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Design and Implementation of Update Script in the IoT-Based Smart Indoor Farming System Module at PT Inastek Using Over-the-Air Programming

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Abstrak

Perubahan iklim yang ekstrem memiliki dampak signifikan terhadap sektor pertanian di Indonesia, negara agraris dengan mayoritas penduduknya bekerja di bidang ini. Penurunan produktivitas tanaman dan peningkatan risiko serangan hama menjadi ancaman bagi ketahanan pangan nasional. Penelitian ini bertujuan untuk mengembangkan sistem smart indoor farming berbasis IoT yang mengintegrasikan teknologi Over-The-Air (OTA) guna meningkatkan efisiensi manajemen firmware. Desain sistem ini melibatkan komponen perangkat keras dan perangkat lunak, termasuk elemen penting seperti sensor, aktuator, dan Human Machine Interface (HMI) untuk pemantauan dan pengendalian kondisi lingkungan secara real-time. Hasil penelitian menunjukkan bahwa integrasi teknologi OTA meningkatkan fleksibilitas dan responsivitas sistem, serta mengurangi kebutuhan intervensi fisik. Sistem ini secara efektif mengoptimalkan manajemen pertumbuhan tanaman di lingkungan indoor dan membuktikan bahwa teknologi IoT mampu mengatasi tantangan pertanian modern, sekaligus berkontribusi terhadap ketahanan pangan nasional.

Kata kunci*— Smart indoor farming; Internet of Things; IoT; Over-The-Air Programming; OTA*

Abstract

Extreme climate change significantly impacts Indonesia's agricultural sector, a country with a large agrarian economy. Reduced crop productivity and increased risk of pest infestations threaten national food security. This study aims to develop a smart indoor farming system based on the Internet of Things (IoT) to enhance agricultural resilience and competitiveness through efficient technology. The method involves designing a system that integrates hardware and software, applying Over-The-Air (OTA) technology to update firmware on the ESP32 microcontroller. The system includes sensors, actuators, and a Human Machine Interface (HMI) that allows real-time monitoring and con- trol of plant growth conditions. Testing and validation were carried out to ensure the system's reliability and stability. The results show that the in- tegration of OTA technology into the smart indoor farming system enables efficient firmware management, reducing the need for physical intervention, and improving flexibility in system maintenance. This system enhances the efficiency of managing plant growth in indoor environments and supports continuous operational adjustments to dynamic conditions.

Keywords—*Smart indoor farming; Internet of Things; IoT; Over-The-Air Programming; OTA*

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1. INTRODUCTION

Extreme climate change has had a significant impact on Indonesia's agricultural sector, a country where the majority of its population relies on agriculture as their main source of livelihood. Unpredictable climate patterns, such as extreme temperature increases, irregular rainfall, and increasingly volatile weather, have led to a significant decline in crop productivity. Moreover, the risk of pest infestations has also increased, affecting both the quality and quantity of agricultural output. These conditions raise serious concerns about national food security, as food supplies may struggle to meet the demands of a growing population.

Amid these challenges, the Internet of Things (IoT) offers a potential solution to address many of these issues. One of the innovations introduced is smart indoor farming, an IoT-based indoor farming system that enables precise control of environmental conditions. This system can manage key parameters such as temperature, humidity, light intensity, and the nutrient levels required by plants. Through careful monitoring and control, plant growth can be optimized, thereby improving both the productivity and quality of agricultural output, even under unfavorable outdoor conditions.

Another critical innovation presented in this study is the integration of Over-The-Air (OTA) technology into the smart indoor farming system. OTA enables remote updates of software or firmware on IoT devices without the need for technicians or engineers to be physically present at the site. Previously, firmware updates required technicians to visit the location and manually update the devices, which not only took time and incurred costs but also posed a risk of contamination in the indoor farming environment, which must be kept clean. With OTA, the update process can be carried out more quickly, efficiently, and without the risk of disrupting the farming ecosystem.

The use of OTA technology in this system not only facilitates efficient software updates but also enhances the system's flexibility and responsiveness in managing indoor farming operations. This technology enables real-time monitoring and management, allowing immediate changes or adjustments to environmental conditions when needed. As a result, the risk of farming failures due to climate change or other external factors can be minimized.

In addition, this technology allows farmers to manage their farming operations remotely, even from their mobile devices or computers. The use of sensors and actuators connected to the internet enables continuous data collection, which can be analyzed to better understand plant needs and make more timely decisions. On a larger scale, this system can be integrated with broader agricultural management platforms to support the development of sustainable smart farming.

The results of this study show that integrating OTA technology into IoT-based smart indoor farming significantly improves operational efficiency, providing practical solutions to the modern challenges faced by the agricultural sector. This system also helps reduce the reliance on physical human intervention, not only cutting operational costs but also improving the overall quality of agricultural production.

In other words, IoT technology integrated with OTA in this indoor farming system not only solves operational problems but also holds great potential for enhancing food security in Indonesia. Through this innovation, Indonesia's agricultural sector can be better prepared to face the impacts of climate change and make a substantial contribution to national food security in the future.

2. DESIGN

2.1 System Architecture

This section outlines the system architecture, which is illustrated in the accompanying diagram. The system is composed of various components connected to the main controller, which manages all operations. The main controller is powered by a 220V AC source, which is regulated and converted to lower voltages of 24V, 5V, and 3.3V to meet the power needs of the other components.

The system integrates sensors and actuators, including those used for monitoring environmental conditions such as temperature, humidity, and water levels, as well as actuators that control elements like lighting, ventilation, and liquid distribution. These components are controlled through appropri ate interfaces for input/output and communication protocols.

The system also supports internet connectivity, allowing for remote firmware updates through an Over-The-Air (OTA) process. During this process, the controller checks for updates via an HTTP request to a designated server, downloads the latest firmware, and installs it automatically. Additionally, the system includes sensors for monitoring key environmental parameters necessary for maintaining optimal conditions within the controlled environment.

Furthermore, the system incorporates a Human-Machine Interface (HMI) that enables users to interact with the system, monitor data in real-time, and perform analysis for decision-making and optimization. This design ensures that the system is intelligent and responsive, adapting to changing environmental needs effectively.

2.2 System Design

The system design for IoT-based smart indoor farming is comprehensively developed to ensure optimal performance and seamless integration between various components. This research focuses on the development and integration of both hardware and software to create a stable and reliable system. The testing phase includes a series of integration tests between hardware and software components, as well as reliability testing during the Over-The-Air (OTA) script update process. Through these efforts, this research aims to make a significant contribution to the advancement of efficient and modern smart farming technologies.

2.3 Testing and Validation

The Over-the-Air (OTA) firmware update process for Internet of Things (IoT) devices utilizing the ESP32 module involves several key steps. The first step is the creation of a firmware file in binary format (.bin), which is then uploaded to a repository server such as GitHub, functioning as the central storage for firmware updates. Once the upload is complete, the ESP32 module periodically checks the GitHub server for available firmware updates. If an update is detected, the ESP32 proceeds to download the new firmware and initiates the automatic update of the IoT device. Upon successful installation, the device reboots autonomously to ensure that the new firmware is properly applied. If no updates are found during routine checks, the ESP32 continues monitoring the server at regular intervals, ensuring that the IoT device always operates with the latest firmware version without requiring manual intervention. This process not only saves time and effort but also ensures that the IoT device remains optimized with up-to-date firmware, enhancing its overall performance and reliability. The flowchart concludes with the successful update of the device, which is then ready to operate with the latest firmware version applied.

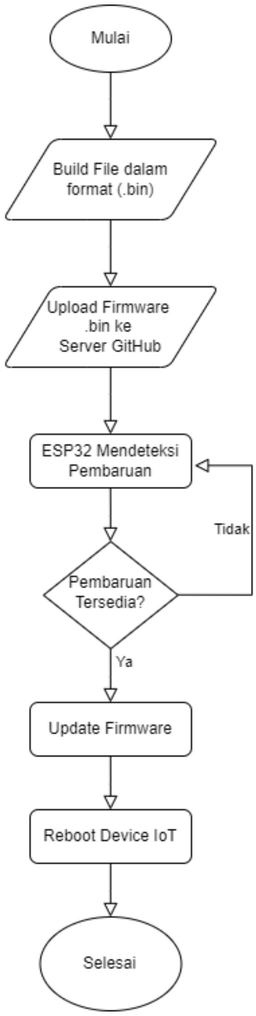

Figure 1 Flowchart

2.4 Software Design

The firmware update method is designed to facilitate the efficient process of updating scripts in the smart indoor farming system. The primary focus of this method is the development of procedures that ensure consistency in the firmware update process, along with the implementation of strict validation mechanisms to guarantee software integrity. As such, this approach is expected to effectively support the development and improvement of the smart indoor farming system modules.

2.4.1 FreeRTOS

FreeRTOS is an open-source, real-time operating system that offers a fast, reliable, and responsive kernel, making it cloud-neutral and ideal for a variety of applications requiring high performance and responsiveness (freertos2023). Designed with a micro-kernel architecture, it supports multi-core computing, enabling efficient utilization of hardware resources to enhance overall system performance. This makes FreeRTOS well-suited for smart embedded systems, IoT devices, and other real-time applications where rapid response times and system reliability are critical.

The flexibility of FreeRTOS in supporting various embedded and IoT devices makes it highly desirable in industries that demand stable and reliable real-time systems. Its customizable implementation and support for multi-core computing make it a suitable option for applications that require strict time management and high reliability, such as industrial control, medical devices, and automotive systems. FreeRTOS not only meets the fundamental requirements of quick responsiveness anD system reliability but also serves as a robust foundation for technological innovations that depend on speed and precision.

2.4.2 HTTP Communication Protocol

The HTTP (Hypertext Transfer Protocol) communication protocol is chosen as a primary method for data transfer between the OTA (Over-The-Air) server and IoT devices during firmware updates. HTTP is widely used for internet-based data transfer due to its simplicity and broad compatibility with various devices and platforms. Its use in the OTA process facilitates efficient and reliable transmission of scripts and firmware, leveraging existing network infrastructures without necessitating significant changes to the architecture.

HTTP also supports various request methods, such as GET and POST, which provide flexibility in the types of data that can be transferred. This allows OTA to not only deliver scripts and firmware but also request additional information or perform other interactions with the OTA server. With features such as data compression and caching, HTTP optimizes throughput and response times during the update process, making it a viable option for IoT applications requiring remote software updates. Its combination of security, flexibility, and broad support makes HTTP a preferred protocol for managing OTA processes in evolving IoT environments.

2.4.3 OTA Server: GitHub

GitHub is a cloud-based software development platform that has emerged as a central hub for devel- opers to store, track, and collaborate on software projects. As an OTA server platform, GitHub is chosen for its robust features that support efficient script updates. Public repositories in GitHub allow IoT devices to access script updates openly, ensuring accessibility and transparency in cloud-based software development.

The version control system in GitHub plays a critical role in tracking changes, allowing developers to manage code evolution seamlessly over time. Additionally, GitHub's public API provides deep integration with other systems, enabling user authentication, controlled access management, and real-time update notifications. Together, these features provide a solid infrastructure for OTA implementation in IoT, ensuring structured and reliable updates.

2.4.5 Hardware Design

The hardware design for a smart indoor farming system encompasses various essential elements that support the functionality and operational reliability of the system. The electrical panel space is specifically designed to house all electronic and electrical components in an organized manner, allowing the system to operate efficiently, safely, and with ease of maintenance. This panel also serves as the control center for monitoring and regulating environmental parameters centrally, enabling optimal plant growth conditions. The support system for hydroponic pipes is a critical component that must be designed robustly to support pipes filled with water, nutrients, and plants, ensuring even distribution of water and nutrients. This design should also consider accessibility for plant maintenance and harvesting, as well as space efficiency within the limited indoor environment. Additionally, the lighting system utilizes strategically placed grow lights to ensure uniform light distribution and adequate Photosynthetic Photon Flux Density (PPFD), which is crucial for the photosynthesis process, promoting healthy growth. The nutrient water storage area is designed to accommodate containers that serve as storage for nutrients, equipped with an automatic or semi-automatic distribution system to ensure timely nutrient delivery for each plant. Finally, the placement of the Human Machine Interface (HMI) is crucial as it serves as the primary interface between the user and the system, allowing users to monitor environmental conditions in real-time, control parameters such as temperature, humidity, light intensity, and nutrients, and receive early warnings in case of issues or deviations from the predetermined ideal conditions.

Figure 2 Hardware Design for Smart Indoor Farming System

3. METHODS

This research adopts a system development approach to design and implement firmware updates wirelessly using Over-The-Air (OTA) programming on a Smart Indoor Farming system based on the Internet of Things (IoT). The system is designed using the ESP32 microcontroller, which provides Wi-Fi and Bluetooth connectivity to facilitate communication between devices in the system.

3.1 Internet of Things (IoT) Method

The Internet of Things (IoT) refers to a concept where non-electronic objects can be connected through the internet to send and receive data. In this research, IoT is applied using various sensors and actuators to monitor environmental parameters in the Smart Indoor Farming system. The sensors are used to detect temperature, humidity, light intensity, and air quality. Data from these sensors are sent to the central controller (ESP32) via the internet, enabling real-time monitoring of the farming environment. The communication protocol between IoT devices is selected to ensure efficient and se- cure communication, maintaining the system's interoperability (Awal, 2019; Gunadi & Rachmawati, 2022; Tohir, 2022).

3.2. ESP32 Usage Method

ESP32 is selected as the main microcontroller due to its advanced data processing capabilities through its dual-core Xtensa LX6 architecture, allowing multi-threading operations. ESP32 sup- ports wireless communication via Wi-Fi and Bluetooth, operating in modes such as Access Point (AP) and Station (STA) simultaneously. This research utilizes ESP32's GPIO, PWM, I2C, and UART features to manage interactions between sensors, actuators, and communication modules. The low-power features of ESP32, including Light Sleep and Deep Sleep, are used to optimize power consumption, especially for IoT applications requiring low energy usage (Espressif Systems, 2020).

3.3. OTA (Over-The-Air) Programming Method

Firmware updates for IoT devices in this research are performed using OTA programming, en- abling wireless updates without direct physical intervention. In this process, new firmware is developed and uploaded to a GitHub platform, which serves as the firmware repository. The ESP32 device automatically checks for firmware updates by sending HTTP requests to the GitHub server at regular intervals. If an update is found, ESP32 downloads and verifies the firmware file before installation. This update process utilizes the ESP32 OTA library, which is designed to securely download, verify, and install new firmware. Once the update is successfully installed, the device reboots and runs the updated firmware (Halder et al., 2020; Mahfoudhi et al., 2022).

3.4. HTTP Request Method

The HTTP protocol serves as the primary communication medium for firmware download requests on the IoT system. In this research, HTTP GET requests are sent by ESP32 to check for available firmware updates on the server. When a new firmware version is available, the system downloads the firmware using HTTP and automatically updates it. This method allows for efficient delivery of software and firmware updates over the internet without requiring direct user or technician interaction. The use of HTTP requests also provides system scalability, allowing the management of multiple IoT devices within a wide network (Madani et al., 2022).

3.5. Testing and Validation

After implementing the OTA system on the ESP32 device, testing is conducted to ensure the reliability of the firmware update process. The following parameters are tested:

a. Download speed: Measures the time taken to download new firmware from the server over the internet connection.
b. File integrity verification: Ensures that the downloaded firmware file is not corrupted and matches the expected size and hash value.
c. Reboot after update: Verifies that the device can reboot successfully with the new firmware installed.

These tests are performed using various firmware sizes and network conditions to ensure the system's reliability and stability in executing wireless updates.

4. RESULTS AND DISCUSSION

4.1 Testing Memory

Memory testing was conducted to evaluate the impact of device memory capacity on the success of firmware updates via OTA (Over-The-Air). The purpose of this test was to ensure that firmware uploads could be completed successfully, even when the device is operating with nearly full memory. The test was performed at three different levels of memory usage, namely 74.9%, 87.1%, and 99.3% of the total memory capacity of 1,310,720 bytes. The results showed that at all memory usage levels, the firmware updates were successfully completed without any issues. The time required for each firmware upload was relatively consistent, ranging between 49 and 52 seconds, regardless of the memory usage level.

Table 1 Memory Test Results

Memory	Time (Seconds)	Description
74,9% of 1.310.720 bytes	49	Successful
87,1% of 1.310.720 bytes	52	Successful
99,3% of 1.310.720 bytes	51	Successful

4.2 Data Transfer Performance Based on Bandwidth Variation

The performance of data transfer is highly dependent on the bandwidth utilized in the system. Tests were conducted at various bandwidth levels to evaluate their impact on the success and speed of the data transfer process. The results from tests conducted with bandwidths of 0.001 MB/s and 0.01 MB/s showed failures, indicating that extremely low bandwidths are insufficient for successful data transfer. This low bandwidth was identified as the primary cause of the failure in data transmission. Conversely, tests conducted with higher bandwidths, namely 0.1 MB/s, 1 MB/s, and 10 MB/s, resulted in successful data transfers. The time required to complete the data transfer at a bandwidth of 0.1 MB/s was 60 seconds, while at 1 MB/s it was reduced to 53 seconds, and at 10 MB/s it was the fastest, taking only 50 seconds. These results clearly demonstrate a correlation between increased bandwidth and faster data transfer, where higher bandwidth allows for quicker completion of the transfer process.

Table 2 Bandwidth Testing Results

Bandwidth	Time (seconds)	Description
0.001 MB/s	-	Not successful
0.01 MB/s	-	Not successful
0.1 MB/s	60	Successful
1 MB/s	53	Successful
10 MB/s	50	Successful

4.3 Firmware Update Testing Results on IoT System

Firmware update testing on the IoT system with a total memory capacity of 1,310,720 bytes demonstrated that the system successfully performed updates across various memory usage levels without failure. However, a pattern emerged showing that the time required to complete the firmware update tended to increase as memory usage rose. This increase in duration became more noticeable when memory capacity approached its maximum limit.

Although the system was able to maintain operational stability even when memory capacity was nearly full, the increase in update time is a factor that should be considered. When memory usage approached 100%, the firmware update duration significantly increased compared to devices with more available memory space. This highlights the importance of efficient memory management to maintain system performance, particularly for devices expected to undergo regular firmware updates.

Monitoring and optimizing memory usage play a critical role in reducing the time required for updates while ensuring that the firmware update process runs smoothly without compromising system speed and stability. Therefore, attention to memory management is crucial in maintaining optimal system performance, especially under high memory usage conditions.

Table 3 Firmware Testing Results with a Total Memory Capacity of 1,310,720 Bytes

Version	Total Memory Capacity	Update Time (Seconds)	Descirption
1.1	99,3%	54	Successful
1.2	97,1%	53	Successful
1.3	77,9%	49	Successful
1.4	80,4%	52	Successful
1.5	81%	49	Successful
1.6	82,5%	52	Successful
1.7	84%	51	Successful
1.8	85,6%	51	Successful
1.9	89,5%	52	Successful
2.0	99,9%	55	Successful

.4.4 Firmware OTA Upload Test Results

The test results show a relatively consistent upload time, ranging between 50 and 54 seconds. The variation in upload time between tests is minimal, with the lowest recorded time being 50 seconds and the highest being 54 seconds. The average upload time is around 52 seconds. This consistency indicates that the testing process was stable and predictable, with no significant fluctuations or major anomalies in the test duration. The stability of the upload time reflects the reliability of the system during testing, both in terms of hardware, testing methodology, and the environment in which the tests were conducted.

Table 4 Test Table and Author Time

Test	Time (Seconds)
1	52
2	53
3	52
4	51
5	52
6	51
7	50
8	53
9	54
10	52

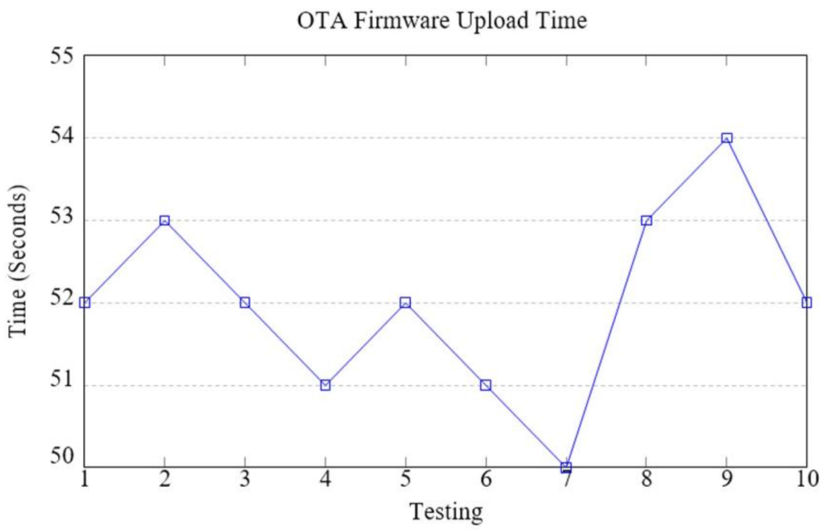

Figure 3 Firmware OTA Upload Time

The test results graph shows that the firmware OTA upload time varied between 50 and 54 seconds across 10 tests. Although there were minor fluctuations, most of the upload times ranged between 51 and 53 seconds. The highest recorded upload time was 54 seconds in the 9th test, while the lowest was 50 seconds in the 7th test. This variation suggests that certain factors influenced the upload duration, although, on average, the upload time remained relatively consistent in the 51-53 second range. This stability indicates that despite minor differences between tests, the system performed reliably under the tested conditions.

4. CONCLUSIONS

The implementation of wireless firmware updates via Over-The-Air (OTA) in the Smart Indoor Farming system has proven to be an effective solution for remote device updates. By utilizing GitHub as the repository for storing the latest firmware versions and GitHub Pages as the distribution platform, the update process can be executed with high efficiency and

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automation. The use of JSON files to check for the latest firmware versions allows IoT devices to detect and download updates directly without requiring manual intervention.

This OTA approach not only reduces the need for manual maintenance but also enhances device performance by ensuring that the firmware is always up-to-date. Additionally, the OTA technology minimizes device downtime during the update process, supporting the overall continuity of system operations. The system is also designed to address various technical challenges, such as network and hardware limitations, making it a reliable option for large-scale IoT applications like Smart Indoor Farming.

The test results indicate that various network and hardware parameters, including firmware size, memory capacity, and network speed, significantly influence the success and efficiency of the OTA firmware update process. Even with nearly full device memory, firmware updates can still succeed as long as the minimum required bandwidth of 0.1 MB/s is met.

Factors such as network speed, firmware size, and IoT device specifications affect the duration of the firmware update process. Therefore, configuration adjustments are necessary to ensure the update process runs optimally. Considering all these variables, the OTA firmware update system can be optimized to improve device performance and stability under various technical and operational conditions.

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