Development of a Network-based Autonomous Firefighting Robot

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Abstract: This paper presents the design and development of a prototype of network-based automated firefighting robot. It addresses the water-based extinguishing system for fire using the spray gun and pump. For this purpose, a mini car washer is used. Gas sensors are integrated to create network system to navigate robot to the target distance. The proper navigation depends on the algorithm of obstacle avoidance. Currently, fire extinguish become challenging especially in a multi-storey building. This work gives a solution to extinguish fire automatically to prevent danger in a residential premise. The prototype is built from the low-cost materials available at the laboratory.

1 INTRODUCTION

Today, the rapid development of science and technology makes it possible to apply new technical approaches, and fire extinguishing means in extinguishing fires, of varying complexity. Among all the possible varieties of novelties in the field of firefighting, it is necessary to single out fire robots in a separate item. Fire robots are the technical means that can radically distinguish fire. A fire robot is a sophisticated technical device designed to extinguish a fire. Depending on the ability to move, there are stationary and mobile robots. Fire robots are used in a situation where people cannot enter near the fire as there is a direct danger to their health and life. The use of fire robots can significantly facilitate the work on extinguishing fires at various industrial facilities, transport, and sometimes even fire robots are irreplaceable, for example, fires on radioactive, chemically hazardous objects. The focus of this research is the design, assembly, and development of a model of an intelligent fire robot that can switch to a fire source offline and extinguish it. This work project includes the electrical, mechanical and computer programming. The sensor network conducts the fire detection. The network of the gas sensors divides the room into sections and detects the presence of fire in them. By the wifi communication between the network and robot, the destination is calculated and navigates the robot accordingly. By implementation of Bayesian Algorithm and using three ultrasonic sensors, the robot reaches the fire. After reaching the fire, the robot starts the pump and water splashes toward the fire, and as a result, fire is extinguished.

There are cases when the fire cannot be extinguished by the conventional ways: the difficulty of reaching by firefighters, the places where the conventional splinker systems cannot be implemented. All these generate the need for a new method of fire extinguishing. The fire extinguishing contains several ways to be performed; the work is dedicated to decreasing the temperature of the fuel. To perform that, the development of the autonomous firefighting robot is crucial. The robot prototype detects the presence of fire, and autonomously extinguish it. The research focuses on existing robots and the methods of elimination of fire.

There are many ideas for creating mobile robots that can work, collect data and information, and look for victims in a dangerous environment for humans. These ideas are continuously enhanced and upgraded. To date, there are models of robots that are effectively used to rescue and evacuate people caught in extreme conditions, such as a burning building or environment of toxic gases. Robots are used to extinguish the flames, both autonomous and remote controlled. Controlled robots are often equipped with a monitoring system and work through a wireless communication system, while autonomous robots are equipped with obstacles avoidance system embedded into its autonomous navigation system. Remote controlled robots are equipped with microphones and acoustic systems to

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communicate victims with the operator during emergency situations. Also, these robots are often equipped with cameras to capture the site of the fire and sensors for measuring the temperature and concentration of CO2 and O2 (Kim, 2009). It allows data transfer, such as video and audio, and also allows us to track the position of the robot itself. Since both autonomous and controlled robots are designed for extreme places, they usually withstand high temperatures, are waterproof and have a shock resistance function.

The shape and design of robots also have a wide variety. Often, crawler mechanisms are used for movement as they consist of metals and are steady to fire, but non-standard types of robots are also found. For example, the rescue robot BEAR (Battlefield Extraction-Assist Robot) from Vecnarobotics is created in the form of a humanoid. This type of robot is used for prospecting since it can raise and carry victims, but its cost is not comparable to its use (Vecna Robotics Co., 2012).

In most of the cases, the movement of fire robots is due to sensor systems or vision-based systems. A sensor-based system is monitored by feedback from various sensors, while a vision-based system uses cameras and the image processing techniques to find the target position. However, there are also robots that use other systems for movement. For example, Tehzeeb is a robot that uses a laser scanner module, a manipulator and map generation algorithms for localization and navigation (Kim, 2009). This system is more effective than vision-based systems in conditions of poor visibility, for example, in dense smoke. The flame sensors detect the flame. The analog output from the flame sensors was fed into the input terminal of the analog converter (ADC) with the microcontroller. A minimum value was set based on the desired sensitivity, and its gradual increase means that the robot moves towards the source of the fire.

Obstacles avoidance system is also an important measure that provides free movement without any collisions during the navigation process in robot creation. For this purpose, the robotic technology uses ultrasonic sensors or range sensors (Harwayne-Gidansky, 2007). In this project, this task was realized with the help of ultrasonic sensors. The obstacle avoidance module is implemented by converting the analog output from an ultrasonic sensor to a digital form (Scott Dearie, 2004). Since the angle to which these sensors operate is limited, this project uses three sensors that are located at a certain angle to capture a sufficient distance for the robot to travel. After the flame sensor detects the source of the fire, the robot moves to the required distance and the fire extinguishing system is activated. For the test, a candle is used as a source of the fire.

2 DESIGN AND DEVELOPMENT

2.1 Conceptual Design

The concept of the model is based on the primary objective which is to develop an autonomous firefighter robot by considering the following criteria:

(a) Autonomous fire detection

(b) Navigate robot automatically to the fire detected by the network-sensor

(c) Autonomously extinguish the fire

The network gas sensor is used to meet the first criteria. The network is designed by using gas sensors placed at different locations in a room and connected to one Arduino board. The Arduino board is connected to the laptop and Bluetooth module of the robot.

The robot has to move towards the fire automatically to meet the second criterion. In the accomplishment of this task, the problem is in identifying the destination toward which the robot should move, and avoiding the obstacles towards the destination. It is done by the Bluetooth module connected to the Arduino board which receives the location of fire by the sensor network. The obstacles are avoided by the ultrasonic sensor which detects the object and avoids it and finds the way towards the flame. The third criterion is to extinguish fire autonomously. The mini car washer is used to meet this criterion. The car washer pump located in the water tank turns on when the robot reaches the destination. It leads to spray the water by the pistol of the car washer.

2.2 Microcontroller Selection

The Arduino Uno is the microcontroller, which based on ATMega328P and is widely used in robotics. The Arduino Uno board has a dimension of length 68.6 mm and width 53.4 mm. The operating voltage is 5V, and an input voltage varies from 7V to 20V, for our purpose this value corresponds to 12V. The number of digital input and output pins of 14 is sufficient for this research. One Arduino board is used to communicate two DC motors by H-Bride, H-bridge also controls three Ultrasonic sensors, Bluetooth module, and pump motor. The second Arduino Uno board is used to communicate with the three gas sensors in the network systems with Bluetooth. The inputs of each gas sensors translated to specific outputs in Bluetooth. The Bluetooth module establishes the wireless communication between these two board module.

2.3 Base Platform Design

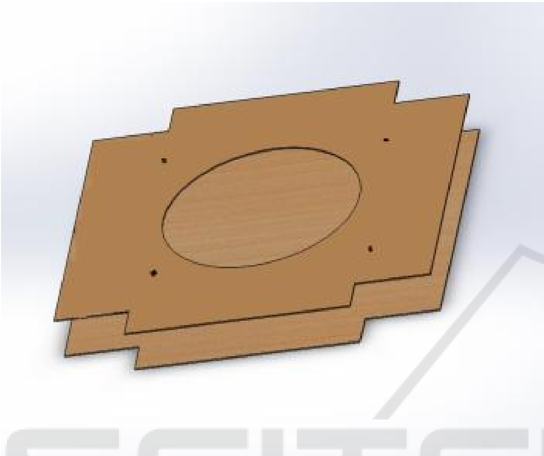

Figure 1: The assembly of the base platform.

Figure 1 shows the base of the firefighter robot. The lower basement part has a dimension of 0.5m x 0.5m and cut-outs of 0.1m x 0.05m. The cut-outs are made to adjust the wheels insides of the robot. The upper part has a dimension of 0.5m x 0.5m and cut-outs of 0.1m x 0.05m and a circular cut in the middle with a diameter of 0.27m. The circular cut is made for the purpose to set up a water tank. **Figure 2** and **3** show handles connected to the pistol as well as the base connected to the handles and pistol.

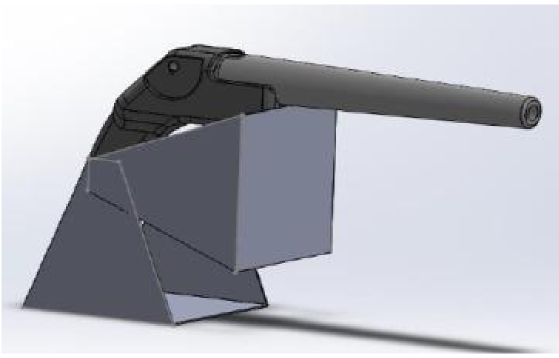

Figure 2: The connection of handlers and pistol.

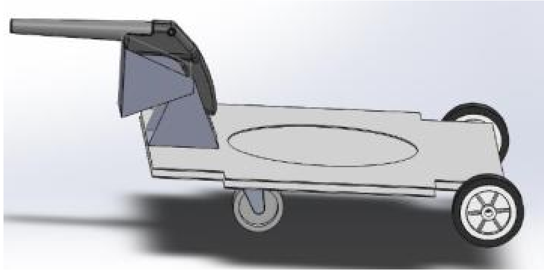

Figure 3: The base prototype.

2.4 Motor Selection

Motor's key parameters are selected based on the following calculations.

2.4.1 Required Speed

The speed of the robot is assumed to be 150 cm/s. This assumption is made to find the RPM, which is provided by the DC motor. The speed conversion from cm/s to RPM is done in the following way:

$$V = r * \omega \tag{1}$$

Where V=velocity, r=radius of the tire, and ω=angular velocity.
By substituting the values, ω=V/r, ω=(150cm/s)/5cm

$$\omega = 30 rad/s \ , \ RPM = \omega / 2\pi \tag{2}$$

RPM=(30rad/s)/2π*60
RPM=286.47rpm.
A minimum 286.47 RPM is needed to meet the desired 150cm/s speed.

2.4.2 Required Torque

The required torque is the next property that needs to be taken into account while selecting the DC motor. The torque produced by the DC motor should be sufficient to carry the total weight of the robot, including the tank with the water. First, the force is calculated as follows:

$$F = \mu_r * N \tag{3}$$

Where, F=Force, μ_r=Rotational friction co-efficient, N=normal force. By substituting the values of the rotational friction coefficient and normal force for an assumed total weight of 27 kg, we get:

F = 0.015*(27kg*9.8m/s^2)
F = 3.969N
The equation of the torque:

$$T = D * F \tag{4}$$

Where, D=distance (in this case D is r=radius of the tire), T = 5cm* 3.969N, T = 19.845 cmN, The selected DC motor needs to provide at least 286.47 rpm and a torque of 19.845 cmN.

3 ALGORITHM DEVELOPMENT

3.1 Obstacle Avoidance Algorithms

In the productive activity and life of the human society, automation becomes increasingly essential. In recent years, due to the significant decrease in resources, global climate change, and population growth, the role of automation is amplified, and it is being expanded. To date, there are practically no technical devices without automation elements - from simple devices used in everyday life to sophisticated industrial installations. Modern humanity uses various devices, without which today it is impossible to imagine a comfortable and safe daily life.

For an autonomous vehicle, the ability to detect and avoid obstacles in real time is a significant embodiment and a fundamental guarantee of a ground mobile robot for performing various tasks. Consequently, there are some studies and solutions to this problem, but most of these solutions require a significant computational load and are complicated, some even completely impossible. In general, there are two types of avoidance technology: the first is based on the global map, and the other is based on sensors. In this work, two algorithms for preventing obstacles in the implementation of low-cost control structures based on microcontrollers and sensors, namely, Bug1 and Bug2 are used.

Bug1 and Bug2 are motion planning algorithms that are applied to mobile robots. For these algorithms, sensors of the sonar range are used as sensing elements. Mobile robots create new traffic planning in those cases when they meet an unknown obstacle while moving towards the goal. Bug's algorithms create a path for moving the robot to the target in a straight line if the path to the target is clear; otherwise, the robot follows the obstacle border with which it encounters (Lumelsky, 1990). These algorithms are based on three assumptions about the mobile robot: i) the robot is a point, ii) it has an ideal localization, and iii) its sensors are accurate (James, 2007).

Bug1 is an algorithm by which a mobile robot moves directly to the target unless it encounters an obstacle. In the event of a collision with an obstacle, the robot examines the outer lines of the obstacle until it moves to the target is available (Sankaranarayanan, 1990). As soon as it encounters an obstacle, it bypasses the obstacle on one side, and then determines the breakpoint, calculating the distance between the current position and the position of the target *G* while traveling around the object. The remaining point is the nearest point around the obstacle to the target. The robot then determines the shortest path to this nearest point to reach the breakpoint, and changes or maintains its direction of the wall, following the shortest path to return to the breakpoint. Then the robot goes to the breakpoint and sends an obstacle in the direction G along the new line. When it encounters the second obstacle, the same procedure applies. This method is inefficient but ensures that the mobile robot can reach any possible goal point (Isabel Ribeiro, 2005). **Figure 4** shows the Bug algorithm.

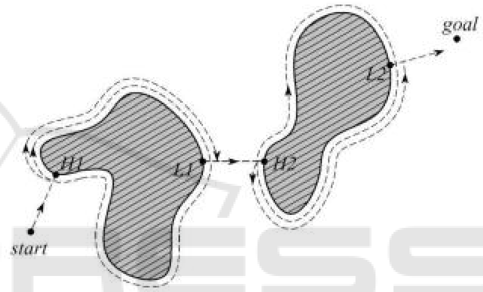

Figure 4: Illustration of the Bug algorithm.

According to the algorithm Bug2 as shown in **Fig. 5**, the mobile robot follows a constant slope, calculated initially between the positions S and G. The mobile robot maintains its motion to *G* if the path on the slope is not interrupted by the obstacle. If the robot is in front of it, the robot follows the edges of the obstacle, using its sonar sensors in a clockwise direction until it finds its original inclination again. This property leads to shorter paths than Bug1, but in some cases the path may take longer than Bug1, for example, searching for a labyrinth (Magid, 2004).

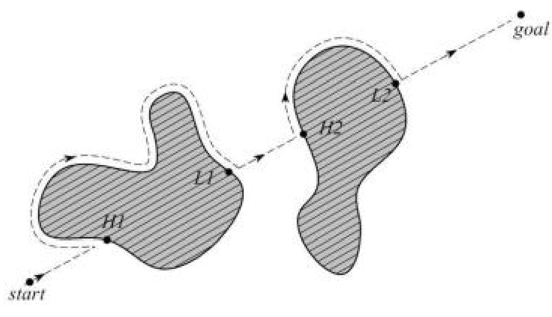

Figure 5: Illustration of the Bug2 algorithm.

3.2 Movement

One of the primary requirements of the robot is the movement. The following components provide the movement of the robot:

(a) Wheels (2 of the conventional and 1 of omnidirectional)

(b) DC motors (Two 12V DC motor)

(c) The connection between the wheels and DC motor, as well as the connection of DC motor and basement

The following **Fig. 6** illustrates the positions of wheels in black color (2 conventional and 1 omnidirectional wheels). All the three wheels provide the forward movement. The turning is resulted by the stop of one back conventional wheel and rotation of another. The omnidirectional wheel provides the turning of the front side, as it can turn in any direction and provide movement.

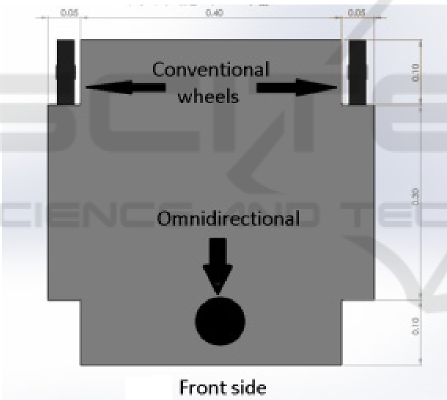

Figure 6: Positions of the wheels.

Two standard wheels are connected to a DC motor by the metallic part by welding. The easiest and reliable way of connection is welding. It leads to simultaneous rotation of the wheels and the DC motor's rotational output. Each DC motor with the conventional wheel is connected to the basement by the two metal strips by screwing them into the lower basement. The omnidirectional wheel is connected to the lower basement by four screws. The following **Fig. 7** illustrates those as mentioned earlier (3) connections.

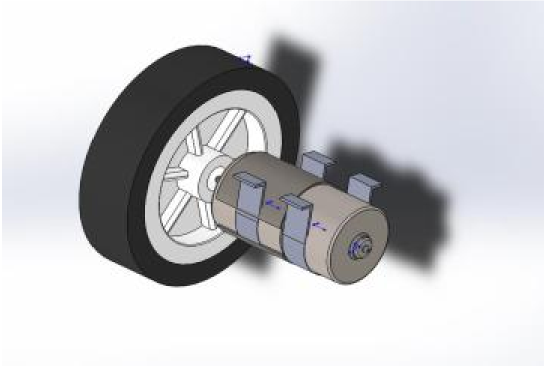

Figure 7: The connection of (1) wheel, (2) DC motor and metal two strips.

3.3 Navigation

The navigation is done in the following way:

(a) The gas sensor gives the location of the fire

(b) Wi-Fi module transfers the destination to the robot

(c) The robot moves toward the fire by avoiding the obstacles using ultrasonic sensors. **Figure 8** explains the location of the ultrasonic sensors.

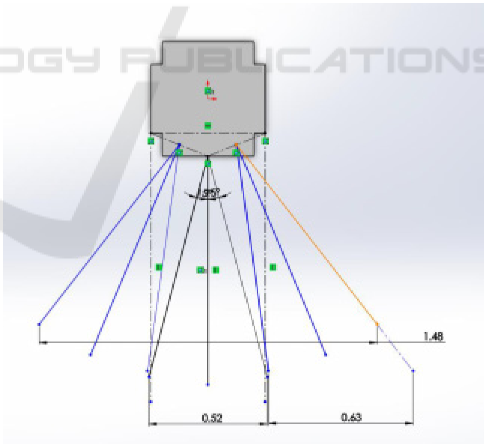

Figure 8: Ultrasonic sensors positioning.

3.4 Gas Sensor Network

The gas sensors are located in the room forming a network to detect the smoke. The MQ-9 gas sensor is used as a smoke detector. The amount of smoke is directly proportional to the voltage output. The supply voltage used in MQ-9 is 5V. **Figure 9** shows the gas sensor.

Figure 9: MQ-9 gas sensor.

As the network the room is divided into three divisions, the following positioning is determined. The network follows the following logic: when the fire is detected at the location of the first sensor, the destination is to be at first 150 x 100cm division of the room; if the second sensor detects the smoke the location is to be a second division, and the third for the third division.

3.5 Obstacle Avoidance

When the robot moves toward the fire, detection of the obstacles on the path should be considered. In the literature review, the logic of the obstacle avoidance is suggested. As the way to avoid an obstacle, the Ultrasonic sensor SRF05 is used. The operating voltage of the sensor is 5V, and the measurement angle is 30 degree.

Figure 10: SRF05 ultrasonic sensor.

Figure 10 shows the ultrasonic sensor used for this research.

4 ASSEMBLY AND TEST RESULTS

4.1 Fire Extinguishing

Water is used to extinguish the fire in this research. The following components and technique are incorporated into the system.

4.1.1 Gun and Water Pump

The last action for the robot is to extinguish fire autonomously. The fire is extinguished by the elimination of heat from the fuel, one of the consistent of the fire triangle, by decreasing its temperature by adding water into it. The water stored in the water tank needs to be splashed into the fire. For this purpose, the "minicar washer" is used. The mini car washer system consists of the following components.

(a) Pump

(b) Water Hose

(c) Water spray or gun

(d) Waterproof power wire

Figure 11: Mini car washer.

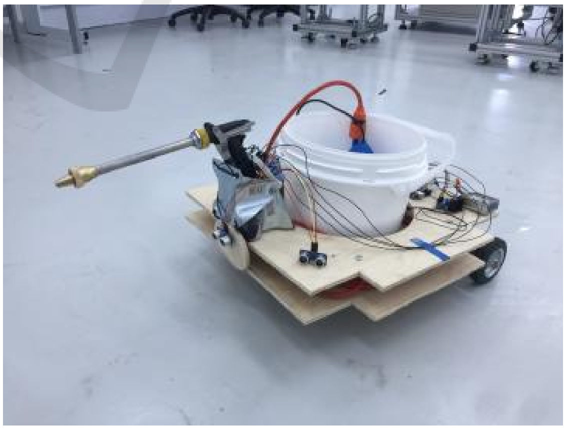

Figure 12: Isometric view of the prototype.

The total weight of the "minicar washer" system is 800g. The operating voltage is 12V. **Figure 11** illustrates the "minicar washer". **Figure 12** highlights the isometric view of the developed prototype.

4.2 Network Room Set up

The network room is built in the laboratory by dividing the 1m x 3m area into three 1m x1m sections. Then, three gas sensors are placed above each section and connected to an Arduino Uno. The Wi-Fi module connected to this Arduino sends the reading of each sensor to the robot. **Figures 13** and **14** show the sensor networking.

Figure 13: Network room.

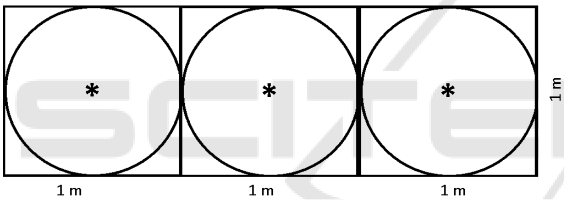

Figure 14: Gas sensor network.

4.3 Prototype Development and Testing

Figures 15 and **16** show the front and rear view of the robot. **Figures 17** and **18** demonstrate the robot's action during fire detection. The testing started with the adjustment of the network room sensors. The height for placement of each sensor and reading range of each sensor configured simultaneously to cover the sections. The robot's navigation is done by changing the Arduino code according to the path of each sector. Then, by implementing Bayesian Algorithm, the code is modified based on the presence of an obstacle. The testing is done using a candle as a source of the fire. The candle is placed in each section and at different places with respect to the sensor location.

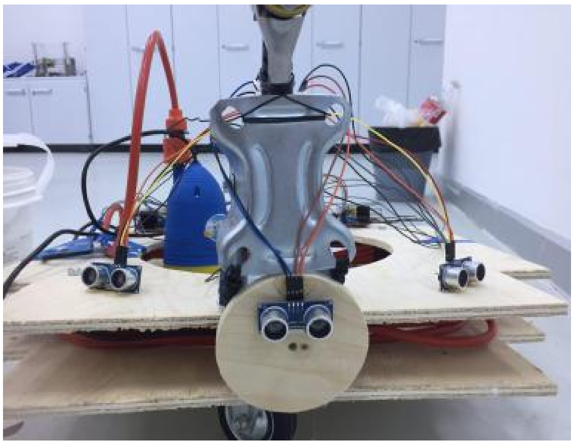

Figure 15: Front view of the robot.

Figure 16: Rear view of the robot.

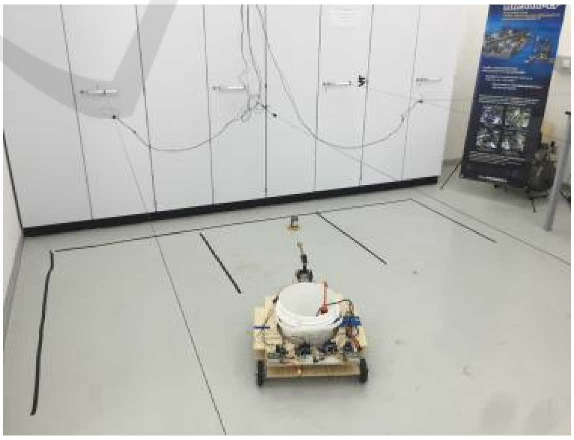

Figure 17: Robot in action.

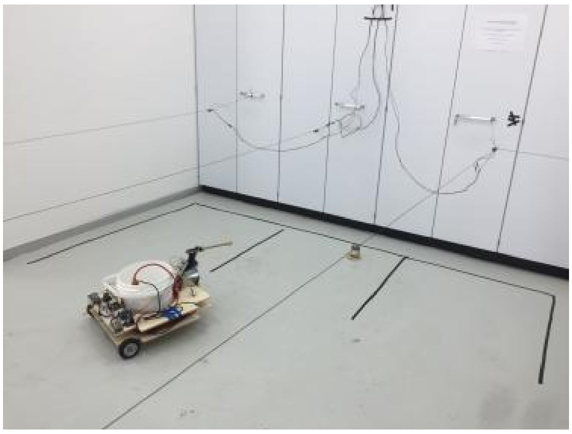

Figure 18: Side view of the robot during fire extinguish.

5 CONCLUSIONS

The focus of this research was the design, assembly, and development of an intelligent firefighter robot that would be able to extinguish a fire source automatically. This work includes electrical, mechanical and mechatronics systems. The sensor network is needed for the fire detection. The network of the gas sensors divide the room into three sections and then detect the presence of fire within the range. By the Wi-Fi communication between the network and robot, the destination signal is transmitted to the robot. By the implementation of Bayesian Algorithm and using three ultrasonic sensors to avoid an obstacle, the robot reaches the fire. After reaching the fire, the robot starts the pump and water splashes toward the fire, and as a result, fire is extinguished. The test results were obtained after several trials to reach the desired destination. Overall, the primary objective of the research; such as autonomous fire detection, robot navigation, and autonomous fire extinguishing is met.

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