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Design and Fabrication of Fire Fighting Robot

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Abstract – The paper proposes a model of a fire fighting robot that can detect the smoke, locate fire and extinguish it. However, this needs more accuracy and more inputs. Hence, usage of sensors for smoke detection, flame detection is done. In order to extinguish the fire, pump operating on water as an extinguisher is used. Alongside, for mobility motors and ultrasonic sensors are used in order to enable the robots ability to move obstacle free. Further, the configuration, working of sensors, their outputs, working of the robot as a whole and experimentation with results and solution is shown in this paper.

***Key Words*:** Fire fighting robot, Automation, Raspberry-Pi, Sensors, Extinguish.

1. INTRODUCTION

Fire is a classical element that has been an equalizer on Earth prior to the start of written history. It has many positive attributes (heat, energy, cleansing, etc.) but it can be extremely dangerous when outside of control. Structure, vehicle, aircraft ship fires and wildfires can wreak havoc and cause serious injuries and/or death. Thankfully, brave men and women have dedicated their lives to protecting others from flames that can occur due to a myriad of reasons anywhere, at any time. Unfortunately, firefighters are only human and can succumb to injury or death as well.

According to the National Fire Protection Association, there were 29,130 injuries reported while fighting fire in 2015. These injuries are also coupled with 68 on-duty deaths. Injuries and casualties are the reason why safety professionals, the government and high-tech companies have come together in order to create firefighting robots that can perform tasks too risky for people.

Robotic firefighting systems are designed with certain tasks in mind. These include analyzing and locating fires, conducting search and rescue, monitoring hazardous variables and the primary task of fire control and suppression. Fixed firefighting robotic systems, like automatic fire sprinklers and alarms, are used in heavily populated and hazardous areas for rapidly extinguishing any threat. These are usually simpler systems relying mostly on UV or IR sensors and as the name suggest, are fixed.

Mobile robotic firefighting systems are another type, mostly in the form of remote controlled vehicles affixed with fire suppression tools like water or foam hoses. These are capable of travelling into areas unsafe for people through an array of sensors, visual camera, IR and more technology that transmits information for navigation to a remote operator. Safety professionals and engineers are even experimenting with aerial robotics like drones for added situational awareness, and close-quarters indoor robots that can eliminate fires at close range.

Our proposed project consists of robot which is programmed using python3 language in Raspberry Pi 3 model B+. It is equipped with an in-built water tank made up of aluminium. This system is basically designed for small house fire.

2. COMPONENTS

A. Microcontroller : Raspberry Pi 3 Model B+

It is the brain of the whole system as all the other components are connected to Raspberry Pi via the GPIO pins. It is just like a small computer that comes with CPU, GPU, USB ports and input/output pins and can be connected with external peripherals and help in running number of operations like regular computer.

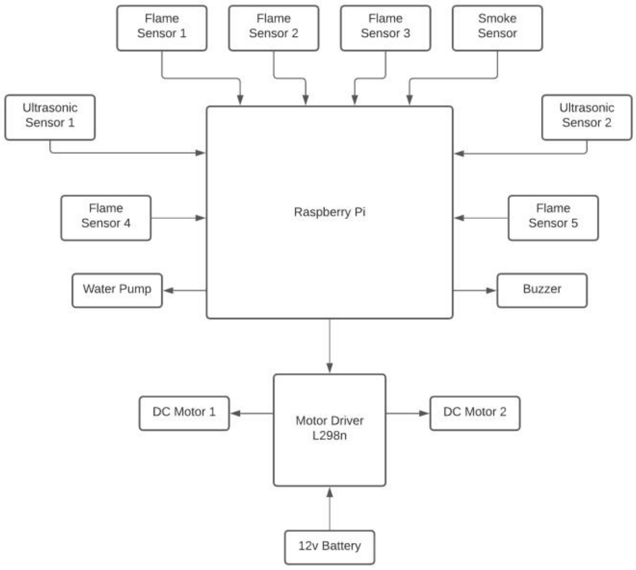

Fig 1.1: Architecture of firefighting robot

Features of Raspberry Pi:

i. Broadcom BCM2837 64bit ARMv7 Quad Core Processor powered Single Board Computer running at 1.2GHz

ii. 1GB RAM

iii. BCM43143 Wi-Fi on board

iv. Bluetooth Low Energy (BLE) on board

v. 40pin extended GPIO

vi. 4 x USB 2 ports

vii. 4 pole Stereo output and Composite video port

viii. Full size HDMI

ix. CSI camera port for connecting the Raspberry Pi

x. Camera

xi. DSI display port for connecting the Raspberry

xii. Pi touch screen display

xiii. Micro SD port for loading your operating

xiv. system and storing data

xv. Upgraded switched Micro USB power source

xvi. (now supports up to 2.4 Amps)

xvii. Expected to have the same form factor has the Pi 2 Model B, however the LEDs will change position.

B. Smoke Sensor : MQ2

MQ2 gas sensor is an electronic sensor used for sensing the concentration of gases in the air such as LPG, propane, methane, hydrogen, alcohol, smoke and carbon monoxide. MQ2 gas sensor is also known as chemiresistor. This sensor works on 5V DC voltage. It can detect gases in the concentration of range 200 to 10000ppm.

C. Ultrasonic Sensors : HC-SR04

An ultrasonic sensor is an electronic device that measures the distance of a target object by calculating the time required for the ultrasonic wave to reach the target. Ultrasonic waves travel faster than the speed of audible sound (i.e. the sound that humans can hear).

In our system we are using the ultrasonic sensor as an obstacle avoidance sensor [1] which are placed at the front side of the robot's extreme ends.

The formula used for calculating the distance between the object and the sensor is as follows:

$D = \frac{1}{2} T \times C$ (where D is the distance, T is the time, and C is the speed of sound ~ 343 meters/second) [1].

Features of HC-SR04:

i. Operating voltage: +5V

ii. Theoretical Measuring Distance: 2cm to 450cm

iii. Practical Measuring Distance: 2cm to 80cm

iv. Accuracy: 3mm

v. Measuring angle covered: <15°

vi. Operating Current: <15mA

vii. Operating Frequency: 40Hz

D. Infrared (IR) Flame Sensors

A flame detector is a sensor used to detect and respond to the presence of a flame or fire, allowing flame detection.

Features of infrared flame sensor:

i. Operating Voltage: 3.3 to 5V DC

ii. Detection Angle: 60^0

iii. Can detect fire or wavelength in 760 ~ 1100 nm

We have used 4 Flame sensors two at the front of the robot, one at the left face of the robot and one at the right face of the robot so that it can sense fire in all directions and the robot can travel in that particular direction to extinguish the fire [4].

E. Johnson DC Motor

We have used Johnson DC Motor to drive the wheels of robot. The purpose of selecting this motor is the low RPM and high torque requirements [2].

Specifications of selected motor:

i. Power Supply: 12V DC
ii. RPM: 60
iii. Rated Torque: 15.2 Kg-cm
iv. Gearbox diameter: 37 mm
v. Motor Diameter: 28.5 mm
vi. Length without shaft: 63 mm
vii. Shaft length: 30mm
viii. No-load current = 800 mA
ix. Load current = up to 7.5 A(Max)

Two Motors are attached to the two wheels at the back side of the robot and are connected to motor driver L298N.

F. Motor Driver (L298N)

The L298N is a dual H-Bridge motor driver which allows speed and direction control of two DC motors at the same time. The L298N motor driver module is powered through 3-pin 3.5mm-pitch screw terminals. It consists of pins for motor power supply (Vs.), ground and 5V logic power supply (Vss.). The L298N motor driver's output channels for the motor A and B are broken out to the edge of the module with two 3.5mm-pitch screw terminals. Two DC motors having voltages between 5 to 35V can be connected to these terminals.

G. Water Pump

A submersible water pump for pumping water on the fire is used. It is a low cost, small size submersible pump motor which can be operated from a 3 ~ 6V power supply. It can take up to 120 liters per hour with very low current consumption of 220mA [2].

Specification of selected pump:

i. Operating Voltage : 3 ~ 6V
ii. Operating Current : 130 ~ 220mA
iii. Flow Rate : 80 ~ 120 L/H
iv. Maximum Lift : 40 ~ 110 mm
v. Continuous Working Life : 500 hours
vi. Driving Mode : DC, Magnetic Driving
vii. Material : Engineering Plastic
viii. Outlet Outside Diameter : 7.5 mm
ix. Outlet Inside Diameter : 5 mm

3. CIRCUIT DIAGRAM

Figure 3.1 shows the circuit diagram of the robot. All the electronic components are connected to Raspberry Pi via breadboards and wires. To avoid circuit complexity and to allow proper positioning of sensors we have used two breadboards. Flame sensors have 4 pins one for digital output, one for analog output, one is for Vcc. and other is the ground pin. The Vcc, ground and digital output pins are connected to 5V, ground and GPIO pin of raspberry Pi respectively. The Flame sensors give input to the raspberry Pi as it senses fire.

For ultrasonic sensors HC-SR04 there are four pins that would be use to interface with the sensor: VCC, Trig (signal output pin), Echo (signal input pin), and GND. The Vcc pin is connected to 5v pin on raspberry Pi, the trigger pin is connected to GPIO pin and the ground pin is connected to the ground pin on raspberry Pi. The Raspberry Pi's GPIO pins have a working voltage of 3.3V. The HC-SR04 operates on 5V logic. If we connect the HC-SR04 directly to the Raspberry Pi, it might break the Raspberry Pi. This is because when the Echo pin (the receiver) of the HC-SR04 receives the sound wave that was originally emitted by the Trigger pin (the transmitter), the Echo pin will go from LOW (0V) to HIGH (5V).This HIGH signal is then sent to one of the GPIO pins on the Raspberry Pi. But since the GPIO pins can only handle 3.3V, it will overload the Raspberry Pi with voltage.

We must reduce the voltage produced by the ECHO pin (5V) to a level that the Raspberry Pi can handle (3.3V). In order to transform a larger voltage into a smaller voltage, we need to make a circuit known as a voltage divider. Hence we are using two 1K Ω Resistors for connecting ultrasonic sensors with Raspberry Pi.

For connecting Dc motors to raspberry Pi we have used a motor driver L298N. This driver gives control on the speed and direction of the motor. The design of the Raspberry Pi L298N Motor Driver Interface Circuit is very simple. First connect 12V Power Supply to L298N Motor Driver Module. Then, make the GND terminals of Raspberry Pi and L298N Motor Driver Module common (connect them together).In order to connect the two DC motors the motor output enable pins i.e. ENA and ENB are connected to GPIO pins on the raspberry Pi. Then coming to the inputs of motor we connect the pins IN1, IN2, IN3 and IN4 of driver to the GPIO pins of Raspberry pi. The output pin ENA and input pins IN1 and IN2 are for one motor say Motor "A" while the pins ENB, IN3 and IN4 are for Motor "B".

The Pump is connected to the Pi with the help of relay. The relay allows us to open and close the circuit containing the water pump, so that we can easily start and stop the pump. The relay consists to three contacts NO contact, NC contact and COM contact. When the relay is on, the COM switch will close to complete the circuit. This means that power will flow to the water pump. The NO contact stands for "normally open," which means that the circuit is open (i.e., incomplete) when the relay is off. The pump is connected to a 9V battery, the red wire of the pump is connected to the NO contact on the relay and the red wire of the battery is connected to the COM contact on the relay. The relay has three pins ground, Vcc and input pin which are connected to the ground, 5V and GPIO pins of raspberry Pi respectively.

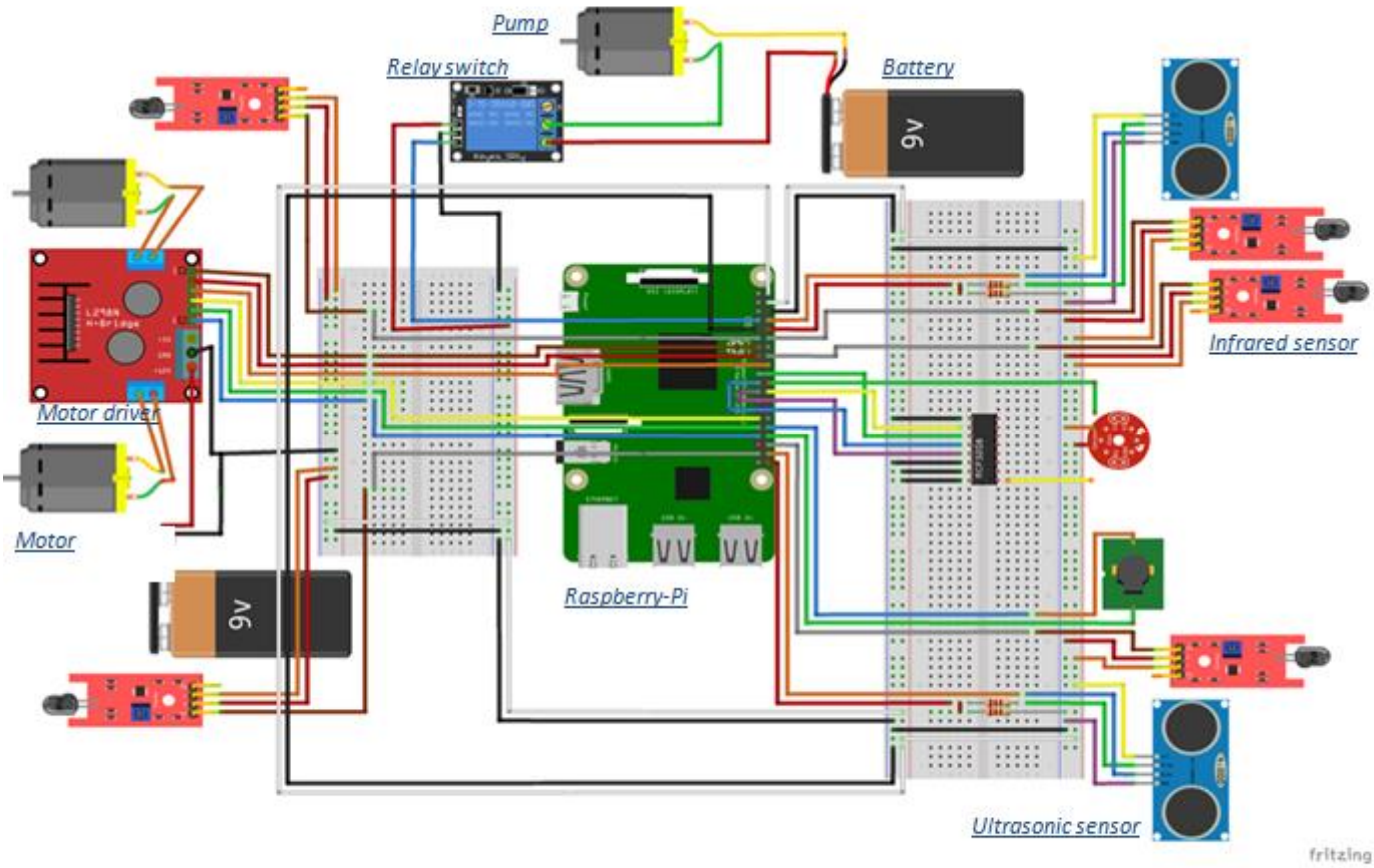

Fig 3.1: Circuit diagram

The gas sensor MQ2 needs about 5 volts of power in order to operate. This is done by connecting 5 volts to Vcc and GND. The Output pin gives out the voltage reading, which is proportional to the amount of smoke that the sensor is exposed to. Again, a high voltage output means the sensor is exposed to a lot of smoke. A low or 0 voltage output means the sensor is exposed to either little or no smoke. MQ2 gives analog output hence, to convert this to digital we have used.

MCP3208, analog to digital converter is connected to the raspberry Pi via breadboards and jumper wires. This completes the whole circuit.

Fig 4.1: Assembly

4. HARDWARE

The whole circuit of the robot is enclosed in L-type aluminium frames. Constructed in a rectangular frame from aluminium and placed a wooden board of 1ft x 1ft over it to place all the components of the circuit. To ensure proper working of flame and ultrasonic sensors we have mounted the sensors on the aluminium frame. Two ultrasonic sensors are mounted on the front frame of the robot at two corners, one flame sensor is mounted on the middle front of the frame and the other two flame sensors are mounted by both sides of the middle sensor. The flame sensors are mounted in such a way that the location of the fire is detected [3].

On the rectangular aluminium frame we have mounted a water tank which has a capacity of 5 litres. The dimensions of the tank are 230x230x100 mm3. On the tank we have attached a PVC pipe of 1.5inch outer diameter and 1ft long which is closed from outside by a cap. Inside the tank a submersible pump is placed and the water from the pump will come out from a pipe of diameter 5mm. This 5mm diameter pipe comes out from the PVC pipe of 1.5inch as shown in the Fig.3. Above the water tank on the front centre we have made an arrangement for attaching the nozzle with water pump. We have used an L bracket of aluminium on which the nozzle is mounted. The Fig.3 shows the whole assembly of the robot.

5. WORKING

The proposed robot can be used for an enclosed area like small industries, labs or house. The Fig. 4 shows the flow chart of the entire system. Initially if fire takes place the robot will start and it will be detecting smoke with the help of MQ2 gas sensor. Once the smoke is detected MQ2 sensor will give analog signal to MCP3208 (ADC) which will convert it to digital signal and give input to raspberry Pi. After receiving inputs from MQ2 gas sensor the Pi will give the output to motor driver which will start the motors. The robot will move forward and flame sensors will start detecting flame, if the flame is detected, the robot will move towards the flame and ultrasonic sensors will be detecting obstacle between the route. If obstacle is detected the robot will take a slight turn around the obstacle and take the same path if there is no obstacle then the robot will move straight.

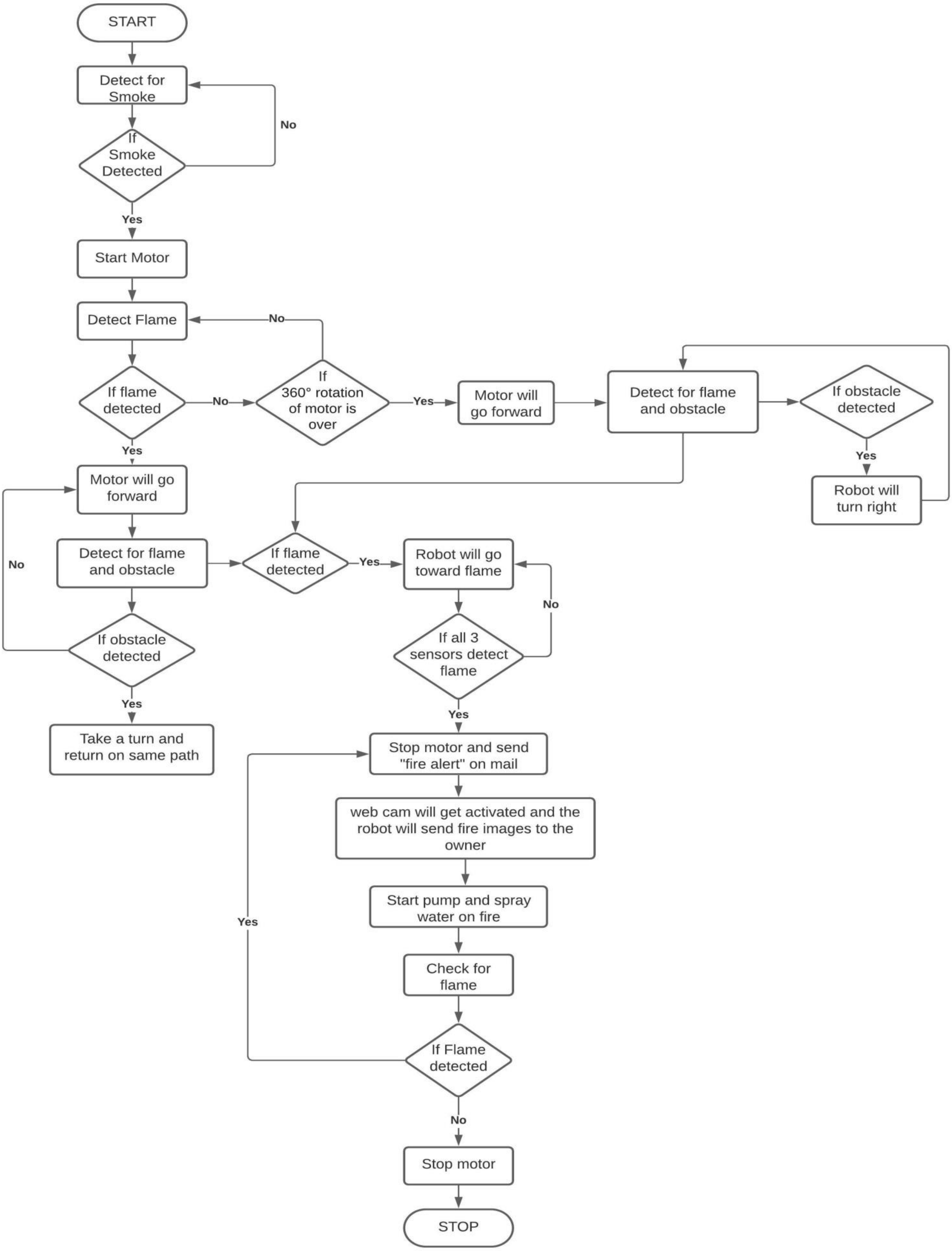

Table 2: Working

If after completing the rotation, fire is not detected then the robot will keep on moving in the forward direction. At the same time flame sensors and ultrasonic sensors will be looking for flame and obstacles.

Here if the ultrasonic sensor detects any obstacle it will give input to raspberry Pi and this input is received by the motor driver which will give input to motors to take a right turn from the obstacle. The right turn is fixed in the coding as we didn't want to make the coding more complex. If no obstacle is detected the robot will go straight and the flame sensors will be sensing fire. Once all the three sensors attached at the front of the robot detect fire we get the position of fire and it will give inputs to Pi which will stop the motor and start the pump. Once the location of fire is received by the Pi it will send a fire alert email to the owners email Id and the webcam will get activated which will click pictures of the scenario and send the same on mail to the owner. The pump will pump water and by using nozzle water will be sprayed on the fire and at the same time flame sensors will be sensing flame the nozzle will spray water until the flame sensors sense fire. Once the fire is extinguished the robot will stop spraying water and the robot will stop.

6. EXPERIMENTS AND RESULTS

After construction of the robot following experimental setups were done and results were observed through which base problems were identified for undesirable outputs given by the robot and proper solution was designed to solve the problem.

A. Robot movement accuracy on different terrains.

Initially the robot has 4 wheels of the same size out of which two front wheels are the driving wheels. Theoretical time taken by robot was compared to the actual time taken by the robot on different surfaces, the observations for the same are given in Table 1. Theoretical and actual calculations are done for the same parameters. All the readings are in SI units.

Parameters considered:

i. Motor speed: 60 RPM
ii. Supplied voltage: 12 V
iii. Supplied current: 600 to 900 mA which is drawn as per requirement by the motors
iv. Weight of robot: 10 kg
v. Radius of wheel: 0.065 m
vi. Linear distance: 1m
vii. Full rotation distance: 1.1 m
viii. Circular rotation: 1.9 m

Theoretical calculation:

Linear speed = Radius of wheel × Angular speed of motor

= 0.14 m/s

Time for straight movement = Distance (D) / Linear speed

= 1 / 0.41

= 2.44 s

Time for full rotation = Full rotation distance/ Linear speed

= 1.1 / 0.41 = 2.68 s

Circular rotation = Circular distance / Linear speed

= 1.9 / 0.41

= 4.63 s

<table>
<tr><th colspan="2">Type of Movement</th><th>Straight</th><th>Full Rotation</th><th>Circular Rotation</th></tr>
<tr><td colspan="2">Theoretical Time Taken (Secs)</td><td>2.44</td><td>2.68</td><td>4.63</td></tr>
<tr><td rowspan="6">Actual Time Taken (Secs)</td><td rowspan="3">Even Surface (Secs)</td><td>2.42</td><td>2.69</td><td>4.63</td></tr>
<tr><td>2.48</td><td>2.67</td><td>4.66</td></tr>
<tr><td>2.49</td><td>2.68</td><td>4.61</td></tr>
<tr><td rowspan="3">Uneven Surface (Secs)</td><td>2.92</td><td>3.52</td><td>5.63</td></tr>
<tr><td>4.11</td><td>3.22</td><td>6.48</td></tr>
<tr><td>3.36</td><td>3.53</td><td>6.99</td></tr>
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Table 1: Observation recorded with 4 wheels

Problem identification:

Though the robot gave constant outputs on plane even surface it did not give constant outputs on rough uneven surface. This was due no traction between the wheels and the uneven surface which resulted in nullification of motor rotation and hence the robot movement was based on the only wheel that was in contact with the surface. Two solutions were found for this problem.

Solution 1: Suspension

Adding suspension to the wheels would ensure constant traction between all the wheels and surface even when the surface is uneven. However, this solution was eliminated as adding suspensions was not feasible for the compact size of the robot.

Solution 2: Three wheel balance

Balancing the robot on 3 wheels instead of four would also ensure constant traction between the surface and the wheels and hence resulting in no nullification of any wheel movement and thus ensuring desired movement of the robot.

Solution 2 was thus applied and observations were made again to ensure the desired outputs were being achieved.

Desired and constant outputs were observed as in Table II after the 3 wheel solution was applied, thus solving the uneven movement problem.

Type of Movement		Straight	Full Rotation	Circular Rotation
Theoretical Time Taken (Secs)		2.44	2.68	4.63
Actual Time Taken (Secs) (4Wheels)	Even Surfaces (Secs)	2.46	2.69	4.63
		2.48	2.67	4.66
		2.49	2.68	4.61
	Uneven Surfaces (Secs)	2.92	3.52	5.63
		4.11	3.22	6.48
		3.36	3.53	6.99
Actual Time Taken (Secs) (3Wheels)	Even Surface (Secs)	2.45	2.69	4.64
		2.46	2.70	4.65
		2.45	2.69	4.65
	Uneven Surface (Secs)	2.46	2.69	4.66
		2.45	2.71	4.65
		2.46	2.70	4.65

Table 2 : Observation recorded with 3 wheels

B. Locating Flame Accuracy

Initially the robot had only one flame sensor at the centre in front. Upon experimenting it was observed that the robot located fire from farther when the fire was bigger and nearer when the fire was smaller. This resulted in errors for spraying water as the nozzle would spray water at a fixed distance. Hence it was concluded that the flame sensors locate fire but do not detect distance at which the fire is located. To tackle this problem basic trigonometry was implemented where in 3 sensors were used. One straight and the other two inclined at an angle of 60° on the inner side, meaning the fire would be located at the intersection of the three flame sensors. This made it possible to detect the location of fire. However, upon actually experimenting another observation was made that the fire sensors actually detect fire within angular range of 60°. Due to this the robot again detected fire and stopped at a position which was out of coverage area of the nozzle. To tackle this problem only a small opening was provided to the photodiode of the flame sensor which detected the flame within the angular range of 2°-3° only. Therefore, solving the problem.

7. CONCLUSIONS

Furthermore, a rigid body can be build which can sustain fire and high temperatures, image recognition can be used to detect flame and fire accurately, and many more things can be done. However this project fulfills the basic purpose of extinguishing the fire or at least alerting the authorities just when it has started for a small area which can turn out to be life-saving. Hence, we can conclude that there remains a lot of future scope for development of automated firefighting robots which can turn out to be a great life-saving machine.

ACKNOWLEDGEMENT

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