Secure Cloud Connected Indoor Hydroponic System via Multi-factor Authentication

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***Abstract*—Now-a-days, the hydroponic farming system with the Internet of Things (IoT) technology is increasingly becoming a trend for researchers to produce a more capable farming device or remote monitoring system. However, this intelligent system is not controlled securely and will be dangerous when system hacking occurs. Therefore, developing a secure indoor hydroponic monitoring device with multi-factor authentication (MFA) method is proposed. The research aims to develop a secure cloud-connected indoor hydroponic system via multi-factor authentication on the ThingsSentral IoT platform with an MFA technique. The developed system comprises an iPhone Operating System (iOS), an Arduino node microcontroller unit and a ThingsSentral web IoT platform. A security software application on iOS phones with MFA techniques is built to authenticate devices before communicating with ThingsSentral.io. Token authentication between ThingsSentral.io and the security software application must be done before the hydroponic monitoring device can send and receive data. An indoor hydroponic monitoring system device with MFA security technique has been successfully produced from the study. An MFA security technique for iOS apps has also been successfully developed. In conclusion, using the MFA technique, this research successfully develops a high-security control and communication system between the field device and the IoT platform. Although the MFA security system developed for this IoT platform has several steps that need to be done before data can be sent to the cloud database, the users themselves can allow or prohibit a device from operating. Besides, users can also control and monitor the security between the device and the IoT platform when they operate.**

Keywords*—Internet of things; intelligent system; remote monitoring; hydroponic; multi-factor authentication

I. Introduction

Due to an increase in population and a country's development, a diverse alternative has dealt with the crisis of adequate food provision. This is because land and farms must be reduced to make room for more excellent homes. The development of indoor hydroponics farming, a relatively successful means of producing a crop, is one of the most recent agricultural technologies established to mitigate this problem [1]–[4]. Hydroponics technology is used throughout the world. Numerous methods and techniques have developed. Most hydroponic surrounding areas are prepared with their temperature, humidity, electrical conductivity (EC) and pH manually measured by producers. Adjustments are then calculated to meet the needs of the plants [5]–[7].

With the advent of IoT technology, hydroponic farming systems can increasingly thrive. The combination of IoT technology in this hydroponic farming system can also monitor and control the condition of the crop environment in real-time. In addition, it can also reduce inefficiencies and improve agricultural performance [8], [9]. Combining the Internet of Things and the agriculture industry can minimize inefficiencies in food production and expand the food market [10], [11]. The potential of IoT systems can connect breakthrough technology like plants that deploy sensors.

IoT technologies that use the medium of internet connection can send data to a cloud server or receive instructions to operate [12]. Most IoT technologies use an open internet connection medium to perform these processes. When an IoT device uses an open internet connection, it will expose to dangers such as information theft or system hacking [13].

Hydroponic farming systems combined with IoT technology are increasingly becoming a trend for researchers to produce a more capable farming device or system. However, studies related to secure hydroponic monitoring systems with IoT integration are still lacking. If this IoT hydroponic farming system is not controlled securely, it will be a danger when system hacking occurs. Hence to solve the problem, the current novelty research proposes the development of a secure indoor

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hydroponic monitoring device with multi-factor authentication (MFA) method.

This study has developed a security authentication application on mobile phones to control the connection between the gateway device and the ThingsSentral application. Next, a gateway device is developed to send the data obtained from the sensors to the ThingsSentral application using the Hypertext Transfer Protocol (HTTP) communication protocol. The security authentication application only needs to be done at the beginning of the gateway device requesting to send data only.

II. Hydroponic Monitoring System

A literature review has been made related to the hydroponic monitoring system. This section describes some research done by other researchers related to electronic technology used in producing hydroponic monitoring systems. This section also shows the results obtained by past researchers during this study.

In the era of technology centuries, human lives have become more accessible in all parts with the growth of wireless technology, the Internet of Things (IoT). Agricultural systems' decisions demonstrate the rapid rise in internet users over the previous decade. The IoT development guarantees that the surveillance system technique becomes more advanced on the 'user's terms and can be accessed anytime and anywhere within a distant place [14]–[16]. The development of a hydroponic farming system communication based on the IoT platform monitors the plant condition at a remote monitoring station. It allows the automatic system to turn on when necessary [17]–[19].

Melchizedek I. Alipio et al. [20] employed a Bayesian network to analyze the data and automate the hydroponics method as the human population expands to meet the food requirement. Using IoT technology in conjunction with hydroponics allows a high-quality farmer to produce more. The farm's hydroponics is linked to the light intensity, pH, EC, water temperature, and humidity sensors. Sensor data were gathered for analysis, and a Bayesian Network was built. The nutrient film method (NFT) was used with sensors and actuators attached to the plant. To use a remote location to monitor and gather data from the hydroponics farm and deliver it to the web interface.

Fuzzy logic was utilized to regulate the supply of nutrients to hydroponic plants, according to M. Fuangthong and P. Pramokchon [21]. Instead of employing soil, water solvent was used to supply nutrients to the crops. Farmers in soilless culture need extra attention from growing plants in hydroponics to analyze nutrient solvent's EC and pH levels. The pH value varies depending on the crop, and the automatic monitoring mechanism provides a nutrient solution. A farmer's practical abilities are required to prevent an excess delivery of nutrient solutions to plants. The Dynamic Root Floating Technique (DRFT) automatically controls the nutrient solvent flow to hydroponic plants using fuzzy logic.

In 2017, Ms.S.Charumathi et al. [22] proposed a novel cultivating crops in soilless culture. Hydroponics can enhance yields while taking up less space and producing high-quality crops. Because of the less fertile soil, farmers utilize pesticides and fertilizers to produce crops that damage human health. In a closed location, the hydroponics arrangement can alleviate traditional framing issues. The Arduino Microcontroller was combined with the IoT concept to detect the situation around the plants automatically. The proposed method has a major flaw in that it requires a farmer's observation because the data is stored locally.

R.Rajkumar and R.Dharmaraj [23] proposed a hydroponics idea with the wireless sensor network. Planting in a contaminated climate is difficult in conventional farming. Improving the yield requires more fertile soil. It also necessitates a higher weed extraction cost and a large growing area. Then, seasonal food processing is only possible at that time. The hydroponics technique allows for year-round production of the crops. Instead of using artificial mineral nutrients, the author experimented with hydroponics using organic ash fertilizer. Moisture, temperature, and water level are all sensed by the microcontroller. The sensor data is sent to the cloud, allowing the farmer to track the progress of his plants from afar. The author uses Blynk, an open-source API that receives sensor data.

M.K.R.Effendi et al. [24] developed smart farms and agriculture. The Internet of Things (IoT) and data analytics are being used to improve farm and agriculture sector operational efficiency and productivity. They devised monitoring, control, or automation system to help the farmer and then gathered all data on rainfall, temperature, humidity, and light intensity. The development included hardware, software, programming, and sensors such as a water sensor, light-dependent resistor sensor, temperature and humidity sensor, and weight sensor for data collection. The project's outcome is that they were able to apply IoT concepts to aquaponics and goat stall monitoring, control, and automation systems.

With the Wireless Sensor Network, Jumras Pitakphongmetha et al. [25] suggested a hydroponics technique to transfer sensor data to the cloud. Compared to conventional farming, hydroponics lets farmers raise money with higher yields. With global warming, the natural climate is challenging to foresee. Hydroponics can solve this issue by introducing without disturbance from the atmosphere in a protected environment. The significant parameter was then calculated using a different sensor around the hydroponics plant.

From the literature review, we found that the study related to hydroponic agriculture monitoring systems is sustainable and somewhat advanced in terms of controlling the environmental conditions of crops. However, most hydroponic monitoring devices are lacking from the perspective related to the security and safety of the monitoring devices. Electronic devices are vulnerable to a cyber-security threat and can be misused by others to cause harm to the community or society. These security and safety aspects are very much lacking and should be given extra attention. Although numerous security techniques and devices are available, most IoT devices do not come with security-enabled capabilities. Amongst the available and often used security methods for the connected or IoT system is via the authentication approach [26] and [27].

Security technologies can be implemented by integrating electronic devices, computers, and wireless communication to provide further protection. The second-factor authentication strategy, often utilized in account defense, is the next degree of protection [28], [29]. Two-factor authentication is a type of authentication that determines its identity using two out of three variables. "Something the user knows," "something the user has," and "something in the user" are three regularly seen variables [2], [30], [31]. The use of this two-factor authentication approach improves network security. This is due to the use of technological devices with an internet connection.

This combination of IoT and urban agriculture will evaluate data automatically by uploading it to the cloud and allowing users to make decisions [32], [33]. Furthermore, this indoor farming system is self-contained and can work safely with this network security mechanism. The ability to produce could change the agriculture industry, helping to enhance the smart but inefficient rural sector in our economy.

III. Secure Indoor Hydroponic Monitoring System Development

This section describes in detail the methodology implemented in this research. The study of how people utilize hydroponic systems was carried out to create a monitoring device for the farming system. Furthermore, the proposed approach makes the hydroponic system simple to maintain. Multiple security can be achieved by using the general design of the system with an MFA approach. This section has two parts: indoor hydroponic device monitoring system design and device security system design.

A. Device Monitoring System Design

Fig. 1 shows the main layout of an indoor vertical hydroponic farming system using the MFA method. Indoor hydroponic devices include three major components: input, controller, and output. On the input side, water electrical conductivity (EC), water parts per million (PPM), humidity sensors, temperature sensors, and keypad (users to enter their Wi-Fi information) were used. Using a Node microcontroller in the controller portion is critical for securing the input part to the output and the input to the cloud database. Because NodeMCU acts as a WI-FI chipset, it can send data to the internet. An OLED panel displays data straight from the sensor on the output side. Fig. 2 shows the sensor and module information connected to the NodeMCU ESP8266. While Fig. 3 shows the indoor hydroponic monitoring device that has been connected.

The system starts with the user configuring the service set identifier (SSID) and the password to connect to the internet using the keypad provided. Once the SSID and password of the nearest internet have been successfully entered, the user needs to enter the user and device id, which can be obtained on the ThingsSentral website. Once the user and device id have been entered, a notification will be sent to the security verification application on the user's phone. Fig. 4 below shows the interface of the security authentication application.

Users can choose either to allow or not the hydroponic monitoring device to function and be able to send data to the ThingsSentral platform. The National University of Malaysia developed ThingsSentral, a cloud based IoT platform (UKM). The ThingsSentral application's UI is shown in Fig. 5. This platform allows users to develop their own cloud based IoT systems for data collection, storage, and retrieval. This system platform communicates over the internet using the HTTP protocol. Data can be sent to or from hardware microcontrollers like Arduino, Node MCU, and Raspberry Pi. ThingsSentral's functioning is based on channels that comprise data fields, position fields, and status fields.

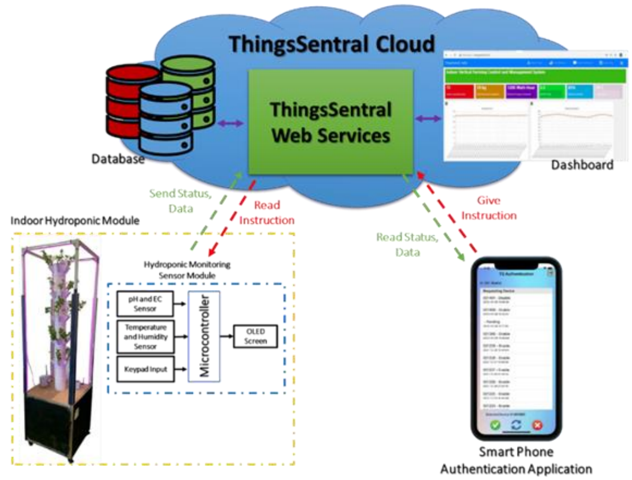

Fig. 1. System Design Framework of Hydroponics Farming System with an MFA Method.

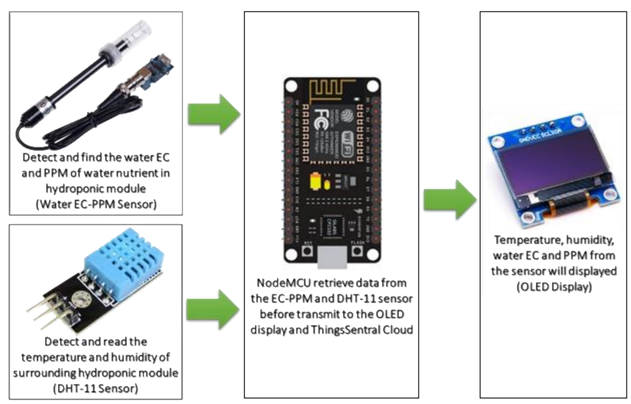

Fig. 2. The Required Hardware for Monitoring Temperature, Humidity, EC and PPM with Component Description [34]–[37].

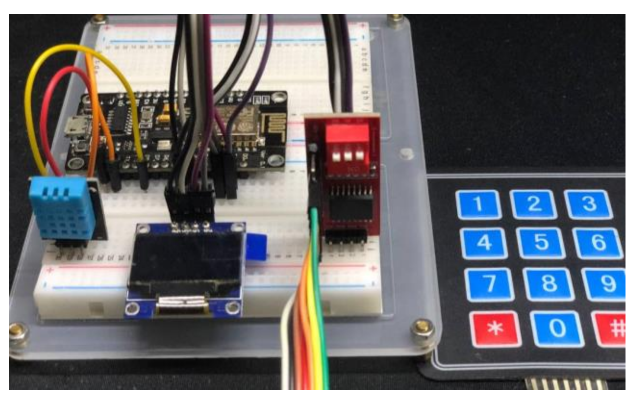

Fig. 3. The Hardware Set Up for the Indoor Hydroponic Monitoring System used in this Study.

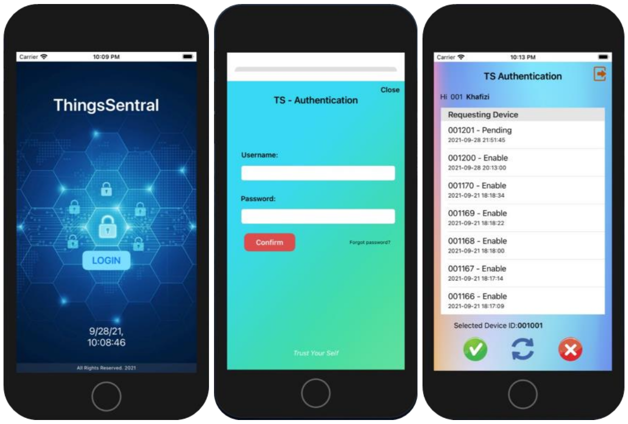

Fig. 4. An MFA Security Interface for Mobile Application.

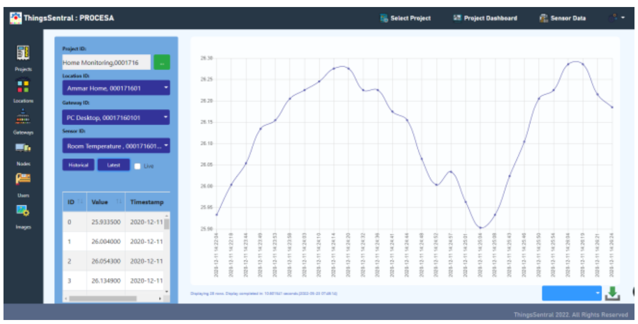

Fig. 5. Thingssentral Application for Live Data Monitoring.

After the user confirms the indoor hydroponic monitoring device, it will read the temperature and humidity of the plant environment. The plant environment data can also be sent to the cloud database. Fig. 7 shows that the hydroponic model was built. While Fig. 6 shows the readings obtained by the ambient temperature and humidity monitoring device.

B. Device Security System Design

This section describes the proposed multi-factor authentication that uses a credential token key. Fig. 8 shows the architecture of the proposed system. The system consists of an IoT device as a client, a ThingsSentral server as a web services platform, and an authentication application as a phone authentication application. All these systems need to perform registration with the ThingsSentral Server. ThingsSentral server generates unique registration IDs for all entities and certificates of credential token keys for IoT devices. In this system, the mutual authentication between IoT device and authentication services, authentication application and authentication services, token generator services, and IoT devices occur. The certificate of a credential token key establishes between IoT devices and ThingsSentral primary services. The proposed security architecture system consists of five processes, which explain as follows.

Fig. 6. Indoor Vertical Hydroponic Model for a Data Monitoring System.

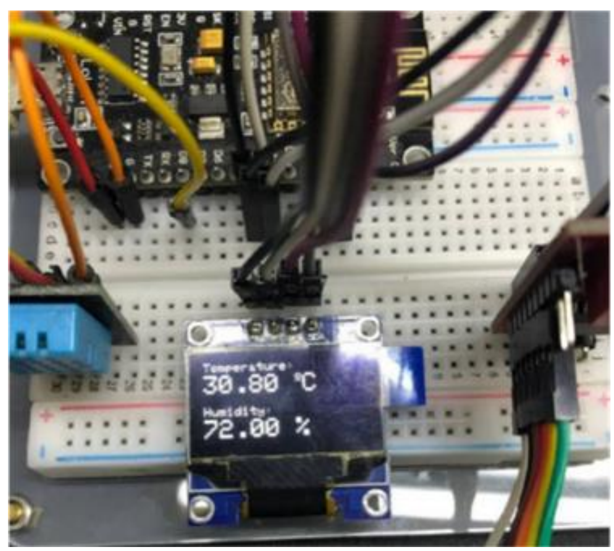

Fig. 7. Live Data Pickup by Sensor Shown in I2C OLED Display.

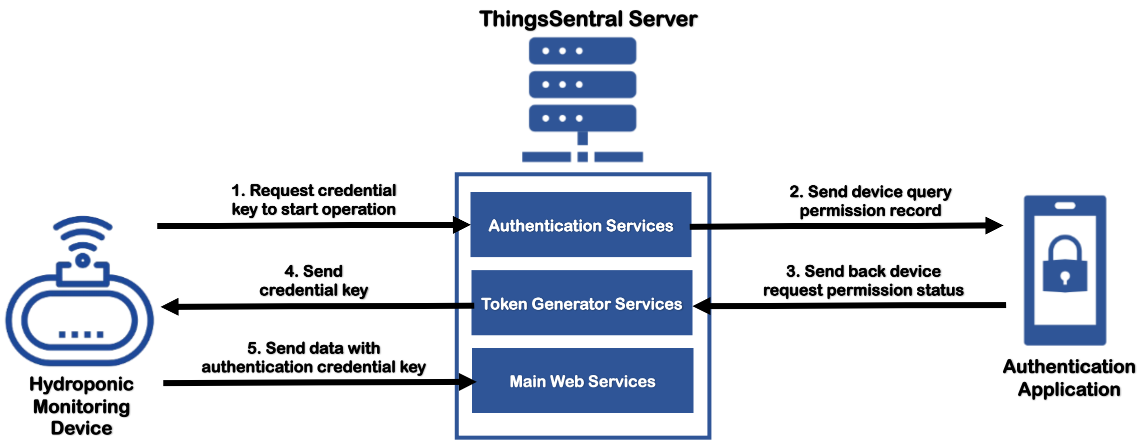

Fig. 8. The Proposed Architecture for the Security System.

IV. Results and Discussion

The results obtained after applying the methods are described presently. The results relate to the indoor hydroponic farming monitoring module and hardware security system using the MFA authentication method.

In order to obtain this result, the study's implementation method and prototype model have been shown in Fig. 2, 3 and 7. Fig. 9 represents the screenshot of the authentication process performed from the start of the monitoring device until the data was retrieved from the water nutrient and DHT-11 sensor. In contrast, Fig. 10 and Fig. 11 show the screenshots of the dashboard display for the IoT-based hydroponic crop monitoring system on a PC/laptop and a mobile phone, respectively. As can be seen, the ThingsSentral platform has afforded an informative, real-time and excellent visualization approach to monitoring the hydroponic crop. The IoT-based monitoring system has successfully implemented a secured system using multi-factor authentication.

The local OLED display module and the centralized cloud dashboard on ThingsSentral will display all data obtained at the hardware module. Then it is displayed on the I2C OLED. The I2C OLED provided the interface for user WI-FI SSID, WI-FI password, user id and device gateway. The water nutrient solution (EC and PPM), humidity and temperature of the surrounding hydroponic module were also displayed on the OLED. The data analysis was based on the data presented in the methodology and also the data obtained from the graph on ThingsSentral, as shown in Fig. 10 and Fig. 11. The real-time timestamps and data for the indoor hydroponic monitoring module on the water nutrient solution and surrounding humidity and temperature were recorded on the ThingsSentral platform. The result for the MFA validation application display is shown in Fig. 4.

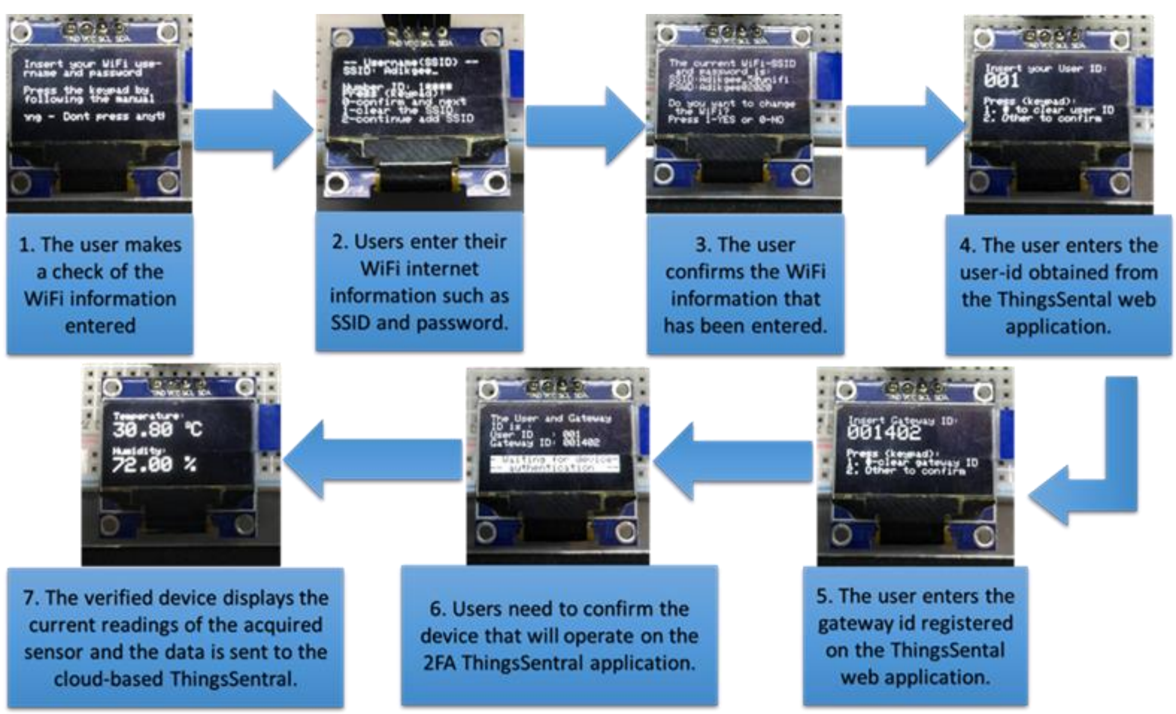

Fig. 9. Dashboard for ThingsSentral Web-based Interface with MFA Method.

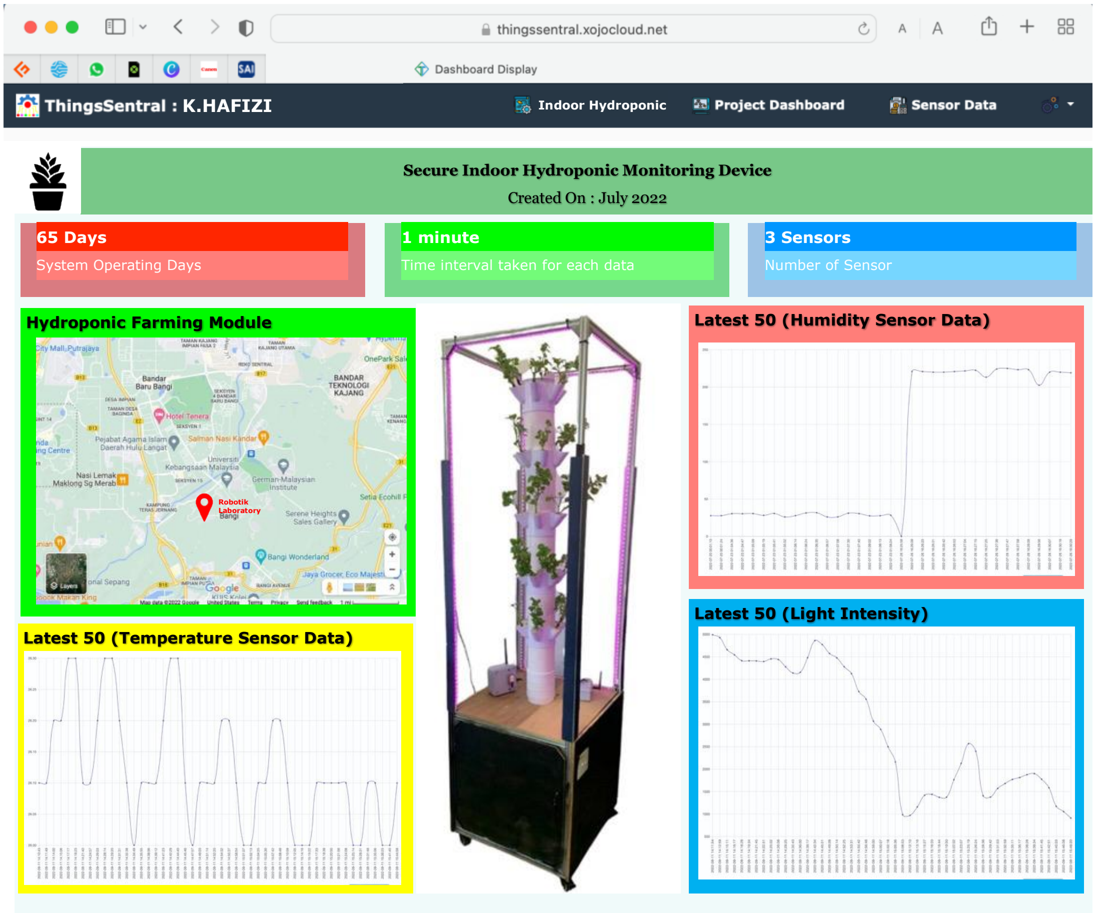

Fig. 10. The OLED Displays Wi-Fi and Device Monitoring Registration Process Flow.

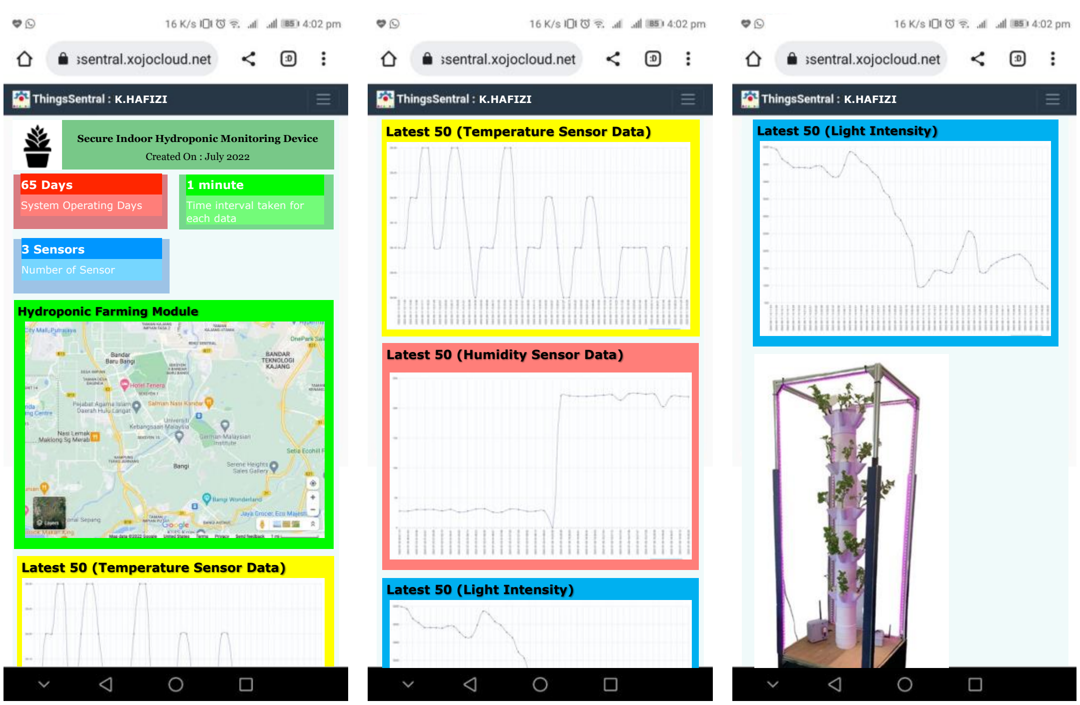

Fig. 11. MFA Method used on a Dashboard for ThingsSentral Web-based Interface Viewed on Mobile Phones.

The hydroponic monitoring module was tested 100 times using proposed IoT platforms. Each time this monitoring device successfully displays the indoor hydroponic module system's current data, this device will be turned off and on again to repeat the device verification process and data transmission to the cloud database. Fig. 12 shows the time graph for 100 times hydroponic monitoring devices to obtain the credential key and send data to the ThingsSentral server. From the data obtained, the average time taken for this system to start operating until the data received on the ThingsSentral server is 579ms (red line). The results for the average time required have been included in Table I and compared with other platforms.

Table I shows the names of the different IoT platforms, the average time taken and their respective security techniques. As result of the comparison that has been made shows that the time taken by the ThingsSentral IoT platform with the MFA technique takes a little longer compared to other IoT platforms. However, the ThingsSentral IoT platform uses the MFA technique that allows users to authenticate a device to operate. ThingsSentral also uses a dynamic credential key every time the device starts operating. Unlike other IoT platforms, they use API keys or token keys only. In addition, this other platform uses a static token key. If hackers or strangers can figure out this token key, they can do unexpected things.

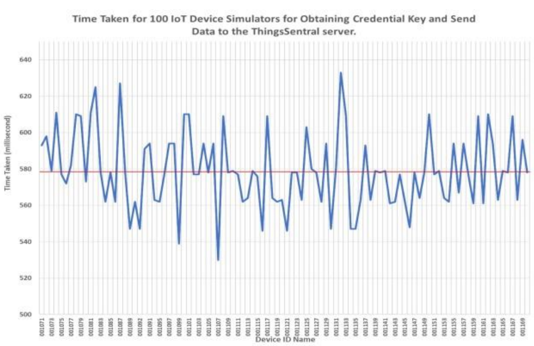

Fig. 12. Time Graph for 100 Times IoT monitoring Device Tested Request Credential Key and Send Data to ThingsSentral Server.

TABLE I. COMPARISON OF SYSTEM SECURITY FOR FIVE DIFFERENT IOT PLATFORMS

IoT Platform Name	**Security Technique**	**Average Time Taken / Response Time (ms)**
Kaa IoT [33]–[38], [40]–[42]	SSL security elements are combined with basic authentication through JSON web tokens.	150
ThingSpeak [43]–[47]	Secured MQTT broker and random static token on personal API Key	25.2
Thinger.io [39], [48]–[51]	SSL security elements are combined with basic authentication through JSON web tokens.	266.7
Thingsboard [39], [52]–[55]	Encryption algorithms on SSL and credential types certificates and access tokens.	217.5
ThingsSentral (proposed platform)	SSL security features on web API services with a multi-factor authentication method on the registered device.	579

V. CONCLUSIONS

This paper describes developing a secure indoor hydroponic farming monitoring system based on a wireless system using the XOJO platform, ThingsSentral IoT, NodeMCU, and hydroponic sensors. The hydroponic monitoring system device was tested on an indoor vertical hydroponics module and the system's functionality was assessed. The system can display temperature, humidity, and nutrient solution content in water. The developed system also uses the MFA method to increase further the level of communication between the monitoring device and the cloud database. This system is also compared with several other cloud database IoT platforms. One noteworthy finding is that this developed system takes a little longer than the use of cloud database IoT platforms. However, this system is safer because the ThingsSentral IoT platform uses authentication from humans or owners to the device itself. Unlike other IoT platforms, they only use the API Key or token that needs to be entered into the device. This study only used one indoor vertical hydroponic module to obtain data. Therefore, the data used is only to measure the security and usage of cloud based IoT platforms at a time. In the future, studies on several indoor vertical hydroponic modules can be used to obtain more data to produce more accurate and valuable results. The data obtained from the hydroponic monitoring module can be compared with the existing device. In addition, future research can be done by developing more hydroponic monitoring sensors to control plant environmental conditions and a phone application by integrating it with the data obtained from the device. The data obtained will be displayed on the user's phone application. Users can also see their crops' condition from time to time, even if they are far from the crops.

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