Journal of the Nigerian Association of Mathematical Physics
Volume 60 **(April – June** *2021 Issue***), pp77 –82**

DEVELOPMENT OF MICRO-CONTROLLER BASED INTELLIGENT FIRE FIGHTING ROBOT

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Abstract

This paper presents the development of an intelligent fire fighter robot that can move through a model structure to locate any fire point and then extinguish it with the help of a water pump mechanism. This device is made of flame, smoke, gas and ultrasonic sensors. The flame sensors are mounted on the robot, a stepper motor to direct the hose in the desired direction, and a water pump to sprinkle out the water through the hose. The microcontroller ATMEGA 328P is interfaced with the sensors and motor drives, and are controlled by the C++ program code. For reinforcement, the robot is covered with a fire proof material to be able to withstand high temperature environment for a long period of time. The developed robot was tested to analyse its performance as well as to demonstrate the ability to extinguish fire at real time. The results show that the proposed robot model is successfully implemented as shown by the fast fire execution time.

***Keywords*:** Intelligent fire fighter robot, Microcontroller, Sensors Stepper-motor, flame, smoke, ultrasonic sensors.

1. Introduction

A robot is a machine that is wired and programmed to sense, think and act to accomplish specific tasks or functions within the shortest period of time taking cognisance of every possible safety precautions [1]. Recently, robotics is one of the fastest growing technology in the engineering field. Robots are designed to remove the human factor from labor intensive or dangerous work and also to act in inaccessible environment. The use of robots is more common today than ever. Robots are designed for different purposes which are the reason for many types such as fixed vase robot, mobile robot, underwater robot, humanoid robot, space robot, medical robot, etc.

On the other hand, fire-fighting is a strenuous and an extremely dangerous task that puts firefighters at risk but still often being carried out by human operators, thus putting priceless human life in a very precarious situation. Consequently, it is highly desirable that the execution of routine and basic fire-fighting tasks to be replaced by an Autonomous Fire Fighter Robot. The robot must be able to detect the fire point, move at relatively good speed automatically and avoid obstacles, and extinguish fire safely.

Yearly, fire fighters lose their lives in the course of carrying out their civic duties. In 2011, research showed that 70,090 fire fighters in the U.S. alone were injured in the line of duty with 61 deaths [2]. Over 60% of the fire fighter deaths and over 20% of the fire fighting injuries are caused by exposure to fire severities such as smoke inhalation, burns, stress, and being trapped. Although there has been research on auditory and tactile perception for the purpose of evacuation under fire smoke environments, these techniques are not enough to support fire fighting tasks in a timely manner. Effective technology is needed to allow robots and fire fighters to accurately image and navigate through zero visibility smoke to rapidly find fires and victims as well as establish escape routes if fire conditions begins to deteriorate. Several robotic technologies have been deployed to extinguish uncontrollable fire [3-5]. For example, fire searcher robot, designed for usage in extreme conditions such as high temperatures or poisonous gases, is often used to monitor the internal situation of a fire site and victims, and

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send back crucial information to its operator at a remote site [4]. On the hand, Jet fighter, deployed as an autonomous fire fighting mobile platform which can be operated and controlled by remote user and has the ability to extinguish flame after locating the source of fire [6]. It is equipped with obstacle avoidance system embedded into its autonomous navigation system. Other robotic technology used to combat fire outbreak are summarized in Figure 1.

ROBOT	Type	Opearting Region	Capabilities	Opearting Mode	Perception	Portability	HPT	Country Of Origin
Fire Searcher	UGV	Outdoor	Fire Extinguishment/ Visual perception	Obstacle-aided Autonomous	Thermometer/ Visual Camera	Poor	Poor	Germany
MPFF	UGV	Indoor/ Outdoor	Fire Extinguishment Visual perception Audio perception Movement Of People	Remote User Obstacle-aided	Thermometer/ Visual Camera Microphone	Medium	High	Malaysia
BEAR	Humanoid	Indoor	Fire Extinguishment/ Movement Of People	Obstacle-aided Autonomous	Thermal IR Stereo	Poor	Medium	United States
Jet Fighter	UGV	Indoor/ Outdoor	Fire Extinguishment/ Visual perception	Remote User Obstacle-aided	Thermometer/ Visual Camera	Poor	Medium	Tokyo
LUF60	UGV	Outdoor	Fire Extinguishment/ Smoke Dispelling Stair Climbing	Remote control/ Rubber Track System	Visual Camera	Poor	Medium	Germany
FINE	UGV	Indoor	Fire Extinguishment	Autonomous	Thermometer	Medium	Poor	New Jersey
Thermite	UGV	Outdoor	Fire Extinguishment	Remote control/ Rubber Track System	HD Analogue Video Cameras Operational Infrared FLIR	Medium	Poor	United States
VOI	UGV	Indoor	Fire Extinguishment	Remote User RF Communication	Thermometer	Poor	Poor	Hong Kong
Brokk	Excavator-like robot	Indoor/ Outdoor	Demolition/ Stair Climbing	Remote control/ Hybrid Locomotion	N.A.	Medium	High	Sweden

Figure 1: Literature review of past works

2.0 Theoretical Analysis

The idea of intelligent robot fire fighter is to design a mobile machine which would extinguish fire more effectively than human operators, and to reduce death rate in fire fighting activity. Hence, it is designed to move automatically inside and outside affected environment without any supervision. Figure 2 shows the network of an Autonomous Fire Fighter.

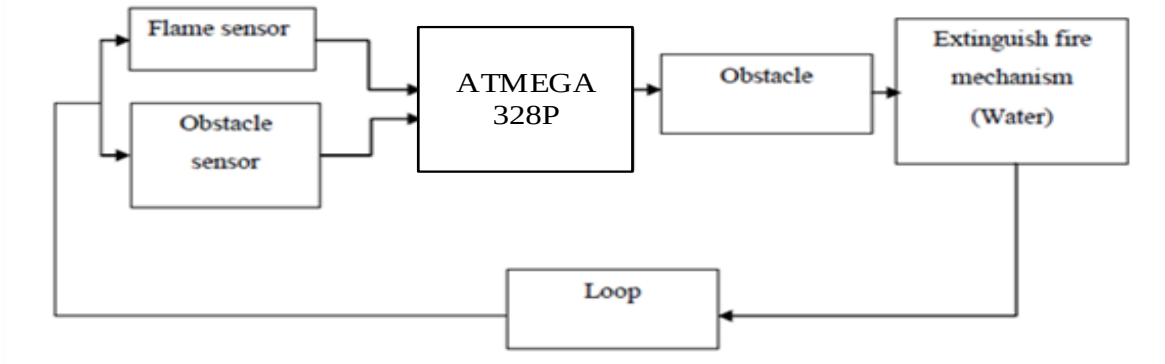

Figure 2: Block Diagram of an Autonomous Fire Fighter

The flame and obstacle sensors are incorporated in the microcontroller ATMEGA 328P, which controls all actions of the robot including the pumping of water to extinguish fire at all points.

Robots can be classified into different types depending on their application, architecture but also their autonomy. They can be divided into two types namely autonomous and controlled robots. Controlled robots operate in compliance with commands received from external systems or human operators. Autonomous robots are "intelligent machines capable of performing tasks in their environment by themselves, without explicit human control over their movements" [7]. Fire Fighting Robot has the ability and capability to avoid obstacles, detect the presence of fire and extinguish the fire using water mechanism. To avoid the obstacle, the robot requires a smoke sensor that is placed in order to detect the presence of

fire. The movement is driven by a direct current (DC) geared motor with encoder. All features are controlled by the Micro-Controller which is the brain that processes information and gives instructions to the machine through the output. A portable intelligent Fire Fighting Mobile Platform is specifically designed to be thrown into the fire site to collect data and information, search for victims and evacuate them from the fire site. This can be controlled by the operator so as to communicate with the victims using the built-in microphone and speaker system during emergency cases. In some design, a camera feature is included to capture the scene of fire site, and also sensors for temperature measurement. Since it is specially designed to be thrown into the fire site, it can withstand high temperature, over 15000C, waterproofed and has impact resistance feature.

2.1 Obstacle Avoidance

Obstacle avoidance is a pertinent feature in this study. It is embedded into the robotics system to ensure the robot does not collide with any obstacle during the navigation process. This measure is taken to ensure the machine can move and achieve its purpose efficiently. The safe distance between the robot and any obstacle, D_s, is updated from time to time to keep the robot away from any obstacle at a relative safe distance. Mathematically, the relationship between the ultrasonic sensor and its distance is given by [8]

$$D_s \leq D_{safe}$$

$$D_{ultrasonic} = \frac{D_{safe}}{D_s}, D_s \geq D_{safe}, \quad (1)$$

where D_{safe} is the preset threshold value (constant) for the distance between the mobile platform and the obstacle while Ds is the value that changes continuously when the mobile platform navigates around. If the mobile platform is not approaching any obstacle, then its $D_{ultrasonic}$ value will always equal to 1. When the Mobile Platform gets too close with any obstacle, the D_s value will be greater than the D_{safe} value and thus yields a $D_{ultrasonic}$ value which is less than 1. The obstacle avoidance module is implemented by converting the analogue output from the ultrasonic sensor into digital form by using the 8 bits analogue-to-digital (A/D) converter inside the microcontroller and performs a comparison with the previously set threshold value to see whether the robot is too close with any obstacle. The obstacle bits will be set in another register if any obstacle is detected. The ultrasonic sensor and the ranging sensor can also be used for obstacle detection and avoidance purpose with the detection range of about 10cm to 85cm. The intensity of the fire is an important factor to be considered in the design which is a function of the material involved in the fire outbreak and extinguishing material required to put out the fire. Table 1 shows different classes of fire caused by various materials, and Table 2 shows the various types of fire extinguishers that can be used to put out each fire.

Table 1: Classes of Fires

Class Of Fires	Materials
A	Solids (Paper, Wood, Plastic)
B	Liquids (Paraffin, Petrol, Oil)
C	Gases (Propane, Butane, Methane)
D	Metals (Sodium, Lithium, Manganese, Aluminium, Magnesium, Titanium etc).
E	Electrical Equipments
F	Cooking oil & fat.

Table 2: Types of Fire extinguisher

Types of Fire Extinguishers	Characteristics
Water	• Cheapest and commonly used to put off Class A fire • Not suitable for Class B fire
Foam	• Slightly expensive than water type • Used to put off Class A and B fire • Not suitable for fire involving electricity
Dry Powder	• Multipurpose Extinguisher • Used for Class A, B, C fires • Best for running liquid fire (Class B) • Effectively extinguishes Class C gas fire
Carbon dioxide	• Ideal for fires involving Electrical apparatus • Disadvantages: Fire might re-ignite for Class B liquid fire
Wet Chemical	• Used to put off Class F fire
Metal	• Used to put off Class D fire

The movement of the robot is controlled based on the conditions in the program code with the response of the obstacle detector. Actuators cannot be driven with the supply provided by the microcontroller output pins. Motor drivers are interfaced with the microcontroller (Arduino) to provide the actuators with the required driving current. The motor drivers require a second external supply which acts as a supply to the H-bridge amplifier. The control signals control the action of the motors, i.e. whether the motor must be driven clockwise or anti clockwise. The motor drivers are also used to boost current for the water pump.

3.0 Experimental Work

The implementation of this design involves the construction of the Autonomous Fire Fighter, interfacing of hardware such as the motor driver circuitry, Light dependent resistor (LDR) sensors circuitry, Flame Sensors; and the developed algorithm for the microcontroller to provide artificial intelligence to the mobile platform itself. The priority is the fire detection capabilities and accuracy for function delivery. This design is implemented using ATMEGA microcontroller platform known as Arduino Mega. It consists of 54 digital as well as 16 analog input/output pins with 4 UARTs and 16 MHz crystal oscillator. The Mega 328P board is specially chosen because of its compatibility with most sensors and modules. The employed motor driver module circuit for firefighting robot is known as L293D motor driver controller. It consists of 4 inputs and 4 outputs to control two DC motors. One of the main features of L293D is to provide up to 600mA current at voltages variation from 4.5 V to 36V. The direction of rotation of DC motor in forward and reverse can be controlled through combining different input logics. Another strong reason to choose this specific integrated circuit (IC) for movement control is the ability to control the speed of two motors using PWM from microcontroller which is required to control the robot for different modes. The basic circuit arrangement of L293D is shown Figure 3 while Table 3 shows the Arduino specification.

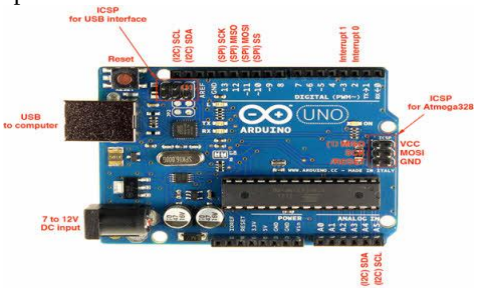

Figure 3: Arduino Micro-controller ATMEGA 328P

Table 3: Arduino specification

Specification of Arduino Uno ATmega328P	
Physical Features	**Specification**
Microcontroller	ATmega328P
Operating Voltage	5V
Recommended Input Voltage	Ranges 7V-12V
Input Voltage	Ranges from 6V-12V
Digital I/O pins	14
Analog I/O pins	6
DC current for 3.3V pin	50mA
Flash Memory	32KB
SRAM	2KB
EEPROM	1KB
CLK speed	16MHz

The main chip monitors all sub modules, and performs the correct actions based on external signal and information. The software component is the programming of the robot activities through the microcontroller. The programming flow chart is shown in Figure 4 while the circuit diagram of the proposed design is shown in Figure 5. The program code is shown in the Appendix. The sensor actuates hardware and check for the selected control mode. If a fire is detected within the range, the sensor provides the information to the microcontroller. The signal is provided in analog values to the microcontroller, and converted to digital values using A/D converter. The converted value is then compared to the predetermined values of the sensors to detect fire. Once fire detection is confirmed, the microcontroller sends signal to the control unit instantly by sprinkling water in the fire.

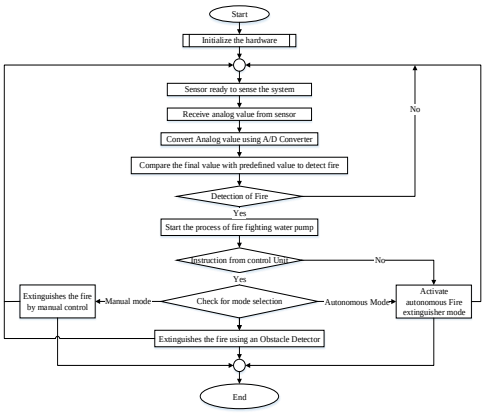

Figure 4: Flow chart for proposed system (move to page 9)

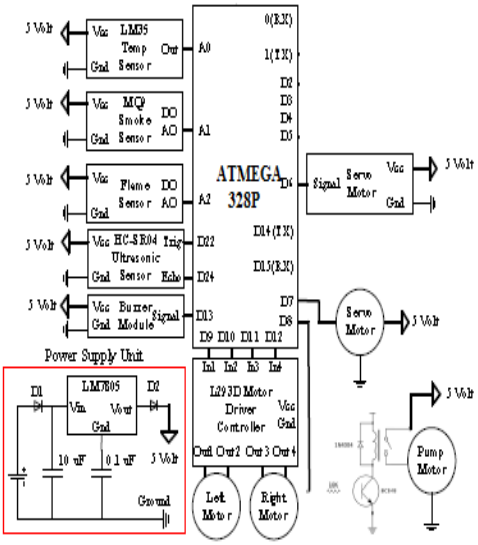

Figure 5: Circuit diagram of proposed fire extinguisher robot.

4.0 Results and Discussion

The intelligent fire fighter robot was subject to extinguish petrol fire outbreak at five (5) different points with obstacles. The robot successfully navigated the obstacles and extinguished the fire at the 5 points. The time taken to extinguish each fire point varies because of the positions of the obstacles which differ from one position to another. This is indicated in Table 4.

Table 4: Extinguishing Time at Different Points.

Points	Extinguishing Time
INITIAL ⟶A	2mins: 23secs
A ⟶B	2mins: 34secs
B ⟶C	2mins: 18secs
C ⟶D	2mins: 44secs
D ⟶E	2mins: 27secs

The Extinguishing Time is thus expressed as;

Extinguishing Time = Robot Moving Time + Water Sprinkling Time (2)

The Robot moving time is the time taken by the machine to move from one point to another while the time to put out the fire by sprinkling water is known as the Sprinkling Time.

The varying extinguishing time can be linked with the unsteady movement of the robot and heat intensity at different fire point. These are obvious limitations in this development that should be considered for future improvement on fire fighting robot at large.

5.0 Conclusion

In this study, an intelligent fire fighter robot that can move through a model structure to locate any fire point and then extinguish it with the help of a water pump mechanism was developed. Using the microcontroller ATMEGA 328P, flame, smoke, gas and ultrasonic sensors, a stepper motor to direct the hose in the desired direction, and a water pump to sprinkle out the water through the hose, the response time to extinguish fire between two points was determined.

The results show that the proposed robot model was successfully implemented as shown by the fast fire execution time.

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