pISSN: 2523-5729 eISSN: 2523-5739

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ORIGINAL ARTICLE

Wireless Robotic Search & Rescue Operation for Calamities

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ABSTRACT

Rescuing human body effected from natural or man-made disasters are considered to be the most important task just after occurring an unavoidable natural calamity. The main objective of this project is to create an autonomous robot that would assist rescue teams in urban search and rescue operations. The robot is meant to reduce human effort during search and rescue operations. This Autonomous robot system implies the application of a mobile robot for USAR (Urban Search and Rescue) missions for calamities to detect the human existence using sensor based localization and motion planning. Sensing parameters taken into account are CO_2 levels by the CO_2 sensor, the distance by Ultrasonic sensor, heartbeat monitoring by EPIC sensor, infrared heat by PIR sensor and monitoring the exact location of the body detected by GPS tracking module. Successful testing is done through the correctness of localization and human detection.

Keywords: GPS, PIR, Ultrasonic Sensor, USAR, Autonomous robot system, EPIC sensor

Author`s Contribution	*Address of Correspondence*	Article info.
[1,4] Data analysis, interpretation and manuscript writing, Active participation in data collection *[2] Conception, synthesis, planning of research and manuscript writing* *[3.] Interpretation and discussion*	*Shahzad Nasim* *Email: shahzadnasim@live.com*	*Received: July 18, 2017* *Accepted: December 22, 2017*

Cite this article: *Hafeez B, Hasan Khan N, Sohail S, Khan A, Nasim S. Wireless robotic search & rescue operation for calamities. J. inf. commun. technol. robot. appl.2017; 8(2):59-67.*

Funding Source: *Nil*
Conflict of Interest: *Nil*

INTRODUCTION

Natural and man-made disasters always bring lots of destructions. Flooding, earthquakes, hurricanes, bomb blast, building collapsed and fires create emergency and unavoidable situation for victims. During these alarming situations, victims need to be rescued as soon as possible. Rescue teams of medical assistance, firefighters and police they are supposed to assist the survivors without getting themselves into danger. Rescue teams require severe protection tools to save the life of the victims. The rescuers must have to make a quick decision within no amount of time for the victim's survival bodies trapped in a disaster. Before moving to save the life of the victims two main approaches are taken by the rescuers. First, they need to determine the status of the victim and secondly the status of the location. Conventionally human detection is performed by dogs and human workers and it consumes greater time to detect the live and injured body trapped under the debris.

In this dangerous and risky situation, mobile robots are proposed to help rescuers to rescue the victims. Robotic studies are increasing its impacts on human life. Nowadays, all over the world Rescue teams are working with USAR robotics institutes and agencies to develop a highly autonomous robot which assists the firemen, disaster agencies and other rescue team workers that can work in very dangerous places without any risk of human life. For the first time, Carnegie Mellon University builds a semi-autonomous robot for Urban Search and Rescue Operation. The major goal of this project is to make a fully autonomous robot which can take better decisions. The proposed goals are to develop a robot that would maneuver in rugged environments (e.g. calamities such as earthquakes), to develop a fully autonomous system for working, to localize the robot in an unknown environment, to search for humans, possible trapped under debris and to wirelessly transmission of data between the receiver base station and the robot. Compare to the other projects, this robot is fully autonomous and locomotive device. An autonomous robot, capable of moving around a rugged terrain of a calamity affected area. The robot will be localized in an unknown environment and search for survivors.

The purpose of using a tank drive here in our project was to illustrate its rigidness and flexibility to localize and move around in rugged environments. A comparison was analyzed between different kinds of mobile robot drives and their drive abilities, and thus “tank drive” was chosen for the benefits it provided. We compromised on driving skills and programming required to ease our work and used a differential drive for controlling the motion of the tank treads. Acquiring data from the following sensors and to merge all the data into a meaningful representation of the environment and human physical parameters was another challenge. Ultrasonic sensors have been used for localization in an unknown environment, while Pyro-electric Infrared Sensors, CO_2 sensors, and PS25451 sensors are to be used for human detection.

LITERATURE REVIEW

A rescue robot has been recommended for aiding in the majority rescuing workforces. In the vast majority of normal perilous that ability rescue robots need aid mining fortunes, urban ruins, detained situations, also blasts. Salvage robots were utilized within those quest to casualties what's more survivors then afterward those September 11 occurrences to New York City. That repayment of rescue robots with these operations incorporate lessened staff rations, lessened fatigue, what's more right should remote what's more distant zones. That Robotic quest and rescue will be profitable since robots might be deployed for risky situations without placing mankind's responders in hazard states.

Some years ago, Urban Search and Rescue was proposed as a Challenge problem to the robotics community, arguing there were significant challenges to be in the areas of human-robot interaction and millirobot operation. In response, the US National Institute of Standards and Technologies introduced physical USAR reference test arenas—environments developed to represent, at varying degrees of realism, challenges associated with collapsed structures. The National Institute of Standards and Technology (NIST) also designed a test bed to aid research within USAR.

In 2011, USAR proposed design and hardware specification consist of three main things. A cost-effective camera to monitor the audio and video signals. Low-cost camera to monitor audio/video signals. A CO_2 sensor that indicates human presence at the certain threshold level. Dc motors of high torque enable the robot to move in the rugged surface. The scarcity and expense of USAR capable robots have severely restricted USAR robotics research. Field research shows that mobility is only one problem hindering effective use of robots for search and rescue (R. Murphy, 2004). The vision of robots working with humans and software component to save lives in an urban disaster is attractive, its realization requires significant scientific advances to locate some challenges. One of them is to coordinate the actions of a set of different robots; existing millirobot coordination algorithms and systems are ill-suited to this domain.

A fully featured search and rescue system should be able to quickly and accurately locate victims, map the search space and locations of victims, maintain communication with human responders and assess victim status and assist with rescue efforts these assumptions and approaches were illustrated by Joshua Reich and Elizabeth Sklar. It is also mentioned in the report of Steve Burion many companies market mobile robots, sensors, and electronics useful for search and rescue work, only a few companies have commercially available robots that designed for USAR.NASA and the United States Department of Defense also have ongoing efforts with various universities to develop intelligent robots with a variety of sensors. The most advanced projects in industry are as follows: iRobot; sponsored by US government, they develop some robots which replace the human in several interventions when it is too dangerous or too small to enter. Inuktun; their robots are generally used in water or flood, also have some applications in urban search and rescue. They can climb obstacles and have the ability to pass through small tubes.

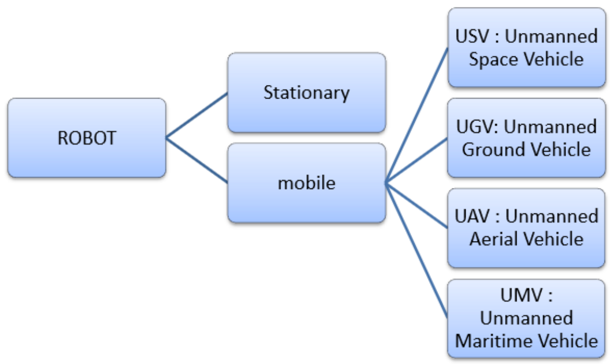


Figure 1(Robot with its Types)

COMPONENTS

A. PICMicro-Controller

The system consists of 2 units one being the Transmitter Unit and the other being the Receiver Unit. On the transmitter unit, we have high-performance controllers PIC18F452 and 18F4550, and the receiver unit has a PIC16F877A. It's a 40- pin DIP controller with 16KB of Flash Program Memory and 1536 Byte RAM Data Memory. Special features include programmable code protection, power saving SLEEP mode and in-Circuit Debug (ICD). Since it uses CMOS Technology, therefore provides low power and high speed.

B. Tower PRO Servo Motor

This servo is capable of rotating 120 degrees and can easily be controlled with the help of a code, hardware or library.

C. Power Window Motor

The 12V power window used has a high torque of 60rpm with a tolerance of ±5rpm and a rated torque of 5.5N.m or more. Its current ratings when no load attached lies between 2.5 to 3.0A and a speed of 45 to 65 rpm.

D. Sensors

In this portion, we have briefly discussed the range finding, human detection sensors.

We will discuss them in two parts:

Area Mapping:

For area mapping, we require rangefinder and magnetometer to set the direction of the robot as per the demand. These include:

i. Ultrasonic ranger finder –HC-SR04:

These sensors are used to detect obstacles by using sound waves that are being emitted at a high frequency up to 40KHz.The time taken for the sound waves to hit a reflective surface and then return back to the sensor is used to find the distance of the object from its nearest obstacle. The range of these sensors is up to 2 to 4cm.

ii. GPS - LS20031Module:

The LS20031 has an embedded antenna and GPS receiver circuits. And uses 57600bps TTL serial interface. This GPS can track up to 66 satellites at a time and provides fast time-to-first-fix, low power consumption, and navigation updates.

iii. Magnetometer - HMCHMC5883L:

In order to find the orientation of the robot in x and y-axis a digital compass have been incorporated, that uses the strength of the magnetic field to tell the direction. The HMC5883L uses an I2C interface for communication.The supply voltage of this sensor is 3.3V with its field range between -8 to +8 gauss.

Human Sensing:

i. PIRHC-SR501:

Pyro-electric Infrared sensors allow you to sense motion with the help of IR radiation that is emitted from live bodies. They are inexpensive, small (32 x 24 mm2) and efficient to use an interface. Works at a voltage between 5V to 20V and has a Sensing range less than 120 degrees within 7m (with the provided Fresnel lens). It provides an analog sinusoid pulse output of 3V.

ii. PS25451EPIC:

The PS25451 is an electrode potential integrated circuit (EPIC) that detects minute disturbances in the electric field and is widely used in biomedical applications which include wireless ECG, EMG, EOG, and EEG. It is used to detect minute changes in the electric field caused my human body without physical contact.

iii. CARBON DIOXIDE SENSOR - CO_2 MG811:

The Carbon Dioxide Gas Sensor is used for detecting the concentration level of Carbon Dioxide gas in the environment. It generates an output voltage with an exponential increase in the concentration of Carbon dioxide. It provides dual signal output (analog output/TTL

Level output) with high sensitivity and selectivity. The Concentration range is 0~10000ppm.

E. Wireless communication (433 MHz RF (RX-TX) MODULE)

Wireless communication is achieved by using a pair of RF sensors. This wireless transmitter and receiver pair works at 433 MHz frequency channel. They can easily fit into a breadboard and work well with microcontrollers to create a very simple wireless data link.

F. Motor drive circuitry:

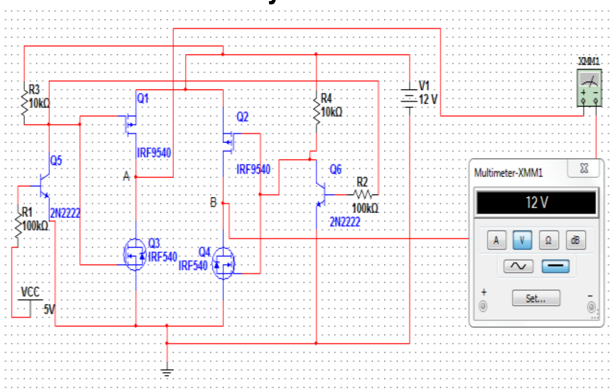
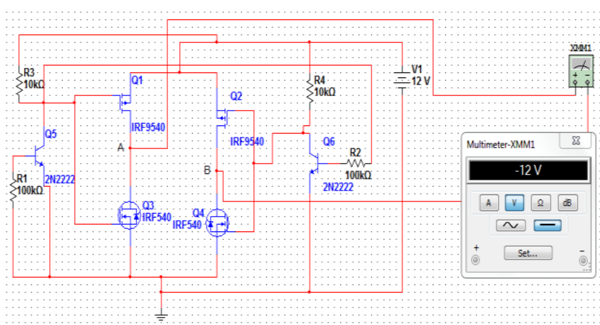
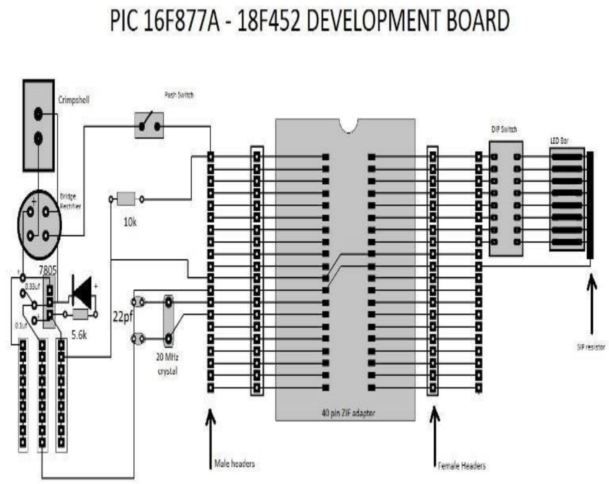


Figure 2 (H-Bridge)



In the above simulation between the nodes, A and B motor will be connected. So, when microcontroller gives 5v as output to the input pin of our h bridge circuit then the motor will get 12v on its one terminal and 0v at the other terminal means it will move forward.On the other hand when microcontroller gives 0v on the input pin of drive circuit then voltages of the motor terminals will be reversed and the motor moves in the reverse direction.To stop the motor it is required to allow 50 % duty cycle with the frequency 1.5KHz.

G. Development Board



HUMAN DETECTION AND LOCALIZATION

This area covers the main objective of our project which is to build a map of an unknown environment and then at the same time navigate it in order to find live humans. To achieve this we incorporated a number of sensors and a GPS whose working will be discussed below with the help of codes and plots.

A. ROOMPLOTTING:

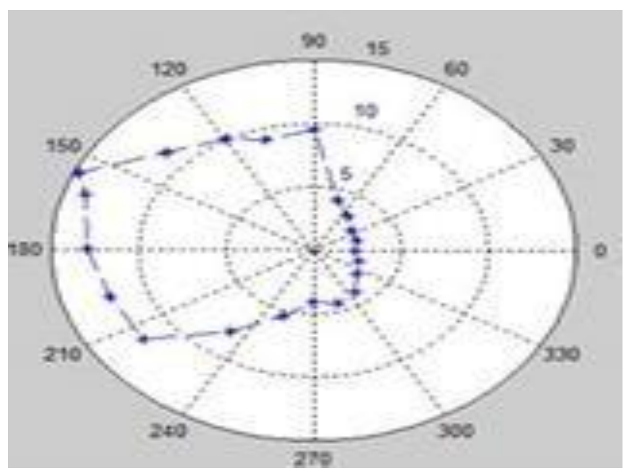


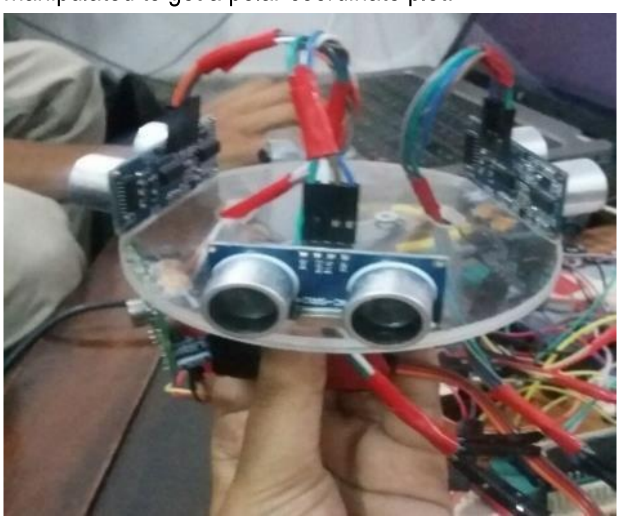
Figure 3 (Room Plotting)

The basic initial step was to be able to acquire a plot in MATLAB which marks the obstacles in a room. We managed to get this kind of plot with the help of polar coordinates where “rho” is the distance of obstacle and theta is the direction. For testing purpose, we used hypothetical values of theta and distance and got the following plot which marks the distance and direction of obstacles from a central location.

B. Ultrasonic Range Finder:

The next step was to use sensors that will tell the distance of robot from an obstacle.For this purpose, we used three ultrasonic sensors which are placed on a circular disc 120 degrees apart. This disc is then mounted on a servo motor that rotates 120 degrees for the first time to get information of obstacles present in the room. The first sensor would cover from 0-120 degrees, the second from 120-240 and third to 240-360, resulting to cover the entire room.

Data from all three sensors is received in a 12 byte string array where the first three byte gives the angle of servo motor, the next 9 bytes gives distance of obstacles from all three sensors each occupying 3 bytes of array (byte[1,2,3]=theta, byte[4,5,6]=sensor1, byte[7,8,9]=sensor2, byte[10,11,12]=sensor3).This string array is then converted into double word.The servo angle and sensors data (obstacle distances)is stored in separate arrays (theta, rho,rho2,rho3)so they can be manipulated to get a polar coordinate plot.



C. Passive Infra-Red Sensor:

Once we have received the plot showing hurdles in the room, our next task was to mark the presence of live humans. So to detect humans we used two PIR sensors placed 180 degrees apart on the same servo disc which we used for ultrasonic sensors. This disc then rotates 180 degrees, this time to detect the humans that are present in the same area.

Data from these sensors and servo angle is received in the form of string array of 5 bytes [byte (1,2,3)= theta, byte(4)=PIR1, byte(5)= PIR2] where first three bytes show angle and last two bytes shows data from both sensors in digital form where 1 means that human is present and 0 shows absence.

This string array is then converted into double word.The servo angle and PIRs data (human presence) are stored in separate arrays(h_theta,h_rho,h_rho2).This data is then plotted on the same map that is the final plot marks both obstacles as well as humans present in a room.

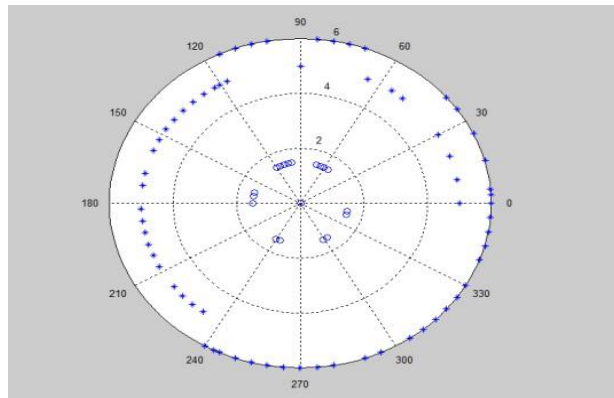
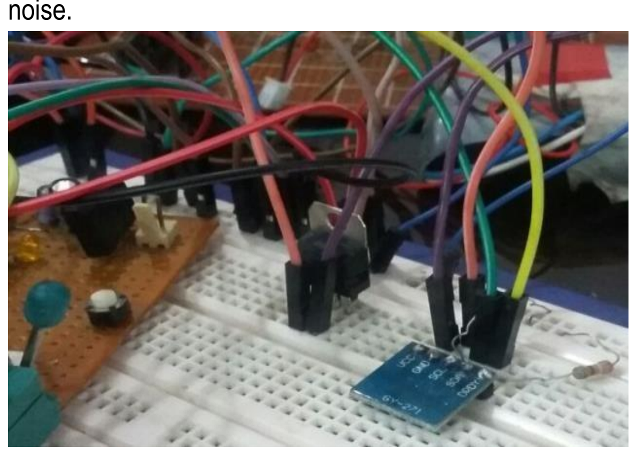


Figure 4 (Infra-Red Sensor Results)

The above plot marks the distance and direction of obstacles as well as live humans where "*" shows obstacles and "O" shows humans.

D. HMC5883L

After receiving the combined map of ultrasonic as well as PIR sensors next step was to move the robot in the direction of the detected human.For this purpose, we used HMC 5883L sensor that will take constant feedback of the horizontal orientation (x,w) of the robot with respect to the localized area. The sensor uses magnetic fields. Therefore to avoid magnetic interferences, it has to be kept isolated from the metallic parts of the robot to avoid noise.



HMC will ask the robot to rotate until the nearest human has been found, as marked on the map. From arrays (array theta [36], array_hp1 [36], array_hp2 [36] as mentioned in the previous code) the robot will check for the nearest human presence. For example it will check the status of each PIR sensor on every value of theta with spacing of 5 if at theta equals to 0, 5, 10 the status of both PIR remained 0 and at the same time at theta=15 degree the status of anyone PIR sensor or both becomes 1 then the HMC will tell the robot to move 15 degree that is in the direction of the first detected human.

E. MG811:

To further direct the robot towards a human we detect a change in concentration of CO_2 gas in the air. As the robot moves towards this human the amount of CO_2 in air increases.For sensing this we use MG811 CO_2 gas sensor with the help of the following data

Normal presence of CO_2 in the air would be around 1000 to 4000 ppm, the closer the robot gets to the human, the concentration increases up to 50,000 ppm. The output of this sensor is in milli-volts which further decreases as the concentration of CO_2 increases so to amplify this voltage we use LM 324 Quad op-amp in non-inverting configuration with the gain set to 80. Since we are acquiring analog data from the sensor, so these values should be quantized with the help of PIC's ADC. This is done using the following code in which sampling size = 8 bits and Sampling time= 50 us. The controller stores and compares three values at time (res1, res2, and res3) ifres1<res2

<res3 means no human is present because the voltage decreases with increase in CO_2 so after digitalizing the steps will also decrease as CO_2 increases.

Quantized value= (5/255) *voltage from sensor

For example the values of res1, res2 and res 3 were 96,97,98 when no human was in its vicinity as soon as a human comes near, this value decreases to res1=99,res2=61,res3=62 showing the presence of a human.

F. PS25451 EPIC Ultra High Impedance Movement Sensor

This sensor is used to further confirm the presence of humans by measuring the disturbances in an electric field that occurs as a result of movement caused by objects in its vicinity. It allows us to detect heartbeats, nerve, and muscle activity without contacting and even through clothing. The signal at the output is received as pulses of amplitude variations (analog).This amplitude increases in microvolts when a human comes in its range. Since this voltage cannot be detected by microcontroller so we amplify it using LM 324 Op-amp IC and then sample it in the same manner as we did for the CO_2 sensor.

G. GPS -LS20031

GPS (Global Positioning System) module takes geographical input from the satellite and locates the earth position and timing information from different satellites' views. GPS receiver requires at least more than 3 or more satellite views in its path to triangulate the exact location of the marked object on the surface of the earth.

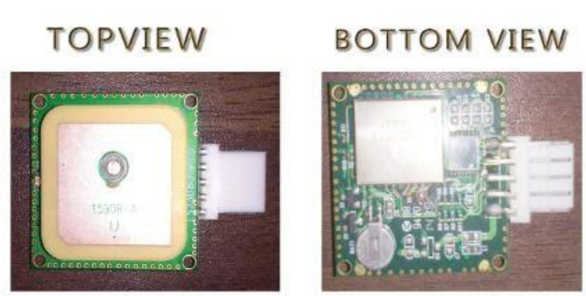
As our robot is fully autonomous, we have used GPS receiver for outdoor localization doing this robot will continuously take the latitude and longitude coordinates from the satellite and update the current position of the robot (GPS receiver).

SELECTION OF GPS RECEIVER MODULE

Following are the modules which are mostly used for navigation:

Product name	Description	Version
LS20030	GPS smart antenna module/USB,VCP,30x30mm	1.2
LS20031	GPS smart antenna module/TTL,9600BPS,30x30mm	
LS20032	GPS smart antenna module/RS232,9600BPS,30x30mm	
LS20033	GPS smart antenna module/TTL,9600BPS,35x16mm	

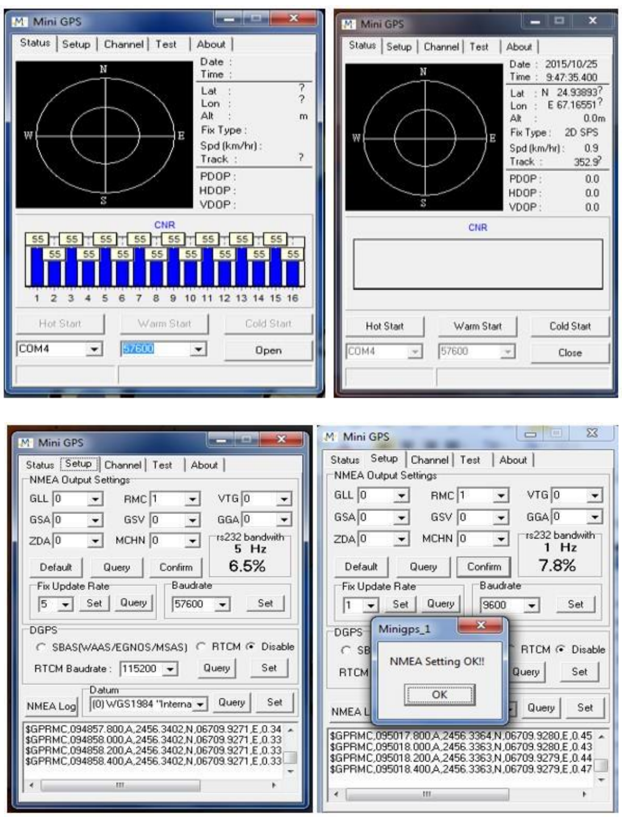
Out of all these LS20032 was our requirement but we decide to select **LS20031** due to its cheaper cost and its availability. As we are using RS232 serial communication so it becomes essential to convert GPS output from TTL toRS232.



SETTING DIFFERENT DATA FORMATS BY USING MINI PGS

Mini GPS is a software which provides a more convenient way to view the status of GPS receiver. Mini GPS is an interface between GPS and people and could also change the settings of the GPS. After connecting the GPS to the source wait for a few seconds until it continuously blinks the red LED mounted on GPS, this indicates that GPS is connected and taking satellite's view now connect the GPS with PC through serial cable and open Mini GPS. This screen will appear:

After setting up the input serial port (PC) and baud rate, the status page will show the status of GPS receiver by providing time and positions. Now, to change the NMEA data and baud rate, click to setup and the following window will appear as:

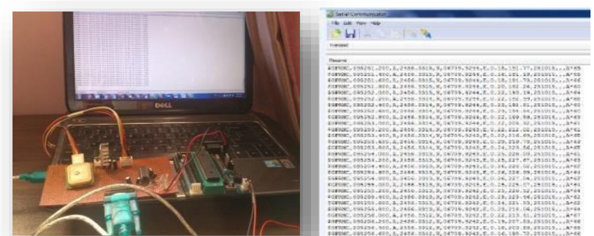


Set NMEA output setting to 1 only for those which are your requirement and all those which you don't need set them 0 after this apply confirm. To change the baud rate set the baud rate and can also change fix update rate. Out of all 6 NMEA different formats, we will only use RMC record data in our project and set our GPS to 9600 baud rate to make it compatible with micro-controller.

A. RMC Data Format:

$GPRMC,133302.000,A,2456.7505,N,06704.5389,E, 0.33,93. 48, 230708(date),,, A*56

B. Obtained GPS Frames on PC Through Serial Cable:



INTEGRATION

Integration of all the discretely worked circuits and designs into a fully functional project was the biggest challenge of the project. The programming was extensive and required step-by-step debugging at different phases.

A. Calibration ofHMC5883L

HMC5883L is a 3-axis gyroscope and a digital compass which gives an apparent angle depending on which quadrant of the coordinate frame it is in. It was first necessary to calibrate the angles with respect to all the 4 quadrants of the 2D x-z frame, using mathematical methods.

→The real angle from the calibration

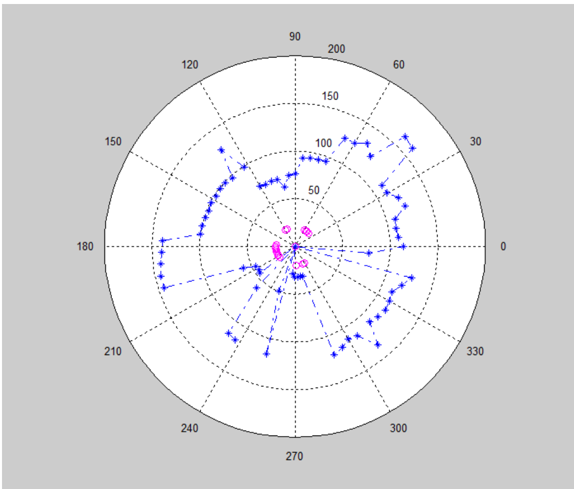
→Apparent angle (from tan-1 [z/x])

B. Coinciding the two frames together

Name	Example	Units	Description
Message ID	$GPRMC		RMC protocol header
UTC Time	053740.000		hhmmss.sss
Status	A		A=data valid or V=data not valid
Latitude	2503.6319		ddmm.mmmm
N/S Indicator	N		N=north or S=south
Longitude	12136.0099		dddmm.mmmm
E/W Indicator	E		E=east or W=west
Speed over ground	2.69	knots	True
Course over ground	79.65	degrees	
Date	100106		ddmmyy
Magnetic variation		degrees	
Variation sense			E=east or W=west (Not shown)
Mode	A		A=autonomous, D=DGPS, E=DR
Checksum	*53		

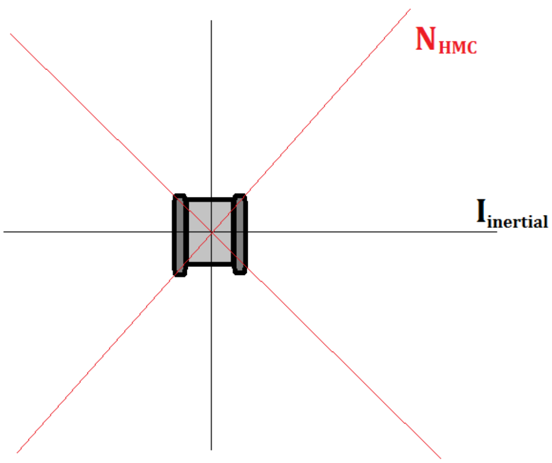
pISSN: 2523-5729 eISSN: 2523-5739

The HMC5883L magnetometer's data is oriented according to the magnetic north, while the polar coordinates of the inertial frame depend on the robot's position at the origin. The robot rotates until both the frames coincide so that calibration becomes efficient.



C. Room mapping

3 ultrasonic range finders are kept at angles of 0, 120 and 240 degrees. Each sensor measures the distance from the walls of the room and creates a map using polar coordinates. The sensors are swept on a disc to 120 degrees with a step size of 5 degrees.



D. Survive or detection

The servo motor is brought back to 0 degrees and swept to 180 degrees for human presence marking. While the polar plot is held in MATLAB, the first possible directions of humans are marked on the same map (by detecting the live humans' IR radiation using PIR sensors). The final map would result as follows:

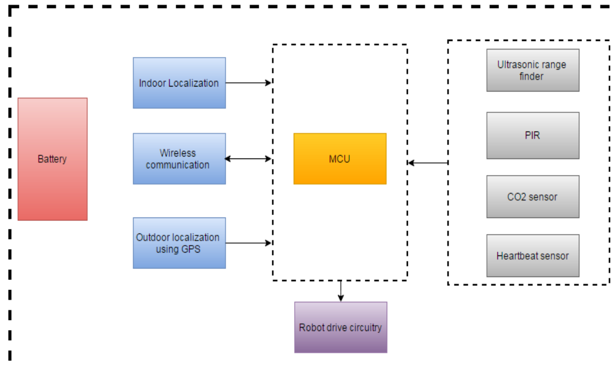
E. Human detection and Motion planning

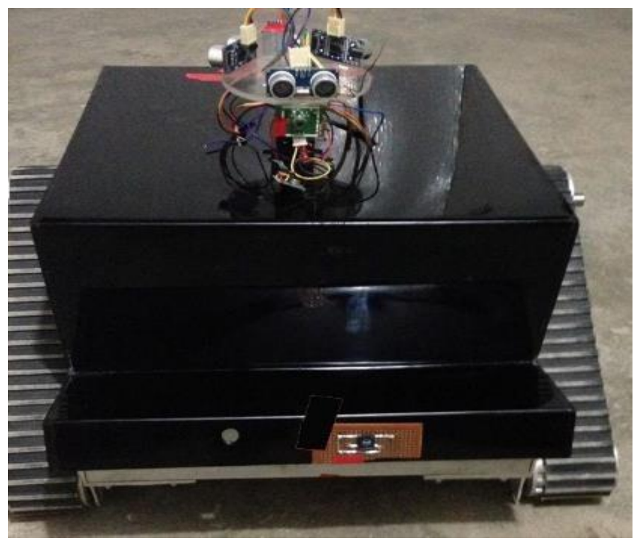
The robot goes to the first human it finds on the map and goes there to check whether it is alive or not (CO_2 levels and heartbeat levels will be monitored (without physical contact). The map can be used by rescue teams to search for other survivors.

F. Repeat

The sequence repeats until all survivors are found in the area affected.

BLOCK DIAGRAM



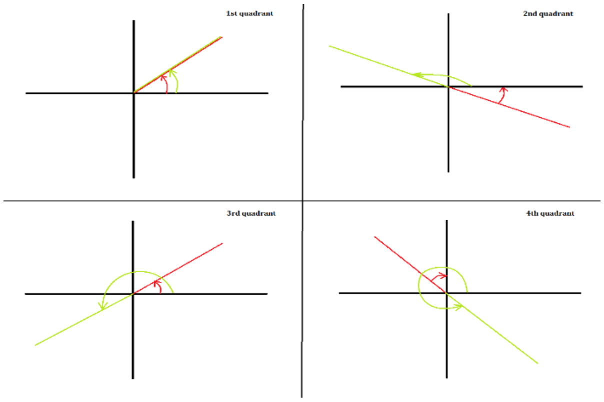


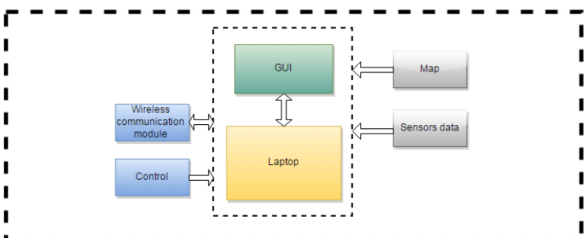
RESULTS AND DISCUSSION

We have successfully made an autonomous robot that would help assist rescue teams in their search for humans in any calamity affected area.

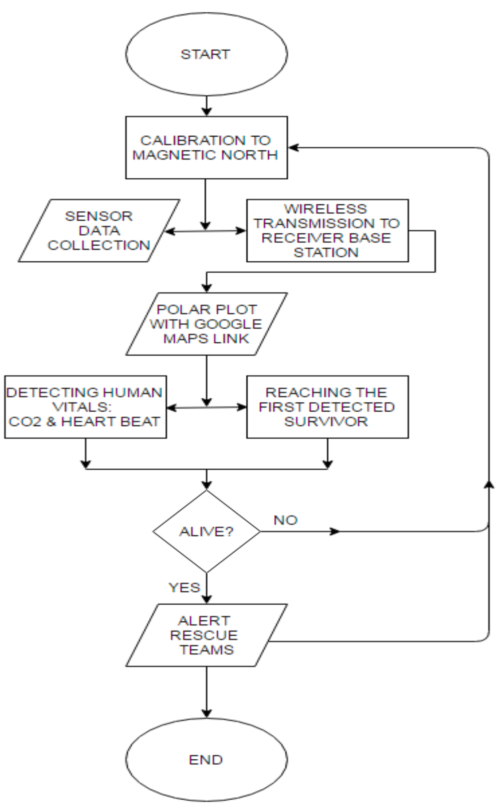
The robot is globally localized using GPS and localized indoors using sensor based localization and mapping. The human detection parameters that have been taken into account are Infrared human body radiations, CO_2 presence around the human, and heartbeat.

The robot can be deployed in any rugged environment and can roam freely there because of tank drive,





Receiving base station



CONCLUSION

The goal of this project is to develop a human detecting robot for the rescue operation. Although there are many USAR (Urban Search and Rescue) robots available with more advanced sensors the main feature of this robot is its cost-effectiveness and its ability to maneuver in rugged environments (e.g. calamities such as earthquakes). An autonomous robot, capable of moving around a rugged terrain of a calamity affected area. The robot will be localized in an unknown environment and search for survivors.

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