Wireless integrated robots for guidance of rescue teams

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Abstract

Nowadays, the number of disasters occurred and the people affected have been increased. Every day, newspapers report new disasters around the world. Immediately after the occurrence of a disaster, the first responders go to the affected region to rescue people and solve eventual problems. These areas offer many dangers to the rescue team. So it is very important to first verify the safety of the environment before sending the rescue team inside the affected area. So intelligent robots equipped with advanced sensors, cameras and integrating wireless networks are attracting attention from researchers and rescuers all around the world. This paper is an application of a robot that will be used for guiding rescue teams when disasters happens using wireless sensor network. The wireless sensor network consists of two fixed nodes and moving nodes with the robot and rescue teams. The searching robot autonomously navigates, searches for living human beings, collects data from the air quality control module, localizes it with respect to the fixed nodes and sends the data. The rescue team can wirelessly receive the data in real time and locate the robot precisely. By that way the rescue team will be able to know if the area is safe or not before entering it.

1 INTRODUCTION

Emergency search and rescue is an integral part of most large-scale humanitarian operations. Over the past decade, natural and human-induced disasters have claimed millions of lives around the world. Earthquakes, typhoons, tornadoes, weaponry destructions and catastrophic explosions can all result in large scale damage to buildings. These collapsed buildings contain many trapped victims; therefore humanitarian search and rescue operations are very important. Search robots equipped with advanced sensors for human search and surrounding sensing have been found to be more efficient in these operations. In a disaster scenario, the damaged building structures are unstable and may collapse any time. Also, the disaster area may be so large and contain many live victims which call for a fast search mechanism for detecting live human beings. Furthermore, there is a possibility of the presence of toxic gases such as Carbon Monoxide (CO) or inflammable gases such as Natural Gas (NG) or Liquid Petroleum Gas (LPG). Hence, it creates a high risk for a rescue team to enter into a collapsed building without prior knowledge of the surroundings. Therefore a low cost autonomous wireless integrated robotic search system with a wireless network consisting of two fixed nodes and multiple moving nodes with the robot and rescue teams is described here. The robot is equipped with an Infrared Detection Module for living human being detection, an Air Quality Control Module to sense the surroundings, Localization and Autonomous Navigation Module and a Wireless Transmission and Reception Module. The robot is localized with respect to the position of the two fixed nodes and the data from the robot will be displayed in the control module held by rescue team members. The robot transmits in real time the exact location of the living human being with respect to the position of the rescue team. Therefore the rescue team can save the victims faster. The nodes with the rescue team members localize themselves with respect to the position of the two fixed nodes. Since the rescue team can know about the surrounding air beforehand, they can take preventive measures in case the building contains any toxic or inflammable gases or smoke. The wireless network is formed between the two fixed nodes, nodes with the various rescue team members and the mobile robots. The following sections describe the related work, necessity of a search robot, wireless network architecture, mechanical design, hardware architecture of the robot, hardware architecture of fixed nodes and rescue team nodes, autonomous navigation algorithm developed with obstacle avoidance, summary and finally the conclusion.
2 RELATED WORK

The papers by Albert W. Y. Ko and Henry Y. K. Lau [1] and [2] discuss various rescue mechanisms including search dogs, camera mounted probes, and audio devices. In the paper by Marques C. [3], he discusses RAPOSA which is a semi-autonomous robot for rescue operations. This robot has an option of using tethered operation for communication and power. The robot also has a wireless communication option. Paper [4] discusses a team of search robots for rescue missions. Each robot contains many sensors including a thermopile array, digital compass, laser range finder, Carbon Dioxide sensor, tilt sensor and microphone. This system can be operated in teleoperated and autonomous mode. Many other implementations of search robots exist in [5] and [6].

3 NECESSITY OF A SEARCH ROBOT

Generally, rescue specialists use trained search dogs, cameras and audio devices to search for victims in the disaster field. Search dogs are effective in finding humans underground, but if the search dog is by itself, then it can neither tell the location nor the surroundings of the victim. Camera mounted probes can provide search specialists a visual image of the area where dogs cannot navigate through, but the issue with these cameras probes is that their effective range is no more than 4-6 meters along a straight line below the ground surface. Instead if wireless robotic systems which can navigate autonomously or remotely are used, then they can go inside the rubbles freely and search for victims. Audio devices can pick up very weak sounds of victims but with these devices it is often very difficult to determine the exact location of the victims. Above all, the additional requirement of search specialists to supervise the search dogs, full time operators to monitor the search probes and audio devices make these methods a lot more challenging and complicated. Generally, search robots can be tethered and un-tethered. In the architecture described in this work, the robot coordinates the infrared human detection module and an optical lens which detects live bodies by analyzing the infrared radiation emitted from these bodies. The robot should have the capability to sense the surrounding air quality and detect the presence of a toxic gas, smoke and two inflammable gases. Therefore the rescue team can take the necessary precautions before entering the scene. Whenever a human body is detected, the robot should be able to provide the rescue team with the location of the victim relative to their position and also the surrounding air quality details, so that the rescue team can reach the victim quickly with the necessary arrangements.

4 WIRELESS NETWORK ARCHITECTURE

The two fixed nodes and the moving rescue team and moving robot nodes form a wireless network, as shown in the figure below. The fixed nodes are placed at ground level. The fixed nodes have GPS incorporated in them, as a result of which their exact locations can be obtained. The two fixed nodes help localize both types of moving nodes using the Received Signal Strength Indication (RSSI). The moving node measures the RSSI of the data coming from the two fixed nodes and uses triangulation to calculate its own position. The moving rescue team nodes localize themselves periodically and broadcast their position. By receiving the location of the rescue teams, the robot determines the direction in which there is no rescue team and continues its search in that direction.

![Figure 1: Architecture of wireless network](image)

5 MECHANICAL DESIGN

This section will introduce the proposed system in details. The robot should make use of the brushless motors to avoid explosions in case of environments filled with gases. Designing the body of the robot will differ depending on the functionalities of the robot. Several scenarios must be considered, the obstacles to overcome,
and also the scenarios where the robot should not operate.
If we want the robot to fit into sewer pipes, then the standard diameter for the robot should be 40 cm. The robot should be also able to climb and descend stairs. The major components for such a robot should contain:

a) Two modules: a main body and a frontal body, whose relative vertical orientation to the main body is adjustable.
b) Two sided tracked wheels to provide locomotion, is coupled to that of the main body.

c) When the robot flips upside down, it should be able to continue its operation flawlessly. This implies that the robot doesn’t have a top or bottom part, and it should detect its orientation and automatically exchanges the commands to the motor and flips the camera images (if it has any) as an example of adjustable autonomy. All these functionalities can be added to the robot to make it more flexible. The perfect width x length for such a robot would be 37 cm x 75 cm.

Cameras and sensors can be placed in the front part of the robot body. This kind of robot design is best fitted for autonomous robots because of its small size. Figure 2 shows the mechanical prototype for such a robot.

![Figure 2: Mechanical prototype for autonomous robot](image.png)

But if we want the robot to accomplish more tasks in the disaster area such as grasping of objects and opening doors. The body for such a robot would be including these parts:

a) Track units: Each track should be actuated by an actuator that consists of a brush-less core equipped with harmonic drive. The idler is utilized for the housing of the track battery. Both tracks need to be connected to the base of the manipulator by an auxiliary actuator utilized for the rotation of the arm and/or the track unit.

b) Manipulator base: It will be preferred to consist of 4 DOF; one obtained utilizing the two track base actuators and other three distributed respectively in the arm shoulder, elbow and forearm. The use of a manipulator to support the robot motion is very effective to obtain high terrain adaptability.

c) Gripper: a gripper will be needed in order to carry out handling operations. It is based on the concept of the robot ankle developed in the authors research group and described in [5]. It consists of a hybrid-parallel mechanism composed of a base actuated by two brushless motors linked to harmonic-drives by timing belts. These are symmetrically connected to the base by two end-rods linkages (ball joints). The base is supported by two plates connected through two passive joints to the wrist pitch and yaw passive axis. As end effector of the hybrid parallel mechanism a simple nipper consisting of one DOF is utilized for grasping operations. The manipulator can be utilized as to support the vehicle motion on rubble.

d) Grippers arm An arm will be needed to hold the gripper. The size for this arm will be decided depending on the size of the robot, and the size of the gripper. Such a mechanical design will be good if the robot to be controlled remotely. Figure 3 shows the mechanical prototype for such a robot.

![Figure 3: Mechanical prototype for remotely controlled robot](image.png)

6 HARDWARE ARCHITECTURE OF THE ROBOT

This section will describe the hardware architecture of a robot that will be navigating autonomously in the affected area.

6.1 Platform

The robot is based on a micro-controller board mounted to a robotic tank platform, in order to enable it to travel on rough terrain. The platform will consist of a number of brushless DC motors driving the tank tracks. The micro-controller board will be connected to a number of
H-Bridge motor driver circuits which drive the motors.

6.2 Human Body Detection Module

The Human Body Detection Module is an Infrared detection module which can detect the presence of live human beings by analyzing the emitted infrared radiation from the victims body. The IR method for living human being detection is previously discussed in [7]. The infrared radiation from a living human body is in the range of 9400 nanometers. Therefore an infrared detection module which can detect infrared radiation within the range of 8-14 micrometers is used. As the output of the infrared detector is very small, it should be amplified and then fed to a comparator and motion detection module. The motion detection module is programmed to avoid false detection by recognizing and ignoring background infrared radiation. The accuracy can be increased by using a wideband pass infrared filter which has a range of 8800-11000 nanometers. The system will work more efficiently if a microwave human search system is used instead of the IR human detection module. However, the microwave system is more expensive. Another alternative for human body detection will be using thermal camera which is sensitive to heat radiations, thus allowing the perception and detection of heat sources. Thermal cameras are expensive when compared to infrared detection methods, theresor it is preferrable to use infrared detection due to it’s low cost.

6.3 Air Quality Control Module

This module is used to analyze the surroundings of the live victims. This module will check for the presence of Carbon Monoxide (CO) - a toxic gas, smoke, inflammable gases, Natural Gas (NG) and Liquid Petroleum Gas (LPG). It sends the data to the robotic platform if the sensor readings are greater than the hazardous threshold values. The module should check the various gas concentrations every five minutes. Various sensors will be needed in order to differentiate between different types of gases. In such a case, we will need 4 types of sensors to detect CO, NG, LPG and smoke gases. Various MQ Series gas sensors can be used for this purpose.

6.4 Range Sensors

Range sensors are used for obstacle avoidance. The narrow beam ultrasonic range sensors are arranged such that by turning the robot, the radial distance from the radial distance of the obstacle from the robot and the angle in which the obstacle exists can be calculated by comparing the values which are received from the different sensors. A more efficient way is to use a 2-D laser range finder. The 2-D laser range finder can give more precise information than ultrasonic range sensors and also it can scan the environment in a 2-D manner. However, the major disadvantage with the 2-D laser finder is its cost. Compared to a laser range finder, the ultrasonic range sensors are much more cost effective, thus ultrasonic sensors are used for obstacle avoidance.

6.5 Wireless Communication Module

XBee-Pro boards are preferred to be used as a wireless communication module since it provide good range even when used indoor. The reason for choosing XBee-Pro for this task is its low cost, low power, and wireless mesh network standard. Low power usage allow longer life for smaller batteries. Mesh networking provides high reliability and more extensive range. This module uses IEEE 802.15.4 networking protocol for fast point-to-multipoint networking. XBee-Pro has longer range than bluetooth and lower power consumption than WiFi and it has a frequency up to 2.4 GHZ. That’s why it is a good choice to be used in such kind of robots where the communication through wireless network plays an important role. This module can calculate the moving nodes distance from the fixed nodes using RSSI and triangulation, as mentioned previously. The exact location of the fixed nodes is known, allowing the robot to determine its own location accurately. Also, this module sends the exact location and surrounding details when the robot detects a living human body to the other nodes with the nearest rescue teams. Figure 4 shows the hardware architecture of the robot.
7 HARDWARE ARCHITECTURE OF NODES

7.1 Fixed Node Architecture
The fixed node will consist of a micro-controller, a GPS module, and a wireless communication module. The GPS module is used to find the position of the fixed node. When the fixed node is initially placed in the disaster field, a reset switch is used for resetting the position. The micro-controller gets the position coordinates from the GPS module. The wireless communication module is used for communication between the fixed nodes and moving nodes with the rescue teams and the robot. Initially the two fixed nodes are placed at a fixed distance. The two fixed nodes know their position and the distance between themselves. Figure 5 shows the architecture of the fixed node.

![Figure 5: Architecture of fixed node](image)

7.2 Rescue Team Node Architecture
The rescue team nodes will consist of a micro-controller, a display module and a wireless communication module. The wireless communication module is for communication between the rescue teams and the robot node and fixed nodes. The rescue team nodes estimate the distance from the fixed nodes by the RSSI method and finds their position. The rescue team nodes broadcast their position periodically. The display module is for displaying the data from the robot nodes to the rescue team personnel. Figure 6 shows the architecture of rescue team nodes.

![Figure 6: Architecture of rescue team node](image)

8 ALGORITHMS

8.1 Autonomous Navigation With Obstacle Avoidance
A navigation algorithm using a wireless network with obstacle avoidance is used in search robots. The algorithm allows the robot to navigate in a target environment with respect to the navigation of rescue teams and search for the goal (a living human body) in directions not searched by rescue teams. If a goal is found, the robot will communicate its position and the environmental status to the rescue team nodes, which can come quickly to assist the disaster survivor. The wireless network consists of two fixed nodes which are placed at ground level. The two fixed nodes have a GPS module in them and thus they know their location. The two fixed nodes help localize both types of moving nodes using the Received Signal Strength Indication (RSSI). The moving node measures the RSSI of the data coming from the two fixed nodes and uses triangulation to calculate its own position. Thus the rescue teams and the robot know their positions relative to the fixed nodes and they broadcast their location periodically. The robot navigates in the target environment avoiding obstacles using the Check Obstacle Ahead algorithm. While navigating in the target environment the robot tries to detect any living human body using the infrared detection module. The robot can detect a living human body from a distance of 6 meters. Whenever a living human body is detected, the robot navigates in the direction of the human body and tries to navigate to the exact location. The robot then localizes itself with respect to the fixed nodes and broadcasts the location data. If the robot is not in the range of the fixed nodes, then robot can localize using the location details from the rescue teams. The robot analyses the location of the rescue teams and find the nearest two rescue teams. It then sends the surrounding air quality details and location to the nearest two
rescue teams. The robot then analyses all received location details from the received packets and finds out a direction in which no rescue team are present and navigates in that direction so that the unsearchable parts of the target environment can be quickly searched.

### 8.1.1 Check Obstacle Ahead Algorithm

The Check Obstacle Ahead algorithm checks for an obstacle in the path of robot. Whenever an obstacle is found in the path of robot, the algorithm determines an angle to turn the robot. The algorithm determines the angle of turn required by analyzing the polar angles and radial distances of the obstacles found. This results in small turn angles avoiding sharp turns for the robot. The robot checks for ultrasonic sensor distance values and radial angles for each sensor. For each polar angle, the radial distance \( R_i \) is the output of the range sensor. The distance from the robot \( D_i \) can be calculated by Equation (1).

\[
D_i = R_i \times \cos(\Theta)
\]  

(1)

For the simple calculation of the turning angle \( \theta_{\text{new}} \), we define a parameter \( P_i \) which is defined by Equation (2).

\[
P_i = 1 - \left( \frac{D_i}{D_{\text{max}}} \right)
\]  

(2)

\( D_{\text{max}} \) is the maximum range of the range sensor. For the ultrasonic range sensor used on our robot, \( D_{\text{max}} \) is 4 meters. We then analyze the polar plot of \( P_i \) and find the threshold for \( P_i \) such that the robot never hits the obstacle. Let this threshold be \( P_{\text{th}} \). We now check for all \( P_i \), if all \( P_i > P_{\text{th}} \), such that there is no forward movement possible for the robot. Therefore, the robot takes a sharp -90 turn to the right. If any \( P_i < P_{\text{th}} \), we find the minimum \( P_i \) and the radial angle corresponding to that minimum \( P_i \). Let that radial angle be \( \theta_m \). Then \( R_{\text{imin}} \) is the corresponding radial distance to that angle. Therefore the angle of turn can be found by Equation (3).

\[
\theta_n = \tan^{-1} \left( \frac{(R_{\text{imin}} \times \sin(\theta_m)) + W_r + c)}{R_{\text{imin}} \times \cos(\theta_m)} \right)
\]  

(3)

Therefore the Radial angle shift which the robot has to take to avoid the obstacle can be found by Equation (4).

\[
\theta_{\text{shift}} = \theta_n - \theta_{\text{min}}
\]  

(4)

Now check whether the \( P_i \) corresponding to the radial angle \( \theta_n \) is greater than \( P_{\text{th}} \). If it is less than \( P_{\text{th}} \), then the robot can take a shift of \( \theta_{\text{shift}} \). If it is greater than \( P_{\text{th}} \), then check for the next minimum of \( P_i \) and find \( \theta_{\text{shift}} \), the turning angle for the robot. Figure 7 shows the flow chart of check obstacle ahead algorithm.

![Figure 7: Flow chart of Check Obstacle Ahead algorithm](image)

### 9 SUMMARY

We have introduced the design of the robot that will be used for guidance of rescue teams. The mechanical design of the robot will be dependent on the requirements of the rescue team, whether they want the robot to be autonomous or remotely controlled. Therefore we have explained the mechanical design for both autonomous robot and remotely controlled robot. The robot will be doing a set of tasks such as checking the quality of the air whether it contains inflammable or poisoned gases, searching for living human beings, avoiding obstacles and navigating in the environment. The robot will gather all the information about the environment whenever a living human being is detected and sends all the data to the rescue team via a wireless network.

### 10 CONCLUSION

In this paper we have explained the hardware architecture, mechanical design and network architecture for a robot that can be used for guidance of rescue teams. We tried to show that such a robot can be built with a low cost. There are both pros and cons for such a robot design. The advantage of this design is the low cost and low power consumption because the robot don’t have a
video transmission or mapping functionality. But sometimes there is a need for more functions which this design doesn’t support like 2D or 3D mapping or may be a camera for seeing the situation in the affected area. All these extra functionalities can be added to the robot but it will consume more power, the video transmission through the network could take longer time and also the hardware parts needed for these functionalities are somehow expensive. So we think that this design is good and effective for rescue teams because it will give an overall picture about the dangerous elements that could exist in the affected area and also the robot will not be that expensive.

References


