Design of Micro Search-and-Rescue Robot System and Analysis of Its Application in Disaster Rescue

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Abstract. In recent years, many major natural disasters have occurred in the world, and among these major natural disasters, earthquakes are the most destructive. In the post-earthquake disaster areas, there are many ruins, which will reduce the efficiency of search and rescue and increase the risk of search and rescue. Some of the ruins were inaccessible to people, and it was difficult for search-and-rescue personnel to determine whether there were survivors. In order to improve the efficiency of search and rescue, reduce the risk of search and rescue, and reduce the investment of search-and-rescue personnel, micro search-and-rescue robots are designed. A variety of sensors are installed on the micro search-and-rescue robot for efficient search and rescue, a communication system is installed for data transmission, and a motor system is installed to overcome obstacles. This paper also discusses possible problems and proposes corresponding solutions. However, limited by existing technologies, some problems cannot be completely solved. In the future, the investment of micro search-and-rescue robots will save more lives.

Keywords: Search-and-rescue robots, sensors, communication system, motor system.

1. Introduction

Natural disasters have always been a great challenge for humanity. Over the past 10 years, the world has seen disasters large and small, including 13 deadly earthquakes in Iran that killed 30,000 people. In the rescue process, there is a problem of large rescue force but low rescue technology [1]. In the complex environment of different disasters, the traditional post-disaster rescue work is not only inefficient and costly, but also prone to secondary accidents such as rescue casualties. Therefore, it is particularly important to design a post-disaster rescue system based on micro-robots, which can detect the location of survivors through sensors, and cooperate with the changeable motion system to shuttle in the post-disaster environment to achieve comprehensive monitoring, and finally export the collected data through mature communication technology, which can well complete or assist in the development of rescue work, with certain practicality and market application prospects. However, after the application analysis of this post-disaster rescue system in different natural disaster scenarios, it is found that there are still some problems in this system, such as the sensor will be affected by environmental factors when detecting, communication will be limited by the size of the robot, and the complex terrain environment will also cause inconvenience to the robot's movement.

In view of these problems, this paper also puts forward corresponding solutions and prospects for future robot post-disaster search and rescue systems. It is believed that in the future, by improving this post-disaster rescue system, the number of casualties caused by natural disasters every year can be reduced, and the rescue work can be safe, efficient and low-cost.

2. Analysis of structure of micro-robotic system

To fulfill the requirement of search and rescue work, the system should consist of three main parts: sensors, communication system and motor system. The whole structure has been displayed in figure 1 below.

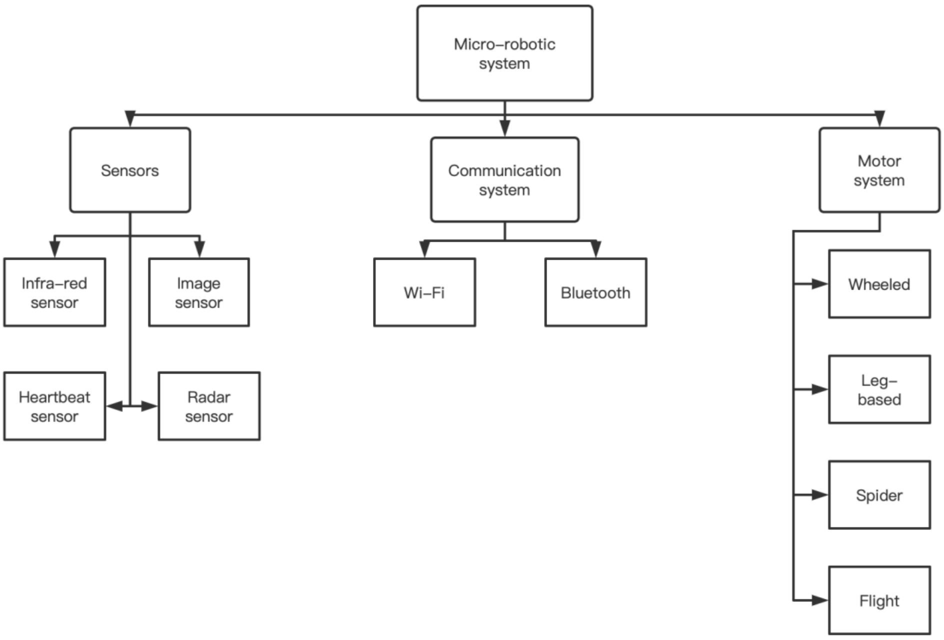

Figure 1. Structure of micro-robotic system (Photo/Picture credit: Original)

2.1 Sensors

A sensor is a device giving usable output in response to a specified measurand. But in order to make a better search and rescue of survivors after disasters, different kinds of sensors should be embedded into the robots, make sure the whole work is done completely and properly, no one is supposed to be left in the debris.

2.1.1 Infra-red sensor

The infra-red sensor is primarily composed of semiconducting materials that can absorb infra-red light. The absorbed light may alter the conductivity of semiconducting material and trigger a tiny electric current which is then amplified and filtered. Final signal of infra-red light created by target object can be thus withdrawn. When it is applied to the robot, it can help distinguish intensity of infra-red emitted by the survivors with that of surroundings and hence locate positions of human beings. The picture of infra-red sensor is shown in figure 2.

Figure 2. Infra-red sensor (Photo/Picture credit: Original)

2.1.2 Image sensor

The image sensor is a device that converts the light image on the photosensitive surface into an electrical signal proportional to the light image, the electrical signal can be used to form an image then. With the aid of image sensor, robots in the debris can transmit live image in real time so that rescue worker can fully understand condition of the wounded. Therefore, an efficient allocation of resources can be made. Figure 3 is displayed below to show what does an image sensor look like.

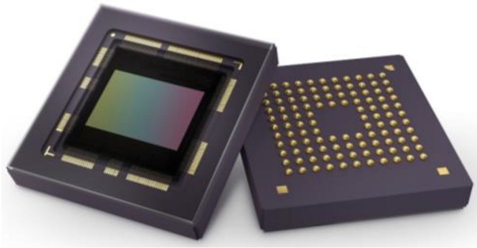

Figure 3. Image sensor (Photo/Picture credit: Original)

2.1.3 Heartbeat sensor

It is surprised that there is a special sensor used to detect heartbeat. The basic heartbeat sensor consists of a light-emitting diode and a detector. The heartbeat pulse causes changes in blood flow to different parts of the body. When tissue is illuminated by a light source, it will reflect or transmit light. Some light is absorbed into the blood, and transmitted or reflected light is picked up by a photo detector [2]. Obviously, it is advantageous in checking victims' health by examining their heartbeat and this does improve plan for further choices. The picture of heartbeat sensor has been shown below as figure 4.

Figure 4. Heartbeat sensor [2]

2.1.4 Radar sensor

First, it emits a brief microwave signal that travels through the air at high speed and bounces back at the object being detected. After receiving the reflected signal, the receiver can compute the position and distance of the object. Basically, it is used in combination with motion system like plane to adapt rugged debris. So, the whole motion can be more fluent and smoother, avoid any possible damage to robots. The image of radar sensor is shown in figure 5.

Figure 5. Radar sensor (Photo/Picture credit: Original)

2.2 Communication system

It is crucial to set up connection between robots and there are already project launched to implement. In post-disaster situations where fixed network infrastructure is unavailable and an emergency network needs to be quickly established, Project DUMBO (Digital Ubiquitous Mobile

Broadband OLSR) deploys Mobile Ad Hoc Networks (MANETs) [3]. To create a wireless communication network, several important technologies should be employed such as Wi-Fi, Bluetooth and WPAN. After weighing pros and cons, WPAN is not a good choice in this case because of its small range of working. In other words, Wi-Fi and Bluetooth are applicable.

2.2.1 Wi-Fi

The Wi-Fi works by transmitting the Internet connection to the device via a wireless router or access point, which receives the signal through the wireless network and sends the data back to the router or access point, thus enabling the Internet connection. It uses wireless signals to transmit data, enabling devices like micro robots to connect to each other and exchange information within a certain range. At last, Wi-Fi can help achieve targets like real-time video transmission, control command transmission, sensor data transmission, etc. [4].

Initially, a network structure should be established as a reliable Wi-Fi network structure is essential to ensure stable signal coverage in rescuing environment. This may require the installation of multiple wireless routers or access point to cover the entire area, which can be done by a drone in air. Secondly, a Wi-Fi module is needed on the rescue robot to allow connection to the wireless network. Ensuring robots' appropriate processing power and storage capacity to process and transmit data. Third, setting up a remote-control center that can receive sensor data sent by rescue robot so that rescuers can understand the environmental information at the rescue site. Moreover, it can give control commands back, the robot then perform the corresponding action after receiving the command such as moving, grasping object, etc. This can be managed by AI that connects to the network via Wi-Fi. Last but not least, data encryption and security should be taken seriously. Considering the importance and confidentiality of the rescue mission, it is necessary to take the security of the Wi-Fi network serious. This can be achieved by using data encryption technology to protect the confidentiality and integrity of the communication content.

2.2.2 Bluetooth

The same goes for using Bluetooth to communicate when Install Bluetooth module instead. However, both techniques have their own advantages and drawbacks. Wi-Fi usually provides a higher transmission rate and supports a larger amount of data transmission. It is also superior to Bluetooth in terms of communication range. Wi-Fi also enables interconnection and communication between multiple devices since it can connect them at the same time. For Bluetooth, lower power consumption and easy paring will be advantageous.

2.3 Motor system

The robot should have a perfect motion system in order to cope with complicated terrain. On one side, the rescue could be more efficient and faster. On the other hand, the system avoid the robot from being damaged. According to different terrain, robot should equip with diverse motor system. For example:

2.3.1 Wheeled system

The rescue robot is equipped with wheels and driven by electric motors. The wheeled system can achieve straight line travel, turning, and smooth movement, suitable for indoor and flat ground rescue missions, which is shown in figure 6. But in case like earthquake, this is not a good choice.

Figure 6. Wheeled robot (Photo/Picture credit: Original)

2.3.2 Leg-based system

The leg-based system mimics the way organisms move, using mechanical legs to achieve movement. This is a novel, multi-legged hybrid robot with a dependable control system. Asgard, a hybrid wheel-legged robot inspired by quadrupeds, served as the method's test subject. The system can move at high speeds on flat ground and can handle a variety of stairs, particularly uneven terrain, and other obstacles thanks to the adaptive compliance controller [5]. The figure 7 below shows appearance of a leg-based robot.

Figure 7. Leg-based robot [5]

2.3.3 Spider system

The spider system combines the features of wheel and leg, with multiple joints and wheels. The system enables a variety of movement modes, including straight line travel, turning and obstacle clearing. Spider systems usually have better flexibility and adaptability which are suitable for complex rescue environments. Figure 8 has shown what a spider robot looks like.

Figure 8. Spider robot (Photo/Picture credit: Original)

2.3.4 Flight system

In some rescue scenarios, flight systems may be necessary. Rescue robots can be equipped with rotors or jet engines to achieve vertical take-off and landing and air flight. The flight system can quickly reach hard-to-reach areas for aerial monitoring, supplies delivery and other tasks. Furthermore, if Wi-Fi or Bluetooth is installed, it can act as a junction in communication system for anti-interference signal and data transmission. The drone has been shown in figure 9.

Figure 9. Drone (Photo/Picture credit: Original)

3. Case study

3.1 Earthquake scene

About 1,000 catastrophic earthquakes occur around the world every year. In the past 20 years, there have been many major earthquakes in China, such as the Wenchuan Earthquake. After the earthquake, there were many high-risk areas in the disaster area, which brought great difficulties to the search and rescue work and made the search and rescue efficiency low. But micro search-and-rescue robots could make a big difference. At present, many researchers have also made forward-looking research on earthquake search and rescue robots.

Tiangong University's Ning Wang used the STM32F103RET6 as the path-finding model robot's primary control chip, finished the task of allocating resources and designing the hardware circuit for the main control part, and discovered a method for controlling the motion motor and the corresponding drive circuit. Through pertinent robot task process trials, the implementation process of the terminal oblique sprint algorithm calculation technique ultimately produced some respectable outcomes [6].

3.2 Mudslide scene

Mudslides refer to the phenomena in mountainous areas or other areas with deep valleys and steep terrain, caused by heavy rain, snowstorm or other natural disasters, where mud, stones, etc. are mixed with a large amount of water and slide along slopes or valleys under the action of gravity. In mudslide disaster areas, the search and rescue are still a dangerous thing, and search-and-rescue robots can reduce the risk of the search and rescue.

Yujuan Zhang from Hebei University of Technology proposed a continuum search and rescue robot. To adapt to the non-structural environment created by catastrophes, which has many barriers and a small working area, the robot has to have exceptional bending ability. Additionally, a range of rescue function modules may be added to it so that the robot and the command console at the catastrophe site can share information. This model has been driven to confirm the accuracy of the theoretical analysis of robot kinematics [7].

4. Deficiencies analysis and optimization direction

4.1 Disadvantages

Of course, micro search-and-rescue robots have their limitations. First, the sensors on the robots can be subject to various types of interference. For example, the infrared sensor may be disturbed by itself and the outside world. In general, there are two types of interference sources for active through-beam infrared sensors: one is produced by external interference from things like sunshine, leaves, etc., and the other is generated by interference from infrared rays passing between infrared sensors. The issue of external interference can essentially be resolved by upgrading hardware, however the issue of infrared cross-interference between infrared sensors is challenging to resolve [8].

Second, the size of the micro search-and-rescue robots is very small, so the communication system on the robots cannot be made very large, which will cause communication problems. In the post-earthquake disaster area, there will be many thick ruins, and the communication signals of the tiny search-and-rescue robots may not be able to penetrate the thick walls. A signal that can penetrate thick walls requires relatively high power, and a high-power communication system must require a large volume and consume more energy, so a high-power communication system cannot be carried on a micro search-and-rescue robot. In addition, the communication system of the robot may be subject to various disturbances.

Third, different disaster areas will have different terrains, and these terrains will cause some movement problems for the micro search-and-rescue robots. For example, there are usually a lot of ruins in earthquake-stricken areas, and the robot needs to have the ability to fly or crawl to enter the house from the gaps in the ruins. In mudslide-stricken areas, robots must have a relatively high climbing ability.

4.2 Solutions

In order to solve the anti-jamming problem of infrared sensors, the method based on optimization algorithm can be adopted. An anti-jamming design based on an improved PID algorithm is suggested to increase the accuracy and stability of the sensor. Using the optimized PID algorithm to alter the parameters, it is possible to achieve constant temperature control; when the constant temperature control system has been adjusted, the stability of the sensor's final output has significantly increased [9]. Another way is based on the robust anti-jamming method. First, a continuous strong jamming detection approach is employed to precisely pinpoint where the jamming occurs. The occlusion jamming is then handled by the particle filter-based trajectory prediction method. Lastly, testing the suggested strategy using simulated data. The simulation results demonstrate that the anti-jamming strategy has higher resilience and accuracy compared to the existing anti-jamming method [10].

To solve communication problems, a system based on RSSI can be used. The system, which also employs drones for communication, subsequently transmits the data packets to other robots [11]. In order to solve the anti-jamming problem of the communication system, an algorithm based on reinforcement learning can be adopted. The Q-Learning algorithm has been proven to have a good performance in sweeping, sinusoidal, and Gaussian random jamming [12].

To overcome the problems caused by different terrains, a micro search-and-rescue robot scheme based on flying insects can be adopted. This robot has both a flying system and a walking system [13]. The flight system consists of many propellers, and the walking system consists of multiple pairs of crawlers. This kind of robot can fly over the target at a relatively fast speed, and then use the walking system to search and rescue. This robot can also use the flying system to cross obstacles when encountering steep slopes. The robot of this scheme can adapt to most terrains.

5. Conclusion

This paper introduces the system structure of the micro search-and-rescue robot, which is composed of various sensors, the communication system and the motor system. Sensors mainly include infra-red sensors, image sensors, heartbeat sensors and radar sensors. The communication system mainly use Wi-Fi. The motor system consists of the wheel system, the leg-based system, the spider system and the flight system. In addition, this paper also introduces the current research on search-and-rescue robots through two scenarios, points out the possible shortcomings of micro search-and-rescue robots and proposes solutions. Potential disadvantages include susceptibility to jamming sensors, communication issues, and terrain adaptation issues. The solution includes using algorithm, RSSI, Q-Learning and so on. However, due to space limitations, this paper does not give the details of the solutions.

In the future, more and more new technologies will emerge, and these new technologies may be applied to micro search-and-rescue robots to completely solve existing problems that cannot be solved at present. It is hoped that the micro search-and-rescue robots can make progress as soon as possible and be used in various disaster areas. The application of micro search-and-rescue robots will save many lives.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Abbasi Mohsen, Salehnia M Hossein. Disaster medical assistance teams after earthquakes in iran: propose a localized model. Iranian Red Crescent medical journal, 2013, 15 (9).

[2] Xiufeng Yang, Zhihao Chen, Chia Ser Ming Elvin, Lam Hong Ying Janice, Soon Huat Ng, Ju Teng Teo, Ruifen Wu. Textile Fiber Optic Microbend Sensor Used for Heartbeat and Respiration Monitoring. IEEE Sensors Journal, vol. 15, no. 2, Feb. 2015.

[3] Kanchana Kanchanasut, Thirapon Wongsaardsakul, Manutsiri Chansutthirangkool, Anis Laouiti, Hajime Tazaki, Khandakar Rashedul Arefin. DUMBO II. Internet Engineering, 2008.

[4] Jiaojiao Wang, Goujin Huang, Zhen Shao. Performance Evaluation of Wi-Fi 6 and Technology Prospects of Wi-Fi. 2022 International Conference on Information Processing and Network Provisioning (ICIPNP), 2022.

[5] Eich, Markus, Grimminger, Felix, Kirchner, Frank. Adaptive compliance control of a multi-legged stair-climbing robot based on proprioceptive data. The Industrial Robot, 2009, 36 (4).

[6] Ning Wang. Research and Design of Miniature Earthquake Search and Rescue Pathfinding Model Robot. Tianjin: Tiangong University, 2021.

[7] Yujuan Zhang. Kinematics Analysis and Simulation of A New Continuum Robot for Search and Rescue. Shijiazhuang: Hebei University of Technology, 2013.

[8] Jingjing Zhao. Research and Application of Signal Interference Avoidance Between Infrared Sensors. Yangzhou University, 2018.

[9] Zefang Li, Desheng Zhang. Design of Anti-Interference Sensor Based on PID Algorithm. 2022 6th Asian Conference on Artificial Intelligence Technology (ACAIT), 2022.

[10] Hong Cui, Zhongling Liu, Qiang Zhang, Feng Liu. An Anti-jamming Approach for Infrared Target Tracking Using Trajectory Prediction and Network Flow. 2018 IEEE 4th International Conference on Computer and Communications (ICCC), 2018.

[11] Tristan Brodeur, Paulo Regis, David Feil-Seifer, Shamik Sengupta. Search and Rescue Operations with Mesh Networked Robots. 2018 9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), 2018.

[12] Zixuan Zhang, Qinhao Wu, Bo Zhang, Jinlin Peng. Intelligent Anti-Jamming Relay Communication System Based on Reinforcement Learning. 2019 2nd International Conference on Communication Engineering and Technology (ICCET), 2019.

[13] Jin Hu, Yuxin Liang, Xiumin Diao. A Flying-Insect-Inspired Hybrid Robot for Disaster Exploration. 2017 IEEE International Conference on Robotics and Biomimetics (ROBIO), 2017.