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Development of a Dual-Mode Fire Fighting Robot

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ABSTRACT

This paper presents a dual fire-fighting robot designed to operate in a variety of environments. Firefighting portends serious safety challenges and high-risk factors for human firefighters. The use of robots for such tasks will surmount these challenges if adequately applied. The dual-mode robotic system described here utilizes two types of fire suppression modes—automatic and manual. Equipped with sensors the robot detects the location and intensity of the fire and can navigate its way to extinguish it. In autonomous mode, the robot senses any occurrence of flame and approaches it and activates its water spraying system to put off the flames and reverse back to its detection/patrol operation. In manual operation, an operator controls the whole movement and the pumping action of the system remotely using a smart device or PC via a Wi-Fi network. The robot was tested in several simulated fire scenarios and demonstrated a high level of effectiveness in extinguishing fires. Results indicate the dual-mode firefighting robot has the potential for safety and efficiency improvement in fire suppression operations in a range of settings.

1. INTRODUCTION

Firefighting is an extremely dangerous task often carried out by human operators, thus putting human life in a very precarious situation. The execution of routine and basic firefighting tasks by humans should be replaced or at least partially assisted by robots to reduce or even avoid possible risks. The development of a remotely controlled firefighting robot by a firefighting officer is presented in Devi *et al* (2020). The robot senses fire and detects obstacles using flame and ultrasonic sensors, but can only be remotely controlled. The use of human control is a concern as robots used for fire extinguishing purposes are expected to find and put out fires (Purbarani *et al*, 2015). This class of robots are being proposed to be made with independent control systems and mechanisms (Rakib and Sarkar, 2016) regarding the level of risk involved in firefighting processes, as well as their use in industries and places where there is the possibility of accidental fire (Memon *et al*, 2018).

The application of humanoid robots is being actively studied to minimize injuries and deaths to firefighters yet increase productivity, safety, efficiency and quality of the given task (Kim *et al*, 2016). These robots may be divided into several groups such as Tele-robots, Telepresence robots, Mobile robots, Autonomous robots and Android robots. Telepresence robots are similar to tele robots with the main difference providing feedback from video, sound and other data. Hence, telepresence robots are widely used in many fields requiring monitoring capabilities, such as in

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child nursery and education, and in improving older adults' social and daily activities (Tanaka et al, 2014; Ahn & Kim, 2016). Certain mobile robots are designed to navigate and carry out tasks with the intervention of human beings (Harik & Korsaeth, 2018; Calderon *et al*, 2015). Meanwhile, autonomous robots can perform tasks independently to affect their environment, as opposed to android robots which are built to mimic humans (Hyung *et al*, 2016; Haksar & Schwager, 2018; Raju *et al*, 2017; Satbhai *et al*, 2016; Nuţă *et al*, 2015).

Here, a dual-mode autonomous fire-fighting robot capable of operating itself, or being remotely controlled from a distance and equally monitored is presented. The developed robot function to identify fire, and take decisions based on the situation and concerning the intensity of the fire.

2. DESIGN METHODOLOGY AND PROCEDURE

2.1 The Robot Development

The entire firefighting robotic system is subdivided into blocks that serve different purposes, as shown in Figure 1, and includes the processing unit, structural support and locomotion unit, obstacle and flame detection unit, water sprayer unit, and surveillance and Remote-control unit. Figure 2a shows the entire circuit diagram of the fire-fighting robot. The chassis framework of Figure 2b provides a rigid mount platform for the system's components.

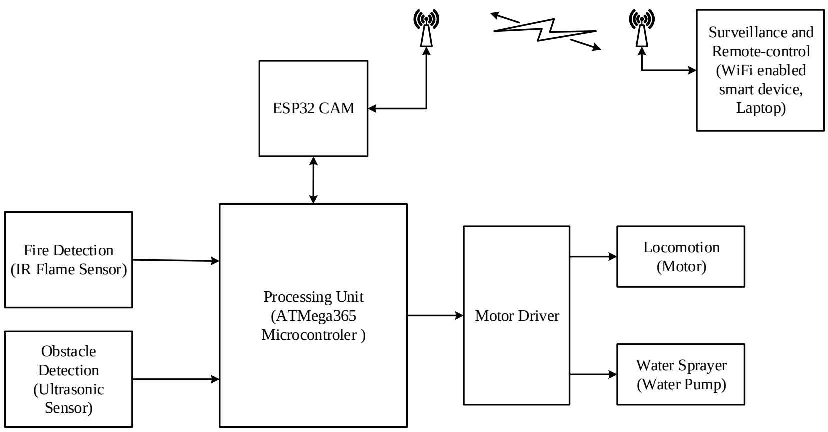

Figure 1: *Block Diagram of the Fire Extinguishing Robotic System*

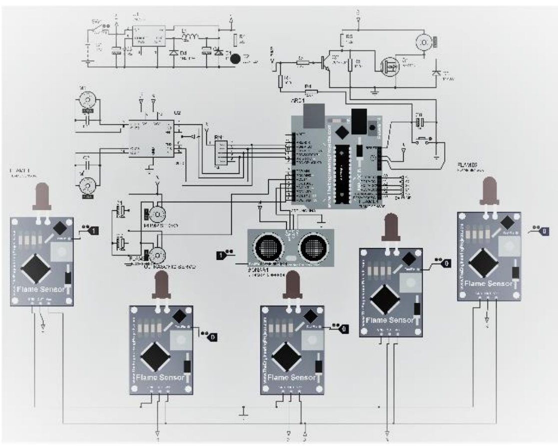

Figure 2a: *Circuit diagram of the Fire-fighting robotic system*

Figure 2b: Robot chassis and wheel

2.1.1. Locomotion and Water Sprayer

The entire firefighting robotic system is mounted on a tracked mobile chassis that runs on two high torque DC motors with rated speed of 45RPM. These motors are controlled through a motor driver (L293D), which enables 5V control digital bits of the processing unit, to turn the wheels for movement and to change direction as required at 12V. The L293D also supports the water spraying process by interfacing the control signals, from the processing unit to a 12V DC electric water pump attached to a water tank with a spraying nozzle mounted on a servo motor for maximum area coverage.

2.1.2 Obstacle and Flame Detection Unit

Obstacles are detected by the fire-fighting robot using an ultrasonic sensor. The ultrasonic sensor sends a signal to an object (obstacle) and generates high frequency sound waves. The reflected wave from this signal (echo) is then evaluated as depicted in Figure 3. The time interval between the sending signal and the reflected signal is measured to know the distance to an object/obstacle. The ultrasonic sensor is mounted on a servo motor, to allow for scanning of a broader area around the robot.

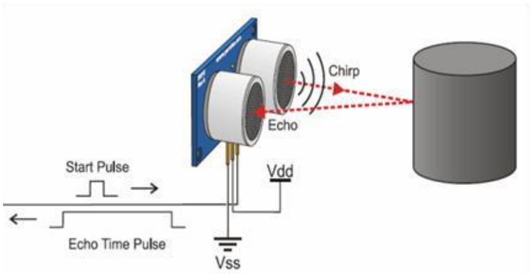

Figure 3: *Ultrasonic Sensor (*Chatterjee &Paul, 2017*)*

The fire detection unit senses the presence of fire incidence and it consists of an infrared (IR) receiver flame sensor, resistor, capacitor, potentiometer, and comparator LM393 in an integrated circuit. It can detect fire and other infrared light of wavelengths 700nm to 1000nm. The sensor converts infrared light detected to current changes. Its sensitivity can be adjusted with a variable resistor onboard and works at a voltage range of 3.3V to 5.2V DC to produce a digital output that indicates the presence of a flame.

A single flame sensor detection angle is around 60^{o} and by using a five-channel flame sensor design, a much wider detection spectrum of over 120^{o} can be achieved. Figure 4 shows the image of the IR flame sensor used for the firefighting robot development. The IR flame sensor recognizes the fire using five independent sensors arranged with 30 degrees of separation. This arrangement provides for sensing overlap and ensures no window of flame is left undetected within the coverage angle.

Figure 5: *IR Flame Sensor [4]*

For the robot not to be trapped in a fire due to re-ignition from behind while on forward action, it is equally equipped with a single channel flame sensor at its back. This sensor is handled with a higher level of priority and detections from it are quickly attended to, causing it to make a full 360-degree turn to focus on the fire to avoid possible trapping of the robot, especially when operating in autonomous mode.

2.1.3 Surveillance and Remote Control

Remote surveillance and control functions of the system are through a wireless interface to other smart devices and are implemented with the ESP-32 CAM camera module (Waveshare, 2022). This small-size module supports both Bluetooth and WiFi communication protocols in addition to its flash camera device. It is capable of streaming life videos and images captured through its WiFi link and operates with minimal power requirement. In its application here, control commands are issued through both the Bluetooth and WiFi terminals, and surveillance video streaming and images are through the WiFi terminal only.

2.1.4 Processing Unit

The processing and control unit of the robotic system is powered by the ATmega328P microcontroller and coordinates the entire activities of the robot. The ATmega328P read binary bits from the flame and obstacle sensors coordinate the robot's decision-making and actions. It also is responsible for implementing commands from connected remote-control devices. These commands, which are communicated to the ESP-32 camera module via a wireless connection, are relayed to the ATmega328P through its serial Tx/Rx terminals. The robot can operate autonomously in an automatic mode or be aided by an operator through remote control commands in a manual mode.

a. Automatic operation

The robot operates in autonomous mode by default when powered on and will run in this mode until a mode-change input signal/command is received by the ESP32 wireless communication terminal. In this mode, all operations are carried out without human intervention. The obstacle detection and a servo mechanism provide free path navigation.

b. Manual operation

The manual control mode is achieved by employing the ESP32-Cam wireless terminal. At power-up, a mobile Hotspot network is generated by the ESP32-cam module. A user retrieves live video feeds or remotely controls the robot using a web browser on any mobile device with Wi-Fi capability by connecting to the generated Wireless Network. Basic movement buttons (forward, backward, right, left) are programmed on the ESP32 control webpage. When linked to a device, it receives key presses through the web page keyboard. The keypresses serve as directional commands to the system. When these commands are received, the ESP32 forwards their bit pattern via serial communications to the microprocessor which then enables (through the L293D motor driver) the robot to move as desired. The operator can adjust the robot's movement patterns without constraint by clicking on these control buttons. Fire and obstacle detection is done manually by an operator through data obtained from the live video feed provided by the ESP32.

2.1.5 Control Algorithm

The algorithm describing the control process of the robotic system is shown in Figure 5. It ensures the selected operational mode at any time by executing the user choice command. At default, the autonomous mode is selected and will remain in that state unless otherwise deactivated. The algorithm of Figure 5 indicates the action path of the robot while operating autonomously.

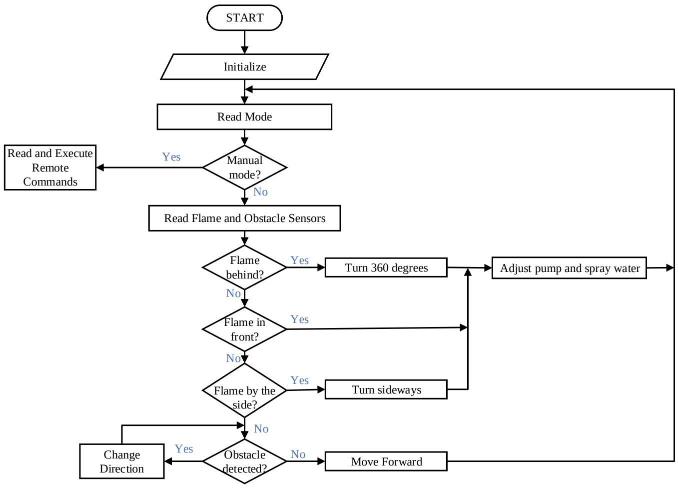

Figure 5: Flowchart of developed fire fighting robot

2.1.6 Operation and Reaction

The developed firefighting robot is shown in Figure 6. The robot, once powered on, starts to move around in the operational environment. The obstacle detection system starts to send out signals to detect obstacles for the robot to manoeuvre its way across such obstacles on its path. Simultaneously, the IR flame sensor is also searching for an incidence of fire. Once at an appropriate distance from the fire, the robot activates its pump system and water is sprayed on the fire from the water tank. The video of this reaction to fire incidence by the robot is then provided through the ESP32-Cam mounted on the robot.

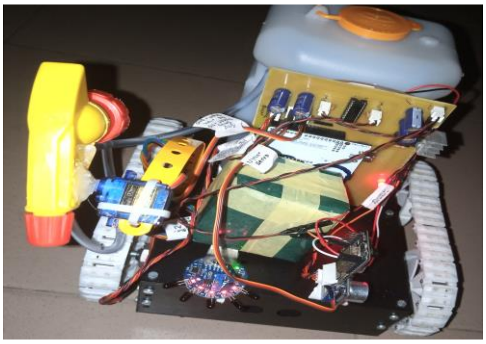

***Figure 6:** The developed firefighting robot*

3. RESULTS AND DISCUSSION

The following experiments were carried out to examine the robot's performance and the speed of its response to fire incidence:

3.1 Obstacle Avoidance Testing

The obstacle avoidance test was carried out first to determine the efficiency and accuracy of the ultrasonic sensor. The tests included exploring a room with obstacles such as tables, chairs, boxes, and manoeuvring out of corners and dead ends. Table 1 and Figure 7 give the distance-time data and graphical representation of the robot approaching fire scenes.

Table 1: Distance-time data of robot to fire scene

Distance to fire (m)	Time to approach fire (s)
0.5	3.95
1	7.9
1.5	11.86
2	15.81
2.5	19.96
3	23.74
3.5	34.65
4	44.89

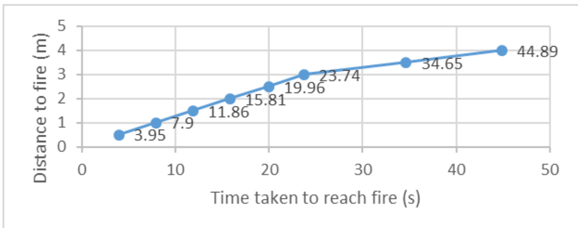

Figure 7: Fire approach rate

The average time taken by the robot to approach a fire scene depends on the route, possible obstacles in the pathway and its average speed at the time.

3.2 Flame Detection Testing

This test was conducted by having the robot detect and extinguish flames of different sizes and at various locations. Burning candles, papers and wood were used as sources of flames for the test. The directions of the nozzle and spray intensity of the water system were observed. Figure 8 shows the reaction of the robotic firefighter to a simulated fire scenario.

Figure 8: *Robot reaction to fire incidence*

Table 2: Radius - Time	
The radius of fire (cm)	Time to extinguish the fire (s)
5	6.32
10	11.25
15	19.22
20	30.63
25	54.1
30	72.86

The time taken for the robot to extinguish different radii of fire is presented in Table 2 and shown graphically in Figure 9.

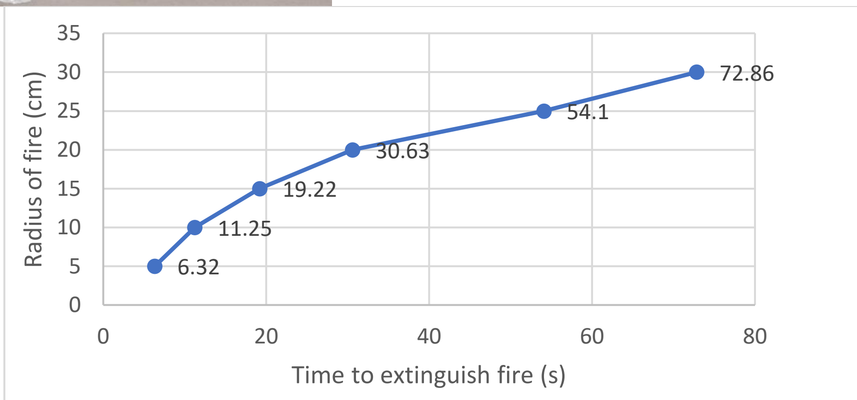

Figure 10: *Radius of fire – time taken to extinguish*

3.3 Streaming and Remote-control Testing

The third form of the test was performed on the ESP32-cam module. This involved connecting a mobile device to the robotic system via Wi-Fi, ensuring a steady video stream of the events at the robot end, and testing for remote controllability from a reasonable distance in an out-of-sight scenario. Figure 10 shows the remote monitoring of the system via a PC.

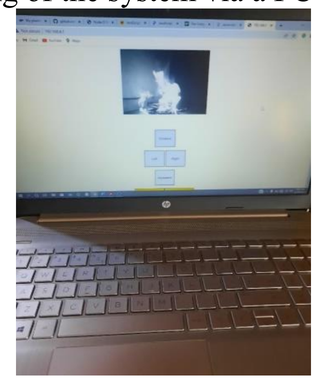

Figure 10: *Video Feed and Control Webpage – View of Robot Approaching Fire*

4. CONCLUSION

In conclusion, the development of a dual-mode firefighting robot presents a promising solution for improving the safety and efficiency of fire suppression operations. The robot's combination of automatic and manual operating modes allows for effective firefighting in different environments. Successful experimentation with the system in simulated fire scenarios highlights its potential for real-world applications. The integration of fire detection sensors and autonomous navigation capabilities makes the firefighting robotic system highly effective in extinguishing fires, while the ability to remotely control the robot via a Wi-Fi network provides additional flexibility and control for the operator. The developed robot was tested with different radii of fire and the time to put out the fire was recorded in each case. Overall, the dual-mode firefighting robot has the potential to revolutionize firefighting operations and improve the safety of firefighting personnel.

References

Ahn, J. and Kim, G. J. (2016). Remote collaboration using a telepresence mobile projector robot teleoperated by a smartphone. *IEEE/SICE International Symposium on System Integration (SII)*, 2016, pp. 236-241.

Calderon, C. A. A., Mohan, E. R., and Ng, B. S. (2015). Development of a hospital mobile platform for logistics tasks. *Digital Communications and Networks*, Volume 1, Issue 2, Pages 102-111, ISSN 2352-8648, https://doi.org/10.1016/j.dcan.2015.03.001.

Chatterjee, S. and Paul, A. (2017). Autonomous, Surveillance Fire Extinguisher Robotic vehicle with Obstacle Detection and Bypass using Arduino Microcontroller. *Communications on Applied Electronics* 7(4), pp 12-17.

Devi, K. S., Akhileswar, K., Vinayaka, C., Karthik, M., and Viswanadham, Y. K. (2020). Fire Fighting Robot, *The International journal of analytical and experimental modal analysis,* vol. 12, issue 7, pp. 1957-1967

Haksar, R. N. and Schwager, M. (2018). Distributed Deep Reinforcement Learning for Fighting Forest Fires with a Network of Aerial Robots. *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Madrid, Spain, pp. 1067-1074, doi: 10.1109/IROS.2018.8593539.

Harik, E. H. C. and Korsaeth, A. (2018). Combining Hector SLAM and Artificial Potential Field for Autonomous Navigation Inside a Greenhouse. **Robotics**, **7**, 22. https://doi.org/10.3390/robotics7020022.

Hyung, H. J., Ahn, B. K., Cruz, B. and Lee, D. W. (2016). Analysis of android robot lip-sync factors affecting communication. 2016 *11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, Christchurch, New Zealand, pp. 441-442, doi: 10.1109/HRI.2016.7451796.

Kim, J. H., Jo, S. and Lattimer, B. Y. (2016). Feature Selection for Intelligent Firefighting Robot Classification of Fire, Smoke, and Thermal Reflections Using Thermal Infrared Images. *Journal of Sensors*, Volume 2016, Article ID 8410731, http://dx.doi.org/10.1155/2016/8410731

Memon, A. W., Du, J., Abro, A. H., Shah, S. I. and Bhutto, M. A. (2018). Design and Implementation of Fire Extinguisher Robot with Robotic Arm. *MATEC Web of Conferences, EECR 2018*. pp. 1-5

Nuţă, I., Orban, O. and Grigore, L. (2015). Development and Improvement of Technology in Emergency Response. *Procedia Economics and Finance*, Volume 32, pp. 603-609. ISSN 2212-5671, https://doi.org/10.1016/S2212-5671(15)01438-0.

Purbarani, S. C., Yunina-Moa, Q. A, Jati, G., Ma'Sum, M. A., Wisesa, H. A., and Jatmiko, W. (2015). Implementation of grid mapped robot planning algorithm in a continuous map for firefighting robot. *2015 International Symposium on Micro-NanoMechatronics and Human Science, MHS 2015*.

Raju, J., Mohammed, S. S., Paul, J. V., John, G. A. and Nair, D. S. (2017). Development and implementation of arduino microcontroller based dual mode fire extinguishing robot. *2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS),* Srivilliputtur, India, pp. 1-4, doi: 10.1109/ITCOSP.2017.8303141.

Rakib, T. and Sarkar, M. A. R. (2016). Design and Fabrication of an Autonomous

Fire Fighting Robot with Multisensor Fire Detection using PID Controller. *2016 5th International Conference on Informatics, Electronics and Vision (ICIEV),* Dhaka, Bangladesh, 2016, pp. 909-914, doi: 10.1109/ICIEV.2016.7760132.

Satbhai, T. N., Karande, R. M., Patil, A. V., and Patil, M. (2016). Fire Fighting Robot. *International Journal on Recent and Innovation Trends in Computing and Communication (IJRITCC)*, **4**(4) pp. 799-803. http://www.ijritcc.org.

Tanaka, F., Takahashi, T., Matsuzoe, S., Tazawa, N. and Morita, M. (2014). Telepresence robot helps children in communicating with teachers who speak a different language. *Proceedings of the 2014 ACM/IEEE international conference on Human-robot interaction*. March 2014, pp. 399-406. https://doi.org/10.1145/2559636.2559654

Waveshare (2022). *ESP32-CAM, Camera Module Based on ESP32, OV2640 Camera and ESP32-CAM-MB adapter Included*. https://www.waveshare.com/esp32-cam/