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Bridging The Gap: A Survey On Edge And Fog Computing For The Future Of Smart Agriculture

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Abstract: In recent years, the agricultural sector has witnessed a paradigm shift towards digitalization, driven by the integration of cutting-edge technologies such as edge and fog computing .Smart agriculture is often perceived as one key enabler when considering the twin objectives of eliminating world hunger and undernourishment. This survey delves into the transformative potential of edge and fog computing in revolutionizing smart agriculture practices. By pushing computational tasks closer to the data source, edge computing enhances real-time data processing, enabling timely decision-making and resource optimization on farms. Edge computing offers a potentially tractable model for mainstreaming smart agriculture. Additionally, fog computing extends this capability by leveraging intermediate nodes to further distribute computational tasks and manage data flows efficiently. Through a comprehensive analysis of existing literature, this survey explores the key challenges, opportunities, and emerging trends in the adoption of edge and fog computing in smart agriculture. Moreover, it investigates the integration of these technologies with other emerging technologies such as Internet of Things (IoT), artificial intelligence (AI), and block chain to create robust and sustainable agricultural ecosystems. By shedding light on the current state and future prospects of edge and fog computing in agriculture, this survey aims to provide valuable insights for researchers, practitioners, and policymakers to harness the full potential of these technologies for sustainable and efficient agricultural production.

Index Terms **- Smart agriculture, Edge computing, Fog computing, Internet of Things (IoT), Digitalization.**

1. Introduction

1.1. Introduction to smart agriculture

Smarter agriculture, an advanced farming technique of contemporary times, uses the technology of the IoT, sensors, and data analytics to improve productivity, efficiency, and sustainability in current farming [22]. The often indispensable and broadly recognized nature of this approach in meeting the specific challenges that arise from the increasing numbers of people on the planet, climate change, and environmental sustainability. It is the advantage of smart agriculture that it makes proper use of resources, poses less threat to the environment, and promotes economic wellbeing for farmers [33].Interestingly, although smart agriculture opens up numerous opportunities, like the spread of direct education among farmers in developing countries and the building of computer networks in rural areas, it also has some problems, like knowledge distribution, which needs to be processed. For instance, the presence of sustainable agricultural techniques, which include precision agriculture and organic farming, is able to reduce, up to some extent, greenhouse gas emissions, thus aiding climate change mitigation [13].

1.2. Introduction – Edge and Fog Computing.

Fog computing, which is occasionally referred as edge computing, is multi-tiered distributed architecture, where all of the data processing, storage, and other services are located very close to the edge of network, where the data is being produced [18]. The second phase of the fog computing model is the service level agreement or QoS area. It is where fog computing also addresses the limitations of cloud computing by doing latency reduction, user experience enhancement and the improvement of QoS and QoE. It becomes particularly relevant matching with the Internet of Things (IoT), the example where a huge number of connected devices create extremely large volumes of data that need immediate processing in real-time [26]. Particularly, even if many of them are perceived as identical to the edge computing, there exist some subtle differences in which they function and what they stand for. Fog computing employs a fog nodes intermediate network layer that is positioned between a fog layer and edge devices. These edge devices include personal computers, Internet of Things devices and other entities [1]. Unlike the idea of edge computing, which is a phrase reserved for processing on devices at the network's perimeter [11], this concept involves on-device processing. While they do not entirely coincide, all the same, the scope of both approaches is to decrease the traffic of the network and to come up with a more efficient method of data processing [7].

1.3. Statement of the Study:

The integration of edge and fog computing holds significant potential for revolutionizing smart agriculture practices. However, there is a notable gap in understanding the current adoption, challenges, and opportunities associated with these technologies in agricultural settings. This study aims to bridge this gap by conducting a comprehensive survey and analysis to explore the status quo, challenges, and future prospects of edge and fog computing in the context of smart agriculture.

1.4. Objectives of the Study:

- To assess the current adoption and utilization of edge and fog computing technologies in smart agriculture.
- To identify the key challenges faced by agricultural stakeholders in implementing edge and fog computing solutions.
- To explore the opportunities and benefits offered by the integration of edge and fog computing in optimizing agricultural operations.

2. The current adoption and utilization of edge and fog computing technologies in smart agriculture

The capability of edge and fog computing in smart agriculture connections and usage by farmers in their daily activities has been evaluated. In this process, the technologies are being incorporated on a variety of problems such as latency, bandwidth, security, privacy and real-time analytics on data which are irreplaceable for the future applications from augmented reality to sensor networks as shown [19]. The novel emphasizes the design of newly built systems and admits the fact that they might possibly increase the efficiency of farming and environmental sustainability while they use Multi-Agent Systems and Digital Twins [20]. However, the existing technologies are being evaluated for the management and planning of resources and as well doing the jobs. Thus, the debates are raised. In addition to this, the IOT is in the plan to use the blockchain technology together with edge computing to keep the integrity and the security of smart agriculture systems. The latest breakthrough technologies like flying fog Mobile Edge Computing have the potential to work in secluded areas to solve the disconnection problems network, and is one of the important tools in Internet of Things (IoT) [1].

3. Challenges and Opportunities

3.1. Challenges in Implementing Edge and Fog Computing in Agriculture

There are certain obstacles that need to be overcome regarding edge and fog computing deployment in agriculture, such as cyber security issues, management of heterogeneous devices [8] and data processing with real time (legislation). Security would, eventually, turn out to be the main issue since the applications of the AgIoT devices are often situated in areas which are far away from any security and therefore, they can easily be attacked. The differences between devices that are comprised of a few types of sensors and actuators of diversified computing power to the increasingly sophisticated devices of today increase the complexity of efficient workload distribution and resource management. Whereas fog computing is meant to lower the delay in processing by taking the computing near to the data source, the communication charges required to support a distributed approach can be pretty huge. This comes across being especially important in agriculture production where there is a need of timely data processing for monitoring climatic conditions and precision farming. Also, technological integration of technologies under different categories such as

Markov models, intrusion detection systems, and virtual honeypot devices with the aim to enhance security during fog environments could be a boon for agricultural purposes.

3.2. Opportunities for Future Research and Development

The smart agriculture with fog and edge computing put forward an extensive room for future research and development. And these parallel paradigms are applied to solve these issues of delay, bandwidth and real-time analytics to achieve the productiveness and the sustainability of agriculture. As the literature shows, the use of cloud, fog, and edge computing can solve several of the specific difficulties met in smart farming, including device domain development, an application generation, sensors failure detection and big data operations [25]. Consequently, there are a few of completely opposite issues and barriers which have to be solve. Resource issues, schedule problem, and task control are mentioned as the most critical factors of smart agriculture application success [20]. Besides this, fog and edge computing are the two main innovative alternatives to cloud computing drawbacks, but the maximal use of these paradigms in smart agriculture, especially within AI, has not been implemented yet.

4. The opportunities and benefits offered by the integration of edge and fog computing in optimizing agricultural operations

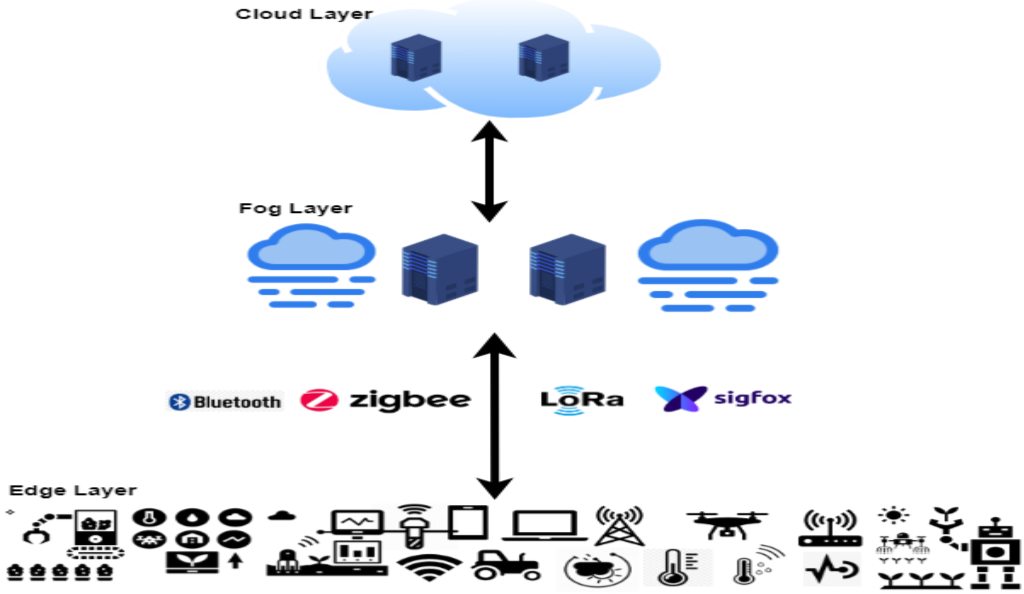
The integration of fog and edge computing brings the possibility and massive impact of improvement of data processing in the agricultural affairs industry. Such technologies can fine tune the precision farming since they provide the characteristics of renewal analytics and data processing which are done at the edge not in IoT sub networks. The high proximity brings the enabling of latency elimination and puts the response time stress on the optimized response, which is crucial to the automaticity of the process (the automated side) for real-time tasks like monitoring crop health and optimizing resource usage. The aggregation of edge computing and fog computing not only aids in smooth execution of agriculture applications, but also remodes response delays, which are key in the adoption of specialized robots in agriculture. They are able to perform duties quickly and effectively without taking breaks as they work twenty-four hours a day which is a useful to cover a labor shortage and the increase in productivity rate [24][26]. To add, the fog computing architecture is not only suits perfectly for handling information processing without hindrance and the accessible technologies can be used by all with no boundaries. Additionally, scalability feature of the architecture guarantees having sufficient and required resources for processing incoming massive data from smart farming.

6. Integration of Edge and Fog Computing with Emerging Technologies

6.1. Internet of Things (IoT) in Agriculture

The association between Edge and Fog computing with the Internet of things (IoT) in agriculture represents a state of the art development which deals with the limiting issues of the cloud-based systems in handling data centralization and high-computation needs in modern agriculture environments. The Edge and Fog computing designs enable collection and storage of data which are near to their sources, despite the fact that there are vast areas that need to be covered in agricultural set-up and thus microsecond level data processing is vital in making the best decisions [15][9]. There will be solutions for those bandwidth and latency issues while Edge and Fog computing serve as problems too rather than providing complete solutions such as sending low-bandwidth transmissions and security concern [29]. The high-end compression methods and advanced Edge AI are key tools for this problem to be solved by making data handling and analytics possible at the local network level, otherwise [15]. Additionally, leveraging Fog computing with the IoT technology to boost the performance of latency-sensitive IoT devices is also vital for the deployments of real-time agri-applications [16, 3].

Fig. 1 Integration of Edge and Fog Computing with IoT in Agriculture



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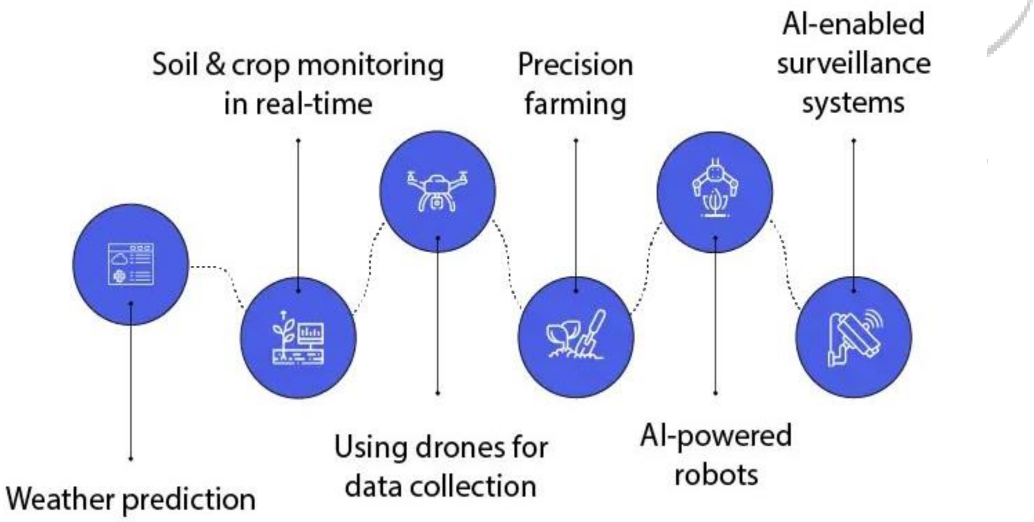
6.2. Artificial Intelligence (AI) Applications in Agriculture

The creation of Fog Computing platforms that integrate with AI applications for agriculture is the spotlight in the field of research and development. Due to edge computing infrastructure, computation and data storage move closer to the place processing is needed, enhancing response times and reducing the amount of the needed bandwidth [12]. Fog computing further develop this idea of decentralizing computing infrastructure which can respond promptly between edge devices and the cloud, support smooth processing and analysis for data[31].

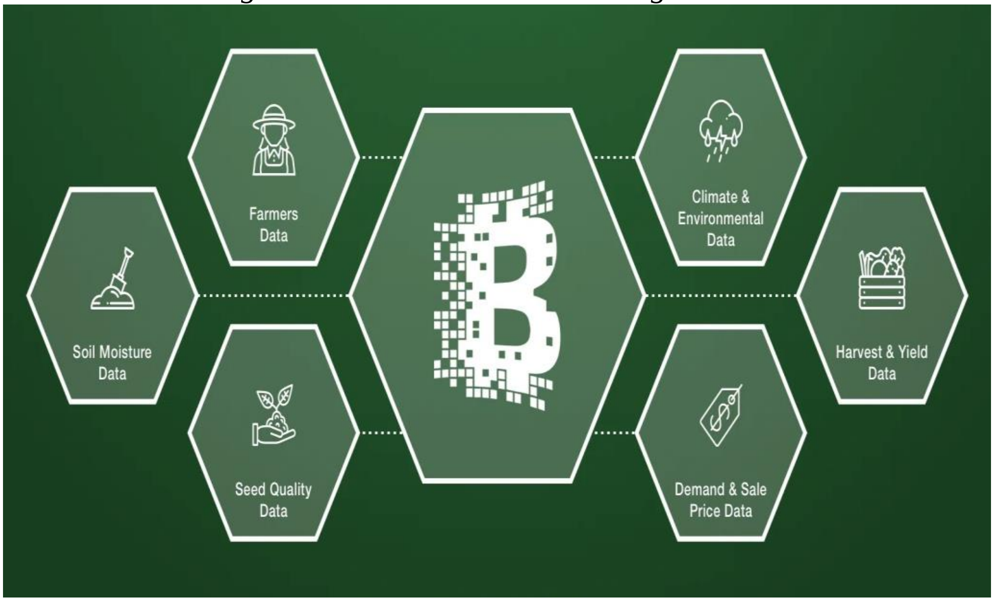
Fig. 2 How Artificial Intelligence (AI) Applications in Agriculture



Source:https://appinventiv.com/wp-content/uploads/2021/04/What-are-the-Applications-of-Artificial-Intelligence-in-Agriculture.webp

6.3. Blockchain Technology in Agriculture

Fig. 3 How blockchain works in Agriculture



Source: https://bitcoinik.com/wp-content/uploads/2020/01/blockchian-in-agriculture-main.png

Combination of edge and fog computing with blockchain technology in agriculture is a new development showing all the promise of being a leading procedure that should bring about data management and the operational efficiency of agricultural operations. Edge computing and fog computing were advanced by this which allows faster data processing closer to the source and at the edge of network, this engineering development improves the scalability and reduces the latency at the same time [4]. Blockchain technology adds an integration of the sector too. This is achieved through the provision of a safe trustworthy platform for transaction and data management and that is especially helpful to the agricultural sector where transparency along the supply chain and integrity of data are of paramount importance [25]. Although blockchain is a bitcoin reference by nature, its tracing of valuable goods in agriculture illustrates its sphere of application and capabilities to handle a region-specific issues like the traceability and the secure data sharing. Thus, it is not the case that the interweaving of these technologies into the existing systems does not have the challenges. Fundamental elements such as scalability, a consensus protocol, data privacy, and standardization should be tackled in order to possess the real potential of blockchain in the context of edge and fog computing well [14].

7. Case Studies: Implementations of Edge and Fog Computing in Smart Agriculture

7.1. Case Study 1: Real-Time Monitoring and Decision-Making with Fog Computing

Implementation of Edge and Fog Computing in smart agriculture will help to incorporate real-time monitoring and decision making system, which will be made possible considering the closeness of both the computing subsystem and the data source. Let's take Flying Fog Mobile Edge Computing, for example, which is particularly instrumental in Smart agriculture's remote locations for the reason of accommodating connectivity issues. It supports offloading real time data processing, thus opening the door for IoT devices to perform functions in a time of need. Moreover to that, coupling Cloud, Fog, and Edge computing with the technologies like Digital Twin and Multi-Agent Systems in smart agriculture can enhance the capabilities of this field to take on the challenges like latency, bandwidth and real time analytics while resource management remains an issue [21]. It is also interesting to think about the contradictions or insights which can be discovered when considering a field other than agriculture, e.g. industrial or logistics. Likewise, after the deployment of the Fog Computing technology in urban surveillance applications, real-time multi-object tracking can be performed. It proves that this technology is both versatile and really effective in deciding real-time current things [10]. Such flexibility is also one of the key points made in the literature where the literature highlights various applications of IoT technologies in the agricultural area which combine the use of Cloud, fog, and edge computing for example, providing high quality of service for IoT devices and enables real-time operations [20].

7.2. Case Study 2: Crop Health Monitoring Using Edge Devices

In conjunction with the increase popularity of edge/fog computing solutions, particularly for crop health monitoring with the help of edge devices, which is attributed to their ability to process data locally, the delay hence becoming insignificant and speeding up real-time response[17]. Through these technologies, data can be processed at the site of origin which makes available the information quickly as there is no passing. What is most intriguing in this context, however, is the fact that while edge computing takes the leading role in local data processing, fog computing builds on top of its foundation which provides for a distributed computing framework with additional computing resources that bring computing closer to the IoT devices. This gives a special edge for crop health monitoring since it entails trait collection and analysis at the farm mostly via sensors and this in turn lead to early detection of diseases and better crop management [17]. In addition, proposals have been made to combine edge computing with the blockchain technology in the area of secure and unattainable smart agriculture data.

8. Summary of Key Findings

8.1 Findings

1. The integration of edge and fog computing with smart agriculture has the potential to revolutionize agricultural practices by addressing challenges such as latency, bandwidth limitations, and real-time data processing.
2. These technologies can optimize resource use, improve decision-making, and enhance agricultural productivity and sustainability.
3. Edge computing enables real-time data processing and analytics at the network edge, closer to where data is generated by agricultural IoT devices.
4. Fog computing extends the capabilities of edge computing by providing a scalable and geographically distributed computing infrastructure for smart agriculture applications.
5. Combining these paradigms with other emerging technologies like IoT, AI, and blockchain can further enhance smart agriculture practices.

8.2 Conclusion

The study proves the substantial possibilities the edge and fog computing could bring for the optimization of agricultural operations and the improvements of intelligent agriculture. Technology serves an two-fold purpose in this domain- it enables for the overcoming of bottlenecks in data processing, resource management and real-time decisions. This sphere (edge and fog computing) is full of obstacles, for example, security, allocation of resources, and regulating considerations. However, the expansion of edge and fog computing in modern agriculture looks advantageous. And it will greatly modify the agrarian sector. The results indicate that edge and fog computing unlock new functionalities and improve machine efficiency in farming activities and lead the sector to smart manufacturing. This technologies have provided a system different from the existing, the ability to analyse large data sets, good use of available resources, and real-time decisions. The development of edge and fog computing in smart agriculture is supported by promising opportunities, but there are still some concerns for instance the security, capital funding and regulations. These concerns should be addressed, but the edge and fog computing looks to be a promising technology for agriculture.

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