SLAM-based Navigation Technology for Rescue Robots in Post-disaster Scenarios

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Abstract. In order to solve the problems of difficulty and high-risk factor in implementing rescue after disasters, this paper designs an intelligent rescue robot autonomous navigation system based on LIDAR synchronous positioning and map building, with a view to achieving autonomous navigation of robots in complex post-disaster scenarios to complete rescue tasks. Firstly, the autonomous navigation system senses the scene by LiDAR and uses gmapping algorithms to construct a map of the post-disaster environment. Secondly, adaptive Monte Carlo localization algorithm is used to achieve robot localization based on radar and odometer data. Then the robot rescue work path is planned to use the Dijkstra algorithm. And TEB local planning path algorithm is used to control the robot. Finally, to verify the reliability of the autonomous navigation system designed in this paper, the ROS system software framework is used as the basis. The SLAM map construction, global path planning, and local real-time obstacle avoidance are tested practically under the scenario to ensure that the autonomous navigation of the mobile robot meets the requirements.

Keywords: Laser SLAM; mobile robot; optimal path planning; autonomous navigation.

1. Introduction

Though people won't want to admit that, it is a truth that the quantity of terrible disasters has risen since 1970, and fire disaster is definitely one of those, bringing irredeemable loss naturally and financially [1]. According to the US Fire Administration, the fire cases happened in the US reached 372,000 and has taken 11,825 injuries and 2,615 deaths,which has a 10% increase compared to a decade ago [2]. Besides, after 10 years from 2011, overall economy loss brought by residential fires has increased by 10%, reaching 8,604,400,000 dollars. The figure below clearly shows the change of numbers of deaths and the trend line has also been plotted.

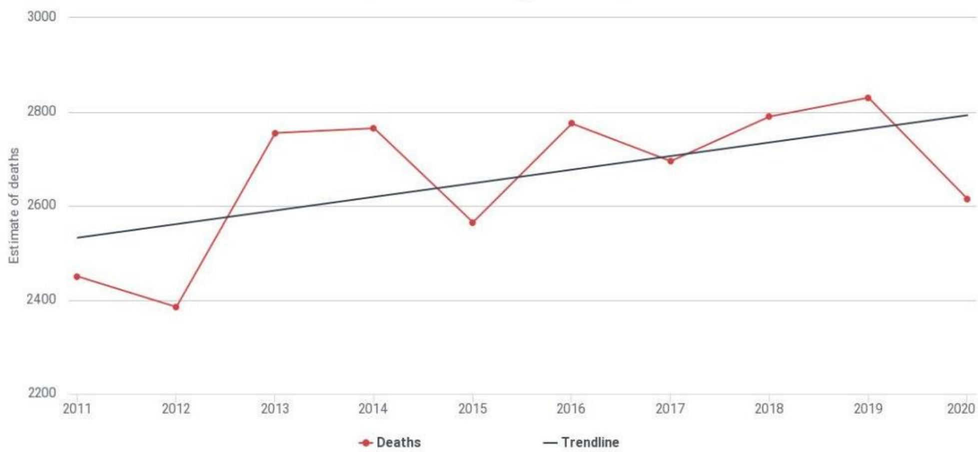

Fig 1. Residential building fire deaths [2].

The rise of rescue robots is the best sign of this tremendous change. However, the complex and narrow environment caused by the earthquake has brought great difficulties to rescue. Through data review, it is noticed the advantages of rescue robots such as small size, high sensitivity, high temperature resistance, and sustainable operation, is of great help in finding the location of the trapped and transporting materials [3].

Currently, countries around the world are still paying great attention to the research of rescue robots, especially with the development of new technologies such as human-computer interaction, the use of rescue robots has rapidly expanded [4].

The concept of robotic urban search and rescue (USAR) has been brought up since the last century and since then scientists all over the world are putting effort on its development. By now, various types of rescue robots were on the stage. A deformable crawler structure was brought up by a well-known platform Quince, aiming to adjust complicated terrains using semi-autonomous control algorithms [5]. However, the ability to locate the patient is just the first step while operating rescue. Field diagnosis robots are invented to determine the health situation of the patients and immediately take essential actions to treat the injured and work as an assistant along with the doctors [6]. One kind of field diagnosis robot named FASTele mainly focuses on internal hemorrhage, which is a common injury after the fire [7]. The robot makes sure that the ultrasonic images of a patient can be transferred to the doctor for efficient treatment, which significantly increase the life expectancy [8]. Sometimes evacuation robots might be used to transfer the injured to different safe spots. A team at the Robotics and Mechatronics Lab at Virginia Tech has invented a rescue robot Semi-Autonomous Victim Extraction Robot (SAVER) using a tilted stretcher to carry the wounded and it could use the Highly Dexterous Manipulation System (HDMS) to control its gesture and then hold the head and neck of the wounded still till they reach the casualty collection area [9]. Whatever robot used, the point is to provide a quicker response system, which means to provide a lower communication delay between the robot and the doctors or rescue team.

Although the fire rescue robot is recognized and used for its ability to perform rescue tasks continuously. It can replace rescuers to go deep into dangerous environments and carry the appropriate tools for life detection and rescue. However, there are still problems in its application that are affected by the high temperature environment of fires and collapse, leading to unsatisfactory rescue efficiency. Therefore, based on the disaster scenario of SLAM, the navigation technology of the rescue robot is improved to make it more adaptable to the complex environment of the fire scene and improve the rescue efficiency.

The purpose of this paper is to make it possible for a robot to perform the function of building a map in a post-disaster scenario and to reach a target point by autonomous navigation. Section II describes in detail the working environment and design process of the autonomous navigation system designed in this paper. Section III presents the methodology of this paper, constructs the post-disaster scene map by LiDAR, and designs the robotic autonomous navigation system by ACML algorithm, Dijkstra algorithm and TEB algorithm. Section IV gives the simulation results of the robotic autonomous navigation system in Gazebo environment and proves the effectiveness of the navigation system. Finally, Section V concludes the paper.

2. System Overall Design

2.1. Analysis of Working Environment

Fires can be induced by illegal use of electricity, careless use of fire, or even bad weather. And in fires, high temperature and oxygen deprived environment are the main factors that cause casualties [10, 11]. In most cases, fires require firefighters to wear equipment to go deep into the fire for rescue, and their rescue difficulty and danger factor are extremely high. In contrast, rescue robots can replace humans for rescue and life detection activities. In the process of performing the task, the robot not only needs to plan the path reasonably according to different fire scenarios, but also needs to avoid the obstacles falling in real time. Therefore, a reliable navigation system is the key for fire rescue robots to complete rescue tasks independently.

2.2. Design of Robot Navigation System

The navigation system for the fire rescue robot is shown in Fig. 2 which mainly includes three parts: the control layer, the data processing layer and the drive layer. The control layer implements the task of rescuing trapped people and monitoring the robot's working status based on the VMware system. The PC sends the target point coordinates and achieves tasks such as rescuing trapped people or transporting materials through multi-point navigation. The data processing layer is developed based on the Ubuntu 18.04 microcomputer, equipped with the Robot Operating System (ROS), and installed with gmapping, AMCL, Dijkstra and TEB algorithms. gmapping is used for map building. ACML algorithm confirms the robot's position in the current map based on radar datas and odometer datas. Dijkstra algorithm plans the robot's working path and TEB algorithm controls the robot to run according to the planned route.

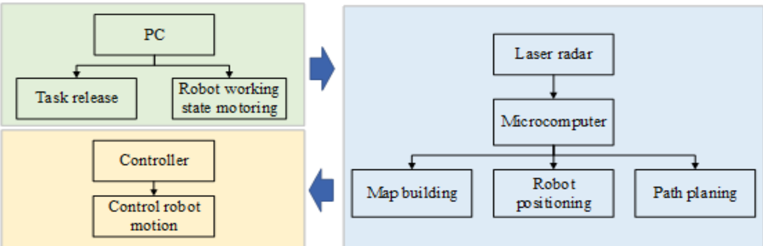

Fig 2. Robot navigation architecture.

3. Methodology

3.1. Post-disaster Scenario Map Construction

To successfully simulate a situation after an earthquake, it is of great importance to catch some basic features of a real-life earthquake including randomly scattered rocks and complex paths. It is a basic need for the robot to automatically plan a route that takes least time and danger. Gmapping-slam algorithm has been used in our project to accomplish this. Based on Rao-Blackwellized Particle Filter, Gmapping is one of the most widely used method while planning routes and it is capable of scanning obstacles on the corner of the map [12]. Plenty of obstacles are set in the map to simulate countless rocks along the way of the robot.

3.2. Principle of Autonomous Robot Navigation

The functional implementation of autonomous robot navigation consists of two parts: robot localization and path planning. In which, the robot localization in a 2D map is first implemented using the AMCL algorithm. Then the global path planning is implemented by Dijkstra algorithm. Finally, the local path planning is realized by TEB.

The AMCL localization algorithm is based on particle filtering to determine the robot's position in the established environment map [13]. The structure of the AMCL algorithm is shown in Fig.3.

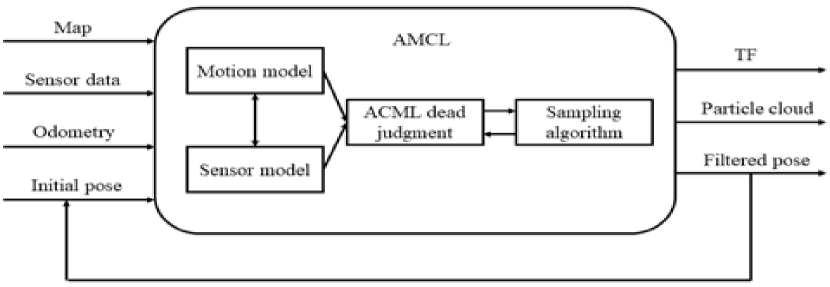

Fig 3. AMCL algorithm structure diagram.

First, the particles representing the robot's poses are randomly distributed in a known environment. Second, a motion model is built to predict the poses of all random particles based on IMU data and odometer data. Then a measurement model is built to update the weights of all random particles based on the LiDAR data, and the final convergence position of the particles is the actual position of the robot in the map. If the initial position of the robot is unknown or incorrect, more random particles are injected globally at this time. The robot's moving particles are updated again to reposition the robot in the created map.

The Dijktra path planning algorithm calculates the shortest path from the starting position to the target point of the robot. The algorithm uses a breadth-first search strategy to set up multiple nodes and traverse the nearest and unvisited nodes from the starting position. During the traversal process, the nearest point from the starting position to the current position of the robot is iterated continuously until it reaches the target position.

The TEB algorithm initializes the given global path to obtain a sequence of poses based on time intervals, then inserts new poses and removes the already initialized ones [14]. The information of path points and obstacles are updated to establish the hypergraph form of the bit pose sequence, time sequence and constrained objective function. Finally, the TEB trajectory is solved iteratively, and the motion trajectory of the robot is calculated based on the adjacent trajectory points, so that the robot reaches the target point.

The robot navigation framework is shown in Fig. 4. The localization and path planning functions of the robot are implemented using the AMCL and move-base function packages provided in ROS. First, the robot is controlled to move in the established post-disaster environment, and a map of the post-disaster environment is created using the gmapping algorithm as a global cost map. Then, the robot uses the Dijkstra algorithm for global path planning according to the target point set by the host PC to obtain the optimal route from the robot to the target point, and uses this route as the global route for the robot motion. However, in realistic scenarios, there will be aftershocks and other situations after the fire. In order to avoid the interference of moving obstacles that the robot may face, local cost maps are introduced based on the real-time data from LiDAR and local paths are planned for avoidance using the TEB algorithm.

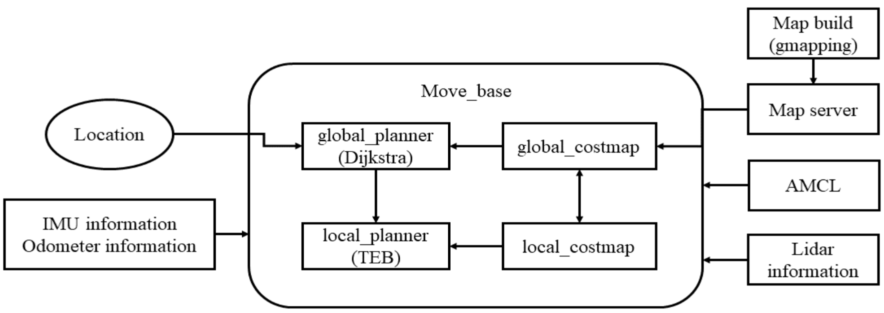

Fig 4. Robot navigation block diagram.

4. Experiment and Analysis

4.1. Simulation Environment

ROS (Robot Operating System) is an open-source meta-operating system for robotics. It contains a rich set of tools and so far, has a large ecology capable of handling rich application scenarios, enabling effective and convenient robot development, simulation, environment awareness, and control.

Gazebo is a 3D dynamic simulator capable of accurately and efficiently simulating crowds of robots in complex indoor and outdoor environments. Similar to game engines that provide high fidelity visual simulations, Gazebo provides high fidelity physical simulations with a full set of sensor models and a very user and program friendly interaction. Gazebo accurately and efficiently simulates the functionality of robot work in complex indoor and outdoor environments, providing an excellent simulation environment for robots developed using ROS.

In this paper, a map simulating a post-disaster scenario is constructed in Gazebo in conjunction with the application scenario, as shown in Fig. 5.

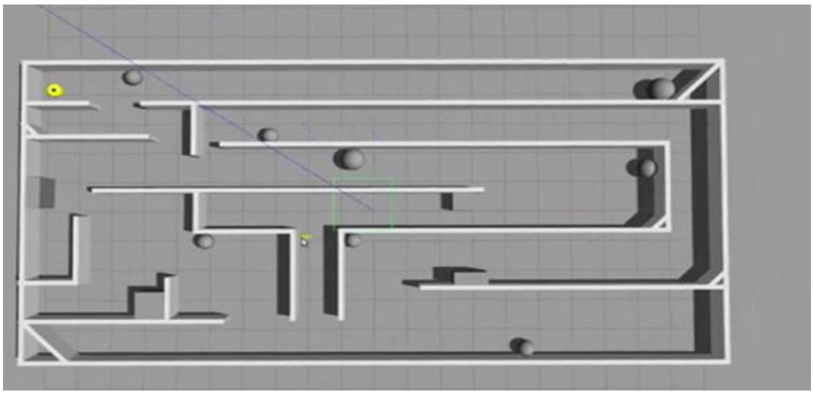

Fig 5. Post-disaster scene simulation map.

4.2. Robot Navigation Experiment

This experiment fixed the starting point of the vehicle and randomly selected the end point, as shown in Fig. 6. In the process of robot mobile navigation, the path planning process needs to use two function packages in the ROS system to achieve it. Firstly, use the ACML positioning function package. In the Rviz simulation environment map, the particle cloud gradually moves closer to the correct position as the robot progresses, as shown in Fig. 7. Secondly, path planning requires calling move-base function package in the ROS system, combined with the TEB algorithm, accurately evaluates the optimal path to achieve path planning from the start position to the end position and autonomous navigation and operation of the robot.

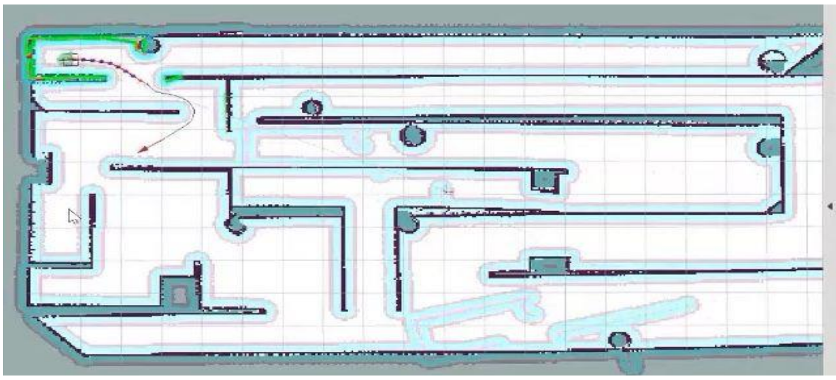

Fig 6. Starting point.

Fig 7. Particle cloud.

After completing mapping and positioning, import the successfully mapped yaml file into the launch file of the navigation framework to achieve path planning and autonomous navigation experiments for the mobile robot. During the experiment, observe the degree of overlap between the laser radar scanning points in the simulation environment map in Rviz and the obstacles, and judge the robot's position in the current map. It can be seen that the obstacles in the map highly overlap with the data of the laser radar scanning points as shown in Fig. 8. At the same time, we also use a cost map to expand the map. As shown in Fig. 9, the global expansion radius is 30 centimeters and the local expansion radius is 15 centimeters, preventing the robot from colliding with obstacles and improve operational accuracy.

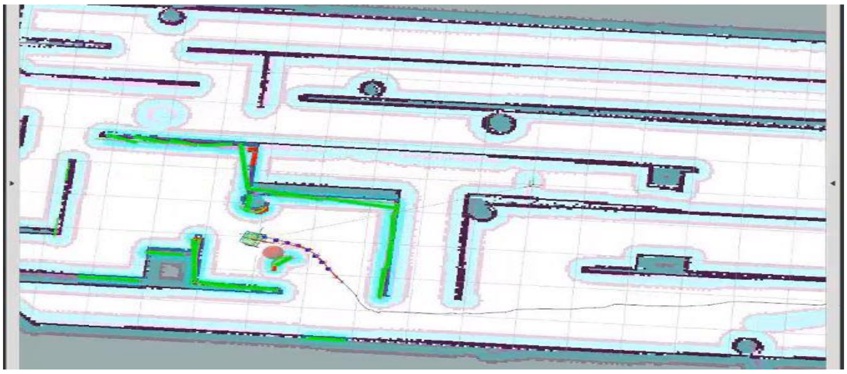

Fig 8. Laser radar scanning points.

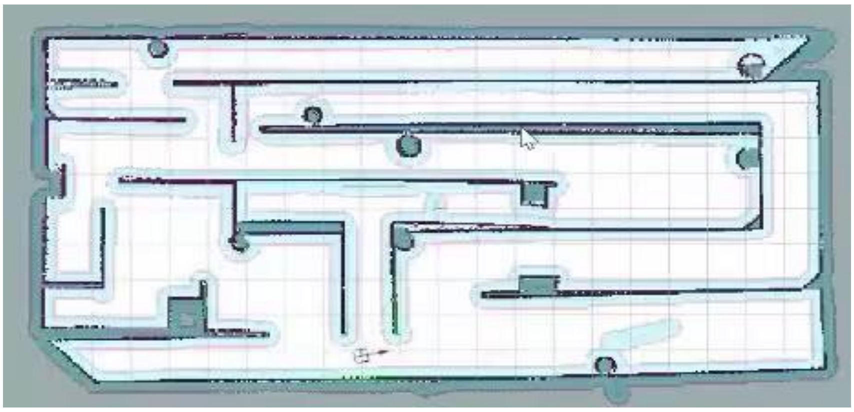

Fig 9. Expanded map.

With the help of a variety of algorithms, this robot can evaluate the best path and navigate autonomously. After many tests, the robot can basically complete the task of avoiding obstacles and reaching the end. The experiment confirms that the robot can be applied to the fire rescue scene and has certain reference value.

5. Conclusion

In this paper, we propose an autonomous navigation system for robots that can be applied in post-disaster scenes. Firstly, in order to understand the post-disaster scene, a map of the post-disaster scene is constructed by laser SLAM using the gmapping algorithm. Then, the robot was localized by AMCL algorithm to get the robot location. Then, the Dijkstra algorithm was used to plan the path so that the robot could reach the target point in the shortest time. To approximate the unexpected situation in a real post-disaster scenario, the TEB local path planning algorithm was used to control the robot to avoid the sudden obstacles. Finally, simulation results in Gazebo demonstrate the effectiveness of the robot autonomous navigation system designed in this paper.

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