Autonomous robotic fire detection and extinguishing system

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Abstract. Firefighting is a dangerous job with a high death rate. Robotics is the new way to protect the environment and human lives. This work proposes an autonomous robot system that can inevitably discover fire using the flame sensor and extinguish it. This project includes Arduino UNO, flame sensor, servo motor, motor driver, relay module, Bluetooth HC-06 module, and water pump. Besides, using the push Bluetooth app at the transmitting end, commands are sent to the receiver to control the robot's movement. The motors are connected to the microcontroller and used to move the robot and sprinkle water on the fire. A water tank and a water pump are mounted on the robot body and automatically detected by the infrared. An ATMEGA328 series microcontroller controls the flame sensor and the whole operation. A motor driver IC, L298N, is interfaced to the microcontroller through which the controller drives the motors. As a result, the robot can detect fire from a distance. The average length for detecting flame is approximately 5.11cm, and Bluetooth transmission is about 300cm. It has the potential to reduce human error and limitations associated with fire extinguishing tasks.

1. Introduction

With the advancement of technology, developments in the face of situations that can result in the loss of human life are becoming more prevalent. Fires are one of the most serious of these involuntary problems caused by the world's growing population. As a result, the robot industry is booming in this area. Robotics technology has become more ubiquitous in the recent industrial revolution. Artificially intelligent robots must interact with humans with little or no supervision or even remotely controlled robots. A robot is defined as a mechanical design capable of performing human tasks or behaving in a human-like manner. As the robotic field is developed, human interaction is reduced, and robots are widely used for a safe life.

Numerous humanoid robots are employed in various applications, including personal assistance and caregiving [1-2], education and entertainment, search and rescue [3-5], manufacturing and maintenance, and healthcare. These robots have programmed some assignments better than humans, but others should be left to humans rather than machines. Robots' increasingly complex capabilities will eventually eliminate some human jobs, but not all. Current robotics technology can only simplify 25% of the unpredictable, human-dependent areas such as construction and nursing. Nevertheless, robots rely on human programming [6-7]. There are as many types of robots as there are jobs [8].
Human population growth and technological advancement have increased fire accidents and hazards. Firefighting is a dangerous job that often results in fatalities. Robotics has emerged as a viable solution for protecting the environment and human lives. The robot will accomplish remote detection of fire. These robots are primarily used in industrial settings [9]. Colossus [10], Thermite [11] and FireRob [12] are the widely used firefighter robots currently available.

The world is progressively moving toward automated systems and self-driving vehicles in the era of automation; firefighters are constantly at risk of losing their lives. In case of gas leakage, there may even be an explosion. So, the system comes to the rescue to overcome this issue and safeguard the hero's life. This work involves an autonomous firefighting robot system. The robot's primary function is to transform into a crewless support vehicle capable of searching for and extinguishing fires.

2. Project Development
The autonomous robot system carries out the main functions, which could move towards the fire and pump out the water around it to put down the fire. This robot system uses Bluetooth technology for movement remote operation. The robot is loaded with a water tanker and a pump controlled over wireless communication to sprinkle water. The push Bluetooth app commands the receiver to control the robot's movement, either forward, left, or right at the transmitting end. With advancements in technology, particularly robotics, it is possible to replace humans fighting fire with robots. This replacement would improve the efficiency of firefighters and would also prevent them from risking human lives. Figure 1 illustrates the block diagram of the robotic system.

![Figure 1. Block diagram of an autonomous robotic system](image)

The smartphone Bluetooth is connected to the Bluetooth module of the system. Android application name "Firefighting Robot System" is the application that acts as an interface between the Android Smartphone and the robot. This android application allows the user to control the movement of the fire, either automatic or manual, for firefighting options. The Android application consists of buttons that are used to move the robot by sending the commands to the Arduino system by pressing the controls of the android application. The android application provides the option to configure the appropriate order for the robot's operation to detect which flame sensor is detected according to the
source of the fire. The codes are decoded by the Bluetooth module and then sent to the microcontroller ATMEGA328 IC. The program will store in the Microcontroller IC, compare these codes in the programming, and provide corresponding instructions to the connected systems to do the movement and extinguishing operations.

2.1. Mechanical design structure
The body kit shields the electronic circuit from external interference, most notably liquid, which could cause the circuit to malfunction. The body kit for the autonomous robotic system was designed around the following concepts:

i. Following the tasks assigned to the robot.
ii. Determine the location of the robot's internal components that will be required to make the robot operational.
iii. Reduce the weight of the load carried by the robot to reduce the amount of power required by the robot.

2.1.1. Robot design chassis. The robotic system's primary structure includes two wheels on the rear and one on the forward-facing side to achieve the desired movement and speed. The front-wheel can alleviate the robot and make a revolution within 180°. The robot's frame is constructed entirely of wood plates to safeguard the electronic circuit. A wood plate is used because it is the most uncomplicated and most affordable material that can withstand the weight of a massive robot. Figure 2 illustrates the layout of the robot body employing a 2WD smart robot car chassis kit suitable for Arduino.

![Figure 2. Design of robot body kit](image1)

![Figure 3. Robot design with a deck](image2)
2.1.2. Deck design structure. Figure 3 shows the robot design with a deck on it by using an acrylic board. An acrylic board was chosen to make a deck for the robot because it is a low-cost item, but it is the most suitable to get the best hardware arrangement to look neat on the robot. The acrylic board on the top of the robot was a perfect housing space, and it appears to look more neat and visible since acrylic is transparent, making way to see through the hardware components.

2.2. Hardware development
The electronic component is a critical component of the robot's development. Flame sensors, a microcontroller, a DC motor with wheels, a servo motor (SG90), an L298N motor driver module, an Arduino relay module, and a tiny DC submersible pump included [13]. The microcontroller receives responses from the parts, principally the flame sensors, and illuminates them using Arduino IDE code. This project uses an Arduino UNO R3 because it has all its native IC ATMEGA328P with additional features. The Arduino board is connected with three flame sensors, a water pump, DC motors, and servo. A 12V power supply is required to power the robot system's motors and pumps, and a 5V power supply is needed to power all connected sensors. The HC-06 Bluetooth module [14] is used as a slave Bluetooth module created for wireless serial communication. The slave module signifies that the module can receive the serial data when serial data is sent out from a master device such as a smartphone or PC.

2.3. Software development
Software development is the process of creating and maintaining software applications, frameworks, and other components. Two applications were used in developing the source code for the robotic system, which are Arduino 1.8.13. and MIT App Inventor. These applications were used separately in producing source code.

![Flow chart of Bluetooth connection](image)
**Figure 4.** Process flow of Bluetooth connection

![Flow chart of fire sensor module operation and robot's movement](image)
**Figure 5.** Fire sensor module operation and robot's movement
2.3.1. Design process flow. Figure 4 and figure 5 show the process flow of the autonomous robotic fire detection and extinguishing system. The first step will be to initialize all of the system's pins and sensors. The following phase will be to detect fire; if it detects a fire, it will proceed but continue scanning for fire until it is detected. Once caught, the system checks which sensor, either right, middle, or left, noticed the fire. As soon as the fire sensor detects which movement, the pump motor will activate to extinguish the fire. Then, again, the robot starts moving and catches fire. When the manual option is activated, the robot's movement is controlled via the mobile application. The right touch key will be managing the right direction, and the left touch key controlling the left path. In contrast, the up and down touch keys control the straight and reverse movement. The manual mode is used to manage the direction of the robot in the fire scene.

2.4. Testing environment
The prototype of this autonomous robotic system is tested through an environment with dimensions of 3 x 3 meters. The automated system entered the region and then moved randomly in response to the conditions of the surroundings. The robotic system was not assigned a course to travel. Random fires are started throughout the testing area. The accuracy of the sensors is tested by measuring the distance of the flame detection. The responses of different sensor positions are calculated accordingly. Regarding Bluetooth control responses, testing is done on measuring the length of Bluetooth transmission between the robotic system and smartphone with an android application.

3. Result and Discussion

3.1. Android application
Figure 6(a) depicts the interface of the autonomous robotic system android application. This interface has the FiBot title in the application. Users will be directed to the second page, which is the main page, as shown in figure 6(b), by clicking on the "ENTER" button. The main page of the android application is divided into three parts: Bluetooth connectivity, mode selection, and action keys for manual mode. To begin using Bluetooth, the user must first "ON" the Bluetooth, which brings up an interface that lists all the paired Bluetooth devices. Users will have to select the HC-06 Bluetooth to connect to the FiBot Bluetooth module. Once the Bluetooth module is selected, it will return to the main page stating that HC-06 is selected and the status "CONNECT THE DEVICE" will appear.

Users can further click on the "CONNECT" button to connect the device. After completion of the connection, the status will change to "CONNECTED". Then, the user will now select the mode they would like to run the robot in auto mode or manual mode. In auto mode, the robot will automatically detect the fire with the sense of the flame sensor and move towards the fire to pump out the water, then continue extinguishing the fire. Figure 7 shows the responses shown in the FiBot android application in real-time: the data will automatically show which flame sensor has detected the fire according to the direction of the fire.

Besides, figure 8 shows an example of the commands in manual mode that will be displayed when clicking on the arrows and the stop buttons. These functions have a delay of approximately 2-3 seconds due to the Bluetooth connection. The manual consists of 5 operations which are forward, reverse, left, right and stop motion.
3.2. Robotic system prototype

Figure 9 shows the prototype of the robot from the side view, and Figure 10 shows the prototype of the robot from the top perspective. The housing space was added with a customized acrylic board to fit the chassis kit to occupy all components and the power sources. A transparent container is placed at the front end of the chassis kit, which acts as a water reservoir, and it is attached with the servo motor to spray water within a radius angle of 80°.
3.3. Sensor module detection and Bluetooth communication

The average distance for detection of flame is approximately 5.11cm. The distance gap is quite far from the theoretical and practical values. The length is tested by measuring flame detection in different directions, as depicted in table 1. Further analysis and testing need to be done to improve the sensor accuracy. For the Bluetooth communication, step 3 was assumed to be a 1-meter distance which was set as a control variable. As referred to in table 2, the number of measures was used to check the Bluetooth transmission distance. In conclusion, the distance where Bluetooth connection gets connected is from 1 - 300cm. Therefore, it is assumed that Bluetooth transmission between Bluetooth module and smartphone is about 3 meters.

| Table 1. Distance on the flame detected |
|----------------------------------------|
| Sensor detected | Distance (cm) |
| Front          | 4.5          |
| Left           | 6.0          |
| Right          | 5.5          |
| Left           | 5.6          |
| Front          | 4.5          |
| Left           | 4.7          |
| Right          | 3.0          |
| Front          | 6.3          |

| Table 2. Distance on Bluetooth connection |
|-------------------------------------------|
| Distance (cm) | Steps | Bluetooth connection   |
|----------------|-------|------------------------|
| 1              | -     | Connected              |
| 100             | 3     | Connected              |
| 150             | 6     | Connected              |
| 200             | 9     | Connected              |
| 250             | 12    | Connected              |
| 300             | 15    | Connected              |
| 350             | 18    | Disconnected           |
| 400             | 21    | Disconnected           |
4. Conclusion

The modular design strategy proposed was an excellent solution for implementing an autonomous robotic system to assist people in critical situations. The robot is capable of forwarding, left, and right movement, as well as stopping. It minimizes human effort and safeguards their property. The robotic system is also capable of detecting the fire, navigating towards the fire, and extinguishing the fire with the help of a water pump. The robot was also successfully controlled by using the Bluetooth module and functions as expected. The robotic system's hardware was developed following the initial design and modified to change conditions and improvements. Arduino software was used to design and develop the code. Through the use of real-time simulation, the completeness of the software library simplifies the project's process. However, although the firefighting robot designed and demonstrated here provides significant human assistance, the fire extinguisher's accuracy could be improved. According to the disaster response robot system presented above, it was operating effectively and efficiently. With the project's objectives met, it is concluded that the prototype's design is reliable and cost-effective and should be used in firefighting operations to help reduce the number of fatalities and property loss in buildings and infrastructure.

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