Remote Control of Gangway System Using ESP32 and MQTT

Muhamad Nizarudin [1*], Ayusta Lukita Wardani [2], Mahendra Widyartono [3], Widi Aribowo [4]
[1* 2,3,4] Universitas Negeri Surabaya, Surabaya, Indonesia

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ABSTRACT

This study aims to design and implement an automated gangway control system based on the ESP32 microcontroller and the MQTT communication protocol, enabling remote operation via a mobile application and real-time visual monitoring using the ESP32-CAM module. The system was developed to enhance operational efficiency and safety in port environments, where gangways are still commonly operated manually. An experimental approach was employed, consisting of hardware and software design, prototype assembly, and system performance testing. The testing focused on evaluating the stability of the DC motor voltage across various PWM values, the gangway's operational speed based on RPM and duration, and the communication range of the MQTT-based remote control. The results show that the system operates optimally at a PWM value of 165, achieving a motor speed of 46.7 RPM with safe operational timing. Motor voltage remained stable between 2.1 V and 10.9 V across PWM variations. The system maintained reliable remote control functionality up to a distance of 15 meters, beyond which the connection began to fail. In addition, the ESP32-CAM provided real-time visualization of the gangway's condition. The novelty of this research lies in the integration of control, communication, and visual monitoring systems into a single ESP32- and MQTT-based prototype, a combination rarely applied specifically for gangway automation in port operations. This system demonstrates strong potential for implementation in industrial automation scenarios requiring remote control and efficient visual monitoring.

INTRODUCTION

Technological advancements in the era of the Fourth Industrial Revolution have significantly transformed operational paradigms across various sectors, including maritime transportation and port operations. In port activities, the gangway—serving as a bridge between the vessel and the dock—is a critical component for ensuring smooth and safe boarding and disembarkation of passengers and crew members. However, many gangway systems still rely heavily on manual operation, which not only consumes time but also increases the risk of operational errors and workplace accidents.This issue presents an opportunity to leverage the Internet of Things (IoT) as a modern solution to improve the efficiency and safety of gangway operations. IoT technology enables physical devices to connect to the internet, allowing for real-time remote control and monitoring. In this context, the ESP32 microcontroller stands out as a highly suitable platform due to its integrated Wi-Fi and Bluetooth capabilities, fast data processing, and low power consumption. A recent study by Maroșan et al. (2024) confirms that ESP32 is an ideal choice for data acquisition and device control in industrial IoT applications, thanks to its stability, reliability, and affordability.

To support inter-device communication within IoT ecosystems, the MQTT (Message Queuing Telemetry Transport) protocol has emerged as a widely adopted and efficient solution due to its lightweight, fast, and bandwidth-saving nature. This protocol allows for effective data exchange, even under unstable network conditions. Research by Muhammad et al. (2023) highlights the reliability of MQTT in controlling various ESP32-based IoT devices, with minimal latency and high effectiveness in transmitting sensor data and actuator commands.Visual surveillance is another essential aspect of designing a safe gangway system. The ESP32-CAM module offers real-time image and video streaming capabilities, making it a popular choice for IoT-based monitoring systems. It has been successfully implemented in home security, remote surveillance, and object tracking applications, as demonstrated in the study by Aziz et al. (2022). Its compact size and affordability allow it to be easily integrated into control systems to provide direct visual feedback from the field. Nevertheless, previous studies integrating ESP32, ESP32-CAM, and MQTT have predominantly focused on smart home or environmental monitoring applications. There has been limited research on their application in automated gangway systems for port or offshore environments. Meanwhile, the dynamic conditions of port environments—such as varying wave heights, vessel movement, and the need for quick responses in emergencies—underscore the need for a more adaptive and intelligent gangway system.

This research responds to that gap by designing and developing a prototype of an automated gangway system based on ESP32, connected via MQTT, and equipped with visual monitoring capabilities using ESP32-CAM. The system allows operators to control gangway movement automatically via a smartphone application while simultaneously monitoring the gangway environment in real-time. A DC motor serves as the main actuator for the gangway, while the ESP32-CAM module streams live visual data to the user. Communication between the system and the user is established through MQTT, ensuring fast and efficient transmission of control commands and feedback.The system was tested in several technical aspects, including voltage stability of the DC motor under varying PWM values, operational speed in terms of time and RPM, and the maximum

Figure 1. Gangway Design
Source : Personal Documents

communication range of the MQTT system under normal environmental conditions. The prototype demonstrated satisfactory results in terms of performance and system stability. The best performance was achieved at PWM 165, equivalent to 46.7 RPM, where the system operated smoothly without overloading the motor or gangway structure. In terms of communication, the system remained responsive up to 15 meters before experiencing significant signal degradation.

Through this approach, the research not only offers a technical solution but also encourages innovation in electrical automation for port operations. The developed system reduces dependence on manual operation, increases the accuracy of gangway movement, and accelerates response time in emergency situations. This aligns with the demands of modern industry, which prioritizes efficiency, reliability, and workplace safety. Based on this background and urgency, this study aims to design, develop, and evaluate an ESP32- and MQTT-based automated gangway control system, with DC motor operation and visual monitoring using ESP32-CAM. The objective is to assess the system's effectiveness and stability during remote operation, focusing on voltage stability, operational speed, and communication range. The expected outcome is an innovative solution that supports the development of smart ports and future industrial automation systems.

RESEARCH METHOD

This study is an experimental research that aims to design, develop, and test a prototype of an automated gangway control system based on the ESP32 microcontroller and the MQTT communication protocol. The research also evaluates the system's performance in terms of DC motor voltage stability, operational speed measured in RPM, and the range of remote control communication. An experimental approach was chosen as it allows direct observation of the relationship between input variables, such as PWM values and communication distance, and output responses such as voltage, operating time, and connection reliability. This applied research focuses on the development of Internet of Things (IoT)-based technology to support automation in electrical systems within the port and industrial sectors. Since this study involves technological engineering, the primary subjects are the hardware components and the developed system. No human participants were involved as respondents. All activities were carried out by the main researcher with the assistance of laboratory technicians and were conducted at the industrial electrical engineering workshop of PT. Surya Metalindo over a period of six months.

The instruments used consisted of key components within the system. The ESP32 Dev Board served as the main control unit, handling both communication and motor control functions. The ESP32-CAM module was used to capture and transmit real-time images or video from the gangway area. The 12V DC motor functioned as the main actuator for raising and lowering the gangway, controlled via an L298N motor driver module managed by the ESP32. The system received power from an AC–DC 220V to 12V adapter, and voltage was stepped down to 5V for the ESP32 using the XL4015 converter. Manual control and movement limitation were supported by push buttons and limit switches. Real-time RPM data was displayed on an LCD I2C 16x2 screen, and a tachometer was used to measure the motor's rotational speed. A digital multimeter was employed to monitor voltage stability during testing, while a smartphone was used as a user interface to control and monitor the system through an application developed with MIT App Inventor.

The research process began with a needs analysis based on the identified issues in conventional gangway operations. This was followed by prototype design, involving mechanical design using SolidWorks software and schematic design of the IoT-based control system. Once all components were assembled according to the design, software configuration was conducted by programming the ESP32 microcontroller in C++ using the Arduino IDE and developing the mobile application using MIT App Inventor. System testing was conducted over five consecutive days in three main categories. First, the stability of the DC motor voltage was tested across seven PWM variations, ranging from 75 to 255. Second, the operating time and RPM of the DC motor during the gangway's upward and downward movement were measured. Third, the maximum communication range of the MQTT protocol under normal environmental conditions was evaluated, from distances of 0 to 18 meters. All test data were recorded systematically in a test log, and repeated trials were performed to ensure consistency.

The collected data were analyzed quantitatively using a descriptive approach. DC motor voltage, operating time, and RPM values were compared for each PWM variation. The results were visualized through graphs and tables to illustrate the relationship between voltage and load, as well as the correlation between motor speed and gangway operation duration. The maximum effective distance for MQTT connection was also recorded to determine the practical range for remote control. System performance evaluation focused on three main aspects: energy efficiency as indicated by voltage stability, actuator performance measured by motor speed and operating time, and communication reliability assessed by system response at varying distances. Any irregularities or significant deviations in performance were analyzed from a technical perspective, including factors such as insufficient motor torque or communication signal interference.

RESULTS AND DISCUSSION

Figure 2. Final Design Of The Gangway
Source : Personal Documents

DC Motor Voltage Performance on PWM Variations

Voltage Stability Testing was conducted on the DC motor using varying PWM (Pulse Width Modulation) values to determine the characteristics of the output voltage delivered by the ESP32-based control system. The PWM range tested was from 75 to 255. Measurement results showed that a PWM value of 255 produced the highest voltage output of 10.9 V, while at PWM 105, the minimum voltage that still generated slow motor rotation was 2.1 V. At PWM 75, the motor voltage dropped to 0 V, and the motor did not operate at all.

Tabel 1 Average DC Motor Voltage in Five Days of Testing

PWM	RPM	Lift Time (s)	Lower Time (s)
255	91,1	7,30	6,40
225	80,4	8,48	8,30
195	66,2	11,45	9,90
165	46,7	11,89	10,91
135	36,5	18,97	13,91
105	25,6	36,11	22,23
75	0	-	-

The difference in operating time between upward and downward movement ranged from 1 to 2 seconds, caused by the effect of gravity during descent and mechanical load during lifting. Based on the data, an RPM of 46.7 (PWM 165) is considered the optimal value, as it provides a moderate and safe operating time for the gangway's mechanical structure.

Operational Speed Analysis Based on RPM and Operating Time

The next test evaluated the operational speed of the gangway by measuring the lift and descent durations, as well as the RPM of the DC motor using a digital tachometer. The results showed that at PWM 255, the motor reached 91.1 RPM with a lift time of 7.30 seconds and a descent time of 6.40 seconds. Meanwhile, at PWM 165, the RPM was recorded at 46.7 with respective lift and descent durations of 11.89 seconds and 10.91 seconds.

Table 2. Relationship between PWM Values, Operating Time, and Motor RPM

PWM	RPM	Lift Time (s)	Lower Time (s)
255	91.1	7.30	6.40
225	80.4	8.48	8.30
195	66.2	11.45	9.90
165	46.7	11.89	10.91
135	36.5	18.97	13.91
105	25.6	36.11	22.23
75	0	–	–

The difference in operating time between upward and downward movement ranged from 1 to 2 seconds, which is attributed to the effect of gravity during descent and mechanical load during lifting. Based on the data, 46.7 RPM (PWM 165) is considered the optimal value, as it provides a moderate and safe operation time for the mechanical structure of the gangway.

Evaluation of Remote Control Operational Range (MQTT)

Range testing was conducted to evaluate the effectiveness of the system in controlling the gangway from a distance using the MQTT protocol. The test covered distances from 0 to 18 meters. The results indicated that the system operated normally up to a distance of 15 meters. At 18 meters, the gangway failed to respond to commands from the application, indicating a loss of connectivity.

Table 3. MQTT Control Range Test Results and Operational Time

Distance (m)	Status	Lift Time (s)	Lower Time (s)
0	✅	7.30	6.40
3	✅	6.58	6.35
6	✅	7.21	6.22
9	✅	7.32	6.80
12	✅	7.04	6.79

15	✅	10.57	10.20
18	❌	–	–

At a distance of 15 meters, there was a noticeable delay in response, with the lift time increasing to 10.57 seconds. This indicates a decline in the ESP32's Wi-Fi signal quality at the maximum operational range. Practically, the system is considered effective for real-time control at distances up to 12 meters.

General Discussion

The results of the study indicate that the ESP32- and MQTT-based automated gangway prototype was able to operate reliably during repeated testing. From the electrical aspect, the DC motor voltage was evenly and stably distributed throughout the five-day testing period. From the mechanical perspective, the system demonstrated consistent operational times and showed no signs of overheating or motion failure, even at the optimal RPM. In terms of communication, the MQTT-based control system proved efficient up to a distance of 15 meters, although some delay was observed. This result is relatively satisfactory, considering that the ESP32 only uses an internal antenna. Previous studies by Maroșan et al. (2024) and Aziz et al. (2022) reported similar outcomes, showing that the integration of ESP32 and MQTT in small-scale industrial systems delivers stable communication and efficient processing performance. The application of this technology is expected to offer a low-cost, lightweight, and flexible automation solution for port operations and may be further developed for full-scale gangway systems using motors with higher torque and faster connection technologies such as LoRaWAN or Wi-Fi mesh. Future research is recommended to integrate features such as automatic load detection, thermal motor protection, and cloud-based multi-node monitoring capabilities.

CONCLUSION

This study successfully designed and implemented an automated gangway control system based on the ESP32 microcontroller and the MQTT communication protocol. The system can be operated remotely via a mobile application and is equipped with a real-time visual monitoring feature using the ESP32-CAM. This prototype presents an innovative solution to the increasing demand for automation in port and industrial environments, particularly in enhancing operational efficiency and workplace safety. Based on the testing results, the system operated stably, with consistent DC motor voltage, optimal performance at 46.7 RPM, and an effective control range of up to 15 meters. The findings demonstrate that the integration of actuator control, wireless communication, and real-time visualization can be achieved in a simple yet reliable manner using low-power IoT devices. A PWM value of 165 was selected as the ideal configuration, as it provides a balance between speed, stability, and mechanical safety for the gangway. Therefore, this research not only contributes to the development of ESP32-

and MQTT-based remote control technology but also opens opportunities for broader applications in maritime transportation systems and other industrial automation fields. The developed system can serve as a reference for further advancements, including improvements in scalability, network security, and cloud integration for multi-device management. In conclusion, the resulting prototype proves that microcontroller and IoT technologies can serve as a strong foundation for creating automation systems that are efficient, safe, and affordable—addressing the challenges of an increasingly connected and digital industrial world.

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