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Enhancing Agricultural Efficiency Through IoT-Based Nutrient Control and Monitoring System for Horticultural Plants

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Abstract*—There is an increasing need for efficient and effective systems to monitor and control the nutrition of horticultural crops using the Internet of Things (IoT). This research aims to develop a system that can monitor and control the nutrition of horticultural crops with high accuracy using IoT-based sensors and actuators. The research method used is Rapid Application Development (RAD), which starts with listening to users to obtain data on problem needs, building systems by making mockups, and rapidly designing devices according to user needs. The developed IoT system was successfully implemented in the natural environment with Android-based software development. The monitoring data from the database shows that this IoT tool works well during cultivation, and there is no time lag in data retrieval. Monitored data includes pH, water temperature, air temperature, EC, and data recording time. IoT tools for nutrient control and monitoring can also help in irrigation and proper maintenance of plant nutrient needs. The developed IoT system can be used as a solution to optimize nutrition in horticultural crops. This system can control and monitor nutrients in plants using parameters such as water temperature, EC, humidity, air temperature, and water temperature measured by sensors. IoT tools for nutrient control and monitoring can also help maintain plant nutrient requirements through proper irrigation. Therefore, the development and implementation of IoT systems on a larger scale is recommended to increase efficiency and effectiveness in agriculture.

***Index Terms*— IoT system; nutrient control; monitoring; horticultural plants; sensors; android-based software.**

I. INTRODUCTION

Global food demand is a pressing issue. It's driven by factors such as population growth, increased food consumption, and the effects of climate change. The United Nations projects a 60% increase in global food production by 2050 to meet these demands [1]. However, arable land is limited, and water scarcity threatens future production potential [2]. To address these challenges, it is critical to focus on increasing yields and advancing agricultural research and innovation[3]. Neglected and underutilized species are recognized as alternative food sources that can be grown on underutilized land without competing with existing crops [4]. In addition, investment in technology, biotechnology and industrial methods for food production is recommended [5]. Agricultural modernization and improved technology are essential for a sustainable agricultural revolution to meet the growing food needs of the population.

The need to carry out nutritional control and monitoring of horticultural crops has arisen due to the increasing demand for food, the decreasing amount of arable land, and the prevalence of micronutrient malnutrition. Precision agriculture systems using Internet of Things (IoT) technology can provide comprehensive agricultural monitoring at multiple levels, enabling optimal resource utilization and increased agricultural production [6]. The biofortification program aims to address nutrient deficiencies in horticultural crops through modern breeding, GMO approaches, and agronomic enhancement, thereby improving the nutritional quality of food crops [7]. Monitoring and control systems for horticultural facilities allow precise control of environmental factors such as temperature, humidity, CO2 and light conditions. This results in an optimal growing environment and improved crop quality [8]. The study of plant nutrition, both on short and long time scales, is critical for understanding the mechanisms underlying nutrient uptake and predicting plant nutrient requirements, providing a basis for fertilization advice and diagnosis through plant analysis [9]. Automated and continuous monitoring of plant constraints, water use, growth, and nutrients in horticultural crops can improve climate management, yield and quality, and reduce environmental impact [10].

IoT-based control and monitoring systems for horticultural nutrition have been proposed in several papers. These systems use sensor nodes to monitor various parameters such as water quality, temperature, humidity, and nutrient levels in greenhouses [11][12][13][14]. These sensor nodes are responsible for controlling pumps and valves, detecting nutrient levels, and scheduling irrigation. Collected data is transmitted wirelessly and can be accessed remotely through a smartphone application-based interface. The system aims to optimize crop growth by ensuring that plants receive the necessary nutrients and are grown in optimal conditions. It also provides features such as real-time data collection, nutrient classification, and an easy-to-use interface to facilitate monitoring and management of nutrient uptake. This IoT-based system offers increased reliability, stability and efficiency in horticultural nutrient control and monitoring.

Research on IoT-based control and monitoring systems for horticultural nutrition has been proposed in several papers. Systems that use sensor nodes to monitor various parameters such as water quality, temperature, humidity, and nutrient levels in greenhouses can be found in the literature. We investigate related work to identify the essential points in this area and the niche of opportunity that comprises advanced methods of this type of system.

In Bahman Javadi's 2017 study [14], To improve the accuracy of nutrient monitoring, researchers proposed an intelligent nutrition monitoring system using IoT technology to collect reliable nutrient intake data from various sensors. The system uses a trunked sensor with an additional camera.

In a 2021 Irawati study [15], This study discussed the design of a system to monitor water quality and nutrients in hydroponic plants using Internet of Things technology. In this study, researchers combined hydroponic plants with the help of Internet of Things technology using hydroponic planting techniques to extend the benefits of Internet connectivity that is continuously connected. The system can monitor water quality and nutrients using the Blynk app and the working NodeMCU microcontroller. The sensor used to measure solids in dissolved water is the DS18B20 sensor.

In Ding Jiong's 2018 study [16], researchers proposed an Internet of Things control system for agriculture consisting of a plant data acquisition unit to obtain plant data. The environmental data acquisition unit is obtained from the environment around plants derived from meteorological data and the central control subsystem to produce plant cultivation instructions and environmental adjustment instructions. Monitoring is carried out in realtime and can be optimally in the process of agricultural production.

In M. Prasad's 2021 study[17], This study discusses IoT in CERAS agricultural systems to create an artificial environment for efficient plant growth. The results of this study show that all plant growth factors are stabilized, so it is possible to grow crops in a shorter time compared to the average plant time because photosynthesis is carried out throughout the day. This farming is done inside an electronic environment packaged with LEDs. Environmental factors such as temperature, humidity and air quality are electronically monitored using sensors. The yield of this farm plant growth rate can be twice as fast as conventional.

In King Venkatesh Gurugubelli's 2021 study [18], Researchers used ESP32 NodeMCU to create IoT-based smart farms in agriculture. In this research using ESP32 NodeMCU, DHT11, and soil moisture sensor, GSM module, and data can be directly monitored in the Things of Speak application, which is an IoT platform that can remotely monitor and control their crops according to modern farming methods. By using this technology, farmers can increase crop yields and save water.

The Internet of Things (IoT) refers to a network of interconnected devices that can communicate and share data over the Internet. By automating tasks and transmitting data without physical interruption, the IoT enables objects to become "smarter" [19]. It involves everyday objects embedded with electronic hardware and software that can be controlled or sensed remotely [20]. IoT has a wide range of applications in areas such as medicine, infrastructure, and education, where IoT can facilitate communication between machines and the development of smart cities [21]. IoT devices can collect data, drive actions, and reduce reliance on human intervention for data collection and interpretation [22]. IoT concepts include the ability to share information and autonomously respond to real-world events, trigger processes, and create services with or without human intervention [23].

The Internet of Things (IoT) is a network of physical objects embedded with electronics, software, sensors, and network connectivity that enables them to collect and exchange data. IoT enables direct integration between the physical world and computer-based systems, resulting in increased efficiency and economic benefits. IoT devices connect to a central management portal to provide data, such as single board computers (SBCs) integrated with sensors[24]. IoT protocols are divided into application protocols, service discovery protocols, infrastructure protocols, and other influential protocols [25]. Common operating systems used in IoT environments include Tiny OS, Contiki, Lite OS, Riot OS, and Android [26]. IoT provides services such as smart buildings, smart homes, smart grids, smart cities, and smart healthcare [27]. IoT sensors enable wide-area connectivity using technologies such as GSM, GPRS, 3G, and LTE, and can be connected via RFID, WiFi, Bluetooth, and ZigBee [27].

IoT uses a variety of network protocols for data transfer and communication. Some commonly used protocols include MQTT (Message Queuing Telemetry Transport) and CoAP (Constrained Application Protocol) [28]. Other protocols used in IoT networks include IPv6, 6LoWPAN, ZigBee, Bluetooth Low Energy (BLE), Z-Wave, Near Field Communication (NFC), SigFox, and Cellular [29]. To improve the interoperability of the services, a protocol-converting method has been proposed, which allows to convert the packets into an intermediate format before converting them into the targeted protocols [30]. The lack of a single connectivity protocol in IoT devices and applications has led to a lack of interoperability. However, efforts are underway to classify and understand different network protocols, such as short-range protocols like Bluetooth, Zigbee, and NFS In addition, routing protocols such as RIP, OSPF, and EIGRB are used to determine the best route path for data transfer in IoT applications [31]

II. METHOD

2.1 Research Methodology

Research methodologies for IoT development include Scrum, Kanban, Scaled Agile Framework, Ignite, and Rapid Application Development (RAD). These methodologies have been evaluated and compared in terms of their capabilities and characteristics for IoT projects [32]. In this research, in order to design IoT and produce software that meets the user's needs, the RAD (Rapid Application Development) methodology approach is used.

Fig. 1. Stage of RAD Methodology

Figure 1 shows the stages of RAD, starting from listening to the user to get data about the problem needs, building the system by making mockups and designing devices quickly according to the user's needs. Explaining the software architecture design, design, user interaction with the system, and design mockups to get a clear picture of the device to be developed.[33].

2.2 System Design

The framework integrates various components to enable automated and efficient irrigation systems. These include sensors to monitor environmental parameters such as temperature and humidity, and actuators to control irrigation equipment. The framework aims to optimize water use, conserve resources, and increase crop productivity. The proposed systems [34], [35] are low cost, easy to use, and accurate in irrigation. The implementation of such frameworks can simplify lawn care, reduce water and energy consumption, and provide advanced technological features for intelligent irrigation systems [36], [37].

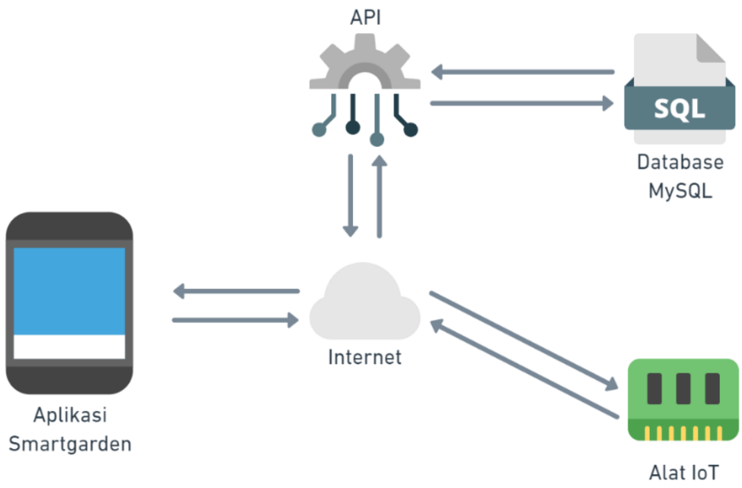

Fig. 2. IoT System Design

Figure 2 IoT devices take data on plant nutrient needs through concentration sensors in the water field, and the data is stored on a server via a wireless network connected to the Internet to communicate with the MySQL database server. The sensor measures the concentration of nutrients in the water used to irrigate crops. Data generated by IoT device sensors is then stored on a server via a wireless network connected to the Internet. Through this Internet connection, the IoT devices can communicate with database servers that use the MySQL database management system.

The system also makes it easier for farmers to control and monitor IoT devices. Farmers can access and control these devices through an internet-connected smartphone app. The app provides an intuitive and easy-to-use interface to monitor and regulate proper plant nutrition. This allows farmers to efficiently control the nutritional system of their horticultural crops directly and remotely, minimizing the time and effort required. In addition to machine-to-machine communication, this system uses an Application Programming Interface (API) stored on the hosting. This API allows efficient communication between devices and systems[38].

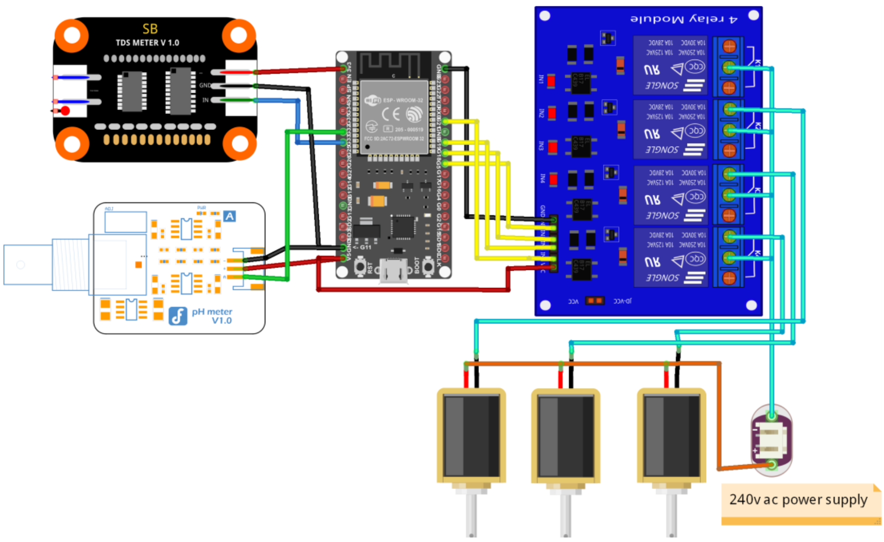

Fig. 3. IoT device schematics Nutrition Control and Monitoring

Figure 3 is a design of IoT devices which are composed of 3 parts: sensors, microcontrollers, and actuators. The sensors used are temperature, humidity, pH, and electrical conductivity (EC) sensors. This EC sensor is used to detect the level of nutrients dissolved in water. The unit of measurement in this EC uses ppm (parts per million) units. As for the microcontrollers, they use ESP32 to control all the components connected to the IoT tools. ESP32 is a microcontroller explicitly designed for use in IoT technology with WiFi support as connectivity[39]. While the actuator monitors and controls various aspects of agriculture connected to IoT tools, such as pumps, cooling fans, etc [40]. in this case the actuator uses a 10-volt relay to control the irrigation pump and pump Nutrient A and Nutrient B.

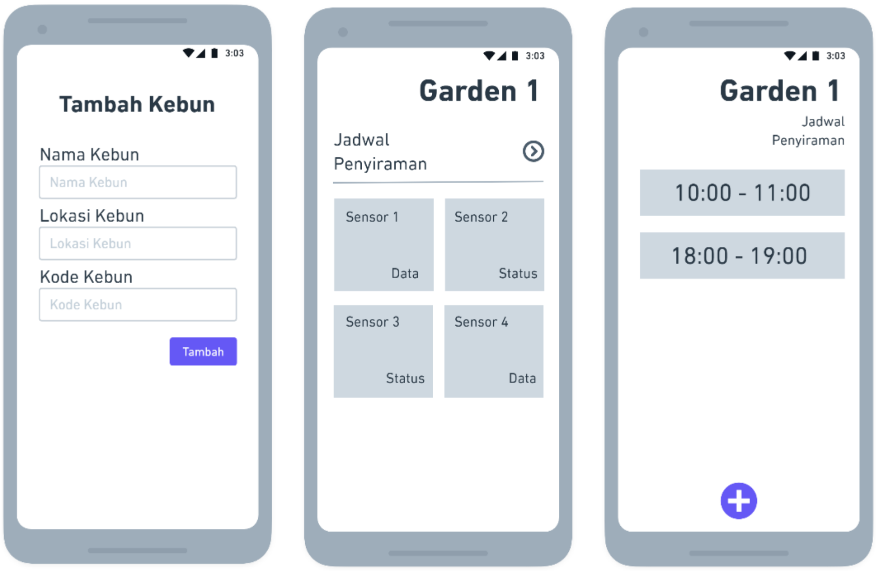

Fig. 4. Control and Monitoring application interface on Android

Figure 4 shows the application design used by farmers to control and monitor IoT devices installed in the garden. This application also has the ability to schedule irrigation according to the farmers' needs. The data displayed by this application includes pH sensor data, EC sensor data, nutrient volume status in the reservoir, water temperature, humidity, and air temperature from the MySQL database.

This IoT tool is implemented in CV Agro Utama Mandiri Lestari, located in Munengan village, Ngadiluwih district. For data collection, one cycle of melon cultivation was conducted, which was about 75 days, with a total of about 800 trees. In terms of testing, functional testing is conducted on Android applications, starting from sensor data, control and monitoring of IoT tools.

III. RESULT AND DISCUSION

This IoT system is implemented in the CV Agro Utama Mandiri Lestari Farm using Android-based software development. To ensure that everything goes well, the monitoring data is retrieved from the database to analyze and shown in Figure 5. The data includes pH, water temperature, air temperature, EC, and data recording time. During a cultivation cycle, the resulting recording data has no time lag, so this IoT tool works well during cultivation.

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<bound method DataFrame.count of          timestamp         ph  suhuair  suhuudara  tds
0       1666646665  34.983482 -127.000  28.139496  320
1       1666646670  34.988834 -127.000  28.085327   91
2       1666646676  35.136864 -127.000  28.032494  327
3       1666646682  34.911415 -127.000  27.982140  283
4       1666646688  35.044170 -127.000  27.948570  103
...            ...        ...      ...        ...  ...
10409   1667077224  34.988003 -127.000  25.713730  236
10410   1669894208  34.919182 -127.000        NaN   95
10411   1667077224  34.988003 -127.000  25.713730  236
10412            0  17.413317 -127.000 -50.000000    0
10413   1833296485  35.194489   37.125  99.999817  521

[10414 rows x 5 columns]>
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Fig. 5. Record Data Details

In the data in Figure 3, the author visualized the data to see the environmental conditions mapped into 3 (three) clusters that can be interpreted as cluster 1 (yellow) showing planting environmental conditions that are nutrient deficient and water deficient, cluster 2 (blue) showing production environmental conditions that are nutrient sufficient but water deficient, and cluster 3 (blue) showing growth environmental conditions that are nutrient sufficient and water sufficient.

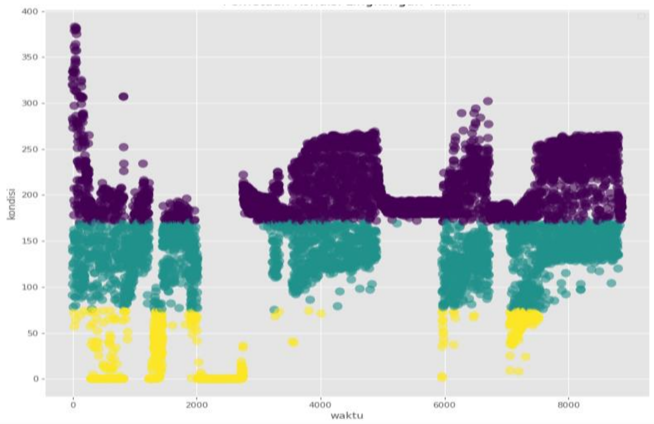

Fig. 4. Mapping of Planting Environmental Conditions

Figure 4 shows that the use of IoT tools for nutrient control and monitoring can help with irrigation. With this IoT tool, farmers can monitor and properly maintain the nutritional needs of plants. The use of IoT in nutrient management can help collect real-time data and optimize nutrient strategies. By analyzing data on factors that affect plant nutrition, farmers can make informed decisions and improve the interaction between plants and their growing environment. This not only helps ensure a better supply of nutrients, but also promotes better health and well-being.

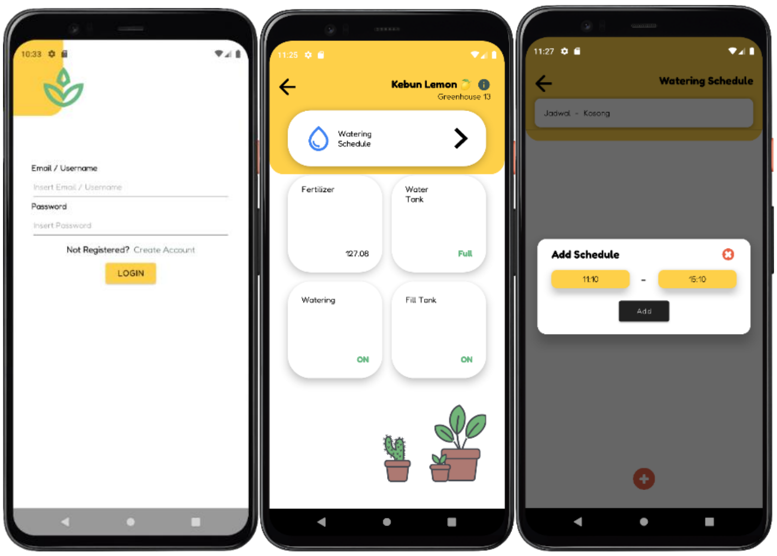

Fig. 5. IoT Application Interface View

Figure 5 shows applications built using the Java programming language with an Android Studio editor. This application system communicates with servers and IoT devices using APIs. The compatibility of this application uses the version of Android 9 (Android Pie) and above. This application is connected to the server, so an Internet connection is required for the application to display data. The choice of Android application as a control interface is because the public popularly uses this application because the compatibility of applications is wide, and Android is designed for touch screen devices and uses touch gestures for direct manipulation [41].

Table 1. Results of testing control irrigation pumps.

No.	Time	Jeda Delay	Note
1.	08.00.00 – 08.00.05	5 seconds	The irrigation pump is on
2.	10.25.02 – 10.21.05	3 seconds	The irrigation pump is on
3.	12.10.04 – 12.10.07	3 seconds	The irrigation pump is on
4.	14.20.20 – 14.20.30	10 seconds	The irrigation pump is on
5.	16.00.33 – 16.00.36	3 seconds	The irrigation pump is on

Average	4,8 seconds

Table 1 shows the recorded data in terms of the average delay when the command in the application turns on the irrigation pump. From this data, the average delay for pump control is 4.8 seconds. This pump start command is initiated by the pump start application that is sent to the ESP32 when the microcontroller forwards the base to the relay actuator to start the pump.

IV. CONCLUSIONS

This paper presents an IoT system implemented in a real environment in a horticultural crop garden. This IoT system can control and monitor nutrients in horticultural crops with parameters of water temperature, EC, humidity, air temperature, and water temperature using sensors. It uses a 10V relay to control farm machinery, enough to control a 450W irrigation pump. The ESP32 in this IoT system is used as a microcontroller or brain system to control the sensors and actuators and transmit data to the server. An Android-based application running on at least Android 9 or Android Pie is used to control the IoT devices.

Overall, this system can be used for IoT-based control and monitoring systems to optimize nutrition in horticultural crops. Data collected in this IoT system is sent wirelessly and can be accessed remotely via a smartphone application. The system aims to ensure optimal plant growth by meeting nutritional needs and creating ideal conditions. With existing features such as real-time data delivery, nutrient classification, and an easy-to-use application interface, this system makes it easy to monitor and manage plant nutrients. With the use of IoT, the system offers increased reliability, stability, and efficiency in controlling and monitoring horticultural plant nutrition.

Further development of this system can begin with the use of more sophisticated sensor nodes so that sensors can be more accurate and precise in measuring and monitoring nutritional parameters. In addition, the use of new and innovative sensor technologies, such as artificial intelligence-based sensors, can expand the system's ability to detect nutritional needs. IoT systems cannot be separated from connectivity and communication, so it is necessary to adopt more sophisticated, faster and stable protocols. Faster data transmission can facilitate the transmission of sensor data to users, so that the recorded data can be more real-time without any delay. Furthermore, this nutrient monitoring IoT system can be integrated with climate control systems and energy management systems to create a more integrated and efficient solution for managing all agricultural facilities.

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