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Quality attributes of software architecture in IoT-based agricultural systems

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ABSTRACT

Software architecture forms the cornerstone for achieving and ensuring various software quality attributes. It encompasses the collected requirements of the product, serving as a blueprint that delineates quality features for all project stakeholders, along with methods for measurement and control. Despite the significant increase in IoT-based agricultural systems, there is a dearth of studies on the quality elements of their software architecture. To address this need, this study offers an overview of components and services tailored to address specific quality attributes pertinent to agriculture systems. It identifies, investigates, and presents quality attributes influencing the design of software architecture for IoT-based agriculture systems. This paper identified and discussed several quality attributes, including performance, scalability, flexibility, interoperability, productivity, extensibility, and security, and mapped them to corresponding components of the IoT-based agriculture software architecture. Also, several issues were identified and discussed for the software architecture quality of IoT-based agriculture systems, such as real-time processing and interoperability due to the various devices and protocols utilized in these systems. The findings of this study offer valuable insights for developing, executing, and refining IoT-based agricultural systems to fulfill the changing requirements of the agriculture industry.

1. Introduction

The projection of the software architecture plan significantly influences how an application operates, as the communication among its components shapes the entire application design process [1]. The software architecture dictates the division of components or modules among members of the development team who will be responsible for specific parts of the architecture [2]. Additionally, it involves the selection of technology, programming languages, communication protocols, and network protocols. Therefore, the software architecture must adhere to specific quality features against which metrics and evaluations can be applied. The State of the Connected World report from the World Economic Forum states that there are more connected devices than people on the planet [3]. By 2025, 41.6 billion devices are expected to be collecting data on how we work, live, navigate our cities, and use and maintain the machines that we rely on [3]. Enhancing agricultural production, addressing concerns related to agriculture, such as food needs, and connecting and intelligently enhancing farms are all achieved through the use of IoT-based agriculture systems. Globally, IoT-based agriculture systems are projected to have a market value of around 15 billion dollars in 2022 and 33 billion dollars by 2027 [3].

IoT plays a significant role in agriculture systems, generating vast amounts of data that necessitate thorough verification, analysis, and filtration. To achieve this, it's essential to meet software quality requirements by utilizing model-checking techniques for the defined software components [4]. Quality control is integral at every stage of the processing process to swiftly and efficiently rectify errors. Control mechanisms involve modifying database files and historical records [5]. Additionally, qualitative analysis benefits from employing machine learning classification algorithms, offering a comprehensive overview of all system functionalities across different processes [6]. Quality attributes of software architecture are interconnected, such that modifying a specific part of the architecture to address one quality attribute can have both positive and negative impacts on other required attributes. The selection of software architecture is often the most critical decision for ensuring the quality of a system or software product [7]. Inadequately established software architecture and poorly defined components can significantly diminish software quality and contribute to heightened complexity [8]. Within the software design process, software architecture serves as a means to achieve quality features as well as to manage

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risks and costs [9]. This process helps delineate the distinctions between visible attributes during execution and internally established features in static aspects. Responsibilities and dependency values within the design process serve as input parameters for defining the optimal solution of the software architecture [8].

During the initial stage of software architecture design, it is crucial to analyze components, categorize them based on the quality attributes they fulfill, and assess their functionalities from diverse perspectives in software architecture [10]. The available literature on the quality features of IoT-based agriculture systems is scarce [5,9]. Accordingly, this paper will fill this gap in the literature and seek to examine the existing software architectures of IoT agriculture systems based on identified software quality features. The paper explores how software architects and designers utilize specific components or services to achieve quality attributes through architectural modeling. The study presented in this paper offers readers an overview of components and services capable of addressing specific quality features outlined for IoT agriculture systems. The analysis prompts several research questions:

RQ1: How can tailored components and services be effectively designed and implemented to address specific quality attributes in IoT-based agriculture systems?
RQ2: What are the key challenges to meeting the unique quality attribute requirements of IoT-based agriculture systems?

This paper provides several contributions to the field of IoT-based agriculture system design, implementation, and optimization. This study offers a thorough overview of the different quality attributes, such as connection, interoperability, precision of sensing, energy efficiency, and data security, that are necessary for IoT-based agriculture systems. In contrast to the assessment techniques and metrics discussed earlier, the analysis of quality features in this paper demonstrates how precisely defined components, modules, and services can fulfill all necessary quality requirements in IoT agriculture systems. Moreover, by identifying these elements, the paper illustrates how each quality attribute can be addressed within the software architecture, drawing from insights gleaned from analyzed papers. Additionally, the analysis explores the application of cloud technology and proposes enhancements for these systems. Lastly, the article recognizes several challenges that IoT-based agricultural systems have, including managing massive data sets, requiring real-time processing, and integrating a variety of sensors and protocols.

The structure of the paper is organized as follows: Section 2 describes background information on software architecture quality features as well as agricultural IoT systems. Section 3 presents the research methodology followed in this paper. Section 4 extracted the quality attributes of the IoT-based agriculture software architecture. Section 5 discusses the techniques followed by previous research to achieve the quality attributes of the IoT-based agriculture software architecture. Section 6 discusses the challenges of these attributes as well as the future research directions, practical implications, and study limitations. Finally, Section 7 concludes this paper.

2. Background and related literature

2.1. Software architecture

The software architecture plays a crucial role in the evolution, maintenance, and implementation of changes within a selected software system. By breaking down the software architecture into modules, the system becomes effectively segmented into smaller units, facilitating problem localization and resolution [2]. The hierarchical architecture enables different levels of systems and functional stand-alone modules and thus improves portability and scalability [11]. The hierarchical simplification of the module with the definition of business logic and the application of the simplicity of compiling the code (using different frameworks and levels) enabled the improvement of the security and stability of the complete IoT system [12,13]. Changes made within one module of the software architecture invariably impact related modules, thereby influencing software quality.

These changes may reveal potential deficiencies in other modules following alterations in one module of the software architecture. Measurement validation during software module design contributes to enhancing software quality [14]. Transitioning from quality requirements during the architectural design phase involves reviewing potential issues and mapping them onto the components of the software architecture and their relationships [9]. The objective is to identify the optimal software architecture solution and present it through modules, enabling designers to address potentially conflicting quality attributes. For instance, [15] states that the software architecture is composed of three layers: the business solution layer is at the top, the edge layer is at the second layer, and the IoT layer is at the bottom. Layered software architecture allows for increased productivity, adaptation, and mitigation (balance) of developed products on the field [16].

2.2. Software architecture quality attributes

During the software architecture design process, it is crucial to identify components that effectively tackle the identified challenges [9]. Software requirements signal the start of the software development journey, providing the framework for clearly delineating software architecture [6]. Subsequently, software quality assessment serves as the concluding phase, evaluating architecture components against specific quality criteria and attributes [16]. Modeling software architecture based on defined quality features through functional requirements is fundamental for developing high-quality software [4]. Automation, as a quality attribute control, can be achieved through the application of an adaptive genetic algorithm during the design, planning, and maintenance phases [17]. By establishing indicators within the software architecture, it becomes feasible to apply appropriate metrics for assessing quality attributes at different stages of software design [5]. The most common software quality attributes are as follows [18,19]: performance efficiency, security, functional suitability, compatibility, usability, reliability, maintainability, and portability. These features will be discussed in Section 4.2.

3. Research methodology

The methodology employed in this study involves analyzing recent literature on IoT agriculture systems, limited to publications within the last six years. The reason why we focused on the last six years was because there was a big adoption jump in using IoT technology in agriculture systems (e.g., about 25 % of firms in 2019 compared to 13 % in 2014), according to McKinsey [3]. The software architecture supporting these systems has evolved to meet the specific demands of users and the technologies employed in agricultural settings.

In order to do this, we searched the available online literature through popular databases such as MDPI, Scopus, Direct Science, Wiley, IEEE, Emerald, and Springer, among others. We use Booleans like "AND" and "OR" to do the search. Since there wasn't much literature available, we didn't apply quality criteria to the search, but we did examine the article's title and abstract. We included the article for further investigation if the title or abstract clearly demonstrated the connection between IoT and agriculture. Also, only items published in English were identified using this search. Since our search resulted in few studies, we used the snowballing approach to find more related studies by browsing through the reference lists of all the articles chosen.

4. Quality attributes of agricultural IoT systems

4.1. Software architecture of IoT-based agriculture systems

The large amount of data obtained from sensors in IoT agriculture systems requires high bandwidth in the application layer of the software architecture. In IoT systems, several features should be maintained [4,9,15,20–22]: 1) Connectivity (i.e., ensures seamless communication and connectivity between IoT devices, enabling efficient data exchange). 2) Interoperability, which facilitates compatibility and interaction between diverse IoT devices and protocols, promoting a unified and integrated system. 3) Sensing accuracy (i.e., the precision and reliability of data collected by IoT sensors), ensuring accurate information for decision-making. 4) Energy efficiency, which focuses on optimizing the power consumption of IoT devices to prolong battery life and reduce environmental impact. 5) Data security, which ensures the confidentiality and integrity of data generated and transmitted by IoT devices, protects against unauthorized access. Other factors that may affect the quality of IoT-based systems include scalability (i.e., the software architecture can scale to handle a large number of IoT devices and data sources that are common in urban environments), real-time data processing, and edge layer (i.e., architectures that incorporate edge computing can enhance efficiency by processing data closer to the source).

The implementation of a layered software architecture facilitates user access through diverse applications, which enables the retrieval of varied data pertaining to the monitored area [23]. The architecture allows for the incorporation of new software components as needed for system expansion or the examination of additional parameters at the monitored site [24]. The software architecture of this system consists of three layers: data acquisition, data curation, and data presentation [25]. In our previous study [9], we introduced an IoT-based architecture for agricultural applications, illustrated in Fig. 1. The sensor data layer (edge layer) acquires information from on-site sensors (IoT devices), and data from drones can be integrated into the maintenance planning system [26]. Moreover, the architecture permits a comprehensive analysis of satellite images through the digital media layer, which offers insights from multiple sources for location assessment.

Reliability is enabled through the communication of edge sensors with the cloud platform while reducing the number of non-existent values in the database [27]. The flexibility and scalability of IoT agriculture systems should allow, within the back-end layer, the addition of new models or theoretical items defined based on experience in the application of these systems. By applying this layer, it is possible to divide the system into modules and thus enable modularity and scalability [28]. The heterogeneity of devices within the IoT system can enable interoperability between devices through which users enter their feedback relevant to the smooth operation of the system [29].

Data security in such a system is possible by applying a single-key encryption standard for each device and communicating with each other. Authentication of each system user must be performed by requesting feedback from peers in the system (sender or receiver). Only when the identity of the user is confirmed can a request for the execution of a certain operation be sent [27]. Each layer consists of independent components, which enable the modularity and scalability of the IoT system [30]. The performance and scalability of the system; however, can be affected by the weaknesses in any of these layers not meeting minimum requirements. For example, a weak internet connection in the communication layer will decrease the performance and scalability of such a system [14]. In this paper, quality features influencing the design of software architecture for IoT-based agriculture systems are identified and analyzed.

4.2. Software architecture quality attributes of IoT-based agriculture systems

During the process of projecting the software architecture, it is necessary to present the components that solve the identified problem in the right way. Software requirements represent the beginning of the software development process, and based on them, the software

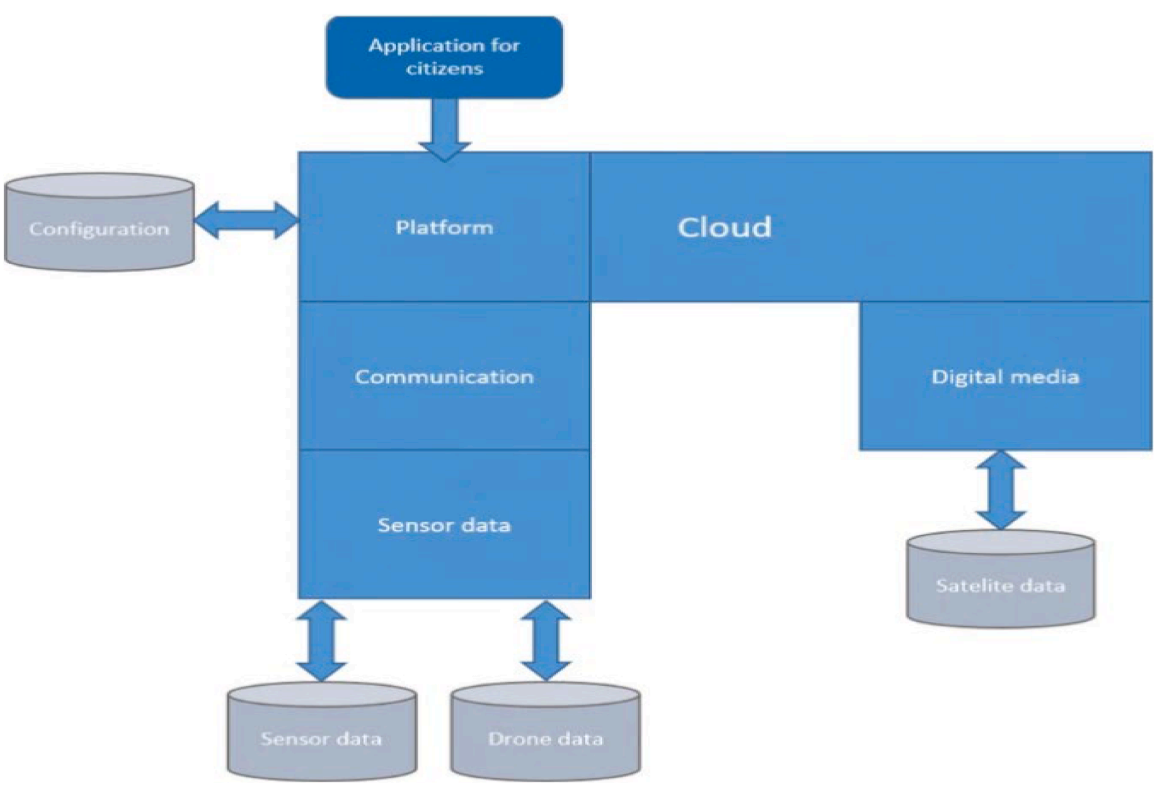

Fig. 1. IoT-based agriculture software architecture (source: [9]).

architecture is clearly defined, and the software quality assessment is the final part in which the components of the software architecture are evaluated according to certain quality criteria and attributes. Thus, software architecture is the foundation for attaining quality in complex software systems [31].

Several features should be considered when applying IoT to agriculture systems, such as the robustness and reliability of IoT devices, since agricultural environments often entail harsh conditions. Moreover, scalability is another concern in the agriculture environment since different variations (i.e., small, medium, and large farms) entail different considerations [32]. Another important factor is the availability of power resources since agricultural locations are remote and far away from power resources. Finally, data accuracy is an essential concern for decision-making processes. Accordingly, and based on the discussion in Sections 2.2 and 4.1, the following quality attributes are investigated in this paper, according to the definitions provided below [4,32–34].

1. Performance: it is the response of the system during the execution of a certain action at a certain time. This attribute includes capacity, resource utilization, and time constraints to meet real-time data processing. It also describes functionality, correctness, completeness, and appropriateness. It also describes the software reliability (consistent and dependable performance of the software).
2. Scalability: it is the ability of a system to withstand a load without reducing performance or the ability to rapidly increase a load. It also describes maintainability (reusability, modifiability, modularity, testability, and analyzability).
3. Flexibility: it is the adaptability of the system to modify and enable interaction with other systems using components that are made according to the standard and are manufactured by independent manufacturers. It also describes portability (adaptability, replaceability, and installability).
4. Interoperability: it is the capability to exchange data or services through various system modules. Also, these system modules should work on different operating system platforms, databases, and protocol conditions. It also describes compatibility (i.e., the consistent and dependable performance of the software).
5. Extensibility: it refers to the possibility of future system growth, system expansion, and the assessment of the level of effort required to implement expansion. Extensions include adding new functionality or modifying existing ones without compromising existing system functions.
6. Productivity: the overall goal of productivity is to minimize the effort, resources, and time needed for the software system's creation and maintenance while optimizing the value it delivers. It also describes usability (prioritizing user-friendly interfaces and intuitive design to enhance the experience of users).
7. Security and privacy: it is the capability of the system to prevent unauthorized access to system functions, prevent loss of information, ensure the protection of software from viruses, and protect the privacy (confidentiality and integrity of the personal data) of data entered into the system.

5. Analysis of the software architecture of the agricultural IoT systems

This section answers RQ1 (the components and services that can be effectively designed and implemented to address specific quality attributes in IoT-based agriculture systems). In general, by monitoring and accurately analyzing crop parameters, as well as using flexible systems, it is possible to allocate resources used for different types of agriculture, reduce the time of response of the devices, increase the quality of the services, increase security, and increase and optimize the quality of crops [27]. In that way, it is possible to control and obtain the necessary quantities and quality of crops, as well as interact with workers or farmers. Also, interoperability helps to study environmental conditions. Data transfer rate allows for better connections between sensor nodes and server platforms [35]. Fig. 2 summarizes the quality attributes of the IoT-based agriculture system and provides supported literature for each attribute.

5.1. Performance attribute

By focusing on the following aspects and leveraging the findings from the referenced studies, IoT-based agricultural systems can be optimized to achieve higher efficiency, productivity, and sustainability. Table 1 summarizes the main findings of the literature about enhancing the performance of IoT-based agriculture systems.

- Emerging technologies: The fast technological development of forest machines has prompted enterprises to invest in virtual learning environments [5]. Crop quality may be enhanced by employing precision fertilization services [37]. Different strategies were recommended, such as microcontrollers [45] to improve system performance in agricultural settings, "long range wireless area network" technology [41] to improve sensor data transmission and reduce resource utilization, IoT sensors and execution layers [40] to streamline task management, and "low power wide area" technology for high-speed data transfer, which were also reported to have positive effects on agriculture systems [43].
- Edge/fog/cloud architecture: The integration of fog computing in agricultural systems was recommended as a way to improve data processing efficiency and lower latency [38]. Strong IoT hardware and software solutions are essential for optimizing system performance in agricultural settings [7]. The use of custom layers and clever techniques to improve system responsiveness and data processing was recommended by [44]. The use of cloud platform resources for big data processing and smart device monitoring was recommended by [14].
- Software architecture improvement: The optimization of software architecture layers to enhance system performance and responsiveness was recommended by [25]. Task definition, control, and management procedures may be enhanced by the execution layer [12]. Additionally, system performance is greatly increased by mixing network protocols in the application layer [35]. Furthermore, using theoretical elements in data processing and analysis might improve performance [28].
- Data management systems: In order to examine data management systems, the authors in [4] carried out a thorough literature analysis, paying particular attention to interoperability, accessibility, scalability, and real-time operating capabilities. In their analysis of how noise in IoT sensor data affects evapotranspiration prediction in smart agriculture, Martín et al. (2024) emphasized the necessity of noise reduction techniques. In [36], the authors highlighted how crucial quality control procedures are to guarantee high data accuracy in agricultural systems based on the IoT. Wireless data transfer and cloud storage were emphasized by [15] and [27] as effective means of analyzing data and making decisions quickly. To enhance system performance, authors in [42] highlighted the function of middleware components in enabling data exchange and rule-based operations. Middleware technology is an independent service or piece of software within the software architecture of a system. In [14], the authors underlined the use of cloud platform resources for big data processing and smart device monitoring.

5.2. Scalability attribute

IoT-based agricultural systems may be made more scalable by utilizing the knowledge from the study's findings. This will allow for effective data processing, management, and growth following operational needs. The major findings of the research about improving the

Fig. 2. IoT-based agriculture software architecture quality attributes.

scalability of IoT-based agricultural systems are included in Table 2.

- Emerging technologies: According to Muñoz et al. (2020), the utilization of MongoDB can enhance the overall system's scalability by facilitating the effective storage and retrieval of substantial amounts of data. According to [42], using the "Drools" component can improve system scalability by facilitating a variety of activities and generating reports following predefined criteria. To improve scalability, authors in [25] stressed the usage of distinct modules in backend software design as well as the use of big data analytics and machine learning approaches.
- Edge/fog/cloud architecture: Edge-layer software design facilitates effective data management and processing at the network edge, which can aid in scalability [15]. Furthermore, by effectively managing data and communication operations, the IoT back-end layer contributes significantly to improving scalability [28]. Additionally, scalability can be enhanced by narrow-band IoT technology, which offers effective data transmission and administration capabilities [45].
- Software architecture improvement: An organized and scalable arrangement of system components is one way that hierarchical architecture promotes scalability [44]. In order to improve system performance and scalability, authors in [30] highlighted the use of four levels of software architecture: hardware, communication, application form, and microservices.
- Data management enhancement: The intricacy and quantity of semantic descriptions may be the cause of data management systems' restricted scalability [4]. Wireless networks can facilitate data management and flexible growth to improve the scalability of IoT-based agriculture systems [7]. Scalability and effective data management may be enhanced by having a strong internet connection while sending massive volumes of data to cloud systems [14]. Furthermore, the authors in [46] emphasized that successful network management and increased system scalability depend on the appropriate administration of new nodes and extra features.

5.3. Flexibility attribute

The findings highlight how crucial flexibility is to IoT-based agricultural systems since it provides effective communication, on-the-spot data processing, and dependable performance in a range of settings and use cases. The primary conclusions of the research about improving the adaptability of IoT-based agricultural systems are compiled in Table 3.

Table 1
Enhancing performance of IoT-based agriculture systems.

Study	Year	Findings/ recommendation
[4]	2024	Promoting real-time operation capability. The edge-fog-cloud architecture reduces bandwidth and delays.
[10]	2024	The noise on the agriculture system sensor has negative effects on performance.
[36]	2024	A quality assurance process to ensure the data collected has a high level of accuracy.
[5]	2023	Rapid technical development with an increasing number of new features.
[37]	2023	Deploying precision fertilization services.
[38]	2022	Deploying fog computing and cloud computing (data centers), measurement architecture
[7]	2021	Maximizing system performance requires the application of stronger IoT software.
[39]	2020	Process monitoring, production evaluation according to legislative or contractual standards, and performance management.
[15]	2020	Deploying wireless data transfer from IoT nodes to the cloud platform.
[27]	2020	Storing data on a cloud platform and transferring data processing to the cloud.
[25]	2020	Application of a three-tiered software architecture (data acquisition, data curation, and data presentation) enables improvement of system performance.
[40]	2020	Dividing the software architecture into layers to update the data (on the first backend layer) without affecting the system performance.
[35]	2020	Combining network protocols in the application layer significantly increases system performance.
[41]	2020	LoRaWAN may increase system performance during sensor data processing and thus raise productivity and reduce resource utilization.
[42]	2019	Data sharing between components should be done through a middleware component.
[43]	2019	LPWA technologies and wireless communication that enable high-speed data transfer.
[44]	2019	The application of the custom layer, control layer, business layer, persistence layer, and data layer enables faster system response and data processing.
[14]	2019	Monitoring smart devices, collect, process, and store large amounts of raw data.
[28]	2019	Application of theoretical items in the process of data analysis and processing.
[45]	2019	The application of smart strategies and microcontrollers.
[12]	2019	The execution layer can enable processes for defining, controlling, and managing tasks.

Table 2
Enhancing scalability of IoT-based agriculture systems.

Study	Year	Findings/ recommendation
[4]	2024	The complexity and volume of semantic descriptions lead to limited scalability.
[7]	2021	The application of wireless networks allows for the necessary scalability of the IoT system.
[15]	2020	Deploying edge-layer software architecture.
[46]	2020	Applying proper management of additional functionalities and new nodes.
[25]	2020	Separating modules of backed software architecture and application of big data analytics and machine learning techniques.
[40]	2020	The application of MongoDB enables greater scalability of the complete system.
[42]	2019	Use the Drools component, which allows various functionalities.
[44]	2019	The custom layer, control layer, business layer, persistence layer, and data layer enable faster system response and data processing. Deploying a hierarchical architecture enhances scalability.
[14]	2019	The internet connection must ensure that a large amount of data is sent to the cloud platform.
[28]	2019	Deploying the IoT back-end layer to enhance scalability.
[45]	2019	Scalability is enabled by using narrow-band IoT.
[30]	2019	Deploying four layers of software architecture: hardware, communication, application form, and microservices.

Table 3
Enhancing flexibility of IoT-based agriculture systems.

Study	Year	Findings/ recommendation
[4]	2024	5 G enables slicing, enabling customized segments tailored to specific requirements.
[7]	2021	Use of flexible WiFi modules to control various environmental factors that influence decisions within the system.
[39]	2021	A domain-specific language may offer flexibility and adaptation to new requirements.
[47]	2020	Wireless sensor networks enable the receipt of information in real time.
[41]	2019	The development of devices with rechargeable batteries that collect energy, recharge, and are available at any time.
[12]	2019	The architecture framework and the division of software components may enable greater availability of components within the system.

- Emerging technologies: 5 G slicing makes it possible to create segments that are specifically suited to meet needs. This flexibility balances latency, bandwidth, and dependability in communication parameters for data transfer [4]. In [39], the authors highlighted the potential of domain-specific language to provide flexibility, which permits modifications and respects available time and scope, fostering transparency and efficient stakeholder communication.
- Software architecture: The use of architecture frameworks and the layering of software components improve the availability of components for a range of system demands, which encourages modularity and scalability [12]. Rechargeable battery sites can be operated remotely thanks to developments in software and device architectural components [41]. This guarantees consistent accessibility and dependable functioning in isolated settings.
- Flexible WiFi modules: Using flexible WiFi modules can regulate a range of environmental elements that affect system decisions, improving the system's capacity to adapt to changing conditions and operate more freely [7]. Wireless sensor networks provide effective data collection and transmission for prompt decision-making by facilitating the real-time receipt of information from sensors and nodes [47].

5.4. *Interoperability attribute*

Interoperability was highlighted in previous studies as a crucial component of IoT-based agricultural systems. Interoperability enables the acquisition and manipulation of data from many sources and devices deployed in diverse situations [4]. As an illustration, consider the interoperability initiatives that the European Commission has funded over the past ten years [37]. To improve interoperability in precision agriculture, thousands of entrepreneurs worldwide provide farm management systems that may be expanded to include additional services. The next observations underscore the importance of interoperability in promoting smooth data transfer and cooperation across heterogeneous IoT ecosystems. This promotes the progress of varied domains, including precision agriculture and data management systems. Table 4 summarizes the main findings of the literature about enhancing the interoperability of IoT-based agriculture systems.

- Emerging technologies: To improve interoperability across various IoT systems, the authors in [7] and [35] suggested using "low power wide area" technology for transferring data over vast distances with minimal power consumption. The use of external services for effective application and connection with current components to improve interoperability and smooth integration inside IoT systems [48]. Taking advantage of the heterogeneity of devices inside IoT networks was suggested to improve interoperability [29].
- Software architecture improvement: To promote cross-platform interoperability, the authors in [38] advised integrating architecture with measuring systems (such as sensors and actuators) and

Table 4
Enhancing interoperability of IoT-based agriculture systems.

Study	Year	Findings/ recommendation
[4]	2024	Ability to interact with components and solutions for visualization, analysis, and decision support.
[37]	2023	Management solutions that expand to new services.
[38]	2022	Integrating the architecture with other measurement systems, such as sensors and actuators.
[7]	2021	Using of LoRaWAN for sending data over long distances with low power consumption.
[39]	2021	Less interoperability leads to difficulty in the use of data.
[35]	2020	Use of LoRaWAN and IEE 802.11ac protocols.
[48]	2019	External services may enable efficient application with existing components.
[29]	2019	Deploying heterogeneity of devices within IoT systems.
[12]	2019	Endpoints may provide interfaces for integration with external systems.

implementing an "application programming interface" to export metering data for usage in other systems. Moreover, it was recommended that endpoints be defined as interfaces for external system integration in order to improve interoperability, which guarantees seamless data transfer across various platforms [12].

- Precision agriculture: In [39], the authors highlighted the difficulties that precision agriculture faces due to fragmentation and a lack of data standards, emphasizing the need for interoperability to enable smooth interactions between software and hardware.

5.5. *Extensibility attribute*

The following insights underscore the importance of extensibility in IoT-based agriculture systems to enable adaptability, scalability, and integration of new functionalities to meet evolving demands and enhance overall system performance. Table 5 summarizes the main findings of the literature about enhancing the extensibility of IoT-based agriculture systems.

- Emerging technologies: By using insights from system usage to guide the integration of new functionality and features, the inclusion of new models based on application experience may improve extensibility [28]. Additionally, authors in [44] emphasized the use of PaaS and IaaS services to improve extensibility by offering various system tiers and useful stand-alone modules, which promote flexibility and scalability.
- Edge/fog/cloud architecture: Data management systems are encouraged to fulfill high power and computational resource needs through edge-fog-cloud designs [4]. With this design, real-time monitoring and action capabilities are made possible, and bandwidth and network latency are decreased while tasks and processes are distributed according to urgency or computing requirements.
- Middleware technologies: The use of different middleware technologies and frameworks within the software architecture to improve extensibility and facilitate the smooth integration of new features and components [7]. The IoT software architecture's features enable the installation of more sensors or components whenever necessary to gather more data for production monitoring and guarantee extensibility [50].
- Dynamic installation of new sensors: The authors in [15] suggested that in order to improve extensibility, which allows the system to adjust to changing requirements and integrate more monitoring capabilities as needed, new sensors for monitoring buildings, animals, and crops should be dynamically installed. It was also emphasized how the distributed software architecture and ability to add sensors in accordance with system requirements allow for extensibility and scalability to support new sensor deployments [27]. Intelligent decision-making and remote diagnostics can be aided by the simple expansion of programs through system components [49].

Table 5
Enhancing extensibility of IoT-based agriculture systems.

Study	Year	Findings/ recommendation
[4]	2024	The edge-fog-cloud architecture provides real-time monitoring and enables the distribution of tasks and processes.
[7]	2021	Application of different middleware technologies and different frameworks within the software architecture of the system.
[15]	2020	Dynamic installation of new sensors for monitoring and tracking of buildings, animals, and crops.
[27]	2020	Sensors can be added according to the needs of the system and the distributed software architecture of the components.
[49]	2020	The extensibility of the application through system components promotes intelligent decision-making and remote diagnostics.
[50]	2019	The capabilities of the IoT software architecture promote the installation of additional devices or components needed for the production monitoring process.
[44]	2019	Different system levels, functional modules, and IaaS and PaaS services.
[28]	2019	Adding new models based on system application experience.

5.6. *Productivity attribute*

Several strategies and tools that are used to increase productivity in IoT-based agricultural systems are explained in the following insights: This ranges from sophisticated analytics and machine learning methods to real-time monitoring and automation. Table 6 summarizes the main findings of the literature about enhancing the productivity of IoT-based agriculture systems.

- Emerging technologies: Agriculture 5.0 emphasizes the use of new technology to streamline workflows and boost production [4]. Improved order management of liquids and supplies utilizing modern digital technology and emphasizing the value of appropriate training has the potential to increase production [5]. Moreover, IoT technologies for agriculture facilitate monitoring, decision-making, and process automation, all of which can increase productivity by offering the required insights and automation capabilities [7].

Table 6
Enhancing productivity of IoT-based agriculture systems.

Study	Year	Findings/ recommendation
[4]	2024	Agriculture 5.0 leverages emerging technologies to optimize agricultural processes, increase productivity, enhance sustainability, and improve resource management.
[5]	2023	Improving order management with new digital technologies.
[1]	2022	Monitoring to prevent losses and improve the overall productivity.
[7]	2021	IoT provides the right tools for decision-making, monitoring, and process automation, leading to increased productivity.
[15]	2020	Edge nodes communicate with the cloud platform while reducing the number of non-existent values in the database.
[46]	2020	Applying cloud technology for data storage and processing within the IoT system.
[47]	2020	Mechanization management may increase productivity while working on large farms.
[49]	2020	Using wireless sensors reduces energy consumption and increases energy efficiency.
[35]	2020	Applying network protocols can improve the speed of data transfer and processing.
[50]	2019	Monitoring systems and quick reactions improve productivity and the proper use of resources.
[43]	2019	Artificial intelligence and the ZigBee component may enable higher system productivity.
[45]	2019	Wireless sensor networks can increase the productivity of IoT systems.
[48]	2019	The "Control Box" may enable real-time control of temperature and conditions that raise the quantity.
[12]	2019	Activity detection using machine learning and the implementation of new functionalities.

- Edge/cloud integration: Productivity may be increased by allowing edge nodes to interact with cloud platforms [15]. This also lowers the likelihood of non-existent values occurring in the database, ensuring data integrity and dependability. The authors in [46] emphasized the utilization of cloud technology in Internet of Things systems for data processing and storage, highlighting this approach as a way to save expenses and boost productivity.
- Software architecture improvement: The authors in [47] remarked on how software architectural elements in charge of mechanization management can boost output, especially on big farms where productivity increases depend on effective management. Network protocols may be used to speed up data processing and transport, increasing productivity and guaranteeing prompt access to crucial information for making decisions [35].
- Activity detection: In [49], the authors suggested that productivity can be enhanced by using wireless sensors to reduce energy consumption and increase energy efficiency. IoT devices that enable real-time monitoring of various parameters can facilitate seamless data collection and analysis, quick reactions, and proper resource utilization to enhance productivity, optimize agricultural processes, and enhance the decision-making process [45,50]. Another suggestion was the application of artificial intelligence [43], machine learning, and ZigBee components for environmental monitoring, which enable higher system productivity through data-driven insights and optimization [12].
- Process optimization: The authors in [48] suggested enhancing productivity through real-time control. This can be enabled by components like the "control box," which allows for temperature and condition adjustments that enhance product quality. In [1], the authors highlighted the importance of monitoring cultures in agriculture to prevent losses and improve overall productivity, which emphasizes proactive measures to optimize productivity levels.

5.7. Security and privacy attribute

The following insights underscore the diverse approaches and technologies employed to enhance security in IoT-based agriculture systems, addressing concerns regarding data integrity, access control, authentication, and secure communication. Table 7 summarizes the main findings of the literature about enhancing the data security and privacy of IoT-based agriculture systems.

Table 7
Enhancing data security & privacy of IoT-based agriculture systems.

Study	Year	Findings/ recommendation.
[4]	2024	Edge-fog-cloud architecture to anonymize the data sent to the cloud.
[21]	2022	System protection has a negative impact; it drains the battery and minimizes performance.
[7]	2021	Adequate application of middleware, blockchain technology, organized storage, and data retrieval.
[51]	2020	Providing data access control to secure data sharing and storage.
[46]	2020	Security mechanisms and access control must work in real time and be applied to both a single-layer and a cross-layer structure.
[47]	2020	Providing gateways and protocols to process large amounts of data and prevent data leakage.
[40]	2020	Fireware can enable open authorization authentication schemes through a proxy function.
[43]	2019	The gateway component acts as an intermediary with the Internet and can protect data storage and exchange.
[44]	2019	Easy compilation of program code by using different frames and levels can enhance security.
[14]	2019	Apply single-key encryption standards for each device and mutual communication.
[45]	2019	Microcontroller boards and the Raspberry Pi may enable greater data security.
[29]	2019	Deploying different types of mobile devices for data entry.
[12]	2019	Clearly defined security protocols enable secure communication between the network layer and the device layer.

- Measures optimization: In their discussion of the detrimental effects of system protection on performance, the authors in [21] advocated striking a balance between system efficiency and security measures. The authors in [46] stressed the necessity of real-time authentication protocols and security mechanisms that enable device authentication. These protocols should include cross-layer techniques and cloud-based analysis for distributed data warehouses.
- Middleware and blockchain: The use of middleware, blockchain technology, structured storage, and data retrieval techniques can all improve security [7]. In particular, for parts and devices not directly linked to the internet or cloud servers, the authors in [43] underlined the significance of the gateway component as an intermediate to manage and store exchanged data securely. Using Raspberry Pi, microcontroller boards, and other software components increases data security within the system [45].
- Access control: In order to improve security, the authors in [51] stressed the significance of strong data storage protocols, safe data exchange across components, and access control. They also recommended thorough testing of sensors and the definition of security standards. The authors in [40] spoke about how to employ "open authorization authentication" approaches via a proxy function to strengthen system security and guarantee safe data transfer.
- Data protection: The authors in [47] emphasized the significance of guarding against data leaks, offering gateways and data processing procedures, and making sure that outside sensors and equipment are physically protected. To guarantee safe data sharing and communication integrity, it was advised to use mutual communication protocols and single-key encryption standards on every device [44].
- Secure data transmission: The capacity of the edge-fog-cloud architecture to choose or anonymize data that is delivered to the cloud provides strong security management capabilities and handles privacy and data security issues [4]. The authors in [12] emphasized the use of certain technologies for precisely specified security protocols, guaranteeing safe connections between devices and network levels, and protecting the confidentiality and integrity of data.

6. Discussion

The purpose of this study is to investigate the quality attributes of IoT-based agriculture systems. This was done by answering RQ1 (i.e., how to address specific quality attributes in IoT-based agriculture systems?), which was covered in Section 5. Also, by answering RQ2 (key challenges to meeting the unique quality attribute requirements of IoT-based agriculture systems), which is covered below in Section 6.1. Then, through the identified challenges, future research directions were stated. We also discuss the practical implications and the paper's limitations.

6.1. IoT-based agriculture software architecture challenges and future research directions

This section answers RQ2 (key challenges to meeting the unique quality attribute requirements of IoT-based agriculture systems). Smart agriculture software architecture based on IoT offers a wide range of opportunities for production optimization. To achieve high-quality integration between IoT and agriculture systems, middleware, edge/fog/cloud computing, data analysis, developing technologies, and AI integration may all be highly combined. However, even with its benefits, several challenges must be resolved, as summarized in Table 8.

6.1.1. Interoperability

Several IoTs are not related to agriculture; they are made for specialized areas of use. Because they employ strict query interfaces or native data structures, they can provide resistance when attempting to adapt to an agricultural context. Many perspectives, including those related to devices, protocol design, rules, logic, and platform variation,

Table 8
Challenges and future directions of IoT-based agriculture systems software quality.

Challenge	Results	Future research direction
Interoperability	• Compatibility issues	• Standardization of protocol, frameworks, and design
Reliability	• Device malfunctions • Erratic network	• Backup measures • Fault-tolerant designs • Automatic upkeep strategies • User-centric design
Scalability	• Amount of data • Farmers requirements	• Edge/fog/cloud approach • Distributed computing models
Security & privacy	• Data loss • Data confidentiality	• Cutting-edge security and privacy measures • Low processing power IoT devices
Real-time data processing	• Delay in data processing • Delay in updates	• Edge processing • Specialized database • Lightweight data model
Data management	• Slow data extraction • More computation resources	• Local or edge database for real-time needs • Distributed database for decision-making

might be applied to this kind of challenge [7]. This can lead to compatibility issues. Standards can be used as a basis for effective data interchange and communication between different systems, interfaces, and other components. Standardization is necessary to provide a broad range of implementations that meet the fundamental requirements for applications connected to the IoT. Thus, creating international standards frameworks for IoT-based agriculture is one of the issues that needs more attention in future research. In order to improve compatibility and interoperability among various IoT designs, future research should concentrate on creating universal protocols and structures.

6.1.2. Reliability

There are several obstacles in the way of keeping IoT-based agricultural systems reliable as well as resilient in the face of unforeseen circumstances and technological malfunctions. Agriculture systems are frequently installed in isolated, hostile locations where device malfunctions and erratic network access are possible [4]. System robustness and reliability may be increased by installing backup measures, creating fault-tolerant designs, and using automatic upkeep strategies [39]. Accordingly, future research may investigate such services to enhance the reliability of IoT-based agricultural systems.

Because agricultural landscapes are diverse and complicated, the opinions of farmers and professionals are crucial to improving the information offered. It is advised to include farmers in the process and provide them the opportunity to contribute comments to the data that field agents collect in order to supplement and rectify it [4]. Accordingly, to ensure that IoT-based agriculture systems are simple to use, effective, and available to farmers and other players, future research ought to take user-centric design principles into account [52]. To create intuitive layouts, simple processes, and context-aware apps that suit farmers' demands and requirements.

6.1.3. Scalability

Scalability is essential to meet increasing data volumes and farmer needs as agricultural systems increase and integrate more IoT devices. Systems face scalability issues when they are unable to accommodate the addition of additional devices and capabilities or grow to meet increasing data loads. To promote IoT-based agriculture system expansion, research endeavors have to investigate novel techniques for scalable architectural designs and data management methodologies [7]. To promote the expansion of IoT-based agricultural systems, research routes include investigating cloud-based scaling mechanisms, edge computing solutions, containerization technologies, and distributed computing methodologies.

6.1.4. Data security and privacy

Due to possible losses, security and privacy concerns are viewed as major obstacles in smart agriculture. In addition to the common security concerns associated with IoTs, such as privacy and authentication, smart agriculture also faces unique challenges related to data storage privacy and security [53,54]. Data collection security and hardware safeguarding are typical security concerns. Fog computing has many benefits, such as distribution processing, closeness to distributed nodes, and control capabilities, among others [55]. However, for IoT-based agricultural systems, as nodes are scattered over large surfaces, controlling decentralized data privacy is more difficult. Moreover, the implementation of blockchain technology has great promise for enhancing openness, safety, and, most importantly, trustworthiness [21,56]. However, it has some appropriate constraints, such as challenges with energy-effective mining and scalability. Since significant agricultural data is sent to the application layer, privacy and data security need to be considered [57]. The low processing power, limited storage capacity, and limited life of batteries in IoT devices must be taken into account when implementing safety precautions and connectivity regulations [4]. Future research on reliable encryption (e.g., creating cutting-edge security measures), robust authentication methods (e.g., blockchain-based authentication), and protection-aware data processing procedures is required to protect the data generated by IoT devices from cyber threats and comply with privacy rules.

6.1.5. Real-time data transmission

One of the biggest challenges for IoT-based farm software design is achieving real-time processing. The capabilities of the technologies being utilized determine whether data can be delivered in real-time [58]. This capacity is directly related to how scalable and responsive the system is to user input or connected components. To achieve real-time processing or reduce the time lag between the time data is acquired and the system's capacity to provide it as replies, there are three main methods [4]: 1) Edge processing: this involves breaking apart the structure between the cloud and the edge so that recently collected data is also saved there. This allows sensors to automatically query the edge and need real-time replies. 2) A specialized database (that is, a database that is used only to store the most recent data). This configuration makes it easier to quickly retrieve recent updates. This database has to remain compact and free of historical data. 3) Lightweight data model: To reduce processing and repository management delays, a system based on a light data structure is implemented.

6.1.6. Data management

IoT devices generate large amounts of data, which makes effective storage techniques necessary, especially for historical data with knowledge extraction in mind. This may hamper system performance and impose a burden on computing resources since they pull information from densely populated libraries. However, there is a noticeable difference in how the system uses current and past data. Historical data are subjected to additional analysis and are frequently used as training data for machine learning models, which use the seasonal trends in environmental data to anticipate and make predictions [59]. On the other hand, recent data can support several purposes, such as tracking crops, real-time decision-making, and anomaly identification. Partitioning internal repositories is recommended to maximize system responsiveness. At the edge, an individual database that contains recent data can minimize resource consumption and communication latency for quick real-time reactions. On the other hand, databases that store historical data could take longer to respond; however, they are better at processing, analyzing, and drawing conclusions that are useful for assisting with agricultural operations. Databases are strategically distributed to preserve the accessibility and integrity of past and present data for agricultural research and decision-making. Future research may focus on studying these databases through different cases.

6.2. Applicability of quality attributes in practical scenarios

Depending on the needs of a given scenario, different quality aspects may be prioritized. In many different IoT-based agricultural systems, performance, scalability, interoperability, and security are generally considered to be among the most important characteristics. However, depending on the intricacy and particular needs of the agricultural use case, flexibility, extensibility, and productivity can play important roles. For example, performance, scalability, interoperability, security, and privacy are essential software quality aspects in precision farming. Performance is the key objective in precision farming since quick decision-making depends on real-time data processing. To manage massive volumes of data from several sensors dispersed throughout enormous farmlands, scalability is essential. In order to ensure seamless operation and data sharing, interoperability is essential for integrating different sensors and farming equipment. Furthermore, to safeguard private information on farms and guarantee safe connections between systems and devices, security and privacy are essential.

In another example, performance, interoperability, scalability, and flexibility are given top priority in automated irrigation systems. In order to ensure effective water consumption, flexibility is crucial for adapting to diverse crop needs and irrigation methods. Supporting several irrigation zones and possibly large-scale activities requires scalability. In order to prevent over- or under-irrigation, proper watering depends on performance and quick response times. For smooth integration and operation, compatibility with different sensors and control systems requires interoperability. Moreover, key characteristics in livestock monitoring are performance, security and privacy, flexibility, and dependability. For efficient management, it is essential to have reliable sources for tracking the location and health of cattle. Performance is crucial for alerts and real-time monitoring since it enables prompt action when necessary. To prevent unwanted access to data about the health and movements of cattle, security and privacy are crucial. Flexibility gives the system versatility in application by enabling it to adjust to various animal species and farm configurations.

Agriculture supply chain management systems have a strong emphasis on performance, productivity, security, and interoperability. For integration with different systems to function smoothly and to provide coordinated data flow from farm to market, interoperability is essential. Throughout the supply chain, security and privacy are essential for protecting transactions and preserving data confidentiality. Streamlining procedures to increase effectiveness and decrease waste is the main goal of productivity, which eventually improves supply chain performance as a whole. Performance guarantees effective handling and processing of massive amounts of data, facilitating prompt and precise decision-making. On the other hand, systems for greenhouse automation need to be flexible, scalable, secure, and private. Scalability enables growth and diversity by supporting numerous greenhouses and different crop varieties. To ensure that various environmental control systems provide the best growth conditions for various crops, flexibility is essential. In order to maintain the perfect atmosphere for plant growth, performance is essential for making real-time modifications to environmental circumstances. The integrity and dependability of the automation system are ensured by security and privacy, which guard the control systems from illegal access.

Performance, scalability, interoperability, security, and privacy are critical features for crop monitoring and disease detection. Performance is the key priority because prompt disease identification and response depend on high-speed data processing. Scalability is necessary to manage data from large fields and various crop varieties, enabling thorough monitoring. In order to integrate different imaging and sensor technologies and provide a comprehensive picture of crop health, interoperability is crucial. Crop health data is shielded from potential misuse and illegal access by security and privacy measures. Finally, systems for market analysis and forecasting place a strong emphasis on performance, productivity, interoperability, security, and privacy. In order to support decision-making processes, productivity is primarily focused on effective data analysis to produce precise market trends and projections. To provide thorough and reliable analysis, interoperability is essential for integrating various sources of market data as well as other analytical tools. Performance guarantees quick data processing and analysis, allowing for insightful decisions and quick reactions to shifts in the market. Market data and analytical insights are protected by security and privacy, preserving their integrity and confidentiality.

6.3. Practical implications

This study offers valuable insights for developers and users of IoT-based agricultural systems. While many agricultural data management systems rely on centralized cloud models, this research highlights the limitations of this approach in farming's specific context. Middleware technology represents the connection between the hardware, the operating system installed on the hardware, and the top-level applications [60]. This technology can reduce the amount of data processing at higher levels of the application and thus improve portability [61]. Moreover, by applying parallel computing, it is possible to improve processing performance, while through cloud solutions and small clients, it is possible to improve the overall performance of the system and reduce resource consumption [62]. Moreover, integrating cloud storage with edge computing enables efficient data processing and analysis closer to farms, reducing latency and costs.

By applying different network protocols in the specified layer, it is possible to improve the data transfer speed and thus improve their processing, analysis, and application in the IoT system [27]. Reliability of the system can be enhanced by combining the best features of LoRaWAN (for sending small amounts of data from sensors with low power consumption) and the IEEE 802.11ac protocol (for sending video data due to higher data rates) in order to reduce the average latency and number of collected data [35]. Also, designing user-friendly interfaces simplifies interaction for farmers and other stakeholders, encouraging wider adoption of the technology.

Designers are urged to employ a layered architecture that ensures flexibility and scalability, allowing components to be updated or replaced independently. Achieving scalability within the IoT system can also be enhanced by applying a service-oriented software architecture (with the use of middleware) and the Apache Storm component that supports more than 1000/sec tasks while working on the Azure cloud solution. The application of big data analytics and machine learning infrastructure allows greater scalability and modularity in order to more precisely control the data [25]. Adopting a distributed architecture that integrates edge, fog, and cloud computing can offer more efficient and scalable data management for smart agriculture [63]. The development of backend software architecture through separate modules can improve the scalability of IoT systems. On the other hand, a three-tiered software architecture, network, and application can enhance the interoperability of a complete system [64].

Implementing robust security measures like encryption and access controls is crucial to protecting sensitive agricultural data. Furthermore, the developers of IoT-based systems are urged to leverage artificial intelligence and machine learning techniques like federated learning, which allows for training artificial intelligence models on distributed data without compromising privacy. This decentralized approach enhances both security and the predictive power of the overall system. Developers are also urged to establish legal and policy frameworks that ensure seamless information exchange and collaboration across organizations with diverse rules and regulations. This covers data privacy, security, ownership, and compliance with industry standards. Security has been improved thanks to layered software architecture, in this case, a transport layer that allows client authentication [65].

6.4. Research limitations

The methodology employed in this study involves analyzing recent literature on IoT agriculture systems, limited to publications within the last six years. While this approach ensures relevance and timeliness, it inherently restricts the scope of the research to developments and insights within this relatively narrow timeframe. Consequently, valuable contributions from older publications may not be fully captured, potentially overlooking significant advancements or perspectives that could provide valuable context or insights into the evolution of these systems over time. Additionally, this study reviewed only articles that focused only on IoT and agriculture systems integration, excluding other literature that may describe this integration under "smart agriculture." However, smart agriculture systems focus on broader technologies such as irrigation, planting, soil, and so on. Accordingly, including smart agriculture literature would make extracting quality attributes very difficult due to the large amount of literature on smart agriculture systems. Thus, while the research provides valuable insights within its defined parameters, acknowledging and addressing these limitations can offer avenues for future research to explore and expand upon.

7. Conclusions

Over the past six years, there has been a noticeable rise in IoT-based agricultural systems. There is, however, a dearth of study on how these systems' software design satisfies quality standards. In order to fill this research gap, this study reviewed the literature to examine how different software architecture quality attributes are applied in IoT-based systems. The key attributes that were identified and discussed in this paper include: performance, scalability, flexibility, interoperability, extensibility, productivity, security, and privacy. The challenges faced in achieving the requirements for software architecture quality for IT-based agriculture systems were also examined in this study. Interoperability, scalability, data security and privacy, real-time data transmission, and data management were identified as key concerns. These concerns highlight the need for creative solutions and strong architectures suited to the particular requirements of agricultural contexts. We identified that extensive frameworks are required to handle issues of scalability and interoperability while integrating a variety of IoT devices and protocols. Furthermore, maintaining data security and real-time functionality continues to be crucial, necessitating the use of cutting-edge strategies including edge processing, specialized databases, and lightweight data models. Future research may concentrate on improving system reliability, scalability, and data management and transmission as the IoT continues to alter agriculture. It may also take security and privacy considerations into account. Collaboration amongst researchers, practitioners, and politicians can open doors for creative solutions that support sustainable agriculture practices, empower farmers, and maximize resource use.

Ethics statement

Not applicable: This manuscript does not include human or animal research.

CRediT authorship contribution statement

Alok Mishra: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Yehia Ibrahim Alzoubi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis. **Nebojsa Gavrilovic:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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