all these 713 publications are not provided due to space limitations.

4. DISCUSSION

In this study, five popular and well-established AI techniques, such as expert systems, artificial neural networks, fuzzy systems, machine vision systems, and hybrid systems (neuro-fuzzy, genetic-fuzzy, etc.), were taken into account. The different subdomains in agriculture were categorized as pest management, disease management, weed control, soil and fertilizer management, irrigation management, yield prediction, general farm management, general crop management, quality control, and a miscellaneous group. The miscellaneous group included some scattered and limited applications relating to agriculture.

The study was conducted with three distinct angles of view. The first one was based on the technologies applied in different subdomains of agriculture; the second was based on the subdomains of agriculture where the popular intelligent techniques were applied, and the third one was based on the chronological trend of applications of each technique.

4.1 Application Trend Based on Artificial Intelligence Techniques

The popular AI techniques widely applied in the major subdomains of agriculture include expert systems, fuzzy systems, artificial neural networks, machine vision systems, and hybrid systems. The number of papers obtained for each of these five techniques against various subdomains is presented in Table 2.

The application trend of popular AI techniques in various subdomains is presented in Fig. 1. As an outcome of the extensive survey, 46 research papers were identified where expert systems were successfully applied to smart agriculture. A nearly equal contribution has been observed in four major subdomains of agriculture; pest management (18%), disease management (18%), soil and fertilizer management (17%), and general crop management (17%). Nearly 13% of total expert systems were designed for miscellaneous subdomains, as presented in Fig. 1.

One hundred fifty-seven papers have been identified where fuzzy systems were applied in agriculture. The maximum contribution (22%) of such systems is found in miscellaneous applications relating to agriculture. The other targeted fields of application of fuzzy systems were soil and fertilizer management (20%), general farm management (20%), irrigation management (11%), and quality control (10%).

Since 1994, 182 contributions have been reported where researchers suggested the efficient application of ANN in the various subdomains of agriculture. It is observed that the maximum contribution of ANN (38%) for designing agriculture assistance systems was concerned with miscellaneous subdomain. Similar contributions have also been found in the other two major subdomains; yield prediction (18%) and general farm management (14%).

In the last decade, successful applications of machine vision systems were started and gradually gained popularity in various subdomains of agriculture. A total of 235 research works were sorted out where machine vision systems have been applied. Presently machine vision techniques are widely and successfully used in the three subdomains of agriculture; miscellaneous subdomain (27%), disease management (23%), and quality control (18%).

A total of 93 papers on the application of hybrid systems were sorted. The significant application of hybrid systems is presently concerned with miscellaneous applications (24%), general farm management (21%), and soil and fertilizer management (18%), as depicted in Fig. 1.

Table 2. The number of papers obtained for five techniques against various subdomains

Subdomains	Expert systems	Fuzzy systems	Artificial neural network	Machine vision systems	Hybrid systems
Pest management	8	6	2	7	1
Disease management	8	5	6	53	1
Weed control	2	0	2	18	3
Soil and fertilizer management	8	31	19	5	17
Irrigation management	4	17	10	1	7
Yield prediction	0	6	33	17	5
General farm management	1	32	25	20	20
General crop management	8	9	12	8	7
Quality control	1	16	4	43	10
Miscellaneous	6	35	69	63	22

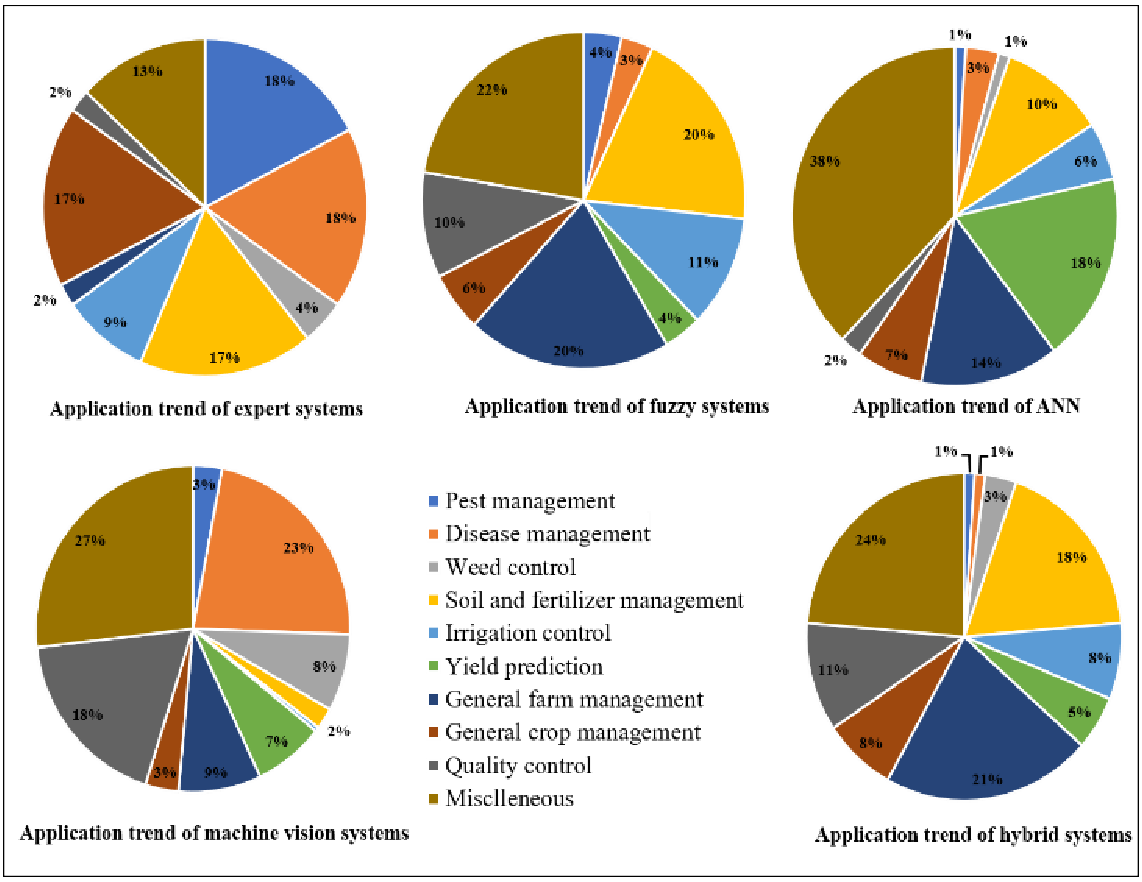

Fig. 1. The application trend of popular AI techniques in various subdomains

4.2 Application Trend Based on Subdomains

The agriculture domain consists of multiple subdomains. The major subdomains for applying such techniques in agriculture are pest management, disease management, weed control, soil and fertilizer management, irrigation control, yield prediction, general farm management, general crop management, and quality control. Some other scattered applications of such techniques have also been reported in allied secondary and tertiary agriculture sectors. All these other diverse applications are categorized into a single miscellaneous group. The number of papers grouped against each subdomain is also available in Table 1. The application trend of popular AI techniques in various subdomains is presented in Fig. 2.

In pest management, three techniques have some remarkable contributions. For pest management, expert systems were used in most cases (34%). The other two techniques, machine vision systems (29%) and fuzzy systems (25%), have also contributed some significant shares.

The diseases of the plants primarily affect the leaves and change their color and texture of the leaves. Field observations or images identify these deformities. Image analysis is highly concerned with designing intelligent disease management techniques. Inevitably, machine vision techniques are the leading choice (73%) in the disease management subdomain. The rest of the applications are shared by expert systems (11%), ANN (8%), fuzzy systems (7%), and hybrid systems (1%).

Since the weed control systems are based on images, most models were designed using machine vision systems (about 72%). The other techniques applied were hybrid systems (12%), expert systems (8%), and artificial neural networks (8%).

Fuzzy systems were the best for soil and fertilizer management (about 39%) and irrigation control (44%). ANN and hybrid systems made other significant contributions in these two subdomains. A nearly similar pattern of applications has been found in general farm management and general crop management. The fuzzy systems contributed more to general farm management (33%) than general crop management (21%).

In yield prediction, ANN techniques were used in most proposed systems (54%). The machine vision systems were also deployed in a significant number of cases (28%), with fuzzy systems (10%) and hybrid systems (8%). However, expert systems were not applied for yield prediction. Like disease management and weed control, most quality control systems (58%) were designed based on the application of machine vision systems. In the miscellaneous subdomains, effective systems were designed with ANN (36%) and machine vision systems (32%).

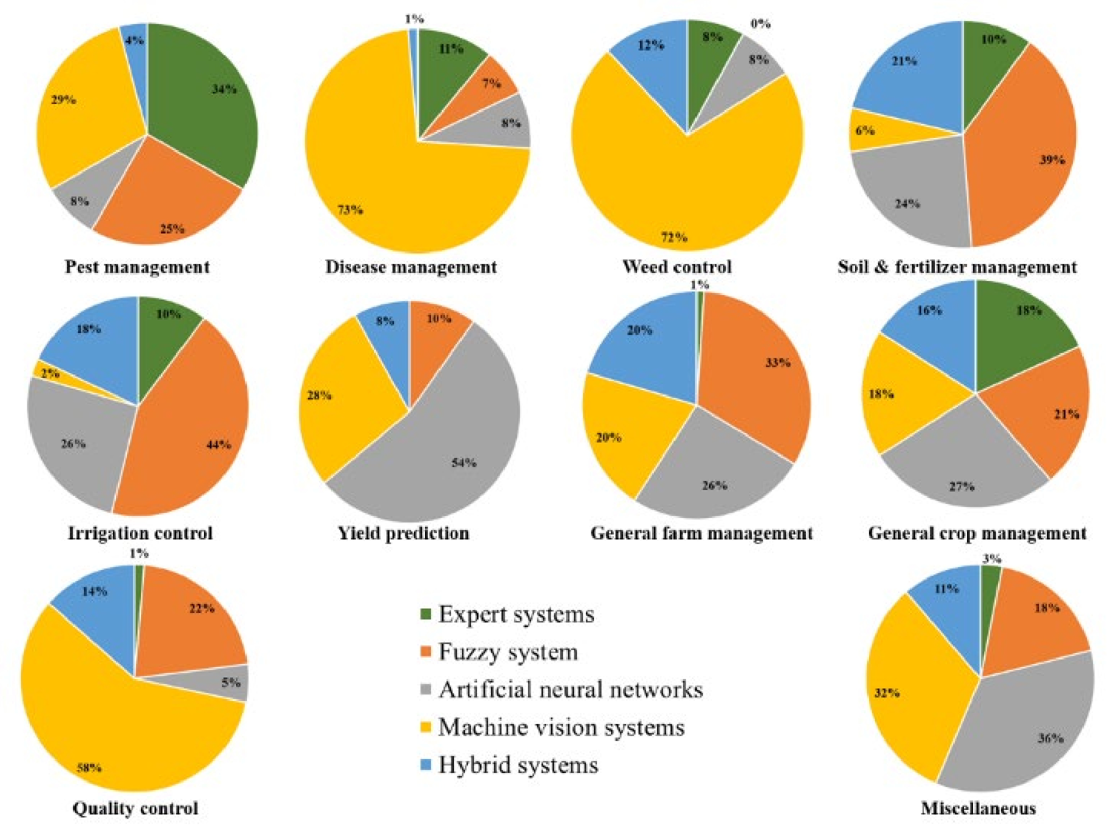

Fig. 2. The application trend of AI techniques based on subdomains

4.3 Application Trend Based on Chronology

To study the chronological trend of applications of five popular AI techniques in agriculture, 713 papers were classified into five groups based on the five techniques. In the next step, the papers within each group were sorted based on four time-scales of publication; 1985–1989, 1990–1999, 2000–2009, and 2010 to February 2020, as presented in Table 3.

The number of papers in each group is plotted against the time scale. The horizontal axis represents the time scale, and the vertical axis represents the number of publications. For a clear view of the application trend, five chronological trend lines are fitted for five data series, as presented in Fig. 3.

5. CONCLUSION

Our main objective of this statistical analysis is to present a precise scenario to the researchers about the applications of different AI techniques in agriculture. A total of 713 relevant papers contributed to this study. This review gives clear answers to the three research questions: how is the application trend of a specific AI technique in various subdomains? how is the application trend of various AI techniques in a particular major subdomain? and what is the chronological trend of applications of each of these popular AI techniques in agriculture? These three different angles of view cover multidimensional aspects of the application trend of intelligent systems as a part of smart agriculture.

To the authors' knowledge, no such comprehensive statistical trend analysis has been reported so far. This paper is a pioneer in projecting the application trajectory of different AI techniques in agriculture. This study will be very beneficial to motivate ambitious researchers to design best-fit intelligent systems for sustained crop production, which will ensure future food security.

Table 3. The number of applications of AI techniques at different time-scale

	1980-1989	1990-1999	2000-2009	2010-Feb, 2020
Expert systems	7	14	13	12
Fuzzy systems	2	24	41	90
Artificial neural networks	0	20	54	108
Machine vision systems	0	10	36	189
Hybrid systems	0	5	17	71

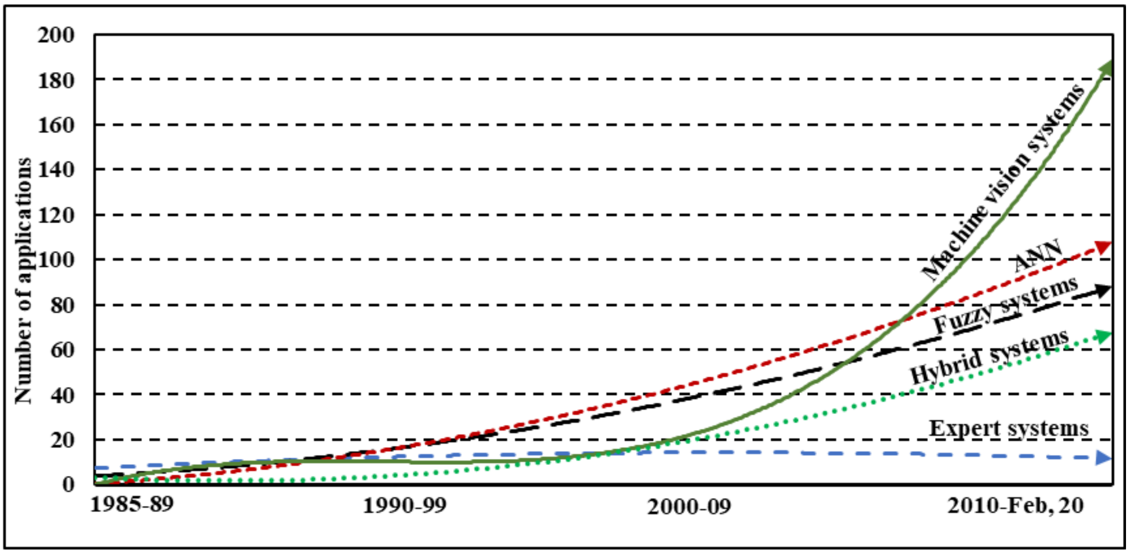

Fig. 3. Chronological trend of applications of AI techniques in agriculture

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