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Prototype of a Smoking Activity Detection Device for School Toilets Based on ESP32

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***Abstract*—This research aims to develop and test a prototype device for detecting indications of smoking activity in the area outside school toilets using an ESP32-Cam microcontroller. The research method used is Research and Development (R&D) with a V-Model approach covering the stages of requirement analysis, specification, system design, component design, coding, unit testing, integration testing, system testing, and acceptance testing. The system integrates an MQ-2 sensor to detect responses to smoke exposure, a PIR HC-SR501 sensor to detect object movement in order to minimize false alarms, and an LCD and buzzer as local warning media. A Telegram Bot is used as a remote notification medium in the form of text messages and image documentation. Integration testing results show 5 True Positive data, 15 True Negative data, 0 False Positive data, and 0 False Negative data from 20 tests limited to a mock-up environment, yielding a system accuracy of 100% and an error rate of 0%. The system successfully identified trigger conditions according to the test scenarios and sent notifications along with images to Telegram with an average delay of 9 seconds. In conclusion, this prototype was successfully designed and functions well in remotely detecting indications of smoking activity on the school toilet mock-up.**

***Index Terms*—Telegram Bot, Smoking Detection, ESP32-Cam, MQ-2, PIR HC-SR501.**

I. INTRODUCTION

Smoking is the activity of inhaling smoke from burning tobacco, which can have a significant impact on the physical and psychological health of its users [1]. Adolescent smokers even tend to have higher stress levels than non-smokers [2]. Based on the Indonesian Health Survey, the number of active smokers in Indonesia is estimated to reach 70 million people, with 7.4% of them aged 10–18 years [3], while globally the number of smokers reaches 1.3 billion people [4].

The government has established Smoke-Free Areas (Kawasan Tanpa Rokok) through Article 151 of Law No. 17 of 2023 on Health, which includes school environments among other areas [5]. Nevertheless, school toilets remain an area prone to being used for smoking discreetly due to their enclosed nature and minimal direct supervision. Observations at SMP Negeri 1 Bitung showed that the implementation of smoke-free areas has not been fully effective, as indicated by the discovery of cigarette butts in school toilets [6].

Several previous studies have developed IoT-based cigarette-smoke detection devices, including ones using MQ-2 and DHT11 sensors to activate an air-neutralizing fan [7], as well as a combination of MQ-135 and MQ-2 sensors with a purifier system [8]. Other research has integrated an ESP32-Cam to capture visual documentation when cigarette smoke is detected [9], but without additional validation in the form of human-presence detection, making it prone to false alarms caused by non-cigarette smoke or gas. The PIR HC-SR501 sensor itself has been proven effective at detecting human presence through changes in infrared radiation [10], but has not yet been combined with a gas sensor in a single integrated system for the context of smoking-activity detection in school toilets.

The identified research gap is the absence of a system that correlates the gas sensor's response to smoke exposure with simultaneous object-movement validation, which creates the potential for detection errors if relying on only one parameter. Based on this gap, this research develops a Prototype of a Smoking Activity Detection Device for School Toilets Using ESP32 that integrates an MQ-2 sensor and a PIR HC-SR501 sensor as dual validation, an ESP32-Cam as the processing unit and documentation camera, a 16x2 LCD and buzzer as local warnings, and a Telegram Bot as the remote notification medium. The system was developed in the form of a laboratory-scale mock-up to test the validity of the programming logic and the synchronization between components, while still observing the ethical privacy boundaries of actual toilet users — the camera is directed solely at the mock-up simulation area, not at a real toilet.

The research problem of this study is how to design a Prototype of a Smoking Activity Detection Device Using ESP32. The objectives of this research are: (1) to develop a prototype ESP32-Cam-based smoking-activity detection device; (2) to integrate MQ-2 and PIR sensors as trigger-condition detection parameters; (3) to test the effectiveness of the device in detecting cigarette-smoke response and human presence; and (4) to test the system's resilience against potential response errors.

II. THEORETICAL BASIS

A. Research and Development (R&D) Development Model

Research and Development (R&D) is a research method aimed at producing and testing the effectiveness of a particular product through structured research stages [11], [12]. This research applies R&D with a V-Model approach, a system-development model that integrates the testing phase in parallel with each design stage, making it suitable for embedded-system engineering that requires close integration between hardware and software [13]. The V-Model stages used include requirement analysis, specification, system design, component design, coding, unit testing, integration testing, system testing, and acceptance testing.

B. System Components

The developed system integrates five main components. The ESP32-Cam is a System-on-Chip-based microcontroller module with integrated Wi-Fi connectivity and an OV2640 camera, enabling it to process sensor data while simultaneously capturing image documentation. The MQ-2 sensor is used to detect the response to smoke exposure with a digital logic output (HIGH/LOW), while the PIR HC-SR501 sensor detects object movement through changes in passive infrared radiation to minimize the risk of detection errors caused by the gas sensor's cross-sensitivity to non-cigarette smoke sources. The 16x2 I2C LCD is used as a local system-status display medium, the active buzzer as an audible warning indicator, and the Telegram Bot as the interface for receiving text notifications along with image documentation wirelessly through the Telegram Bot API.

C. System Design

The functional relationships between components are illustrated through the block diagram in Fig. 1. The ESP32-Cam acts as the processing center that connects the MQ-2 and PIR sensors as inputs, with the buzzer, LCD, and Telegram Bot as the system's outputs.

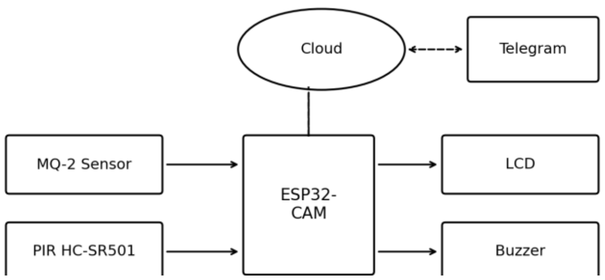

Fig. 1. System Block Diagram

The way the system works is illustrated through the flowchart in Fig. 2. The system performs component initialization, checks the internet connection, then continuously reads the status of the MQ-2 and PIR sensors. If both sensors show a HIGH condition simultaneously, the system displays a warning on the LCD, activates the buzzer, captures an image via the ESP32-Cam, and sends a notification along with the image to the Telegram Bot. This process runs continuously (looping) as long as the device is connected to a power source.

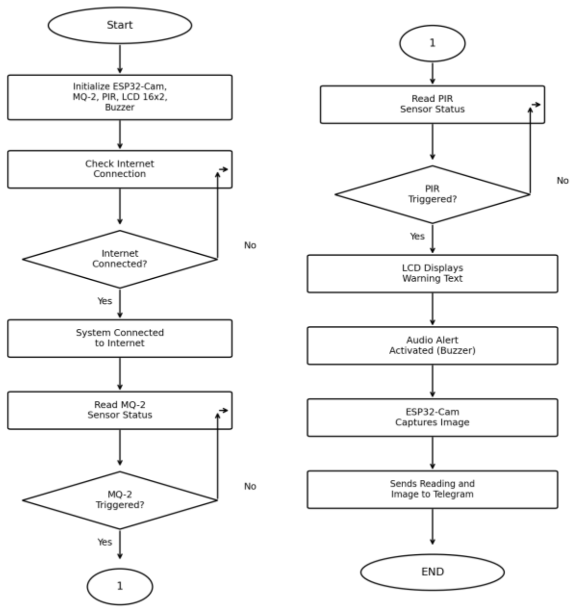

Fig. 2. System Flowchart

III. METHODOLOGY

A. Research Location and Time

The research was conducted at the Control Instrumentation Laboratory, Electronics Engineering Education Study Program, Faculty of Engineering, Universitas Negeri Jakarta, from January to July 2026.

B. Research Method

This research uses the R&D method with a V-Model approach consisting of nine stages: requirement analysis, specification, system design, component design, coding, unit testing, integration testing, system testing, and acceptance testing. Each design stage in the verification phase is directly linked to its corresponding testing stage in the validation phase, so that the chemical-sensor and motion-sensor readings are validated gradually before the system's integration logic is tested comprehensively.

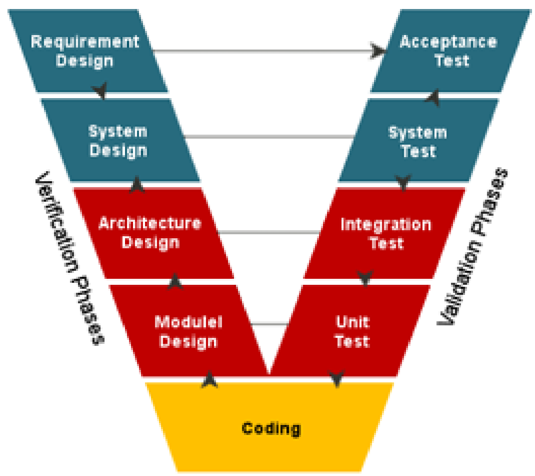

Fig. 3. V-Model Methodology

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The V-Model methodology directly connects each system-design phase with its testing or verification phase. This process begins with requirement analysis to map the technical and non-technical functions of the device being built. The next step is specification, which clarifies technical details of the system such as output type, sensor criteria, and warning mechanisms. Next, system design is carried out to arrange the microcontroller architecture, working diagram, and inter-module integration, which is then further detailed at the component-design stage. Once the entire design is finalized, the coding and hardware-assembly stages are carried out. Once the physical system is formed, the testing process begins with unit testing on each component individually. The stages then continue to integration testing to check the connections between modules, system testing to observe the device's performance under real conditions, and conclude with acceptance testing to ensure the system meets user expectations and is ready to be operated.

C. Instruments and Device Specifications

The hardware used includes the ESP32-Cam, an MQ-2 sensor, a PIR HC-SR501 sensor, a 16x2 I2C LCD, an active buzzer, and a 5V 2A adapter as the power supply. The software used includes Arduino IDE v2.3.8 for C++ programming, Fritzing v0.9.3 for schematic visualization, SketchUp v25.0.634 for mock-up design, and the Telegram application as the notification interface. The MQ-2 sensor is connected via the DO line to GPIO 2, the PIR sensor to GPIO 13, and the buzzer to GPIO 12 on the ESP32-Cam. The operating-voltage specifications of each component are shown in Table 1.

TABLE I. PROTOTYPE COMPONENT SPECIFICATIONS

No.	Component	Function in the Prototype
1	ESP32-Cam	Processes system logic and captures image documentation for test scenarios
2	MQ-2 Sensor	Detects the response to smoke exposure in the test scenario
3	PIR HC-SR501 Sensor	Detects object movement in the test area
4	16x2 I2C LCD	Displays status text and warnings locally
5	Active Buzzer	Provides a local audible warning

D. Data Analysis Technique

Testing was conducted by classifying the sensor-reading results against four test scenarios: standby condition, motion detected only, smoke detected only, and trigger condition met (smoke and motion detected simultaneously), each repeated five times. Each test result was classified into a confusion matrix consisting of True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN). The system's accuracy and error rate were calculated using the following formulas, referring to [14]:

$$Accuracy = (TP + TN) / (TP + TN + FP + FN) \times 100\% \qquad (2)$$

This formula is used to calculate the classification system's accuracy by dividing the total correct predictions (TP + TN) by the total number of data samples. The result is multiplied by 100% to obtain the percentage value. The numerator represents the valid system responses, while the denominator covers all possible outcomes during testing.

$$Error\ Rate = (FP + FN) / (TP + TN + FP + FN) \times 100\% \quad (1)$$

This formula is used to calculate the classification system's error rate by dividing the total incorrect predictions (FP + FN) by the total number of data samples, then multiplying by 100%. The numerator represents error parameters such as false triggers or detection failures, and its value is the complement of accuracy. This matrix evaluation aims to assess sensor sensitivity and refine the program logic to measure the system's success.

IV. RESULTS AND ANALYSIS

A. Product Realization

The smoking-activity detection device prototype was successfully realized in the form of a laboratory-scale mock-up representing the layout of a school toilet, as shown in Fig. 4. The ESP32-Cam camera is placed outside the toilet-stall area and directed purely at the mock-up simulation area, not toward anything that could record the face or activity of an actual toilet user, as a form of privacy protection.

Fig. 4. Prototype Realization on the School Toilet Mock-up

B. Unit Testing Results

Unit testing was conducted separately on the MQ-2 sensor, the PIR HC-SR501 sensor, the 16x2 LCD, and the buzzer. Based on 20 trials on the MQ-2 sensor divided into four test scenarios, TP = 10, TN = 10, FP = 0, and FN = 0 were obtained, yielding an accuracy of 100% and an error rate of 0%. Testing of the PIR HC-SR501 sensor over 10 trials yielded TP = 5, TN = 5, FP = 0, and FN = 0, with an accuracy of 100% and an error rate of 0%, as summarized in Table 2. Testing of the 16x2 LCD showed that all five display conditions (“connecting WiFi,” “Status clear,” “smoke detected,” “person detected,” and “Detected, check the restroom now”) matched the program logic, while the buzzer consistently remained LOW in the standby condition or when only one sensor was active, and switched to HIGH only when both sensors were active simultaneously.

TABLE II. SUMMARY OF MQ-2 AND PIR HC-SR501 SENSOR TEST RESULTS

Sensor	Tests	TP	TN	FP	FN	Accuracy
MQ-2	20	10	10	0	0	100%
PIR HC-SR501	10	5	5	0	0	100%

C. Integration and System Testing Results

Integration testing combined all components into a single system tested across four scenarios — standby condition, motion detected only, smoke detected only, and trigger condition met — each repeated five times (20 trials in total). The test results show that the system consistently remained in the standby

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condition (not activating the buzzer, warning LCD, or notification sending) when only one parameter or no parameter was met, and only executed all warning actions when both the MQ-2 and PIR sensors were simultaneously HIGH. A summary of the test results in the form of a confusion matrix is presented in Table 3.

TABLE III. CONFUSION MATRIX OF SYSTEM INTEGRATION TEST RESULTS

	Actual Positive	**Actual Negative**
System Detects Positive	TP = 5	FP = 0
System Does Not Detect	FN = 0	TN = 15

Based on Table 3, the system's accuracy and error-rate calculations using Equations (1) and (2) are as follows:

$$Accuracy = (5 + 15) / (5 + 15 + 0 + 0) \times 100\% = 100\% \quad (3)$$

Through this calculation, the system is shown to produce an accuracy percentage of 100%. On the other hand, to measure the system's potential failure, the error-rate value was also calculated using the following formula:

$$Error\ Rate = (0 + 0) / (5 + 15 + 0 + 0) \times 100\% = 0\% \quad (4)$$

These results show that the system was able to functionally identify trigger conditions across 20 limited test scenarios in the mock-up environment. Testing of the Telegram Bot interface showed that text notifications along with image documentation were successfully sent automatically with an average delay of 9 seconds after the trigger condition was met, while in the standby or partial conditions, the system consistently did not send any notification.

D. Discussion

Compared to the study by Faoziah et al. [7], which relied solely on MQ-2 and DHT11 sensors to activate a neutralizing fan without object-motion validation, and the study by Alexander Rombang et al. [8], which focused on a purifier system based on MQ-135 and MQ-2 sensors, the system in this research adds dual validation through the PIR HC-SR501 sensor to minimize the risk of detection errors caused by the gas sensor's cross-sensitivity. Compared also to the study by Oka Priyatna et al. [9], which had integrated the ESP32-Cam with Telegram but did not yet have an additional motion-detection parameter, this research shows that the simultaneous integration of the MQ-2 and PIR HC-SR501 sensors is able to suppress the potential for false alarms down to 0% at a limited testing scale.

Nevertheless, these test results still have limitations, namely the absence of a comparison instrument such as a ppm measuring device to quantitatively validate smoke concentration, and testing that was only conducted at the laboratory mock-up scale and not yet on an actual school toilet. Therefore, the 100% accuracy obtained needs to be interpreted as the system's functional success under limited test scenarios, not as a guarantee of performance under actual field conditions.

V. CONCLUSION AND RECOMMENDATIONS

Based on the results of the research and development using the R&D method with a V-Model approach, a prototype smoking-activity detection device for school toilets based on ESP32-Cam has been successfully designed, integrating the MQ-2 and PIR HC-SR501 sensors as dual validation, a 16x2 LCD and buzzer as local warnings, and a Telegram Bot as the remote notification medium. The integration test results across 20 limited trials in the mock-up environment produced TP = 5, TN = 15, FP = 0, and FN = 0, with an accuracy of 100% and an error rate of 0%, as well as a notification-sending delay to the Telegram Bot of 9 seconds. Thus, this prototype is declared to have met the design specifications and functions according to the established test scenarios.

This research is still limited to the laboratory mock-up scale and has not yet used a comparison instrument in the form of a ppm measuring device for quantitative validation of smoke concentration. Suggestions for further research development include integrating the system with an independent application or web-based platform so that it does not depend on third-party applications, adding sensors and a calibration procedure if the measurement results are to be expressed in ppm units, adding testing variations in the form of interfering gases as well as variations in the distance and detection angle of the PIR sensor, and implementation in an actual school environment, which must go through institutional permit procedures and thorough privacy review.

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