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Applications of the Internet of Things (IoT) and Blockchain for Agriculture in Indonesia

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ABSTRACT

The agricultural sector is a source of food, clean water, and natural medicine, which is very important for human life. Agricultural problems need to be handled by the massive use of robotics and artificial intelligence technology along the agricultural value chain from upstream to downstream (from land to consumer) with the help of satellites and drones for remote sensing. Precision Agriculture is a system where input, process, and output parameters are measured and controlled precisely and accurately to produce efficient and productive agriculture. This paper aims to present the applications of Internet of Things (IoT) and blockchain technology in Indonesia's agriculture. Three case studies and conceptual designs are presented, i.e., IoT and machine learning for quality monitoring of mango in long-distance transportation, IoT and blockchain application for logistics and supply chain system of melon, and IoT application in Smart Algae Pond for microalgae biomass production.

Keywords: agriculture, blockchain, Indonesia, Internet of Things, machine learning

INTRODUCTION

Being on the equator and the third most biodiverse country, Indonesia is one of the largest agricultural countries and the sixth-largest exporter of agricultural products in the world. The agricultural sector is a source of food, clean water, and natural medicine, which is very important for human life. If this sector is left without a touch of advanced digital technology, such as robots and artificial intelligence (AI), agricultural problems will become more severe and can disrupt national stability (Arkeman, 2021).

Agricultural problems in Indonesia need to be handled by the massive use of robotics and artificial intelligence technology along the agricultural value chain from upstream to downstream (from land to consumer) with the help of satellites and drones for remote sensing. This system is called Precision Agriculture because the input, process, and output parameters are measured and controlled precisely and accurately to produce efficient and productive agriculture. An intelligent system allows the agribusiness and supply chain managers to determine, for example, when to harvest certain plants in the fields or gardens, in what quantity, what quality, where to market, when to reach consumers, and at what price. Therefore, a balance between supply and demand can always be maintained. This system applies to agriculture broadly, including fisheries, marine (maritime), livestock, and plantations (Arkeman, 2021).

Numerous applications of Precision Agriculture in developed countries included driverless tractors for land cultivation, drones for fields and plantations monitoring, and even the combination of bioinformatics and genetic algorithms to search for superior seeds. Automated harvest and postharvest processes use rapid and non-destructive quality testing methods. The agricultural product collection system can determine the shortest vehicle route with ant colony optimization techniques. Blockchain technology and big data increase the transparency of the flow of goods and monetary along the value chain of agricultural products (Arkeman, 2021).

For future agro-industry development (Agro-industry 4.0), there are several other robotics and artificial intelligence technologies, i.e., intelligent packaging systems, adaptive inventory systems with non-linear models for perishable agro-industry products, intelligent vision systems for product sorting, non-destructive quality testing for final product quality assessment, intelligent bioreactors, intelligent agro-logistics systems using blockchain technology and agent-based modeling techniques to study changes in consumer preferences and many others (Arkeman, 2021). Therefore, applying high-precision technology in agriculture and agro-industry can overcome agriculture and food shortage problems. This study aimed to present the applications of Internet of Things (IoT) and blockchain in Indonesia's agriculture. Three case studies and conceptual designs are presented in this article.

INTERNET OF THINGS AND BLOCKCHAIN: STATE OF THE ART

Internet-of-Things (IoT) aims to integrate the physical world with the virtual world by using the internet as a medium for communicating and exchanging data. IoT is a system of interrelated computing devices, mechanical and digital instruments, objects, or people equipped with specific identifiers and data transferability over a network without human-to-human or human-to-computer interaction (Elijah *et al.*, 2018). The implementation of IoT in various aspects of agribusiness has been studied and reported, especially in developed countries (Tzounis *et al.*, 2017; Villalobos *et al.*, 2019).

For instance, IoT architecture has been applied in many developed countries worldwide to monitor quality and support decision-making by supply chain management. The IoT architecture design along the supply chain connects various supply chain actors with data input from supply chain actors, machine learning and cloud computing for data processing, and communication networks for information transfer. Applying local sensing and communication architectures can create a more comprehensive online monitoring of fresh produce quality, especially for short distances using trucks, compartments, or cold storage rooms. This sensor can be integrated with a Wi-Fi interface or 3G / 4G network to communicate data to users (Pang *et al.*, 2012; Jedermann *et al.*, 2014; Pal and Kant, 2020; Torres-Sánchez *et al.*, 2020). The supply chain operations of fresh produce are transforming rapidly with the infusion of information technology, from non-destructive quality assessment, automation in product handling, labeling standardization, packaging, logistics management, and many more. Online monitoring and operational control have been utilized to maintain food freshness and safety, reduce food loss and waste, and increase transportation and distribution efficiency (Pal and Kant, 2020).

In addition, the intelligent monitoring and control of the cultivation system are crucial in agriculture because it increases the production and quality of products and prevents the critical conditions for the key parameters that can compromise the farming system. Dorado *et al.* (2016) designed an intelligent farm system to classify and grade tomatoes. The process automatically used image processing and fuzzy logic. The system classified if a tomato was damaged or not and distinguished if a specific fruit or crop is under-ripe, ripe, or overripe. It was believed that the study was of great help to farmers for high yield and productive plant harvests. Esposito *et al.* (2017) developed an affordable and easy-to-use IoT application for the control and monitoring of a microalgae cultivation equipped with biological modeling for Decision Support System (DSS) to the operator for managing a production plant in Southern Italy.

Along with IoT, blockchain is becoming a preferred solution for improving traceability and security problems in the food supply chain. It is a chain of blocks that stores all information from network activities in a supply chain (Tian, 2016). It is a traceable database that allows all users to add data as a transaction. Users can review each data submitted by other users, but without the ability to change it. A mining process controls the security and validity of the system by verifying the data (block) before adding them into the chain. Surasak *et al.* (2019) designed and developed a traceability system for Thailand's agriculture products. Blockchain enhances transparency and data integrity. They added OurSQL on another layer to help the query process of the blockchain database, making the system more user-friendly than an ordinary blockchain database. Users can use the website and android application to follow the product tracking information.

In the agricultural sector in Indonesia, important information such as grain prices, soil quality, and land ownership from farmers and farming agents can help Indonesian farmers increase annual yields. Indonesia is fertile land for agricultural and plantation production such as rice, secondary crops and oil palm, but the entire industry is still hampered by a series of deep-rooted problems, such as poor land use practices, very long supply chains, adulteration, and fraudulent middlemen. Therefore, IoT and blockchain technology should be introduced and spread urgently in Indonesian agriculture to overcome those problems.

Agriculture is an activity that is prone to risk, because the commodity is easily damaged. A traceability system is needed to ensure that the commodity is received in good condition by consumers. In agricultural supply chain management, blockchain technology allows actors to trace the supply chain of their products, so they can control the quality of these agricultural commodities. The adoption of blockchain technology can help reduce the business risks. For example, blockchain technology can reduce the number of suppliers or players in a long supply chain process. This is the importance of blockchain technology in improving agribusiness supply chain management (Vikaliana *et al.*, 2020).

Blockchain is exceptional in alleviating the utilization of smart contracts. Shahid *et al.* (2020) proposed a reputation system to maintain the credibility of agrifood supply chain entities. They provided algorithms and discussed the performance of smart contracts in blockchain. The coupling of the blockchain database with the Internet of Things allows the traceability system to collect real-time information and store it in a secure database. It is essential in improving food safety and quality control in any part of agribusiness activity in Indonesia.

METHODOLOGY

System design

The general method used in the study consisted of several stages, i.e., problem identification, architectural design, program implementation, and evaluation (Figure 1). More specifically, a desk study preceded the study to identify background and problems. Requirement analysis provided comprehensive information to develop a system design. It included the requirements of the users and the system, which were essential to formulate the business process and would be needed in the evaluation stage after implementing the system design (Figure 2).

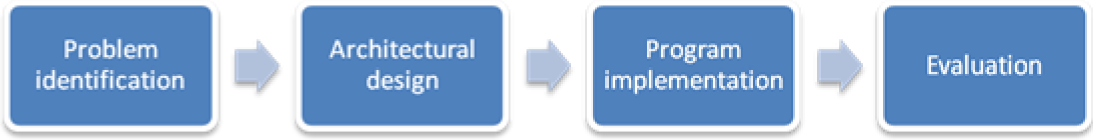

Figure 1. The general method of system design development.

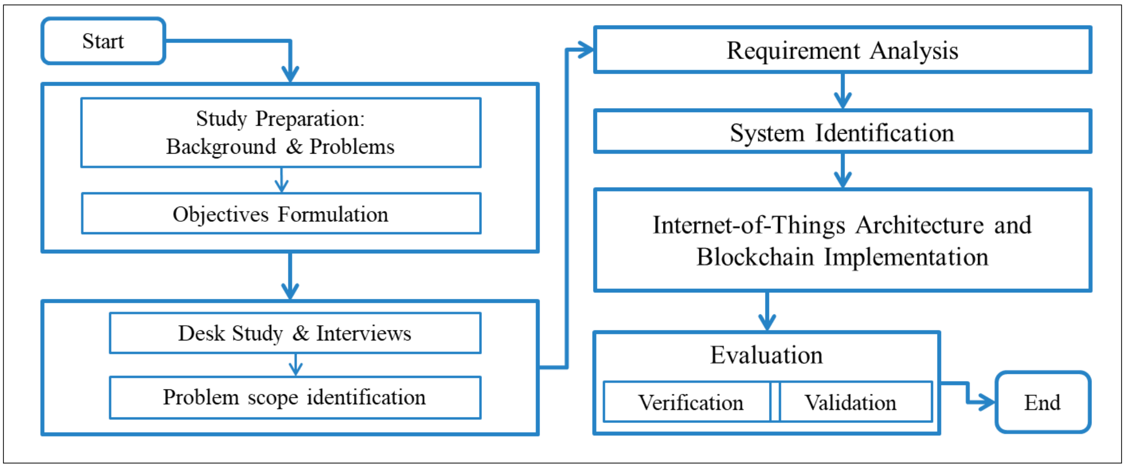

Figure 2. The flow chart of the implementation of the system design.

Requirement analysis guides researchers in developing their method and architecture development. Generally, an IoT architecture consists of four layers, covering different stakeholders' requirements. Data collection, processing, network connection, and communication / application are performed in separate layers. A well-designed IoT system provides continuous monitoring and triggers the appropriate events according to the requirement (Mondal and Rehena, 2018). Surasak *et al.* (2019) designed the system architecture into two main components, i.e., hardware and service. The hardware-oriented design included IoT devices, servers, and smartphones. In contrast, the service-oriented design included client, system management, and cloud services.

Michael *et al.* (2019) focused on the privacy concerns of the data flow in six stages, i.e., data source, data capture, primary use, data storage, data reuse, and data removal. Iswari *et al.* (2019) emphasized that the development of a blockchain system needs to be preceded by a system requirement analysis to determine the required components in the blockchain system. The requirement analysis also helps the coding process. Two diagrams of Unified Modeling Languages (UML), i.e., use case diagrams and sequence diagrams, are used to analyze the system requirement. Their study results showed that the blockchain system needs two inputs, i.e., (1) the structure of the supply chain and the activities that occur in it, and (2) four stakeholders (farmers, collectors, agroindustry, and exporters.

The IoT architecture design developed starts from data communication settings to the system used for monitoring and controlling. The IoT architecture designed is based on three important layers, i.e., the perception layer which functions as a sensor that takes data from the environment and sends data to the network layer in a certain form; the transport layer which functions to connect the sensor with the application through the microcontroller; and the application layer as an application that interacts directly with the user (Sethi and Sarangi, 2017). The system testing carried out includes functional testing, and performance testing. Functional testing is carried out on the system that is made whether it can run well or not by using the black-box method. Meanwhile, the performance testing of a protocol includes several aspects, i.e., protocol delay, packet loss and bandwidth used.

THREE CASE STUDIES AND CONCEPTUAL DESIGNS

IoT and machine learning for quality monitoring of mango in long-distance transportation

Mango is one of Indonesia's superior fruits. Some of the main challenges in Indonesia's mango trading activity are the long supply chain, both for domestic trading and export, the perishability of the fruit, and the lack of quality monitoring. These challenges have resulted in quality uncertainty and insecurity, high postharvest losses, and inconsistent export performance.

The challenges mentioned above have been addressed in the global trade environment by monitoring real-time transportation conditions (Jedermann *et al*., 2014; Lin *et al*., 2015; Hsiao and Huang, 2016; Torres-Sanchez *et al*., 2020). Moreover, real-time quality prediction has become available now that machine learning techniques and IoT have grown rapidly (Jedermann *et al*., 2014; Badia-Melis *et al*., 2018; Pal and Kant, 2020. The development of IoT architecture and a well-built information system would be the foundation of the real-time quality monitoring system. The framework is presented in Figure 3.

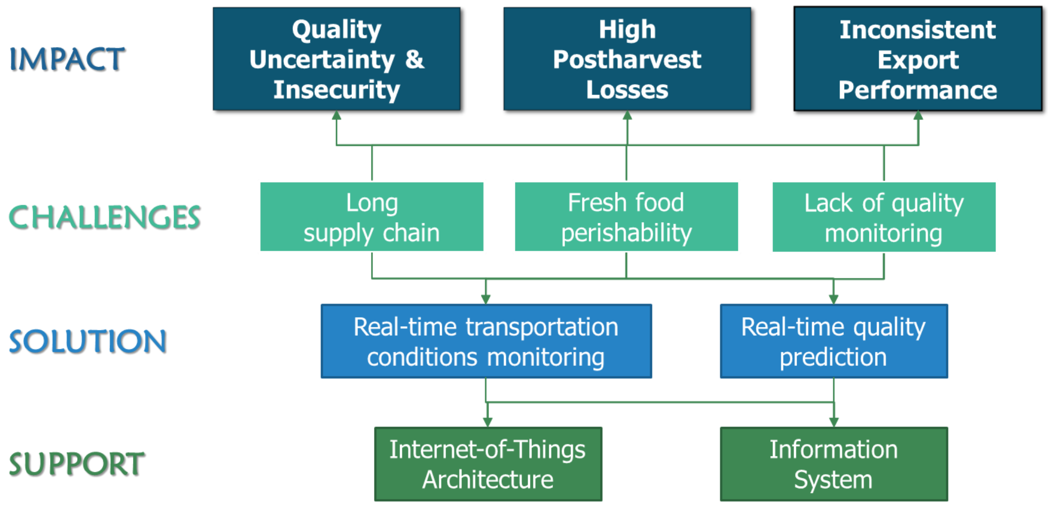

Figure 3. The framework of the quality monitoring system development.

Among the main factors influencing mango quality are maturity level and transportation conditions (Medlicott *et al*., 1990). As in other climacteric fruits, mango's ripeness does not occur simultaneously in each tree. This characteristic is a serious challenge in global trade and long supply chains. In order to achieve better sorting and grading results, advanced technology, such as thriving non-destructive techniques, needs to replace manual subjective evaluation methods. More importantly, combining non-destructive techniques with AI technologies can produce a more accurate prediction of fruit maturity classification.

Recent studies have shown that ICT implementation can achieve optimization of perishables supply chains. Real-time information, such as temperature and humidity, and ultimately the remaining shelf life, should be accessible to stakeholders (Jedermann *et al.*, 2014; Lin *et al*. 2015; Hsiao and Huang, 2016). Integration of AI and IoT allows accurate and timely reports for stakeholders. Therefore, the quality of monitoring system is supported with sufficient information for supply chain actors to make better logistics decisions (Badia-Melis *et al.*, 2018).

IoT implementation in various agribusiness aspects has been studied and reported, especially in developed countries (Pang *et al.*, 2012; Tzounis *et al.*, 2017; Villalobos *et al.*, 2019). The non-destructive method integrated with IoT technology is a rapid and practical provider of quality information on fresh produce. Integrating IoT technology with the non-destructive quality measurement and monitoring transportation environment conditions allows supply chain actors to exchange and obtain information regarding products' real-time quality, anytime and anywhere.

The presented paper focuses on a supply chain of mango, which includes long-distance transportation and quality monitoring problems. We propose an approach to address the problems using artificial intelligence and IoT integration. A quality monitoring system can use data from the non-destructive measurement of initial maturity level and the real-time transportation conditions from IoT sensors to predict the final grade of mango after long-distance transportation. Figure 4 describes the activities conducted to develop the quality monitoring system.

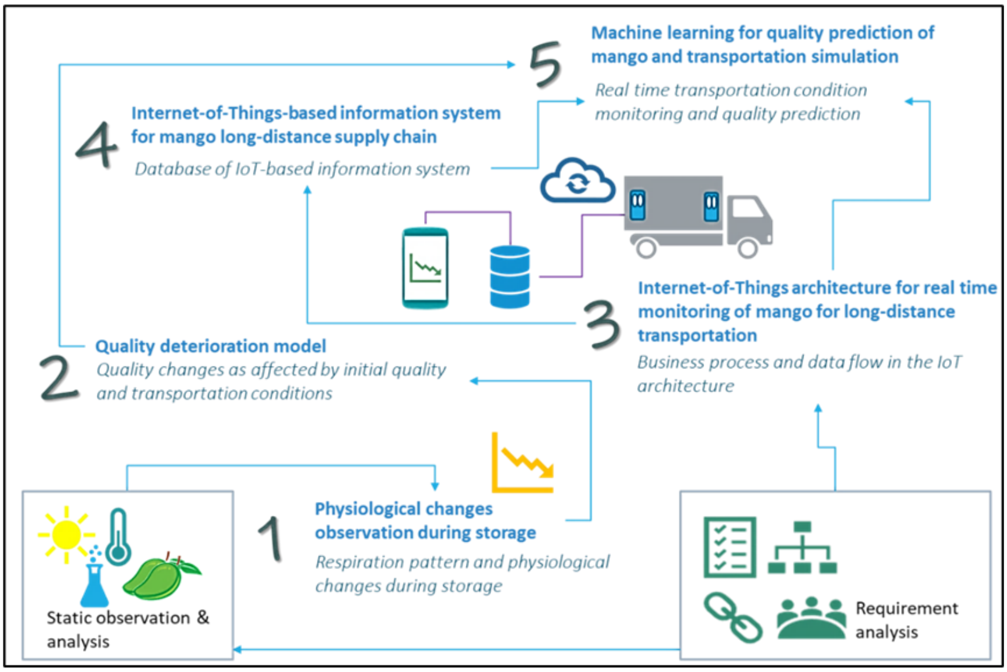

Figure 4. Research stages of developing a real-time quality monitoring system for long-distance transportation of mango.

The first stage is a thorough laboratory experiment that includes destructive and non-destructive measurements to obtain mango's respiration patterns and physiological changes during storage. The data obtained in the first stage is used to develop a quality deterioration model in the next stage. Simultaneously, an IoT architecture is built (stage 3) and integrated into an information system to provide stakeholders with real-time data (stage 4). The quality deterioration model and the real-time transportation condition streaming from the IoT devices are utilized to develop the quality prediction model in the last stage.

The IoT architecture development in the study includes building four layers, i.e., sensing, network, service, and application (Ray, 2018; Jagtap and Rahimifard, 2019), as shown in Figure 5. The IoT architecture design will meet the needs of the supply chain actors to monitor the transportation conditions and predict the final quality of mango upon arrival. The IoT architecture will consist of a series of sensors, a storage and linkage system (such as database, servers, and distributed computer networks), and several wired and wireless communication infrastructures (Wi-Fi, cellular, satellite, power line) (Gubbi *et al.*, 2013). Due to its pervasive nature, all sensors and devices generate a vast amount of data, processed to extract meaningful information to support decision-making (Zaslavsky, Perera, and Georgakopoulos, 2013).

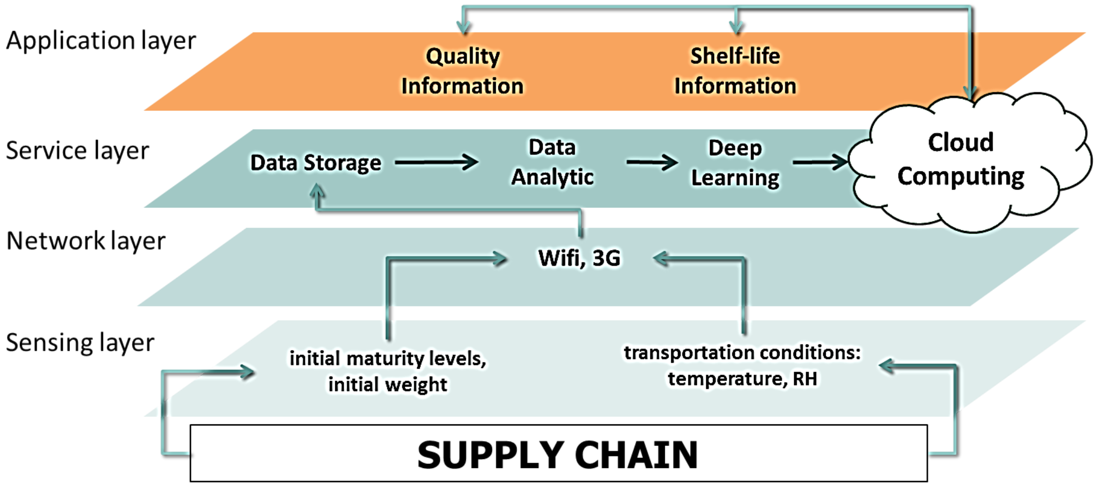

Figure 5. The IoT architecture for real-time quality monitoring of mango for long-distance transportation (modified from Jagtap dan Rahimifard (2019)).

In this study, the quality prediction of mango mainly used the data of initial maturity levels and real-time transportation environment conditions, i.e., temperature and relative humidity, to predict the final grade (Figure 6). Initial maturity level data obtained from non-destructive measurement using a NIR instrument and the transportation conditions data retrieved from the IoT sensors were processed and analyzed by a machine learning. The data are stored and processed in the Cloud and accessible to stakeholders by connecting to Wi-Fi or a 3G/4G network.

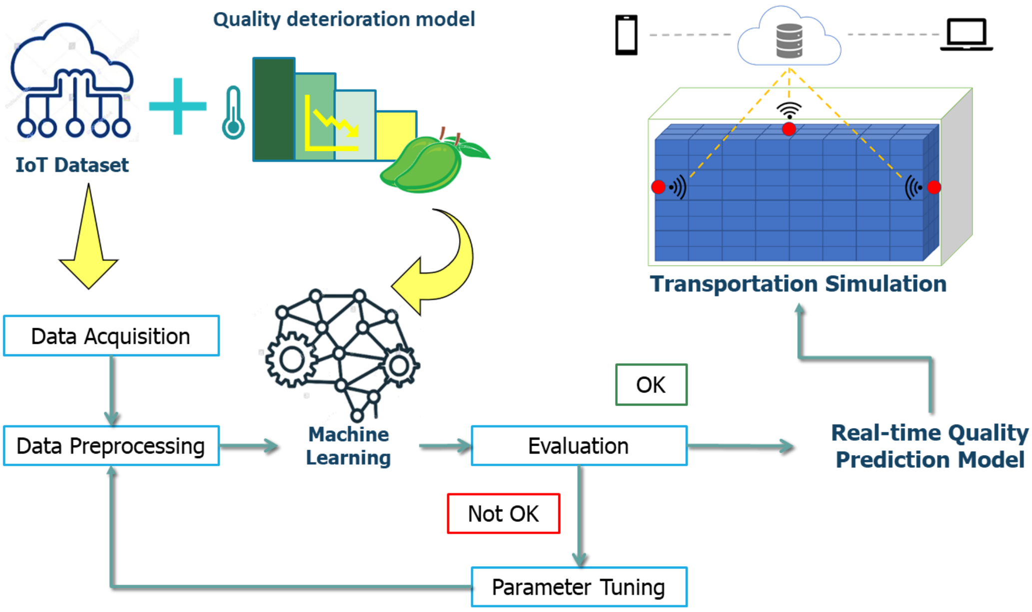

Figure 6. The integration of machine learning into the IoT architecture to develop a real-time quality prediction system.

Finally, the success of IoT architecture implementation in a system is determined by its design and service. Sayar and Er (2018) analyzed two IoT implementations in manufacturing companies. Successful implementation required solid product design and, more importantly, a well-designed system and well-executed service. Customer needs have to be monitored so that companies can anticipate and address various needs that would arise.

IoT and blockchain application for logistics and supply chain system of melon

Melon (*Cucumis melo* L.) is one of the most important fruits consumed and grown globally and plays an important role in horticulture around the world (Zhang *et al.* 2020). Indonesia produced more than

122,105 tons of melons in 2019 (Central Agency on Statistics, 2019). In tropical environments like Indonesia, heat and humidity are common throughout the year. This climate affects fruit quality after harvest, including melon quality (Darmajana *et al.*, 2018).

Fruit quality is a major concern for the government and consumers, industry players, and policymakers (Lehtinen 2011). The origin of the product, raw materials, production methods, applicable work standards, and the production process's environmental impact are essential issues (Khan *et al.*, 2018). Because the supply chain of agricultural products, in general, is still long, the quality of final consumer products is not maintained due to the length of the supply or distribution chains. As a result, end consumers are increasingly concerned about the origin, delivery conditions, and food quality. Therefore, this growing supply chain sector requires a complete, efficient and effective food traceability system (Tsang *et al.*, 2019).

To overcome the above challenges, a blockchain-IoT based melon freshness tracking system was proposed in this study to achieve the following objectives: (i) to integrate blockchain and IoT technology for efficient and effective traceability, and (ii) to support shelf life adjustment and quality loss assessment to improve quality assurance. For better computing load, the blockchain was modified as a lightweight blockchain to be associated with cloud computing to support IoT monitoring and can be vaporized after the entire traceability lifecycle to release system computing resources. Based on these reliable data sources, decision support in food quality can be performed using blockchain technology and IoT, and artificial intelligence in managing the shelf life of melons.

Integrating blockchain technology and IoT is an important contribution expected to revolutionize digital transformation in many fields (Makhdoom *et al.*, 2019). Blockchain can be validated and deployed across many heterogeneous IoT networks as a distributed ledger. One of the most promising trends in which blockchain and IoT can work together in 2030 is tracking and managing global supply chains. In addition, blockchain and IoT benefits in digital energy and smart networks are another important trend in 2030 (Yang *et al.* 2017). This study discusses in more detail the design patterns of blockchain, IoT, and supply chains for agriculture, the main solutions that blockchain can provide for IoT challenges, and the latest blockchain protocols in IoT networks.

The planning stage of melon's supply chain management system is based on IoT and Blockchain. There are four participating entities; each participating entity has a role and interaction with smart contracts (Figure 7).

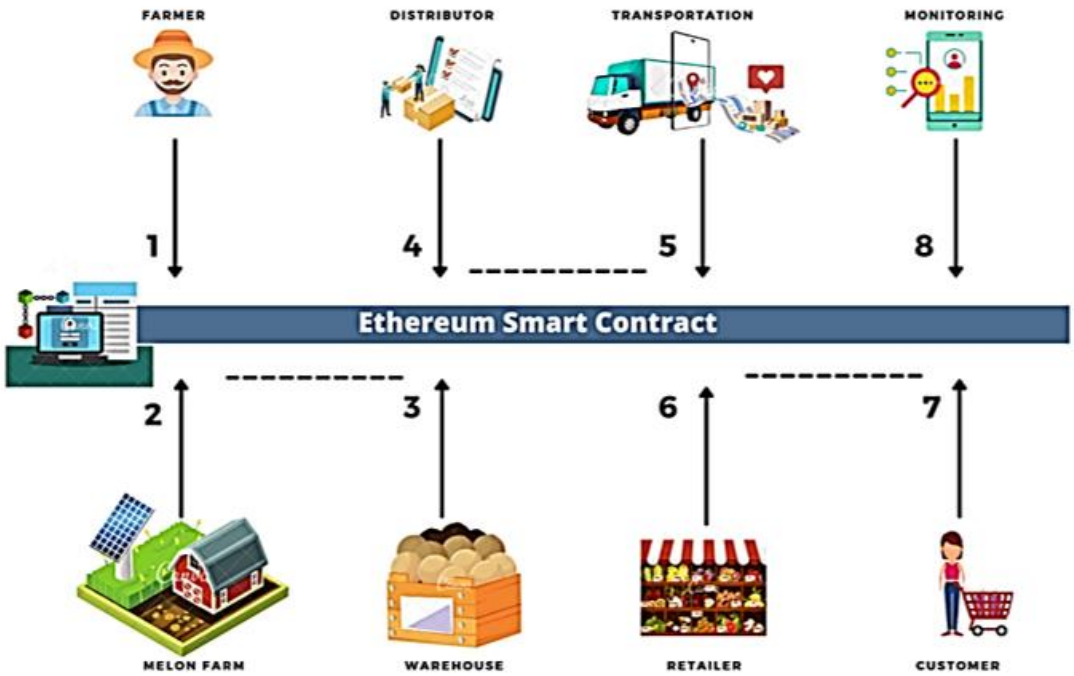

Figure 7. Flowchart of blockchain system in IoT-based melon supply chain management.

This research was conducted in several stages. The first stage was to classify the melon's temperature, and humidity dataset entered into the NodeMCU ESP8266 Module, then processed into the temperature and humidity sensors. The sensor used was the DHT11 sensor. The second stage was implementing IoT devices for all stakeholders in the melon supply chain, including those stored in melon storage warehouses, distributors, and retailers. Smart contracts then blocked the results of the information provided by the temperature and humidity sensors. The third stage was building a blockchain, in which transaction data related to the freshness of melons was encrypted into the blockchain.

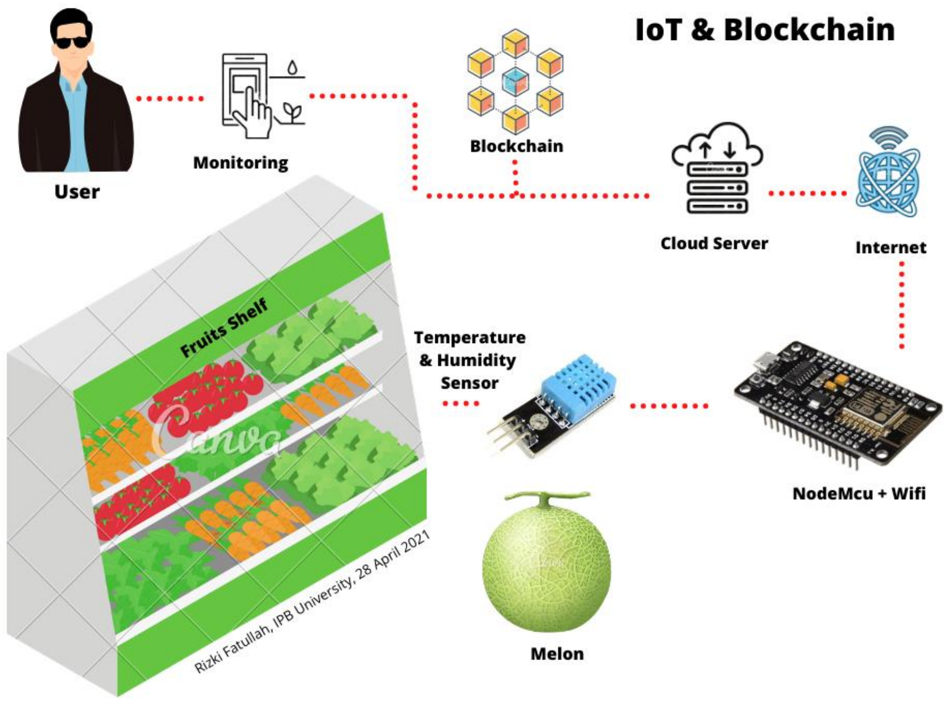

Figure 8. Flowchart of IoT-based melon's freshness monitoring system (retailer).

This study was designed to investigate the importance of integrating blockchain technology and the IoT in developing intelligent systems and applications in precision agriculture. The integration of these technologies demonstrates that blockchain performance introduces new solutions to food safety and transparency issues in IoT-based precision farming systems.

This research is one of the efforts to investigate how the integration between IoT and blockchain can be implemented in the precision agriculture domain, especially in fresh fruit traceability. Finally, in this case, the traceability of fresh melons requires more research to study and prove the relationship between blockchain technology and IoT.

IoT application in Smart Algae Ponds for microalgae biomass production

Microalgae biomass production is promising as a source of food, feed, high value chemicals, and sustainable biofuels (Yen *et al.* 2013; Chew *et al.* 2017). The main challenge to the production of microalgae biomass lies in the scale-up of production, high production and processing costs. These costs are mostly caused by energy consumption, operations and production systems that are not controlled effectively and efficiently (Wibawa *et al.* 2018). This article reported the development of a precision agriculture approach through the sensor applications and Internet of Things (IoT) applied in a Smart Algae Ponds to achieve optimal microalgae biomass production that is controlled effectively and efficiently.

Design and architecture of IoT for the microalgae cultivation process has been successfully developed (Figure 9). The monitoring side has succeeded in sending data to the database through the broker system and the controlling side has succeeded in giving orders to the actuators properly. In addition, a secure and fast data communication system using AWS IoT Core has been successfully established. The MQTT protocol can be implemented on the IoT architecture, so that the system can run effectively and efficiently in the monitoring and controlling of microalgae cultivation process. Sensor data can be accessed in real time on the LCD and can then be monitored with the IoT system via the internet (web application).

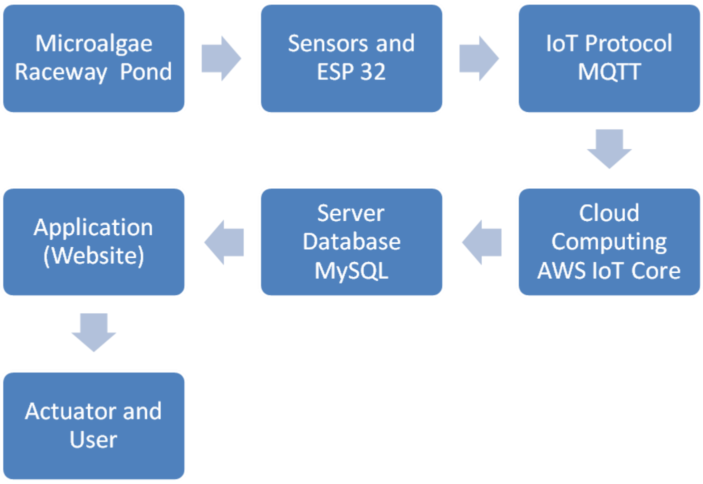

Figure 9. IoT architecture in the Smart Algae Pond application.

The microalgae raceway pond with a volume of 120 L was designed and used in the study. The Smart Algae Pond design includes three main functions (Figure 10): smart mixing to regulate the mixing of microalgae media/culture (paddle wheel speed) based on the light intensity, smart monitoring and control of nutrients, CO_2 supply and pH, and smart automated harvesting system that are connected to the IoT architecture (Hermadi *et al.* 2021).

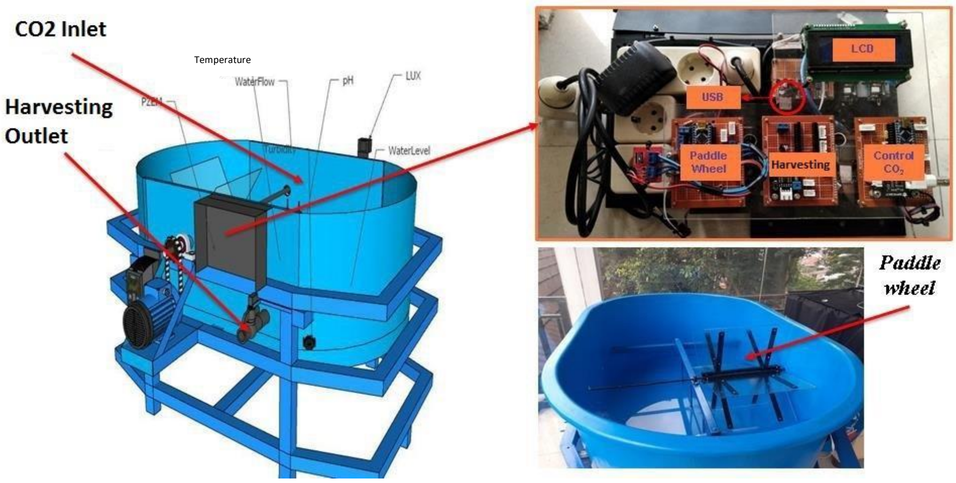

Figure 10. Design of the Smart Algae Pond.

One of the IoT-integrated systems used in this Smart Algae Pond is the smart mixing system. The principle of the smart mixing is that the paddlewheel mixing speed can be adjusted automatically based on the light intensity (Hermadi *et al.* 2021). In this system, sensors for measuring temperature, electric current and voltage and light intensity sensors can be controlled by the microcontroller, the data from the readings is sent to ESP32, then ESP32 transfers the data to HTTP protocol to be sent to database MySQL. This system makes the paddlewheel only move at the appropriate speed based on the light intensity. In this case when there is no light, for example at night when there is no photosynthesis, the mixing system will work slower as necessary.

The photosynthesis process can be optimized by controlling the mixing which is automatically based on the intensity of the incoming light. In addition, using the smart monitoring and control, photosynthesis and respiration processes are more optimal by controlling the supply of CO_2 as required. The pH value is stable compared to the uncontrolled supply of CO_2. This system allows the cultivation system to work efficiently and have electricity savings. The design for the smart mixing system is illustrated in Figure 11.

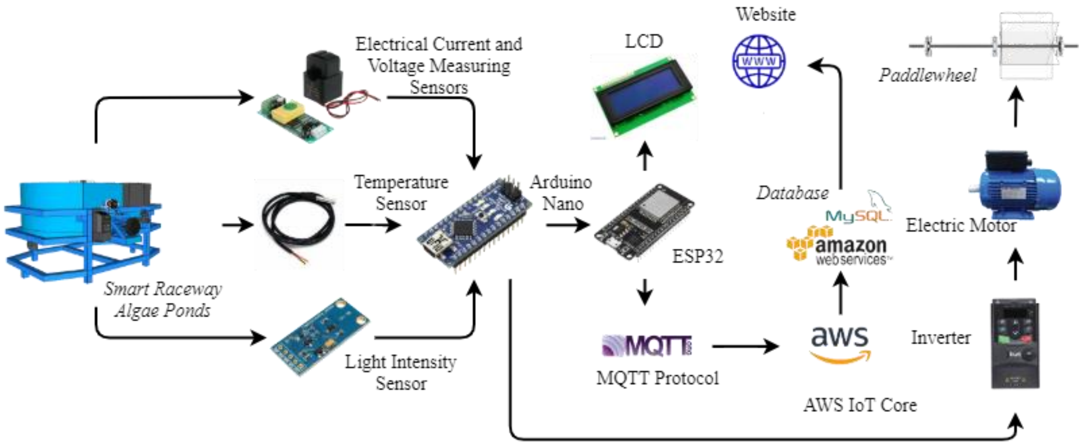

Figure 11. Design of the smart mixing (paddlewheel) system (Hermadi *et al.* 2021).

The development of precision agricultural systems in microalgae cultivation using advanced digital technology, i.e., IoTbased monitoring and automation of microalgae cultivation operations is very important to significantly increase the precision and yield with the aim of achieving more effective and efficient microalgae biomass production (Elijah *et al.* 2018). Monitoring with sensors will improve the proper operation and management of environmental factors and controlled microalgae growth and nutrient supply (Hermadi *et al.* 2021). IoT has proven to be helpful in making appropriate decisions and management in microalgal biomass production systems (Esposito *et al.* 2017).

CONCLUSIONS

The integration of machine learning and the IoT architecture, supported by the information system, creates a quality monitoring system to deliver real-time transportation information and quality prediction. The system improves the supply chain actors' capability in logistics-related decision-making. Integrating blockchain technology and the IoT in developing intelligent systems and applications in precision agriculture introduces new solutions to food safety and transparency issues in Indonesian farming systems. The design and architecture of IoT for three important agricultural commodities, i.e., mango, melon, and microalgae, have been successfully developed. The formulated solution for the mango quality monitoring problem in a supply chain with long-distance transportation can improve stakeholders' capacity to make better logistics decisions and increase the quality assurance of the products. This achievement will lead to Indonesia's better ability to distribute mango across the country, meet export demand, and ultimately improve agroindustry development. The applications of sensors and IoT could improve the real-time quality monitoring and automatic control of the product effectively and efficiently. The blockchain and the IoT integration in developing intelligent systems and applications has been demonstrated in Indonesia's precision agriculture.

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AUTHORS' CONTRIBUTIONS

Y.A., S.I.K., R.F. acquired funding; Y.A., S.I.K., G.S., R.F. designed research; S.I.K., G.S., R.F. performed research and analyzed data; Y.A. supervised research; Y.A., S.I.K., G.S., R.F. wrote the original manuscript; S.I.K., G.S. revised and edited the published manuscript.

COMPETING INTERESTS

Y.A., S.I.K., G.S., and R.F. declare that they have no conflict of interests.