Design and Development of Directional Fire Extinguisher Prototype Using Thermal Camera MLX90640 based ESP32

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Abstract

Fire is a frequent incident, especially in enclosed spaces where people often fail to recognize the danger until the fire has grown. In 2023, there were 1,323 recorded fire cases. To address this, a directional fire extinguisher system was developed to reduce fire incidents and save lives. Using the MLX90640 thermal camera, heat sources can be detected early and accurately, allowing targeted water spraying to minimize waste and increase efficiency. The prototype can automatically detect and extinguish fire within 1.8 meters and detect heat up to 3 meters. However, the rotation mechanism is still stiff, requiring more time to aim precisely. The nozzle can rotate up to 180°, but the servo cannot move beyond that, making the system not yet fully aligned with the initial design.

Keywords : *Flame, Thermal, MLX90640, ESP32, Microcontroller*

1. INTRODUCTION

Fire is one of the most frequent incidents, especially in enclosed spaces where people often fail to realize they are in a critical and dangerous situation. By the time it is noticed, the fire has usually grown larger. According to an online report from *Tribun Pontianak.co.id*, an investigation by the Pontianak City Police revealed that the cause of a house fire was due to an electrical short circuit in an enclosed room (Ferryanto, 2023). Based on this case, it was recorded that there were 1,323 fire incidents across Indonesia (Mustajab, 2023), with many cases in enclosed spaces being neglected or unnoticed.

Several students from different universities have previously developed similar fire extinguisher devices. For example, Wahyu Hari Suwito from Universitas Brawijaya designed a fire extinguisher system based on a Raspberry Pi using a Logictech C170 camera that detects fire through HSV color processing. By converting the captured image into HSV format, the camera can detect and mark fire with red points. The results showed a fire detection accuracy rate of 88.9% (Suwito, 2019).

Another prototype was developed by Fauziah using a Raspberry Pi, but instead of a camera, it employed UVTRON TPA81 and flame sensors. This system not only extinguishes fire but also notifies users via WhatsApp when a fire is detected and extinguished. However, it had a limited extinguishing range of only 2.5 meters (Fauziah, 2022).

The use of the MQ-2 gas sensor is supported by other research, such as by Fisal Oktafian Penta Sandova, who found that the MQ-2 can accurately detect thick smoke at a distance of 3 meters, with a detection time of 27 seconds (Sandova, 2024). Furthermore, according to Muhammad Noor Fachry, the average detection time for the MQ-2 sensor is 6.46 seconds per 5 cm distance variation (Fachry, 2021). Regarding the MLX90640 thermal camera module, as explained by Satriyo (Satriyo, 2021) in *Jurnal ELIT*, it contains multiple infrared sensors arranged in a square

grid, allowing the detection of thermal patterns corresponding to the heat emitted by objects

2. METHOD

This research uses a Research and Development (R&D) approach, aimed at designing and testing a prototype of a directional fire extinguisher system using the MLX90640 thermal camera module and ESP32 microcontroller. The development process includes literature studies, observational ,and experimental testing to evaluate the system's performance.

To that end, the performance testing of the device is based on several criteria to be fulfilled, namely:

- The directional fire extinguisher system is controlled by an ESP32 microcontroller as its main processing unit.
- Fire detection is carried out using the MLX90640 thermal camera module.
- The MQ-2 sensor assists the MLX90640 by measuring smoke density, serving as an early indicator of fire presence
- The fire extinguishing system is designed for operation within a 3 x 3 meter enclosed space.

2.1 Research method

This reseach involves three primary stages:

- Literature Study Method

  At this stage, the theoretical foundation and literature review are conducted. The researcher collects related journals and previous research to serve as the basis for developing the system and understanding existing methods.

- Observational Method

  This stage includes data observation and collection from real cases, particularly fire incidents in enclosed spaces. The researcher reviews news sources and statistical data to establish the urgency and relevance of developing an automatic directional fire extinguisher.

- Experimental method

  This is the main stage involving the design, construction, and testing of the prototype. It includes integrating the MLX90640 thermal camera with the ESP32 microcontroller, programming the input sensors, and evaluating the prototype's performance based on criteria such as detection range, extinguishing accuracy, and system responsiveness.

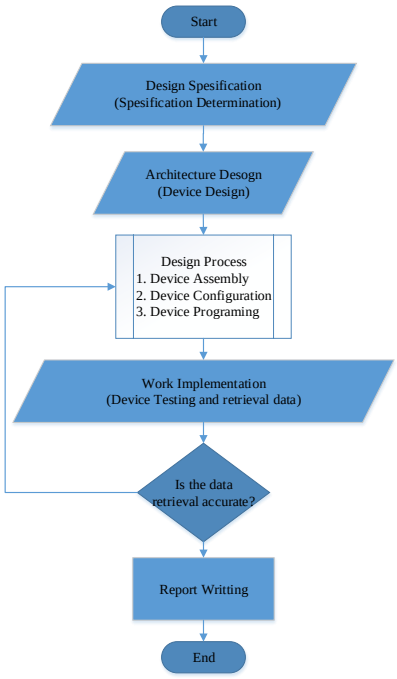


Figure 1 Research flow method

2.2 Block Diagram

The block diagram consists of three main sections: input, processing, and output blocks. The input block receives data or information from external sources and includes four components: the power supply, buck converter, smoke sensor, and the MLX90640 thermal camera module. The information from the input block is passed to the processing block, which consists solely of the ESP32 microcontroller. This block functions to process and convert input data into appropriate output signals. Finally, the output block is responsible for executing mechanical actions based on the processed data. This block consists of several components, including servo motors, a relay module, and a water pump.

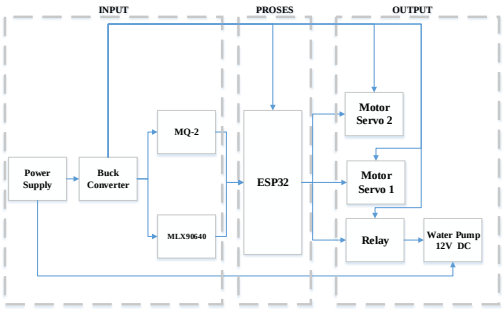


Figure 2 Block Diagram

2.3 Flowchart

In the flowchart of the developed device, the following sequence of operations is described:

1. The system initiates its operation by reading data from the MQ-2 smoke sensor.
2. If no smoke is detected, the device will continue to monitor the MQ-2 sensor. However, if smoke is detected, the process proceeds to the next component.
3. The next component is the MLX90640 thermal camera. If no heat source is detected in front of the camera, the servo motor will rotate the extinguisher nozzle by 60°. If a heat source is detected, the servo stops rotating, and the relay module is activated.
4. Activation of the relay triggers the water pump to turn on.
5. The device continues to read from the MLX90640. If the fire is still present—as indicated by a persistent heat signature—the second servo will begin adjusting the nozzle vertically. This process continues until the fire is no longer detected.
6. Once no heat source is detected and the temperature has decreased, the relay is deactivated, which turns off the water pump.

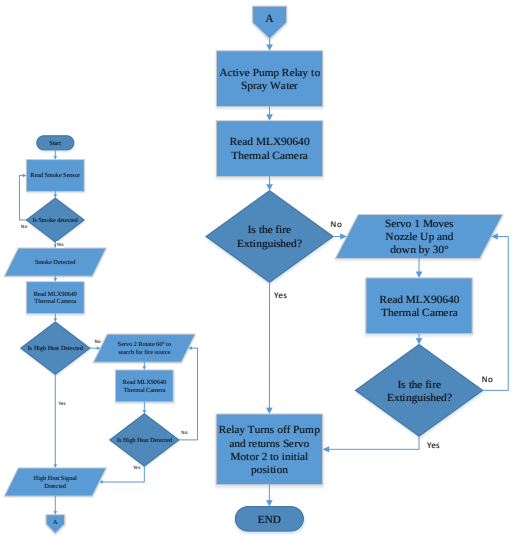


Figure 3 Flowchart

2.4 Module and Component

The modules and components used in this study are as follows:

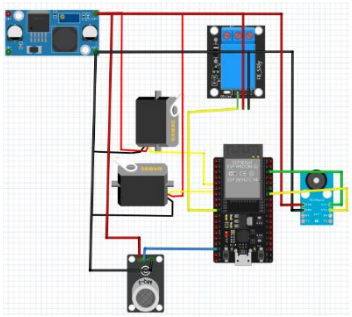
- MLX90640
  This module is a thermal camera used to detect heat. Its function is to determine and precisely align the direction of the fire with the extinguisher nozzle. The MLX90640 contains an array of infrared sensors arranged in a 32x24 pixel resolution, by utilizing this infrared detection the camera is able to process the infrared emission pattern and target at the center point accurately.

- MQ-2 Sensor
  The MQ-2 sensor serves as a supporting component for the MLX90640 in identifying the direction of the fire. It is a sensor module for detecting smoke and gas.
- ESP32
  The ESP32 is a microcontroller module that functions as the main unit responsible for processing data from input modules and controlling output components.
- Arduino Ide
  To operate all components on the ESP32, Arduino IDE is used. It is a software application that supports programming and controlling microcontrollers.
- Servo
  The servo motor is an actuator used to adjust the direction of the fire extinguisher
- Water Pump DC
  Water is the extinguishing medium used in this system. A water pump is employed to deliver water for extinguishing the fire
- Relay
  To enable the ESP32 to control the activation and deactivation of the water pump, a relay module is used as a switch
- Power Supply
  The fire extinguishing system uses a DC power source from a power supply. The required voltage is 12 volts DC, as needed by the water pump
- Buck Converter
  Since the voltage from the power supply is too high for components other than the water pump, a buck converter is used to step down the voltage, allowing other components to safely operate using the same power source.

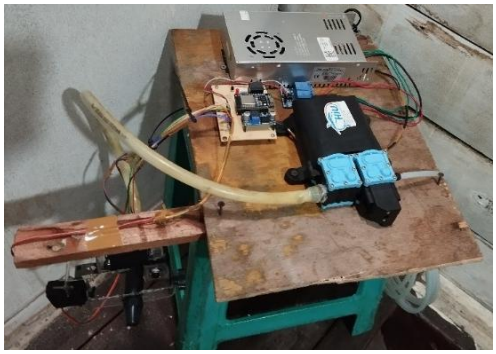
3. RESULTS AND DISCUSSION

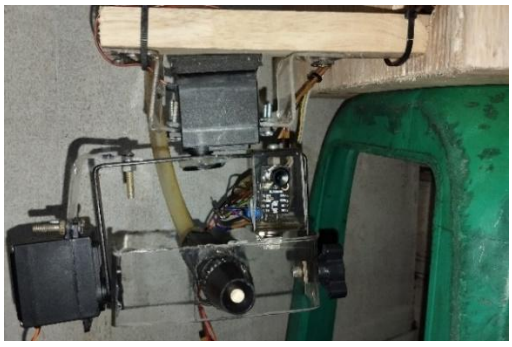
3.1 HARDWARE IMPLEMENTATION RESULTS

The following is the appearance of the device, along with the completed system circuit and final model.



This fire extinguisher device consists of two separate sections. The first section is the main unit, which includes the power supply, DC water pump, and the main control board. The second section is the extinguisher arm, responsible for detecting and extinguishing the fire. This section consists of a servo motor, MLX90640 thermal camera, MQ-2 sensor, fire hose, and nozzle.





3.2 MLX90640 TESTING RESULTS

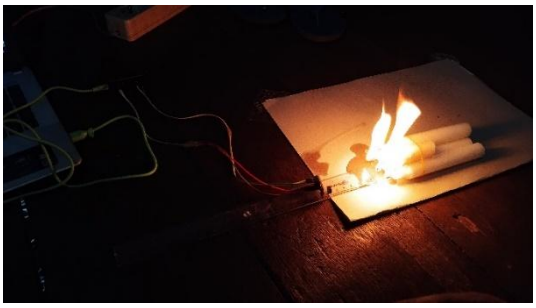


Table 1 Fire temperature readings

NO	Distance (cm)	Temperature Reading			
		1 Candle		5 Candle	
		MLX 90640	Fluke Thermometer	MLX 90640	Fluke Thermometer
1	1	135 °C	140°C	175°C	173°C
2	2	120 °C	120°C	173 °C	156°C
3	3	109 °C	112°C	167 °C	152°C
4	5	97 °C	110°C	158 °C	137°C
5	9	60 °C	86°C	130 °C	115°C
6	10	54 °C	72°C	120 °C	95°C
7	11	41 °C	65°C	108 °C	102°C
8	12	38 °C	46°C	96° C	93°C
9	14	35 °C	38°C	86 °C	80°C
10	17	28 °C	33°C	70 °C	83°C
11	21	27 °C	33°C	77 °C	70°C
12	27	27 °C	33°C	66 °C	79°C
13	30	27 °C	33°C	54 °C	79°C
14	37	27 °C	33°C	31 °C	66°C
15	45	27 °C	33°C	31 °C	68°C

The MLX90640 readings show results that are close to those of a standard temperature measuring device; however, its drawback is that the MLX90640 has a

shorter detection range compared to the temperature measuring device

3.3 MQ-2 SENSOR TESTING RESULTS

Table 2 Smoke density readings

NO	duration(s)	Measured Smoke Concentration(PPM)
1	6	432
2	12	435
3	18	461
4	24	453
5	30	400
6	36	386
7	42	389
8	48	390
9	55	405
10	60	369

Based on the table above, the smoke measurement values do not show a significant difference,It was initially assumed that the smoke density would increase over time, as the fire occurred in an enclosed space, causing the smoke to become trapped and grow denser.

3.4 FIRE EXTINGUISHING TEST RESULTS

Figure 4 Extinguishing Test on Torch Flame

Table 3 Extinguishing time testing

NO	Distance (m)	Duration of extinguishing(seconds)			
		0°	45°	90°	180°
1	0.5	18s	24s	32s	40s
2	0.7	20s	26s	38s	43s
3	1	22s	28s	36s	42s
4	1.2	23s	29s	41s	60s
5	1.5	60s	66s	78s	80s
6	1.6	79s	85s	95s	97s
7	1.8	77s	83s	99s	100s
8	2.1	-(Detected only)			
9	2.5	-(Detected only)			
10	3	-(Detected only)			

As shown in Table 3, the fire extinguisher is only capable of extinguishing fire at a distance of up to 1.8 meters. Beyond this range, the system can still detect the fire, but the water cannot reach the flames, resulting in a reduced effective extinguishing range.

3.5 POWER SUPPLY MEASUREMENT RESULTS

Figure 5 Power Supply Measurement

Table 4 Power Supply Measurement

NO	Unit	Voltage (V)	Amper e (I)	Power(W)
1	ESP32	5 V	0,5 mA	2,5 mW
2	Motor Servo 180°	5 V	3 mA	15 mW
3	Motor Servo 360°	5 V	1.62 mA	8,1 mW
4	Modul Relay	5 V	0,3 mA	1,5 mW
5	MQ-2	5 V	1.11 mA	5 mW
6	MLX90640	5 V	0,37 mA	1,85 Mw
7	Buck Converter	12 V	171 mA	2,052 W
8	Pompa	12 V	1, 8 A	21,6 Watt
		Total	1, 97 A	23,68595 Watt

Based on the power supply measurements, the fire extinguisher system requires a total power of 23.68 watts to operate, using a 12V DC voltage. This allows the possibility of adding a battery with an equivalent capacity for portable use.

4. CONCLUSION

Based on the results and discussion of this study, the following conclusions can be drawn:

1. MLX90640 module demonstrate a relatively high degree of accuracy when compared with a

standard temperature measuring device, making it reliable for detecting heat sources.

2. MQ-2 sensor is not specifically designed to detect or measure smoke values, but rather to detect and read gas levels in the surrounding air
3. The prototype can only extinguish fires at a relatively short distance of approximately 1.8 meters, although it is still capable of detecting fire up to a distance of 3 meters.
4. The entire system operates on an estimated power consumption of 24 watts using a 12-volt DC power supply, based on measurement data of each module, including the water pump and sensors
5. The device has not yet been able to effectively cover an entire 3-meter area. However, this limitation can be addressed by placing the device at the center of the room, enabling it to cover a 3 x 3 meter space due to its effective operational radius of about 1.5 meters.

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