DOORMOR: A Functional Prototype of a Manual Search and Rescue Robot

Fahim Faisal
Dept. of Computer Science and Engineering
Daffodil International University
Dhaka, Bangladesh.
embeddedfahim@gmail.com

Syed Akhter Hossain
Dept. of Computer Science and Engineering
Daffodil International University
Dhaka, Bangladesh.
aktarhossain@daffodilvarsity.edu.bd

***Abstract*—In this paper, we have discussed about DOORMOR - a standalone, fully functional search and rescue robot prototype which can come to aid for humans in many cases. With the help of Wi-Fi technology, this robot can be controlled within up to hundred meters. It can search for alive human bodies underneath a pile of debris, clear out debris and other obstacles, stream live video of the surrounding environment wirelessly and assist people in search and rescue operations. In this paper, we have tried to give a brief idea about DOORMOR, it's architecture, facts and features, used components and techniques used to build up the whole robot.**

Keywords*—Bot, Live Video Streaming, Control Application, Living Body Search, Debris Clearance, Microcontroller, PIR Sensor

I. Introduction

Nowadays, robotics and mechatronics is considered as one of the most prominent topics in research. In robotics, architecture, design, manufacturing is important as well as implementation of software to give robots better artificial intelligence to make them appropriate for the tasks which they should handle. Mechatronics is the consolidation of mechanical, computer and electronic engineering in the design of integrated systems with high capabilities that accommodate numerous intelligent traits [1]. It's a derived branch of engineering which is getting more and more popular in this era. From defense to public sectors, robots are being used everywhere. Today, due to unplanned civilization and industrialization, environment pollution has become earth's greatest enemy and a threat to our existence. We have never been more prone to natural calamities as we are today. Earthquakes, cyclones, tsunamis are becoming common incidents day by day. But, often due to lack of proper disaster management and implementation of technology, people die in large numbers. In this particular area, robots can help save many valuable lives. Often, humans face a situation while rescuing that, they can't reach the affected people due to lack of proper path and there is always a risk of the rescuers getting hurt themselves. Robots on the other hand don't have these limitations, they can slip through even the smallest and slender paths, and they can operate without anyone getting hurt.

II. Related Works

The concept of search and rescue robots is still relatively new. It emerged roughly at the beginning of the 1980s. Nevertheless, actual developments in this field began after the 1990s. Although robots are not widely used in actual search and rescue operations at the moment, the development in this field seems quite promising. In Eastern Japan Earthquake, various robot technologies were applied and achieved productive results for nuclear plant accident response, port inspection, victim search, structural inspection, etc. [2].

Trupti B. Bhondve, Prof. R. Satyanarayan, et al proposed a rescue robot, which can search for alive humans in disaster events in both auto and manual mode. They used a Radio Frequency (RF) modem to maintain connection to the bot from the control device [3]. Albert Ko and Henry Y. K. Lau proposed an autonomous bot circumscribing a wireless network of sensors specially designed for rescue operations. This robotic system can navigate autonomously into rubbles and search for living human body heat using its thermal array sensor [4]. Zachary Cody Hazelwood and Dr. Saleh M. Sbenaty proposed a robot that can move autonomously and avoid obstacles while moving. It also has a user input mode in which the robot takes instructions from the user [5]. Siobh´an Grayson proposed the deployment of multiple robots in disaster events, each having different functionalities. The robots each would have their own assigned tasks [6]. Luis Pineda, Takeshi Takahashi, et al introduced a smart, sophisticated algorithm which is capable of automatically detecting distressed people in the event of a disaster and ease the work of the rescuers [7]. Jingchao Zhao, Junyao Gao, et al introduced a robot which is capable of sensing various kinds of gases in coal mines. Live video of the surrounding environment is captured through a webcam and then broadcasted over a local wireless area network [8]. Jaeeun Shim and Ronald C. Arkin introduced deception of robots in SAR contexts and presented a novel computational approach for an autonomous rescue robot's deceptive action selection mechanism [9]. Johannes Maurer, Gerald Steinbauer, et al tried to document the state of the art in disaster robotics in their paper, in order to provide an overview of the technology already available or currently under development [10]. Illah R. Nourbakhsh, Katia Sycara, et al, in their paper, discussed about the automatic determination of disaster victims using sophisticated algorithms [11]. J. Ju´arez-Guerrero, I. Pissokas, et al, in their paper, discussed about the implementation of smart algorithms for determination of disaster victims in unknown environments without human assistance [12].

III. Design and Bot Mechanics

At the very core of the bot design, four wheels have been used for moving the bot. On the front side, two wheels have been used, and on the back, another two, thus two wheels have been used per side. The chassis was designed in a way that it can carry all the electronic equipment like batteries, circuits, drivers as well as the arm and other components. Full dimension of the bot is 9.5″ × 7″ × 7″. The dimension of the chassis of the bot is 9.5″ × 7″ × 2″. The body is built of stainless steel to ensure maximum distortion tolerance. When we try to turn the bot in the left direction, the right wheels go

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forward and left wheels go backward thus creating an uneven pressure in the bot's body and the bot turns left. When we try to turn the bot in the right direction, the left wheels go forward and right wheels go backward, and the bot turns right. In this bot, four gear motors [13] have been used so that moving on an uneven surface becomes easy.

The bot's arm has three parts: base, elbow and wrist. The base and the elbow of the arm can rotate up to 180 degrees. The bot uses two servo motors [14] to perform this task. The servo motors [14] are placed respectively in the base and elbow, which gives a sophisticated hand movement. Using two servo motors [14] gives us two Degrees of Freedom (DOF). The claw [15] used in DOORMOR is two fingered, which also holds a servo [14] for materializing the grabbing action. The bot is designed this way so that it can overcome any hazardous situation.

IV. Bot Electronics

The main controller of the bot is the microcontroller *Atmel ATMega328P*. In other words, it's the brain of DOORMOR. An *Arduino Nano* [16] has been used for utilizing this microcontroller and programming it easily. A microprocessor was needed for rendering live video data as microcontrollers don't possess such powerful CPUs. So, a *Raspberry Pi 3* [17] has been used which has a quad-core *Cortex A57* CPU, more than capable of rendering HD video data.

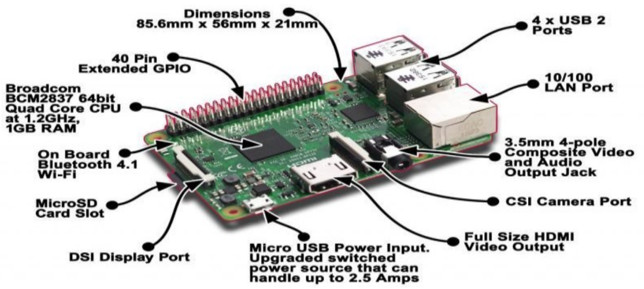

Fig. 1: Raspberry Pi 3 Model B.

Two 2A 5V Lithium-Ion rechargeable power supplies [18] have been used to power the bot. One for powering all the power-hungry components such as, gear motors [13], servo motors [14] and the motor driver [19]. The other one is for powering the *Raspberry Pi* [17] and the *Arduino Nano* [16]. The *Raspberry Pi* [17] requires steady 5V to operate properly and the optimum voltage for the servo motors [14] is also 5V (Input Range: 4.8V – 7.2V). The *Arduino Nano* [16] receives 5V directly from the *Raspberry Pi* [17]. No separate power supply was used for the Passive Infrared Ray (PIR) sensor [20] as it receives power directly from the *Arduino Nano* [16] pins. There is also a 5MP camera module [21] which is powered through the Camera Serial Interface (CSI) port on the *Raspberry Pi* [17]. The L293D dual-channel motor driver [19] has been given 5V as input because the gear motors [13] that we have used, perform best under 5V. Four gear motors [13] have been used to power up four wheels and all of them are given power through the motor driver [19]. Two motors are connected in parallel with reverse polarity on each channel of the motor driver [19]. As both of the power supplies [18] have onboard voltage regulators, additional voltage regulation wasn't required. In average, the total current consumption of the whole bot is around 3A in medium terrain. The power supplies that have been used, can handle the loads flawlessly. The *Arduino Nano* [16] was used to control everything and collect sensor data because it's easier to connect different modules to it as it has 5V output whereas the *Raspberry Pi* [17] has an output of 3.3V, which some modules and sensors don't accept. Also, generating Pulse Width Modulation (PWM) signals with various duty cycles for servo control with the *Pi* is a bit inefficient.

Fig. 2: PIR Sensor Module.

V. Communication System

FCC standards and regulations were followed regarding the communication between the bot and the control device. A 2.4 GHz Wi-Fi router [22] has been used to transfer video data from the bot to the network and control signals from the control device to the bot. The onboard Wi-Fi module of the *Raspberry Pi* [17] which connects to the Wi-Fi router [22], was used to transmit video information to the local network and receive control signals from the control device. IEEE 802.11 b/g/n wireless standard was utilized in all the network components. An android app (DOORMOR Controller) was used to maintain the connection from the control device to the bot. The control commands are collected from the app and then sent to the *Arduino Nano* [16] by the android device through the *Pi*'s onboard Wi-Fi module. The Passive Infrared Ray (PIR) sensor is hooked up to the *Arduino Nano* [16] and feeds data directly to the microcontroller. The microcontroller then redirects the data to the control device through the Wi-Fi module and Wi-Fi router [22]. The redirected data is then translated in the app.

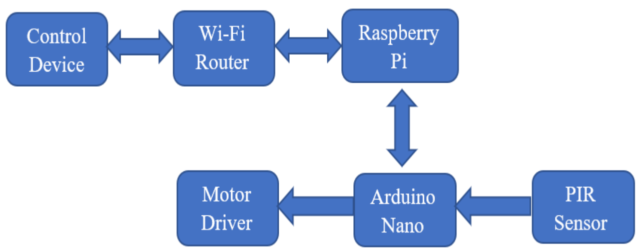

Fig. 3: Diagram of the Communication System.

VI. Live Video Streaming

The 5 Megapixels camera module [21] has been used to remotely see what is going on at the desired location. It is connected to the mainboard [17] via the Camera Serial Interface (CSI) port. It was set up in a way so that we can avoid data loss and other consequences. It can capture full HD (1920x1080) videos at 30 frames per second. The video data is transmitted over a Wireless Local Area Network (WLAN) created by the Wi-Fi router [22] and can be viewed from any smart device connected to the network through a web browser. The video encoding has been implemented by the FFMPEG [23] open source video library. Video data is temporarily stored in a webserver inside the *Pi* and then it is broadcasted over the WLAN.

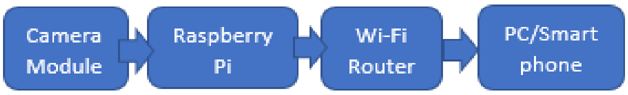

Fig. 4: Video Data Transmission Path.

Fig. 5: Raspberry Pi Camera Module (5 MP).

VII. Bot Software and Associated Hardware

The microcontroller (*Atmel ATMega328P*) was programmed in the *Arduino* language (a subset of C++) for ease of programming. The *Raspberry Pi* [17] was programmed in Python as it is the official programming language for the device. The *Raspberry Pi* [17] works as a server and the controlling and viewing devices act as clients. Server-client communication is implemented using Transmission Control Protocol (TCP) for secure and reliable data transmission. We used two separate webservers for bot/arm control and live video streaming. The server for control was programmed in Python and the live video streaming server was set up using LIGHTTPD [24], which is a light, flexible, fast and less resource-consuming webserver. Single-board computers like the *Raspberry Pi* [17] are usually low on hardware resources and as such, we need lightweight software to compensate for the hardware limitations. Additionally, CRTMPSERVER [25] was set up for temporarily storing the video data coming from the camera module [21]. In order to display the live video, a webpage was required. PHP and HTML languages were used to create the webpage, which is hosted on the LIGHTTPD [24] webserver. We used STROBE Media Playback software on the webpage to play the live video.

The bot software, i.e. the control app establishes a central control system to control the bot from a remote distance with the help of an android device. It offers a user-friendly Graphical User Interface (GUI), which includes all the necessary tools and information display areas.

```python
import serial
from socket import *
from time import ctime

arduino = serial.Serial('/dev/ttyACM0', 9600)

HOST = ''
PORT = 21567
BUFSIZE = 1024
ADDR = (HOST, PORT)

tcpSerSock = socket(AF_INET, SOCK_STREAM)
tcpSerSock.bind(ADDR)
tcpSerSock.listen(5)

while True:
    tcpCliSock,addr = tcpSerSock.accept()

    while True:
        data = ''
        data = tcpCliSock.recv(BUFSIZE)

        if not data:
            break
        else:
            arduino.write(data)

tcpSerSock.close();
```

Fig. 6: Server Code for Bot and Arm Movement Control (Python).

```javascript
var parameters = {
            src: "rtmp://" + window.location.hostname + "/flvplayback/myStream",
                autoPlay: true,
            controlBarAutoHide: false,
            playButtonOverlay: true,
            showVideoInfoOverlayOnStartUp: false,
                optimizeBuffering : false,
                initialBufferTime : 0.1,
                expandedBufferTime : 0.1,
                minContinuousPlayback : 0.1,
            poster: "strobe/images/poster.png"
        };

// Embed the player SWF:
swfobject.embedSWF
  ( "strobe/StrobeMediaPlayback.swf"
  , "strobeMediaPlayback"
  , 1080
  , 720
  , "10.1.0"
  , {}
  , parameters
  , { allowFullScreen: "true"}
  , { name: "strobeMediaPlayback" }
  );
```

Fig. 7: Partial Source Code of Webpage.

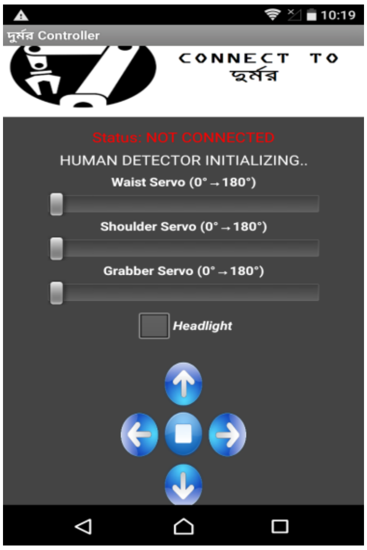

Fig. 8: DOORMOR Controller (Control App/Client App).

A. Bot Movement Controller

The motor driver [19] has six control pins. Four are for controlling the direction in which the motors [13] should rotate, e.g. clockwise or anti-clockwise. They are also used to start or stop the motors [13]. So, these pins are pulled HIGH and LOW with a combination from the L293D's truth table [26] to execute different actions. Six *Arduino Nano* [16] digital pins are connected to the motor driver [19]. Four of them generate HIGH and LOW logic to materialize the desired bot movements. The client software named "DOORMOR Controller" was written in the Java (Android) programming language. It has a GUI which consists of FORWARD, BACKWARD, LEFT, RIGHT and STOP buttons as well as a status box to display the state of the bot. These buttons have predefined string values which are sent in packets. With the help of sockets [27], the *Raspberry Pi* [17] communicates with the client, receives these values and sends appropriate signals to the microcontroller.

Input A	Input B	Motor State
High	Low	Turns clockwise
Low	High	Turns anti-clockwise
High	High	Braking occurs
Low	Low	Braking occurs

Fig. 9: Single Channel Truth Table of L293D.

B. Arm Movement Controller

A portion of the 'DOORMOR Controller' app has the necessary tools to control the arm movement. There are three sliders for controlling the three servos [14]. The sliders have values from 0° to 180°. These sliders need to be moved in a systematic way in order to obtain desired arm movements. The status area of the control app shows in which degree the servo [14] is at, whenever the concerned slider is highlighted.

On the programming side, these sliders have different predefined underlying values at different points, e.g. the first slider has a value range of 1000-1180, the second slider has a value range of 2000-2180 and the third one has a value range of 3000-3180. These values are sent as strings which are further converted to integers and stored inside arrays in the microcontroller. The first digit represents the servo number and the rest three digits represent the degree at which the servos need to rotate and stay. After receiving signals from the control device, the microcontroller generates appropriate Pulse Width Modulation (PWM) signals for driving the servos [14]. PWM signal generation is handled by the Servo library of the *Arduino* language.

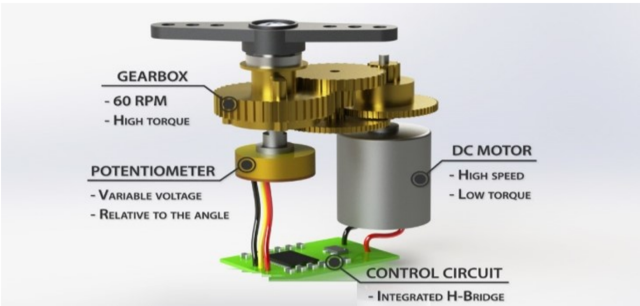

Fig. 10: Servo Mechanism.

```
seekBar1 = (SeekBar) findViewById(R.id.seekBar1);
txtAddress = (EditText) findViewById(R.id.ipAddress);

seekBar.setOnSeekBarChangeListener(new SeekBar.OnSeekBarChangeListener() {
    @Override
    public void onProgressChanged(SeekBar seekBar1, int progress, boolean fromUser) {
        getIPandPort();
        CMD = "1" + String.valueOf(progress);
    }

    @Override
    public void onStartTrackingTouch(SeekBar seekBar1) {

    }

    @Override
    public void onStopTrackingTouch(SeekBar seekBar1) {

    }
});
```

Fig. 11: Partial Android Code.

```
if(realservo >= 1000 && realservo < 1180)
{
  int servo1 = realservo; //storing values for servo 1..
  servo1 = map(servo1, 1000, 1180, 0, 180); //mapping down to suitable degree values..
  myservo1.write(servo1); //sending positional information to servo 1..
  Serial.println("SERVO 1 ON"); //prints confirmation message on the serial monitor..
  delay(10); //waits for 10 millisecond for the servo to adjust it's position..
}
```

Fig. 12: Partial Arduino Code.

C. PIR Sensor Status

Another portion of the 'DOORMOR Controller' app displays the status of the PIR sensor [20]. The PIR sensor [20] can detect Passive Infrared Rays (PIR) emitted from living beings, such as, alive humans and other animals [28]. A dead body doesn't emit such rays. Inside the PIR sensor, all the thermal energy is at first focused on to the Pyroelectric sensor through the focusing lens in front of the sensor. If PIR is available, the voltage across the sensor changes. This change in voltage is too delicate to be detected by the microcontroller, so we need an amplifier circuit which will amplify the change. The output of the amplifier is connected to a voltage comparator, which compares voltages from the amplifier with a reference voltage and generates HIGH/LOW logic [28]. So, the module sends a HIGH logic to the microcontroller whenever it detects a living being within 1 meter. The microcontroller then sends a signal to the control device through the *Pi* and the Wi-Fi network. This signal is translated in the app. The app shows "Human Detected" in the sensor status area, whenever a living body is detected. If there's no living body, the app shows "No Human Detected". The mechanism of the PIR sensor [20] is shown in Fig. 13.

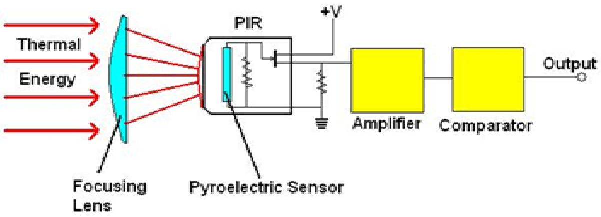

Fig. 13: Passive Infrared Sensor Mechanism.

VIII. Description of the Tasks

The bot can perform several tasks. They are respectively:

1. Searching for alive humans under pile of debris.
2. Picking up and clearing debris using the arm.
3. Capturing live video of surrounding environment and streaming it through a wireless network.

Task 1 is shown in Fig. 14, where the bot has detected the existence of a living body.
Task 2 is shown in Fig. 15, where the bot is picking up demo debris.
Task 3 is shown in Fig. 16, where the bot is streaming live video to a Windows PC connected to the bot's wireless network.

Fig. 14: Live Human Detection.

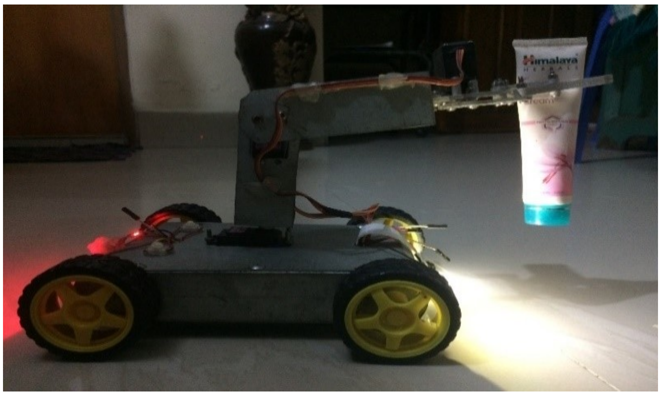

Fig. 15: Demo Debris Cleaning.

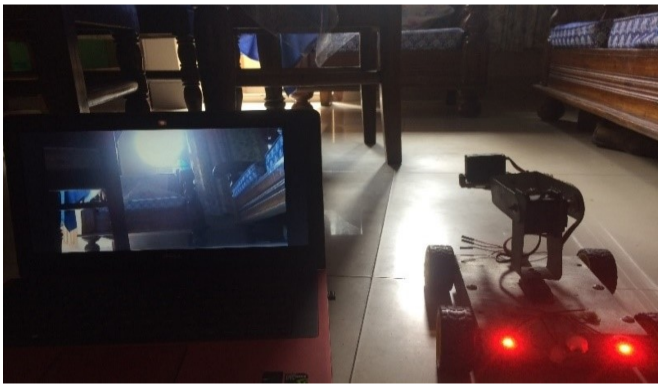

Fig. 16: Live Video Streaming.

IX. Observations and Experiments

Several experiments were conducted to ensure proper functionality of the bot. This helps to accurately determine the future complications that may occur in actual field. The experiments can be split into several steps:

A. *Live Video Streaming Test:* Success scenarios of the bot during the live video streaming test are shown in Table I.
B. *Traversing Test:* Success scenarios of the bot's traversing test are also shown in Table I.
C. *Arm Test:* Success scenarios of the bot's arm test are shown in Table II.
D. *Sensor Test:* Success scenarios of the bot's PIR sensor test are shown in Table III.

TABLE I. Bot Test Results

Test Run	Terrain	Vision	Control	Status
1	Plane	Operator's eye	With bot	Success
2	Medium	Bot camera	Blind from operator	Success
3	Plane	Operator's eye	With bot	Success
4	Medium	Bot camera	Blind from operator	Success

TABLE II. Arm Test Results

Test Run	Type of Object	Weight	Action Performed	Status
1	Demo Debris	50 gm	Picked up & moved	Success
2	Demo Obstacle	100 gm	Picked up & moved	Success

TABLE III. Sensor Test Results

Test Run	Sample	App Output	Status
1	Living body	Human Detected	Success
2	Living body	Human Detected	Success
3	Living body	No Human Detected	Failure
4	No living body	No Human Detected	Success
5	No living body	No Human Detected	Success

As seen in the tables above, DOORMOR showed success scenarios when tested. The sensor test returned a success rate of 80%. We conducted further investigations on the signal range of the bot and found out that DOORMOR sometimes does not respond to control signals at distances more than 90 meters and stops responding completely at distances greater than 95 meters.

X. Advantages of DOORMOR

The main advantage of DOORMOR is that it doesn't require any additional remote controller or wireless network for operation. Any android device can be used to control the bot and any existing Wi-Fi network can be used to transfer video data and control signals between the control and viewing devices and the bot. Wi-Fi repeaters can be used anytime to expand the range of the bot without any kind of hassle. These features also add to the overall cost reduction of DOORMOR and make the robot distinguishable from rest of the similar systems.

XI. Areas of Further Development

As this is only a prototype, the actual robot will be superior to the prototype in many ways. First, the chassis will be a lot stronger compared to the prototype's chassis with better metal alloy construction. Metal chain will be added on the wheels for traversing on rough terrain for hours. The wheels will also be made out of metal. The metal alloy will be selected in such a way that the robot can withstand extreme pressure and heat for a descent amount of time. Better motors will be used to ensure maximum torque and Rotation Per Minute (RPM) under heavy load. The motors will be picked in a way so that they can be powered through the available power source. The power source will also be upgraded to ensure maximum current supply to the components for a longer period of time. The camera module will be upgraded to a night vision camera module to ensure clear imagery even in the dark. The arm will be redesigned with better gears to ensure maximum performance. The Degree of Freedom (DOF) of the arm will be upgraded for better arm movement. Face and object recognition will be added in order to recognize people and objects while searching an affected area. This will help the rescuers to efficiently locate the distressed people. The robot can also be slightly modified for military use, specially bomb disposal. The claw [15] can be replaced with a cutting tool that will allow the robot to cut wires for disposing bombs. Also, the robot can be used as a spy robot.

Another interesting addition would be live GPS location streaming which would help us pinpoint the bot, and addition of sonar sensors which would stop the bot automatically before it accidentally crashes into something. Thus, some sort of Artificial Intelligence (AI) would also be in action.

XII. CONCLUSION

In this modern era, robotics has become such a field which has made our lives easier, safer and efficient through variety of its applications. In almost every aspect of our daily life, we can see the benefits of this particular field. However, our effort was to develop a life saver. Its applicability is not confined within the pre-specified scientific tasks. Again, its software and the integration amongst the associated hardware components made it equally capable of performing other similar tasks with minimum modification. In the previous section, we have discussed areas of further development. Concentration on traversing task gave the bot such an infrastructure that can withstand expected adversities up to a certain limit and made it capable of exploring places that are almost out of bounds for humans. The compilation of the mechanics, self-developed control system, software and hardware provides the blueprint of such a standalone system that can accommodate certain utilities in favor of assisting humans in various horizons. As there is no end of perfection, with more resources and logistics support plus keen observation of its performance on different sectors, the scope of improvement of the bot is still on the table.

XIII. ACKNOWLEDGEMENT

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