Firefighting Robots Incorporated Using Swarm Technology

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***Abstract*—Swarm robotics is a type of collective behavior in which many individual independently functioning robots work collectively to complete the task in hand in a more efficient manner. Each individual robot has a mind of its own and is autonomously working. Firefighting robots incorporating this technology have been suggested in this paper. As a prototype, a main robot and a second robot referred to as slave is used. The master robot is used to control the movement of the slave robot. Both the master and slave are independent firefighting robots and are capable of detecting and fighting fire on their own. This paper provides a detailed implementation of object and fire detection, and use of Bluetooth module to provide communication between the nodes.**

***Index Terms*— Bluetooth; Firefighting Flame; Ultrasonic.**

I. INTRODUCTION

Swarm robotics is a new approach to the coordination of multi-robot systems, which consists of large numbers of mostly simple physical robots. Firefighting robots, on the other hand, are devices that use sensors to learn the environmental conditions and have a software that instructs them to function in a required manner. Firefighting robots incorporating swarm refers to a system with multiple robots that are controlled by one main robot to overcome firefighting problems.

There are various types of firefighting robots present which may be broadly classified as fixed or mobile systems. In this project, fixed firefighting robots are used. Fixed firefighting robots mainly use ultrasonic sensors or IR sensors whereas mobile systems have more advanced features that include navigation. In either type of robots, it is possible to implement swarm intelligence. Swarm intelligence is derived from the study of bees or termites [2]; where each individual termite or bee learns its job from the neighboring one. Swarm behavior may also be referred to as a collective or emergent behavior. Each individual robot is capable of extinguishing fire, and it adapts to the environment quickly using the sensors.

This project is a prototype of the aforementioned theory. There is the main master robot and another robot called the slave. Both the master and the slave have the ability to sense and fight fire but the movement of the slave will be controlled by the master robot. The master has ultrasonic sensors which are used to detect an object and both the master and slave have fire and gas sensors to detect fire. Swarm is a combination of centralized as well as decentralized control. The movement of this implementation is centralized but the robots have a brain of their own and can extinguish fire which makes it decentralized.

Robotics in the field of firefighting is being studied to reduce the risk of lives of firefighters exposed to dangerous environments. The implementation of this project provides a more efficient method to fight fire. Robots adapt to the environment immediately and if any one of the slaves fails, it won't impact the others. All the robots work collectively which appears to look like a single entity.

Swarm robotics is a promising upcoming technology which helps manage multi-robot systems rendering it an efficient way of communication. Using this technology for real time applications like firefighting will be revolutionary if implemented on a larger scale.

II. LITERATURESURVEY

Reference Paper: Based on the literature survey on the paper "An Extensive Review of Research in Swarm Robotics" [1], the prototype of the working model was designed and thereby derived the following conclusions:

1. Biological Inspiration

Swarm robots was inspired by the behaviour of ants and bees. Ant swarms usually tend to search, retrieve, deposit and rest. Similarly, the robots in this prototype search for an object and extinguishes if a fire is present.

2. Communication

In this prototype, explicit communication has been implemented where the robots communicate with each other using a wireless communication module.

3. Control Approach

There are two types of control approaches commonly used in artificial intelligence. They are:

a) Centralized system: There exists a master that is in-charge of the decisional process for the entire group.

b) Distributed system: There is no master and it performs its duties based on the collective decision of the group.

In this prototype, a balance of centralized and distributed control has been implemented where the master makes the decision with respect to the movement of the robots keeping in mind if the slave has completed its assigned task.

4. Learning

Based on various learning algorithms considered, this prototype uses supervised learning. Supervised learning uses the help of an external supervisor. With respect to the feedback received from the supervisor, the robot decides the best course of action to be taken.

III.GENERAL DESCRIPTION OF THE MODEL

The working prototype of firefighting robots using swarm consists of one master and one slave robot. The master node comprises of three ultrasonic sensors, two flame sensors and a gas sensor for object and fire detection respectively. The slave node, on the other hand, consists of only two flame sensors and one gas sensor, the combined outputs of which help the slave node to detect fire. The fire extinguishing modules on eachrobot consist of a water tank, a water pump and a servo motor to direct the water flow where the fire is present.

The ultrasonic sensors fixed on the master node, guide the movement of the master. The master then transmits its movement information to the slave node, via a communication device (Bluetooth module in case of the aforementioned prototype), which follows the master's movement. The slave node has no motion control of its own. It relies on the master for its motion. This behaviour is based on the principle called Swarm Intelligence.

The master continues its motion, until an object is detected and the slave replicates its motion. On detection of an object, the fire sensors affixed on the master as well as slave check for the presence of fire. If fire is present, the fire extinguishers on each robot function to extinguish it, with the combined action of the water pump and the servo motor. If sensors on both the robots detect fire, extinguishers on both the robots are used. If sensor on one robot detects fire and the other doesn't, then only the robot that detected the fire will extinguish it, while the other one remains idle.In the event that no fire is detected, the master stops and moves backward, transmitting the same information to the slave which follows its instruction. The master, in synchronization with the slave, then moves right, and continues the movement until another object is detected.

The same process is then repeated.

A. Block Diagram

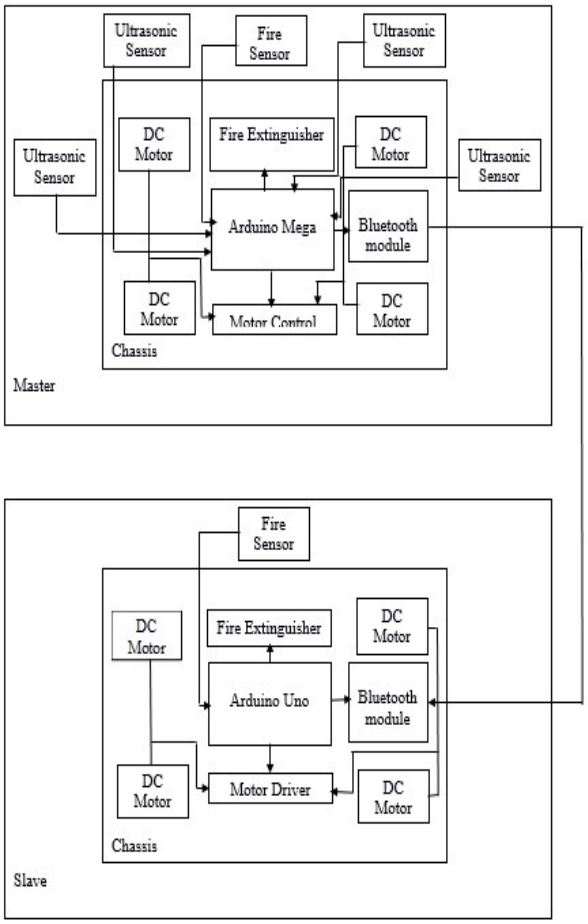


Fig 1. Block diagram of the master and slave module

As seen in Fig. 1, unlike the slave node which does not need ultrasonic sensors, the master requires more number of pin connections to be made to the Arduino. Owing to this, an Arduino Mega is used in the master node as it offers a provision for more number of pin connections. The slave node, on the other hand, requires lesser pin connections due to the absence of ultrasonic sensors. Hence, an Arduino Uno is used in the slave node.

Three different types of sensors are used on the master robot. The ultrasonic sensors [5], flame sensors [6] and a gas sensor.The gas sensor is used because the flame sensor may sometimes provide an output the same as that of a flame for ordinary light. Both the flame and gas sensor outputs are combined and act as an input to the Arduino.

For the movement of both the master and slave robots, DC motors are used that are driven by a motor driver module.For wireless communication between the master and the slave nodes, a Bluetooth module is used.

B. Overview

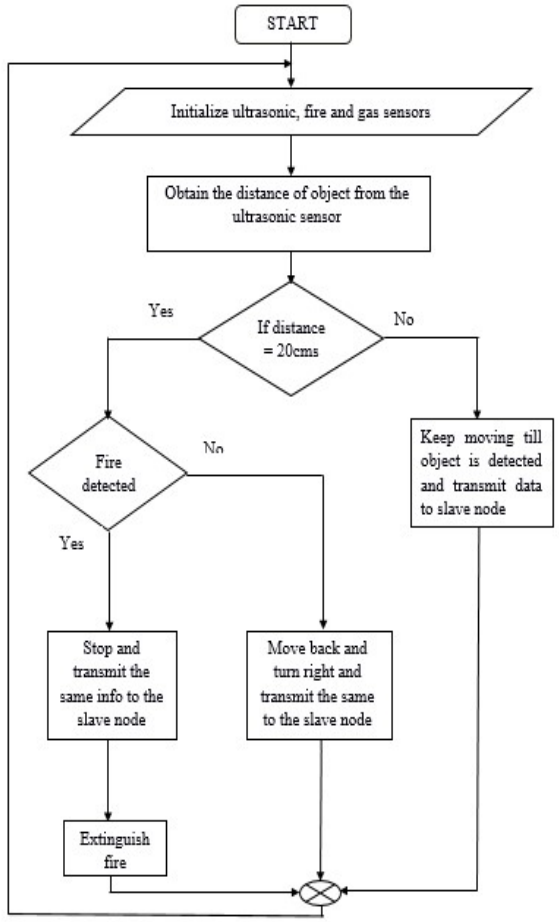


Fig. 2. General flowchart for master module

The Fig. 2, shows a general flowchart for the working of the master node in the firefighting robots.

As seen from the above figure, the following steps are involved in the functioning of the master robot:

Step 1: Initialize the values for all the 3 sensors.

Step 2: Obtain the distance of the object from the master that is calculated by the ultrasonic sensor.

Step 3: Check if that distance is equal to 20 cm.

Step 4: If an object is detected at a 20cm distance from the master, then check if there is fire present on that object. If an object is not detected at 20cm from the robot, then keep moving till an object is detected and transmit the same information to the slave node.

Step 5: If fire is detected on the object, stop and transmit the same information to the slave. If fire is not detected, move back and turn right and transmit the same movement instructions to the slave.

Step 6: Extinguish the fire if detected

Step 7: Repeat Step 1

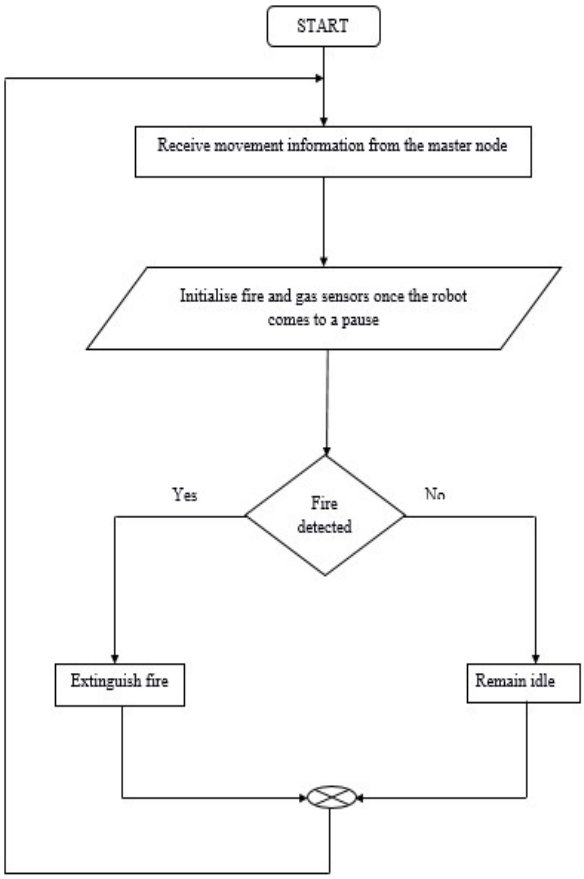


Fig 3. General flowchart for slave module

IV. IMPLEMENTATION

The working model of the prototype of firefighting robots incorporating Swarm technology has been implemented, where the master node must first have the ability to detect an object with the help of the ultrasonic sensors mounted on it. Once it has transmitted the same movement information to the slave node and both the robots have positioned themselves, each one independently tests if fire is present in front of it and thereby takes the required action.

A. Flowchart for Master

Fig. 4, depicts a detailed working flowchart of the master module that describes both its object as well as fire detection and extinguishing features.

The following steps are involved in the working model of the master node:

Step 1: Include the servo and software serial header files.

Step 2: Define the input and output pins for the sensors, the motor driver, water pump and servo motor.

Step 3: Initialize trig pin of each sensor as output, echo pin of ultrasonic sensor as input, 4 motor driver signals as output, LED buzzer, servo motor and water pump as output.

Step 4: Provide a 10us high pulse to the trig pin of all ultrasonic sensors.

Step 5: Obtain the duration of time taken by the second pulse to reflect back at the echo pin and hence obtain the distance of the object from all the ultrasonic sensors

Step 6: Check if any one of the 3 ultrasonic sensors fails.

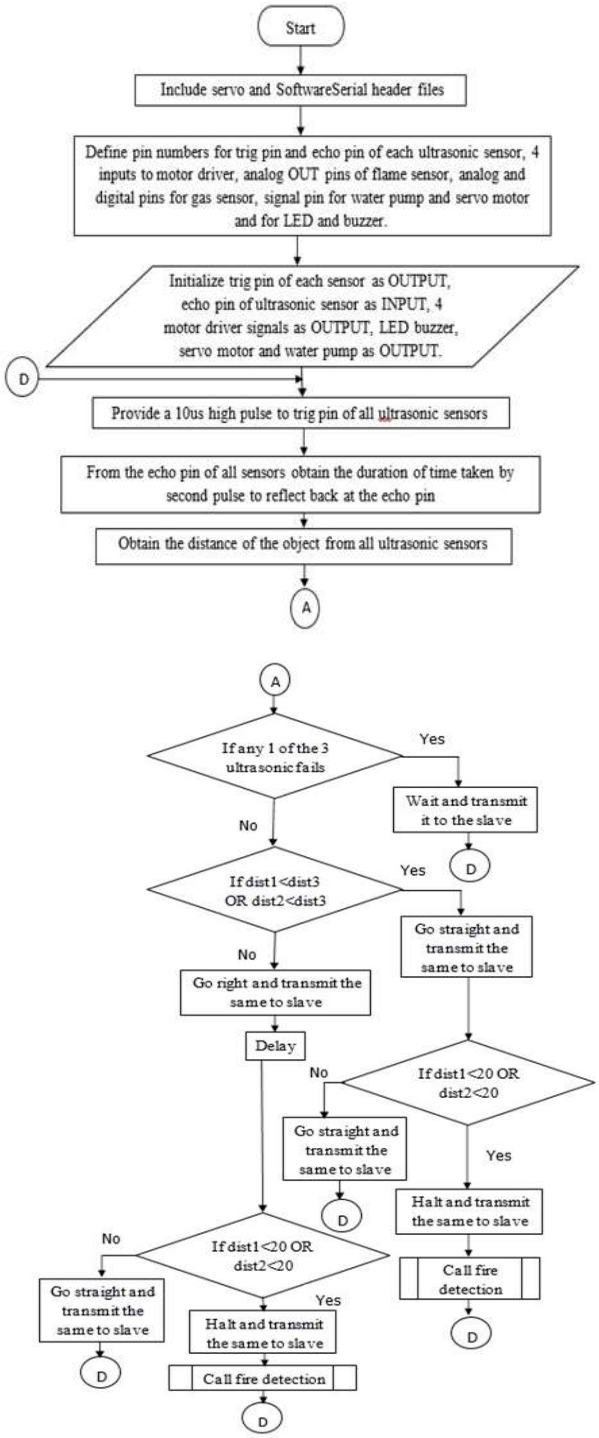


Fig. 4. Flowchart for implementation of master robot

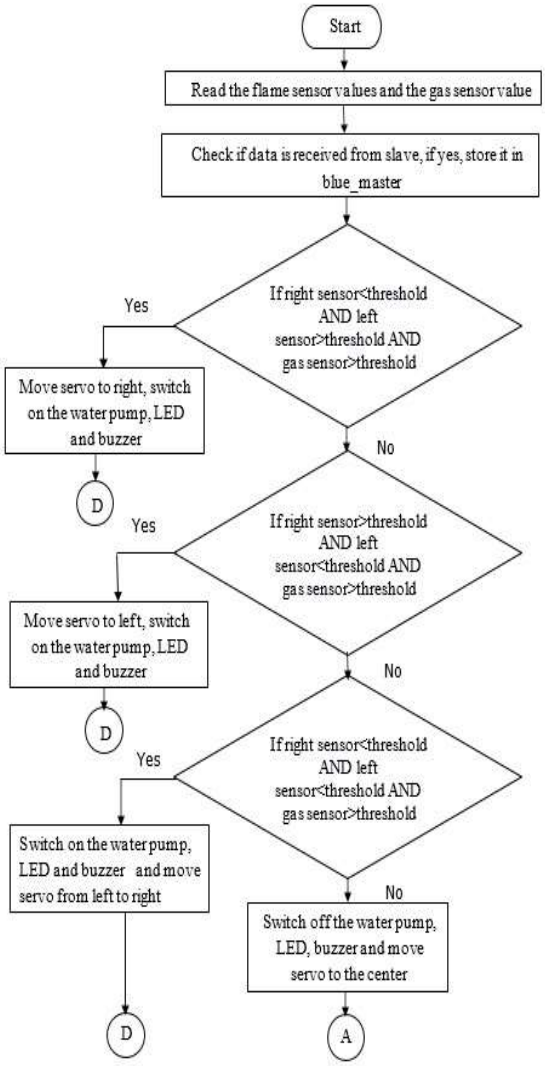
Step 7: If it fails then halt and transmit that information to the slave and repeat step 4. If none of the 3 ultrasonic sensors fail, then check if either of the distance 1 or 2 is less than distance 3.

Step 8: If either of the distance 1 or 2 is less than distance 3, go straight and instruct the slave to do the same else go right and instruct the slave to do the same.

Step 9: If it moves straight, check if either of the distance 1 or 2 is less than 20cm. If yes then halt and transmit the same to the slave and call the fire detection function and repeat step 4, else go straight and transmit the same instruction to the slave and repeat step 4.

If it moves right, Check the same condition but after a delay and follow the same procedure.

Fire detection function (Master)



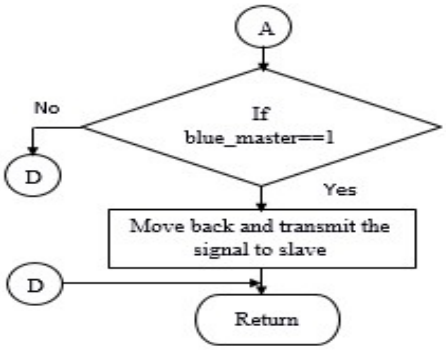


Fig. 5. Flowchart for fire detection function of master robot

Fig. 5, shows the fire detection function called by the master node. It has the following steps:

Step 1: Read the flame and gas sensor values.

Step 2: Check if data is received from slave, if yes, store it in blue master.

Step 3: Check if right sensor value is less than threshold and left sensor value is greater than threshold and gas sensor value is greater than threshold.

Step 4: If the condition is satisfied, move servo to the right, switch on the water pump, LED and buzzer and return to the main program. Else, check if right sensor value is greater than threshold and left sensor is less than threshold and gas sensor value is greater than threshold.

Step 5: If the above condition is satisfied, move servo to the left, switch on the water pump, LED and buzzer and return to the main program. Else, check if right sensor value is less than threshold and left sensor value is less than threshold and gas sensor is greater than threshold.

Step 6: If the above condition is satisfied, switch on the water pump, LED and buzzer and move the servo from left to right and return to the main program. Else, switch off the water pump, LED and buzzer and move the servo to the centre.

Step 7: Check if blue master equal to 1

Step 8: If yes, then move back and transmit the signal to the slave and return to the main program. Else, just return to the main program

B. Flowchart for Slave

Fig. 6, depicts a detailed working flowchart of the master module that describes both its object as well as fire detection and extinguishing features.

The following steps are involved in the working model of the master node:

Step 1: Define pin numbers for 4 signals of motor driver, analog pin for flame sensors, analog OUT of gas sensor, signal of water pump and servo motor, LED and buzzer.

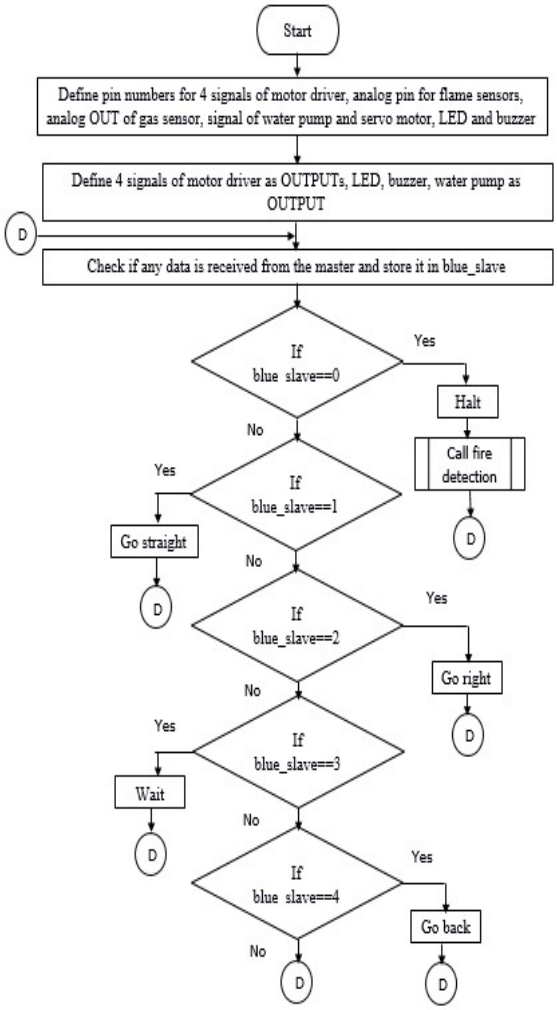


Fig. 6. Flowchart for implementation of slave robot

Step 2: Define 4 signals of motor driver as outputs and the LED, buzzer and water pump as output.

Step 3: Check if any data is received from the master and store it in blue slave.

Step 4: Check if blue slave equals to 0.

Step 5: If yes then halt and call the fire detection function and repeat the step 3. Else, check if blue slave equals to 1.

Step 6: If yes then go straight and repeat the step 3. Else, check if blue slave equals to 2.

Step 7: If yes then go right and repeat the step 3. Else, check if blue slave equals to 3.

Step 8: If yes then wait and repeat the step 3. Else, check if blue slave equals to 4.

Step 9: If yes then go back and repeat the step 3. Else, repeat step 3.

Fire detection function (Slave)

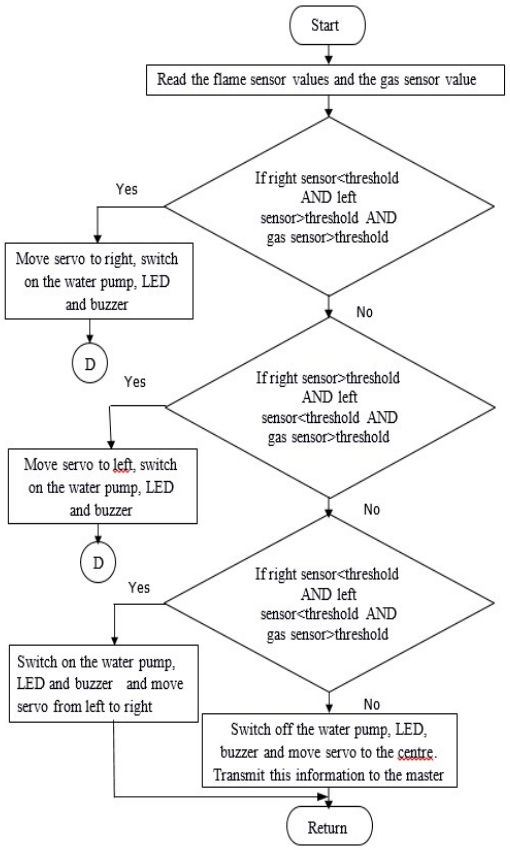


Fig. 7. Flowchart for fire detection function of slave robot

Fig. 7. shows the fire detection function called by the slave node. It has the following steps:

Step 1: Read the flame and gas sensor values.

Step 2: Check if right sensor value is less than threshold and left sensor value is greater than threshold and gas sensor value is greater than threshold.

Step 3: If the condition is satisfied, move servo to the right, switch on the water pump, LED and buzzer and return to the main program. Else, check if right sensor value is greater than threshold and left sensor is less than threshold and gas sensor value is greater than threshold.

Step 4: If the above condition is satisfied, move servo to the left, switch on the water pump, LED and buzzer and return to the main program. Else, check if right sensor value is less than threshold and left sensor value is less than threshold and gas sensor is greater than threshold.

Step 5: If the above condition is satisfied, switch on the water pump, LED and buzzer and move the servo from left to right and return to the main program. Else, switch off the water pump, LED and buzzer and move the servo to the center and transmit the information to the master.

Step 6: Return to the main program.

V. Result Analysis

A. Object Detection (Master)

The master node was first implemented and tested to act as an object detection [4] module. In the stepwise implementation of the project, the first step was for the master robot to be able to detect the presence of an object in the range of detection of the ultrasonic sensors. In order to achieve this, the trig pins of each sensor were initialized as output, echo pins of each sensor as input and 4 signals of motor driver as output. When a 10us high pulse was provided to the trig pin of all the ultrasonic sensors, sound pulse travelled from each sensor thereby calculating the distance of the object from the master, as is the feature of an ultrasonic sensor. Distance 1 and 2 were defined to the be the distances from the front two sensors and distance 3 to be that

from the right sensor. An algorithm was designed such that if any of those three distances were to be less than 20cm, the master was designed to halt. Else, it was supposed to check if either of the distance 1 or 2 is lesser than distance 3. If so, the master would move straight, else after a delay it would turn right. Then, check for either of the distance 1 or 2 to be less than 20cm. If yes halt, else keep going straight.

B. Fire Detection

After the object detection was implemented for the master, the next step was to implement fire detection. In this project, fire detection was first tested on the slave. The servo motor and digital out pin of gas sensor were initialized as outputs. The next step was to read the values from the front two flame sensors and the gas sensor. If the right sensor value was found to be less than threshold and left sensor to be greater than threshold and gas sensor value to be greater than threshold, the servo was supposed to move to the right and start the water pump in order to extinguish fire. Else it would check if the right sensor value was found to be greater than threshold and left sensor to be less than threshold and gas sensor value to be greater than threshold. If yes, the servo would move to the left and start the water pump to extinguish fire. Else, it would check if the right sensor value was found to be less than threshold and left sensor to be less than threshold and gas sensor value to be greater than threshold. If found to be true, it would switch on the water pump and move the servo from left to right. Else the sensor values would be read and the above steps would be repeated all over again. If no fire was detected, the servo would halt at the center and the water pump would be switched off.

C. Communication

After the object detection in the master robot was implemented along with the fire detection and extinguishing in both the robots, the last implementation carried out was that of swarm. This had to be done in order to facilitate communication between the master and the slave robots. This communication was necessary for the master to provide instructions to the slave robot regarding its movements as the

slave does not have ultrasonic sensors required for the same. A Bluetooth module [3] was used in this project for communication between the master and the slave robots. It was seen that, after the two Bluetooth modules synchronize, the slave would follow the movement of the master. If an object was encountered by the master, it would halt at a distance of 20cm from the object and transmit that information to the slave. Once both the robots would come to a halt, they would check for the presence of fire in front of each of the robots independently. If fire was detected, they would move the servo motor in the direction of fire and start the water pump. If no fire is present in front of either one of the robots, that robot would remain idle until the other robot has extinguished the fire completely. The slave would then wait for the master which would move back and turn right and continue the process. If no fire was detected on the object, the robots would move back and turn right after the given delay.

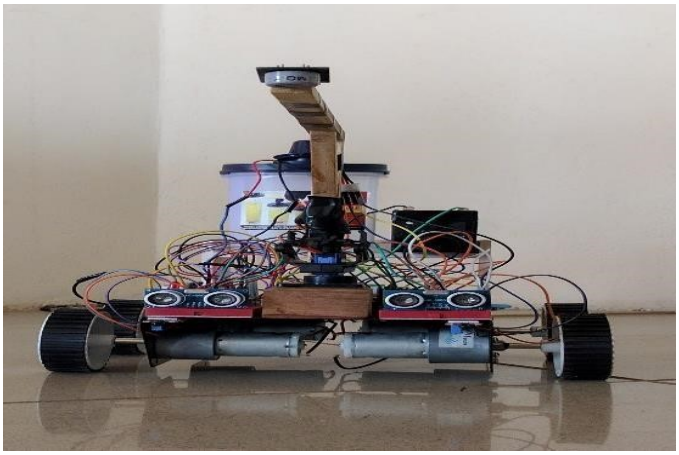


Fig. 8. Model of the Master robot

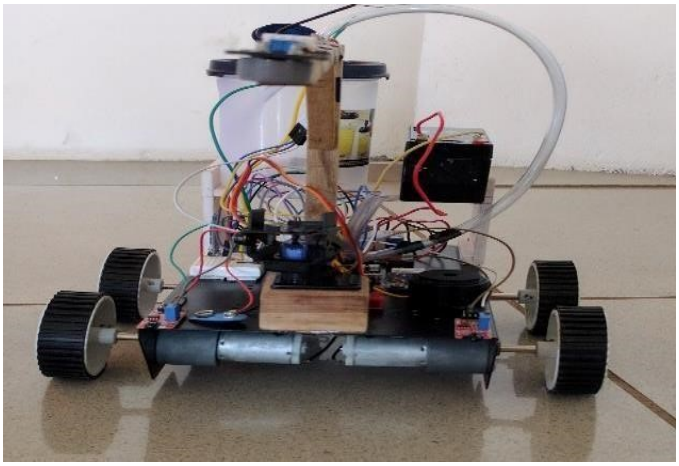


Fig. 9. Model of the Slave robot

VI. CONCLUSION

Swarm technology [7] is a very promising new technology that manages efficiently the communication in a multi-robot system.

This project is an application of Swarm technology in a very vital real-life application of firefighting that poses a threat to human life and property. As a prototype to the same, we have implemented one master and one

slave robot that are capable of detecting and fighting fire, having ultrasonic sensors on the master for its efficient movement and flame and gas sensors on both robots for detecting the presence of fire.

A. Advantages and Disadvantages

The advantages of this firefighting module include:

1. Although the movement of the robots is controlled by the master, each slave will have its own ability to detect and extinguish fire independently.
2. Since the movement of the slaves is controlled by one master, ultrasonic sensors need not be mounted on any slave robot which reduces the system complexity.
3. In case of failure of one of the slave robots, it will not affect the total working of the system.
4. The robots adapt to the situation and make decisions based on the external conditions.
5. Swarm can complete a complex task having high flexibility.
6. Swarm ensures that the tasks are well distributed among the robots, thus improving efficiency.
7. The manpower can be employed for rescuing lives that are trapped in the burning building.

The disadvantages of this firefighting module are:

1. Depending on the environmental conditions, the threshold values of the sensors will have to be calibrated.
2. The water tanks may need to be refilled manually from time to time.
3. Bluetooth modules require time to sync.

B. Future Scope

The small scale working prototype created in this project is a glimpse of a revolutionary breakthrough in the field of firefighting if implemented on a larger scale with multiple slave robots depending upon the scale of the operation.

Although this project includes only two robots, it is possible to connect at least seven slaves to the Bluetooth module. But when implemented on an even larger scale, though, ZigBee series should be considered instead of Bluetooth module to facilitate communication.

Additional features such as camera control mechanism can also be added to make this system more efficient when implemented in real time.

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