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Email : editorijhess@gmail.com

Development Of A Smart Fire Fighting Robot Based On Arduino Uno With A Fire Detection System And Hybrid Manual-Automatic Control

Fadhilatun Akhsan[1)]*, Ali Rosyiqin[2)], M Heru Pratama Putra[3)], Anggi Fajar Masurogo[4)], Tateng Sukendar[5)]
[1,2,3,4,5)] Program Studi Teknik Elektro, Universitas Dirgantara Marsekal Suryadarma

*Corresponding Author
Email : Fadhilatunakhsan@gmail.com

Abstract

Fire is one of the disasters that can cause material losses and casualties if not handled quickly. This study aims to design and develop a Smart Fire Fighting Robot based on Arduino Uno with a fire detection system and hybrid manual-automatic control. The system uses flame sensors to detect fire sources, an infrared temperature sensor for heat validation, DC motors for movement, a servo motor to direct the nozzle, and a water pump for extinguishing. The robot can operate in automatic mode to detect, approach, and extinguish fire autonomously, as well as in manual mode controlled via Bluetooth to improve operational flexibility. The test results show that the system is able to detect fire accurately, navigate toward the fire source, and extinguish fire effectively in small-scale fire simulations. This system is expected to support fire mitigation efforts and reduce risks to humans during emergency situations.

Keywords: Fire, Arduino Uno, Fire Fighting Robot, Flame Sensor, Bluetooth, Hybrid System.

INTRODUCTION

Fire is one of the most common disasters that can cause significant material losses, infrastructure damage, disruption of activities, and even loss of life if not handled promptly and effectively. Fire suppression operations often involve high risks for firefighters, particularly in confined spaces, smoke-filled environments, hazardous industrial areas, or locations with a high potential for explosions. Therefore, technological innovations are needed to support fire detection and suppression processes in a faster, safer, and more efficient manner.

Recent advancements in robotics and embedded systems have enabled the development of intelligent robots capable of assisting humans in hazardous environments. One of the most promising applications is the fire-fighting robot, which is designed to detect fire sources, navigate toward the affected area, and extinguish flames autonomously without exposing human operators to danger. Such robots can serve as an effective solution for early-stage fire mitigation and emergency response.

Several studies related to fire-fighting robots have been conducted in recent years. Most existing systems utilize flame sensors as the primary means of fire detection and employ DC motors for robot locomotion. However, many of these studies still exhibit limitations, as they rely solely on a single fire detection sensor and implement only one control mode, either automatic or manual. These limitations may reduce system reliability when sensor inaccuracies occur or when operational flexibility is required during emergency situations.

Previous studies by Ardiansyah and Putra (2020) and Suyanto and Prasetyo (2020) employed flame sensors as the primary fire detection mechanism but did not incorporate temperature sensing systems, Bluetooth communication, or hybrid control capabilities. Consequently, fire validation and operational flexibility remained limited. In contrast, the present study integrates multiple sensing and control technologies to enhance system performance and reliability.

This research develops a Smart Fire Fighting Robot based on the Arduino Uno microcontroller by integrating a flame sensor and an MLX90614 infrared temperature sensor. The flame sensor is used to detect the presence and direction of fire through infrared radiation emitted by flames, while the MLX90614 sensor serves as a validation mechanism by measuring temperature increases in the detected area. The combination of these sensors is expected to reduce false detections and improve the accuracy of fire identification. All sensor data are processed by the Arduino Uno, which functions as the main controller for robot navigation, actuator operation, and fire suppression mechanisms.

In addition, the robot is equipped with an HC-05 Bluetooth module that enables hybrid control operation, allowing the system to function in both automatic and manual modes. Automatic mode enables autonomous fire detection, navigation, and extinguishing processes, whereas manual mode allows users to directly control the robot through a Bluetooth-connected device when specific operational interventions are required.

Therefore, this study aims to design and develop a Smart Fire Fighting Robot based on Arduino Uno with a hybrid manual-automatic control system and dual-sensor fire detection mechanism. The proposed robot is expected to detect fire more accurately, autonomously navigate toward fire sources, perform extinguishing actions effectively, and provide operational flexibility through Bluetooth-based manual control. The resulting prototype is expected to contribute to safer and more effective fire mitigation efforts, particularly in small-scale indoor environments and educational robotics applications.

RESEARCH METHODS

This study employed an engineering research method focusing on the design, development, implementation, and testing of a Smart Fire Fighting Robot based on Arduino Uno. The proposed system integrates flame sensors and an MLX90614 infrared temperature sensor to detect the presence of fire. Sensor data are processed by the Arduino Uno microcontroller to determine robot movement, control the fire-extinguishing nozzle through an SG90 servo motor, and activate a water pump during fire suppression. In addition to automatic operation, the system is equipped with an HC-05 Bluetooth module that enables manual control through a smartphone.

The research process consisted of literature review, system design, hardware implementation, software development, testing, and performance evaluation. The literature review involved studying scientific journals, books, component datasheets, and other relevant references related to fire-fighting robots, embedded systems, sensors, and wireless communication technologies. System design included the development of hardware architecture, software flowcharts, wiring configurations, and robot mechanical structures. Hardware implementation was carried out by assembling the Arduino Uno, flame sensors, MLX90614 temperature sensor, L298N motor driver, DC motors, SG90 servo motor, relay module, water pump, and HC-05 Bluetooth module according to the proposed design.

The system architecture consists of three flame sensors positioned to detect the direction of the fire source, an MLX90614 sensor for temperature validation, and a Bluetooth module for manual operation. All input data are processed by the Arduino Uno, which generates control signals for the motor driver, servo motor, relay, buzzer, LED indicators, and LCD display. The robot was built on a four-wheel-drive (4WD) chassis equipped with four DC motors, while the fire-extinguishing nozzle was mounted at the front and connected to a servo motor for directional control. A water tank and pump were installed on the upper section of the chassis to support the extinguishing process.

Software development was conducted using Arduino IDE and the C/C++ programming language. The program was designed to process sensor readings, control robot navigation, manage fire suppression mechanisms, and receive user commands via Bluetooth. In automatic mode, the robot continuously monitors flame and temperature data, determines the direction of the fire source, navigates toward the target location, and activates the water pump until the fire is extinguished. In manual mode, users can remotely control the robot and operate the water pump through a smartphone connection.

System testing was performed to evaluate the functionality and performance of individual components as well as the integrated system. The tests included flame sensor detection, temperature measurement accuracy, DC motor operation, servo motor performance, water pump activation, Bluetooth communication, and overall fire detection and extinguishing capabilities. The collected data were analyzed to assess the effectiveness of the proposed system in detecting fire sources, navigating toward fire locations, and performing fire suppression tasks reliably and efficiently.

RESULTS AND DISCUSSION

System Deployment

After describing the software and hardware specifications, Figure 7 presents an overview of the experimental environment in the form of a deployment diagram.
Tables and charts or captions are arranged in the form of a phrase (not a sentence) succinctly.

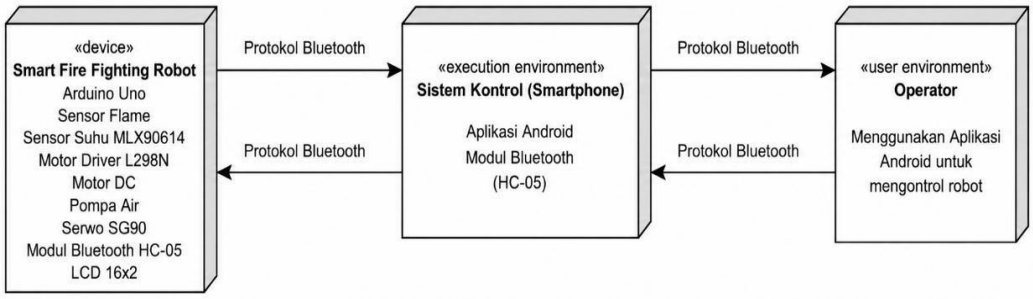

Figure 1. Deployment Diagram

System Performance Evaluation

No	Perangkat	Ekspektasi	Hasil	
			Bisa / Tidak Bisa	Keterangan
1	Arduino Uno	Dapat menyuplai daya ke seluruh rangkaian	Bisa	Berhasil
		Dapat memproses program dengan benar	Bisa	Berhasil
		Dapat membaca data dari sensor	Bisa	Berhasil
		Dapat mengirim perintah ke aktuator	Bisa	Berhasil
2	Flame Sensor	Mendeteksi keberadaan api	Bisa	Berhasil
		Menentukan arah sumber api (kiri, tengah, kanan)	Bisa	Berhasil
3	Sensor Suhu MLX90614	Membaca suhu lingkungan	Bisa	Berhasil
		Membaca peningkatan suhu saat ada api	Bisa	Berhasil
4	Bluetooth HC-05	Terkoneksi dengan smartphone	Bisa	Berhasil
		Menerima perintah dari aplikasi	Bisa	Berhasil
		Mengirim data status ke aplikasi	Bisa	Berhasil
5	Motor Driver L298N	Dapat mengendalikan arah putaran motor	Bisa	Berhasil
		Dapat mengatur kecepatan motor	Bisa	Berhasil
6	Motor DC	Bergerak maju	Bisa	Berhasil
		Bergerak mundur	Bisa	Berhasil
		Belok kiri	Bisa	Berhasil
		Belok kanan	Bisa	Berhasil
7	Servo SG90	Menggerakkan *nozzle* ke kiri	Bisa	Berhasil
		Menggerakkan *nozzle* ke kanan	Bisa	Berhasil
8	Pompa Air Mini	Menyemprotkan air	Bisa	Berhasil
		Berhenti menyemprotkan air	Bisa	Berhasil
9	LCD 16x2	Menampilkan status sistem	Bisa	Berhasil
		Menampilkan nilai suhu	Bisa	Berhasil

Table 1. System Performance Evaluation

Performance Analysis of the Flame Sensor and MLX90614 Sensor

Testing was conducted to evaluate the capability of the flame sensor and the MLX90614 infrared temperature sensor in detecting the presence of fire and temperature changes. The experiments were carried out by exposing the sensors to a fire source at various distances and conditions, while observing the sensor responses displayed by the system.

Flame Sensor Testing Results

The flame sensor was tested to evaluate its response to the presence of fire under different distance conditions. The test results indicate that the flame sensor was able to detect flames effectively and provide a reliable response when exposed to a fire source. As the distance between the sensor and the flame increased, the sensor's sensitivity gradually decreased; however, the sensor remained capable of identifying the presence and direction of the fire within its operational range.

Based on the testing results presented in Table 3, the flame sensor was able to detect the presence of fire effectively at distances ranging from 10 cm to 20 cm. Within this range, the sensor exhibited a fast response time, with detection occurring between 0.5 and 1 second. However, at distances of 25 cm and 30 cm, the sensor's sensitivity began to decrease, resulting in inconsistent fire detection. This reduction in performance was caused by the decreasing intensity of infrared radiation received by the sensor as the distance from the fire source increased.

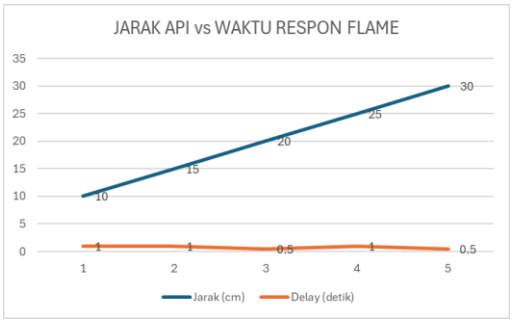

Figure 2. Relationship Between Fire Distance and Flame Sensor Response Time

The graph shows that the flame sensor was able to respond effectively to the presence of fire within a distance range of 10–20 cm. At greater distances, the sensor response became less consistent, indicating the need for an additional sensor to validate fire detection results.

MLX90614 Temperature Sensor Testing Results

The MLX90614 sensor was tested to measure environmental temperature changes before and after the presence of a fire source. The sensor operates using a non-contact measurement method and transmits temperature data to the Arduino Uno as an additional validation mechanism for fire detection.

Table 2. MLX90614 Temperature Sensor Testing Results

No.	Distance from Fire to Sensor (cm)	Measured Temperature (°C)	Condition
1	No Fire	28.5	Normal
2	50	35.2	Temperature Increased
3	40	42.8	Hot
4	30	55.6	Hot
5	20	68.9	Fire Confirmed

The testing results indicate that the temperature values measured by the MLX90614 sensor increased as the distance between the sensor and the fire source decreased. Under normal conditions without fire, the ambient temperature was recorded at 28.5°C, whereas at a distance of 20 cm the measured temperature increased significantly to 68.9°C. These results demonstrate that the MLX90614 sensor can effectively serve as an additional validation sensor to confirm the presence of a fire source, thereby reducing the likelihood of false detections that may occur when relying solely on a flame sensor.

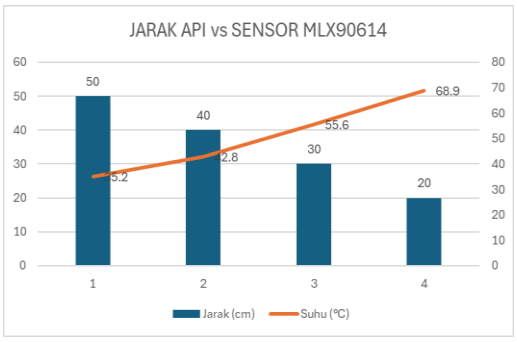

Figure 3. Fire Distance vs. MLX90614 Sensor Temperature Reading

Water Spraying Test Results

This test was conducted to measure the amount of water discharged by the water pump over different spraying durations. The results of the water spraying test are presented in Table 3.

Table 3. Water Spraying Test Results

No.	Pump Spraying Duration	Water Discharged	Spraying Range
1	1 second	12 mL	1 m
2	2 seconds	24 mL	1.5 m
3	3 seconds	36 mL	2 m
4	4 seconds	48 mL	2 m
5	5 seconds	69 mL	2 m

Based on the test results, the amount of water discharged by the pump increased proportionally with the spraying duration. At a spraying duration of 1 second, the pump delivered 12 mL of water with an effective range of approximately 1 meter. Meanwhile, at a duration of 5 seconds, the discharged water volume reached 69 mL with a maximum spraying range of approximately 2 meters. These results indicate that the water pump provides adequate performance for fire suppression applications at the prototype scale.

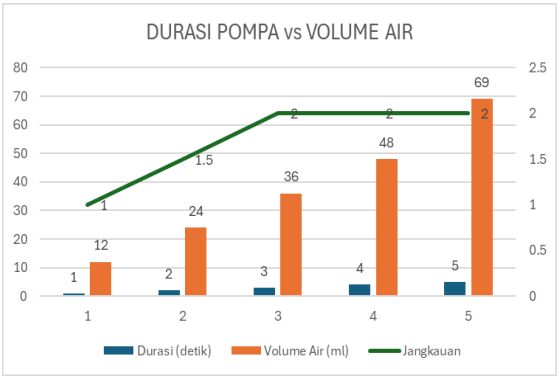

Figure 4. Pump Duration vs. Water Volume

Based on the graph, the volume of water discharged by the pump increased as the spraying duration became longer. At a duration of 5 seconds, the pump produced the highest water volume, reaching 69 mL, indicating that the system is sufficiently effective for fire suppression applications at the prototype scale.

Control Interface Display

The control interface serves as the main page for operating and controlling the robot. Through this interface, users can send commands to the robot, control its movements, and activate the fire-extinguishing system using a smartphone connected via Bluetooth. Figure 5 illustrates the appearance of the robot control interface.

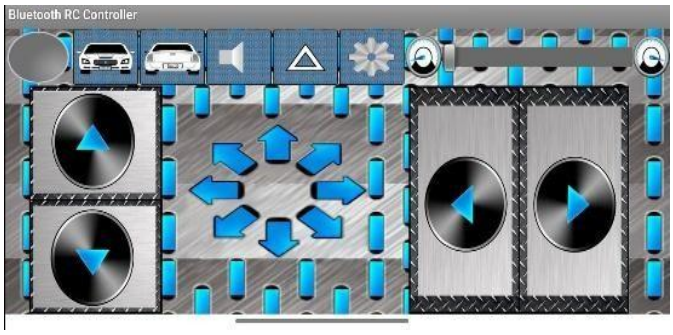

Figure 5. Robot Control Interface Display

System Performance and Integration Analysis

Based on the testing results, the Arduino Uno-based Smart Fire Fighting Robot successfully performed all system functions according to the proposed design. The fire detection system, consisting of flame sensors and the MLX90614 infrared temperature sensor, operated in an integrated manner to

identify the presence of fire and validate temperature increases in the detected area. The combination of these sensors provided more reliable fire detection performance compared to the use of a single sensor.

In automatic mode, the robot was able to detect fire sources, determine the appropriate navigation direction, move toward the fire location, and activate the water pump automatically to extinguish the fire. Furthermore, the manual mode enabled through the HC-05 Bluetooth module allowed users to directly control the robot according to operational requirements. The testing results demonstrated that data communication, navigation, and fire suppression mechanisms functioned properly without significant interruptions.

Overall, the integration of hardware and software components was successfully implemented. The robot was capable of detecting, approaching, and extinguishing fire sources within the prototype testing environment, indicating that the objectives of this study were successfully achieved.

CONCLUSIONS

Based on the design, implementation, and testing results, it can be concluded that the Arduino Uno-based Smart Fire Fighting Robot was successfully developed and operated according to the intended specifications. The fire detection system, which integrates flame sensors and the MLX90614 infrared temperature sensor, was able to identify the presence of fire sources and validate temperature increases within the testing environment. The integration of both sensors provided a more reliable detection mechanism, thereby improving the decision-making process of the system.

The experimental results demonstrated that the robot was capable of navigating toward a fire source, directing the extinguishing nozzle using a servo motor, and activating the water pump to perform automatic fire suppression. Furthermore, the implementation of a hybrid control system through the HC-05 Bluetooth module enabled both manual and automatic operation according to user requirements. Overall, the integration of hardware and software components was successfully achieved, allowing the robot to perform fire detection, navigation, and extinguishing tasks effectively within a prototype-scale environment.

Future research may focus on enhancing the fire detection capability by integrating additional sensors, such as smoke or gas sensors, to improve the accuracy of fire identification under various environmental conditions. Furthermore, camera-based image processing techniques may be incorporated to support visual fire detection and tracking.

From a system perspective, the implementation of Internet of Things (IoT) technology could be explored to enable remote monitoring and control of the robot. Improvements in power capacity, locomotion systems, and fire suppression mechanisms are also recommended to enhance operational performance and adaptability in more complex environments. These developments are expected to increase the reliability and effectiveness of the system, enabling its application in broader fire mitigation scenarios.

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