

Predicting The Detection Delay Of An ESP32-Based Fire Detection System Using Flame Sensor, MQ-2 Sensor, And Multiple Linear Regression

Willnotus Daniel Awil¹, Candra Gudianto², Azriel Christian Nurcahyo³, Charley Orilya
Grasselly Alfa Delfiny Hartoyo Uray⁴

^{1,3,4}Department, Shanti Bhuna Institute, Bengkayang, Indonesia

²Information System, Shanti Bhuna Institute, Bengkayang, Indonesia

*Corresponding author: willnotusdanielawil@gmail.com

ABSTRACT

Fire is one of the most common non-natural disasters that can cause significant material losses and threaten human safety. Therefore, an effective fire detection system is required to provide early warnings and minimize potential risks. This study proposes an Internet of Things (IoT)-based fire detection system integrated with a Flame Sensor, an MQ-2 gas sensor, an ESP32 microcontroller, the Blynk platform, and Telegram notifications for real-time monitoring and early warning. A Multiple Linear Regression model was developed to predict the system detection delay. The independent variables used in this study were Fire Detection Intensity (X_1) and MQ-2 Sensor Value (X_2), while the dependent variable was Detection Delay (Y). A total of 500 experimental data records were collected through the Blynk platform, consisting of 350 training data and 150 testing data. The proposed model achieved an MAE of 0.050535 s, an MSE of 0.003343, an RMSE of 0.057822 s, a MAPE of 3.16%, and an R^2 value of 0.988871, indicating excellent prediction performance. The comparison between the actual and predicted detection delays also demonstrates that the proposed model accurately estimates the system response time. These findings indicate that the proposed Multiple Linear Regression model is effective for predicting the detection delay of an IoT-based fire detection system.

Keywords: Fire Detector, ESP32, Multiple Linear Regression, Flame Sensor.

1. INTRODUCTION

Fire is one of the most common non-natural disasters and can cause significant material losses as well as threaten human safety. Fire incidents often occur due to human negligence, electrical failures, or uncontrolled fire sources, particularly in residential kitchens and other indoor environments. Therefore, early fire detection is essential to minimize potential damage and improve public safety (Suherman, Refni Wahyuni, Abdi Muhaimin, 2022).

Recent advances in Internet of Things (IoT) technology have enabled the development of intelligent fire detection systems capable of monitoring environmental conditions in real time. Flame Sensors and MQ-2 sensors are commonly used to detect fire and smoke, while the ESP32 microcontroller provides data processing and wireless communication for remote monitoring through platforms such as Blynk and Telegram (Yahya et al., 2024) and (Agustanti et al., 2022).

In a previous practical work conducted by the author, an Arduino Uno-based fire detection system was successfully developed to detect fire and activate warning devices. However, the

system evaluation was limited to basic functionality without analyzing its detection performance. In particular, the relationship between sensor readings and system detection delay was not investigated, making it difficult to estimate the response time under different fire conditions.

To address this limitation, this study applies the Multiple Linear Regression (MLR) method to develop a prediction model for the system detection delay. MLR is widely used to analyze the relationship between multiple independent variables and a dependent variable and to build predictive models with good accuracy (Sulantari et al., 2024) and (Halif et al., 2025). In fire detection systems, sensor-based and data-driven approaches have also been shown to improve detection accuracy and reduce detection delay (Park et al., 2025).

This study proposes an IoT-based fire detection system integrating a Flame Sensor, an MQ-2 sensor, an ESP32 microcontroller, the Blynk platform, and Telegram notifications for real-time monitoring. Fire Detection Intensity (X_1) and MQ-2 Sensor Value (X_2) are used as independent variables, while Detection Delay (Y) is used as the dependent variable. The developed Multiple Linear Regression model is expected to accurately predict the system response time and improve the effectiveness of IoT-based fire detection systems.

2. METHODS

2.1 Research Type and Approach

This study employed a quantitative research approach because the research process involved collecting numerical data obtained from system testing, which were then analyzed using statistical methods. Quantitative research enables researchers to evaluate relationships among variables objectively by using measurable experimental data and systematic statistical analysis.

The study applied Multiple Linear Regression (MLR) to analyze the relationship between Fire Detection Intensity (X_1), MQ-2 Sensor Value (X_2), and Detection Delay (Y). The developed regression model was used to predict the system detection delay based on experimental data collected during system testing.

The study was conducted by designing an Internet of Things-based fire detection system capable of automatically detecting fire-related conditions, followed by collecting experimental data generated during system testing. The collected data were then analyzed mathematically to determine the relationship between sensor readings and system response performance. Recent studies on fire detection systems have shown that experimental approaches combined with data-driven modeling are effective in evaluating system performance and improving the reliability of fire detection technologies (Diaconu, 2023).

2.2 Data Collection Method

Data collection in this study consisted of observation, literature study, and documentation. Observation was conducted to identify fire-prone conditions and determine the system requirements for developing the proposed IoT-based fire detection system. The literature study

provided theoretical and technical references related to fire detection systems, Internet of Things (IoT), ESP32, Flame Sensor, MQ-2 Sensor, and Multiple Linear Regression (MLR).

Documentation was performed throughout the research process, including system development, hardware implementation, experimental testing, and data recording. The collected experimental data were subsequently used to develop and evaluate the Multiple Linear Regression prediction model.

2.3 Research Stages

The research stages in this study were carried out systematically to ensure that the research process was conducted in accordance with the objectives that had been established. Each stage was designed to ensure that the developed system could be implemented, tested, and analyzed in a structured manner. The research stages conducted in this study are described as follows.

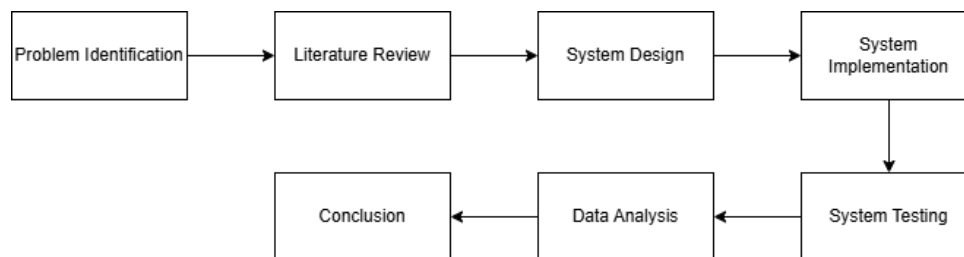


Figure 2. 1 Research Stages

1. **Problem Identification**
The study began by identifying the need for an automatic fire detection system capable of providing early warnings and predicting detection delay under different fire conditions.
2. **Literature Review**
Relevant references on IoT-based fire detection systems, ESP32, Flame Sensor, MQ-2 Sensor, and Multiple Linear Regression were reviewed to support the system development and research methodology.
3. **System Design**
The hardware and software of the proposed fire detection system were designed, including sensor integration, data processing, alarm activation, and IoT-based monitoring.
4. **System Implementation**
The designed hardware and software components were integrated into a complete system using the ESP32 microcontroller.
5. **System Testing**
Fire scenarios were simulated to collect experimental data consisting of Fire Detection Intensity (X_1), MQ-2 Sensor Value (X_2), and Detection Delay (Y).
6. **Data Analysis**
The collected data were analyzed using Multiple Linear Regression (MLR) to develop and evaluate the prediction model for detection delay.
7. **Conclusion**

Conclusions were drawn based on the implementation and evaluation results to determine whether the proposed system achieved the research objectives.

2.4 System Architecture

The proposed system is an Internet of Things (IoT)-based fire detection system that integrates an ESP32 microcontroller, a Flame Sensor, and an MQ-2 sensor for real-time fire monitoring. The ESP32 acquires and processes sensor data, then activates local warning devices, including a 16×2 I2C LCD, buzzer, and LEDs, when hazardous conditions are detected. The processed data are transmitted via Wi-Fi to the Blynk platform for remote monitoring, while Telegram is used to deliver instant warning notifications. The overall system architecture enables continuous monitoring and rapid response to potential fire incidents.

2.5 Research Variables and System Testing

This study employed two independent variables, namely Fire Detection Intensity (X_1) and MQ-2 Sensor Value (X_2), while Detection Delay (Y) was used as the dependent variable. Fire Detection Intensity was obtained from the Flame Sensor, whereas the MQ-2 Sensor Value represented the concentration of gas or smoke detected during the experiment.

The experimental procedure was conducted by simulating fire conditions under different testing scenarios. During each experiment, the ESP32 simultaneously acquired data from the Flame Sensor and MQ-2 sensor while recording the corresponding detection delay. A total of 500 experimental records were collected through the Blynk platform and divided into 350 training samples and 150 testing samples. The training dataset was used to develop the Multiple Linear Regression model, whereas the testing dataset was used to evaluate its prediction performance.

2.6 Multiple Linear Regression Model

The data obtained from system testing were analyzed using the Multiple Linear Regression method to determine the simultaneous relationship between independent variables and the dependent variable. Multiple linear regression is a statistical technique used to examine the relationship between one dependent variable and two or more independent variables, allowing researchers to analyze how several predictor variables simultaneously influence an observed outcome (Adhikari, 2022).

Multiple linear regression is widely applied to develop predictive mathematical models and estimate the contribution of each independent variable toward the dependent variable based on observed experimental data. In this study, the regression model was used to predict system detection delay based on the influence of fire detection intensity and gas or smoke concentration detected by the sensors. The mathematical model used in this study is expressed as follows.

$$Y = a + b_1X_1 + b_2X_2$$

Where:

Y = System Detection Delay

a = Regression Constant

b_1 = Coefficient of Fire Detection Intensity Variable

b_2 = Coefficient of MQ-2 Sensor Variable

X_1 = Fire Detection Intensity

X_2 = MQ-2 Sensor Reading

The resulting regression equation is expected to predict system performance based on the relationship between sensor variables and system response speed in detecting fire conditions. The analysis results are expected to provide an overview of system reliability and serve as a reference for further development of more optimized fire detection systems in future studies.

2.7 Model Performance Evaluation

To evaluate the predictive performance of the proposed Multiple Linear Regression model, five evaluation metrics were employed, namely Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Percentage Error (MAPE), and the coefficient of determination (R^2). These metrics were selected because they provide comprehensive information regarding prediction accuracy, prediction error, and the goodness of fit of regression models. As explained by (Hodson, 2022) and (Miller et al., 2024), each evaluation metric measures different aspects of regression model performance; therefore, multiple metrics are recommended to obtain a comprehensive assessment.

The Mean Absolute Error (MAE) measures the average absolute difference between the actual values and the predicted values. A lower MAE indicates better prediction accuracy.

$$MAE = \frac{1}{n} \sum_{i=1}^n |Y_i - \hat{Y}_i|$$

The Mean Squared Error (MSE) measures the average squared difference between the observed values and the predicted values.

$$MSE = \frac{1}{n} \sum_{i=1}^n (Y_i - \hat{Y}_i)^2$$

The Root Mean Squared Error (RMSE) is obtained by taking the square root of MSE.

$$RMSE = \sqrt{MSE}$$

The Mean Absolute Percentage Error (MAPE) expresses the average prediction error as a percentage of the observed values.

$$MAPE = \frac{100}{n} \sum_{i=1}^n \left| \frac{Y_i - \hat{Y}_i}{Y_i} \right|$$

The coefficient of determination (R^2) measures the proportion of variance in the dependent variable that can be explained by the regression model.

$$R^2 = 1 - \frac{\sum_{i=1}^n (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^n (Y_i - \bar{Y})^2}$$

Where:

R^2 = coefficient of determination

Y_i = actual value of the dependent variable

$\hat{Y}_i$ = predicted value of the dependent variable

$\bar{Y}$ = mean of the actual dependent variable values

n = number of observations

Σ = summation operator

An R^2 value closer to 1 indicates that the regression model explains a larger proportion of the variance in the dependent variable.

3. RESULTS AND DISCUSSIONS

3.1 Hardware Implementation

The proposed fire detection system was successfully implemented using an ESP32 microcontroller integrated with a Flame Sensor, an MQ-2 gas sensor, an I2C LCD, a buzzer, and Wi-Fi communication. The ESP32 functions as the main controller that reads sensor data, processes the information, activates the buzzer, displays system status on the LCD, and transmits data to the Blynk platform through an internet connection. The Flame Sensor detects fire based on infrared radiation, whereas the MQ-2 sensor measures the concentration of smoke or combustible gases in the surrounding environment.

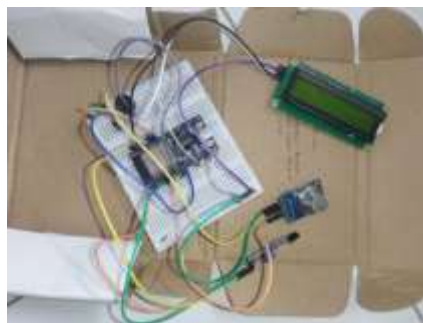


Figure 3. 2 Hardware Implementation of the Proposed System

Figure 3.1 presents the hardware implementation of the proposed IoT-based fire detection system. The prototype consists of an ESP32 microcontroller, a Flame Sensor, an MQ-2 gas sensor, and a 16×2 I2C LCD module assembled on a breadboard. The ESP32 serves as the main controller that acquires sensor data, processes the measurements, and transmits the collected data to the Blynk platform through a Wi-Fi connection. The recorded data are subsequently used to develop the Multiple Linear Regression model for predicting the system detection delay.

3.2 Software Implementation

The software was developed using Arduino IDE. The ESP32 continuously reads the Flame Sensor and MQ-2 sensor values before transmitting the collected data to the Blynk platform. Whenever fire is detected, the system also sends an automatic notification through Telegram. In addition to functioning as a monitoring platform, Blynk stores all sensor readings, which are subsequently exported into Microsoft Excel format and used as the experimental dataset for the Multiple Linear Regression analysis.

1. Blynk Monitoring Interface

The Blynk platform is utilized as a real-time monitoring interface for the proposed fire detection system. In addition to displaying sensor readings, the platform automatically stores all transmitted data received from the ESP32. These recorded data are then exported as the experimental dataset used for developing the Multiple Linear Regression prediction model.



Figure 3. 3 Blynk Monitoring Interface

Figure 3.2 illustrates the Blynk dashboard used for real-time monitoring of the proposed fire detection system. The dashboard displays the Fire Detection Intensity, MQ-2 Sensor Value, system status, historical sensor graphs, and alarm indicator. In the monitoring interface, the displayed sensor values indicate a SAFE condition, meaning that no fire or excessive smoke was detected. The sensor data were automatically transmitted from the ESP32 to the Blynk cloud platform via Wi-Fi and stored as the experimental dataset for developing and evaluating the Multiple Linear Regression model.

2. Telegram Notification Interface

To provide an early warning mechanism, the proposed system is integrated with the Telegram messaging application. Whenever a fire is detected, the ESP32 automatically sends a notification to the user, allowing immediate awareness of potential fire hazards even when the user is not physically present at the monitored location.



Figure 3. 4 Telegram Notification Interface

Figure 3.3 shows the Telegram notification generated by the proposed system. When the sensor readings indicate a potential fire, the ESP32 automatically sends a warning message to the registered Telegram account. This notification provides users with real-time information regarding the system status, enabling prompt response to potential fire incidents.

3.3 Experimental Data

The experimental data were collected automatically through the Blynk platform. During the experiment, the ESP32 continuously transmitted the Flame Sensor readings, MQ-2 sensor readings, and system detection delay to the Blynk cloud server. All recorded data were exported into Microsoft Excel format and used as the research dataset.

A total of 500 experimental records were successfully collected. Each record consists of two independent variables, namely Fire Detection Intensity (X_1) and MQ-2 Sensor Value (X_2), as well as one dependent variable, namely System Detection Delay (Y).

Tabel 3. 1 Tabel Experimental Data

No	Fire Detection Intensity (X_1)	MQ-2 Sensor Value (X_2)	Detection Delay (Y)
1.	2621	189	1,56
2.	1436	174	2,41
3.	2831	147	1,61
4.	961	144	2,8
5.	2094	176	1,94
⋮	...	...	...
496.	3438	163	1,16

497.	1036	144	2,73
498.	3324	179	1,17
499.	3026	162	1,42
500.	930	159	2,78

Table 3.1 presents a sample of the experimental dataset collected from the proposed fire detection system. The dataset consists of three variables: Fire Detection Intensity (X_1), MQ-2 Sensor Value (X_2), and Detection Delay (Y). A total of 500 data records were collected through the Blynk platform. Only several representative records are presented in this paper, while the complete dataset was used for training and testing the Multiple Linear Regression prediction model.

3.4 Multiple Linear Regression Prediction Model

The experimental dataset was divided into two subsets consisting of 350 training data and 150 testing data. The training dataset was used to establish the Multiple Linear Regression model, while the testing dataset was employed to evaluate the predictive performance of the model.

Tabel 3. 2 Variables Used in the Regression Model

Variable	Description
X_1	Fire Detection Intensity
X_2	MQ-2 Sensor Value
Y	Detection Delay (s)

Tabel 3.2 presents the variables used in the Multiple Linear Regression model. Fire Detection Intensity (X_1) and MQ-2 Sensor Value (X_2) were used as independent variables, whereas Detection Delay (Y) served as the dependent variable in the prediction model.

Based on the regression analysis performed using the training dataset, the following prediction model was obtained:

$$Y = 4.147923 - 0.000609X_1 - 0.005291X_2$$

The regression coefficients indicate that both independent variables have negative coefficients. This implies that increasing the Fire Detection Intensity and the MQ-2 Sensor Value tends to reduce the system detection delay. Consequently, stronger fire indications detected by the sensors result in a faster system response.

3.5 Prediction Performance Evaluation

The prediction model was evaluated using 150 testing data. The evaluation employed five statistical metrics, namely MAE, MSE, RMSE, MAPE, and the coefficient of determination (R^2).

Tabel 3. 3 Prediction Performance of the Proposed Model

Evaluation Metric	Value
MAE	0.050535
MSE	0.003343
RMSE	0.057822
MAPE	3.16 %
R^2	0.988871

Tabel 3.3 summarizes the performance evaluation results of the proposed Multiple Linear Regression model using the testing dataset. The model performance was assessed using five evaluation metrics, namely Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Percentage Error (MAPE), and the coefficient of determination (R^2). These metrics were employed to evaluate the prediction accuracy and the ability of the developed model to estimate the system detection delay.

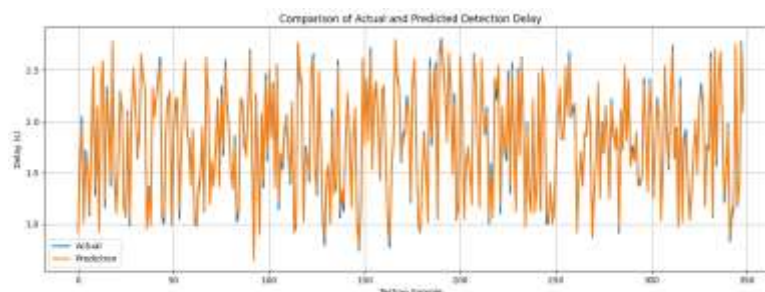


Figure 3. 5 Comparison of Actual and Predicted Detection Delay

Figure 3.4 compares the actual and predicted detection delays obtained using the proposed Multiple Linear Regression model. The close agreement between both curves, supported by an R^2 of 0.988871 and a MAPE of 3.16%, demonstrates the model's excellent prediction accuracy.

The results demonstrate that the proposed Multiple Linear Regression model is capable of accurately predicting the detection delay of the IoT-based fire detection system. This is supported by the evaluation metrics presented in Table 3, where the model achieved an MAE of 0.050535 s, an RMSE of 0.057822 s, a MAPE of 3.16%, and an R^2 value of 0.988871. The low prediction errors and high coefficient of determination indicate that the developed model successfully captures the relationship between Fire Detection Intensity (X_1), MQ-2 Sensor Value (X_2), and the system detection delay. Therefore, the proposed model can be considered reliable for estimating the response time of the fire detection system under different fire conditions.

4. CONCLUSION

This study proposed an Internet of Things (IoT)-based fire detection system using a Flame Sensor, an MQ-2 sensor, an ESP32 microcontroller, the Blynk platform, and Telegram notifications for real-time monitoring. A Multiple Linear Regression model was developed to predict the system detection delay based on Fire Detection Intensity (X_1) and MQ-2 Sensor Value (X_2).

The proposed model achieved an MAE of 0.050535 s, an MSE of 0.003343, an RMSE of 0.057822 s, a MAPE of 3.16%, and an R^2 value of 0.988871, indicating excellent prediction performance. These results demonstrate that the developed model can accurately estimate the detection delay and effectively support IoT-based fire detection systems. Future work may investigate more advanced machine learning methods and additional environmental variables to further improve prediction accuracy.

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