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Multi-sensor Fusion Glass Detection for Robot Navigation and Mapping

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Abstract— **Simultaneous Localization and Mapping(SLAM) has become an essential function of the robot, but existing SLAM algorithms cannot work robustly and stably in a glass environment, especially when using low cost sensors. In this paper, we propose an efficient and robust method to detect glass based on multi-sensor fusion technology of ultrasonic and laser scan data. By integrating the glass detection algorithm with SLAM, we have improved an existing SLAM algorithm to provide more accurate mapping and localization results. On this basis, we proposed a new robot navigation method and experimented on the robot platform, the experiments show that the new navigation frame increased robot navigation efficiency by 11% in glass environment.**

I. INTRODUCTION

For any robot device, navigation in its environment is important. Robot navigation can be defined as the combination of the three fundamental competences: self-localization, path planning and map building. Self-localization and map building can be merged into one question, called simultaneous localization and mapping (SLAM). Most of state-of-art SLAM algorithms [1-4] based on laser lidar can provide highly accurate map. Because laser lidar measures the distance between obstacles and robots by light reflection, when in dealing with transparent objects such as glass panel [5], most laser signals without being reflected to the laser sensor, laser rangefinders sensor will detect nothing. On the contrary, glass materials are used in modern buildings, especially in indoor scenes (Fig. 1 a). In this kind of environment, there are some problems caused by glass detection failure (Fig. 1 b), bad map [6,7], collision with glass and bad localization accuracy. These problems have caused the robot to not work properly.

Accurate and robust glass detection is the key to solve these problems. Classical SLAM algorithms use ranges information of laser rangefinders to obstacle, when laser rangefinders can't provide correct distance, the algorithm will not work normally. [5,7,8] measuring the intensity of reflected laser signals from the normal incident angle to the panels, by looking for areas with large gradients in the intensity data, the algorithm will think that there is glass in these areas, record the location of glass, the slam system is working at the same time. Integrate glass location with SLAM, we get a more accurate map. The process of find glass is compute consumes a lot of computing resources and memory, limit the application in embedded environment. Another important method is sensor fusion [9-11]. Sensor fusion is the combination of sensor data or data from different sources, making the information more reliable than using these sources alone [9]. When different sensors measure the same obstacle, they can verify each other and improve measurement accuracy. The comprehensive utilization of sensors data will improve mapping and localization performance dramatically [12]. For example, ultrasound sensor is an acoustic instrument, the presence of transparent glass does not affect its normal operation, so we can fuse laser rangefinders and ultrasound data lies in their complementary character.

The intensity data of low-cost lidars has no obvious features when facing the glass, methods based on lidars intensity data are not applicable in this case. Therefore, glass detection based on sensor fusion is the only viable method when using low-cost lidars.

In this paper, we propose an efficient and robust method to detect glass panels based on sensor fusion of ultrasound and laser lidar data. By integrating the glass detection with SLAM, we have improved an existing SLAM algorithm to provide more accurate mapping and localization results. We propose a new navigation framework that improves the original navigation framework, the frame uses two maps for localization and path planning respectively, achieving more accurate localization and path planning. We tested the improved SLAM algorithm and navigation framework on our robot platform.

(a) A corridor with large glass panels.

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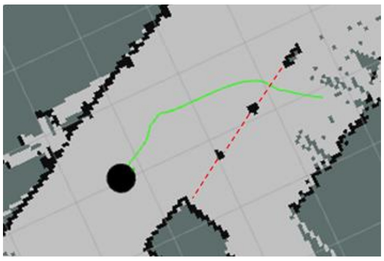


(b) Bad map generated by Gmapping SLAM.

Figure 1. Impact of environment with glass panels on robot.

In the following sections. Section II introduces the basic principles of the glass detection algorithm based on sensor fusion. Second III will introduce the improved SLAM algorithm and navigation frame. In the Section IV, experimental results are given. Finally, Section V concludes the papers.

II. SENSOR FUSION GLASS DETECTION

In general, laser rangefinders sensor is used to build maps, and ultrasonic sensors are used to avoid obstacles. Most robots have both laser rangefinders and ultrasound sensors. When the robot is operating in a glassed environment, if only lidar range information is considered, the robot will think that the glass area is accessible, which will cause collision with glass panels. Ultrasound sensor can detect glass normally in the situation because of it is an acoustic sensor. Therefore, the ultrasonic sensor can be used as a supplement to the laser radar, considering the data of the two sensors synthetically and obtaining an accurate map in a glass environment.

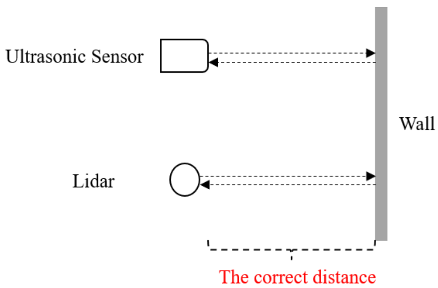


Figure 2. Robot sensors detect wall.

First, we assume that the data from both sensors are reliable. When encountering normal obstacles (Fig 2), laser rangefinders and ultrasonic sensors measure the same obstacle distance. when there is a glass plane in front of the robot, unless the lidar's laser beam is exactly perpendicular to the glass, lidar will measure the distance of obstacles behind the glass, the ultrasonic sensor can still read the distance between the robot and the glass, there will be a difference between the ultrasonic sensor data and laser rangefinders data (Fig 3).

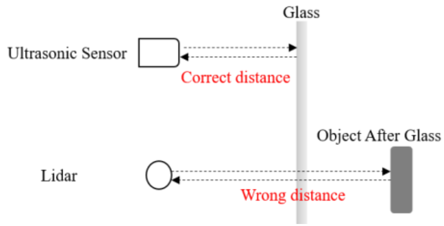


Figure 3. Robot sensors detect glass.

We can continue to track the difference between the two sensor measurements in the direction of the ultrasonic sensor and the size of the difference can indicate the confidence of the detected glass. When the difference is 0, we think that no glass was found. When the difference is large, we think that the glass has been detected. Let s represents lidar data:

$$s = \{s_i | i = 1,2 \dots N\}. \quad (1)$$

z represents ultrasonic sensor data:

$$z = \{z_j | j = 1,2,3\}. \quad (2)$$

Take the data of the laser radar in the direction of the ultrasonic sensors and subtract it from the ultrasonic data.:

$$\Delta_k = \{s_i - z_j | i = 300,360,420, j = 1,2,3\}. \quad (3)$$

According to the difference between the two sensors, we can judge whether the glass is detected. In the experiment, we achieved the best result when the threshold is 0.5.:

$$f(\Delta_k) = \begin{cases} Glass, \; if \; \Delta_k \geq threshold \\ Not \; Glass, if \; \Delta_k < threshold \end{cases}. \quad (4)$$

III. IMPROVED SLAM AND NAVIGATION FRAME

A. Improved SLAM with Glass Detection

If there is glass in the environment, the measurement data of ultrasonic sensors and laser rangefinders will be significantly different. Because the ultrasonic sensor has directionality, we can calculate the position of the glass through the data of the sensor, record the position of the glass while the robot is running, at last, add the recorded glass position to the map generated by the existing SLAM algorithm, we can get more accurate maps.

Gmapping is probably most used SLAM algorithm [13], it uses Rao-Blackwellized particle filter to Generate maps with lidar and robot position data. We modified the code of the gmapping SLAM and added a glass detection function to it. The robot operating system(ROS) is a flexible framework for writing robot software [14]. We create a ROS node to run the glass detection algorithm. The node performs the following processing:

(1) Subscribed to the laser rangefinders, ultrasonic sensor, robot position and map topic.

(2) The glass detection algorithm uses ultrasound and lidar data to calculate the confidence level of the glass at the current location to determine if glass is present.

(3) If glass is found, calculate the position of the glass relative to the robot based on the body information of the robot, otherwise, return to (1).

(4) Combine the position information of the robot to calculate and record the position of the glass in the global map.

(5) Superimpose glass information on the original map to get an accurate map.

Through the above steps, we can get a map of the original gmapping SLAM algorithm and a map that integrates glass location information.

B. Improved Navigation Frame

Robot navigation means that the robot can determine its own position in its global coordinate system and then plan the path to a certain target position [15]. In order to navigate in its environment, the robot needs to represent the environment map and the ability to interpret this representation. In an indoor environment, since the environment is basically fixed, we usually use the SLAM algorithm to build the environment map and then run the robot's navigation algorithm on this basis.

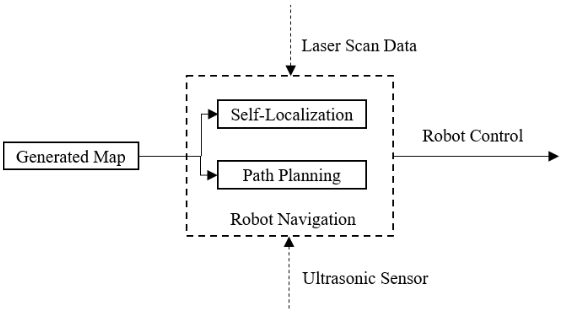


Figure 4. Classical Robot Navigation Frame.

Robot navigation includes self-localization and path planning [15]. Robot gets its position by matching the sensor data with the map that has been obtained, limited range of ultrasonic sensors, we rely on lidar data usually. Robot path planning includes global path planning and local path planning, global path means that the robot plans a communicative path in the map that has been obtained, local path planning means that the robot avoids obstacles in real time during the operation to the target position. The original map retains abundant environmental information and can ensure the positioning accuracy of the robot. However, the original map and the actual environment cannot be completely coincided, for example, the robot may plan a path through the glass panel, causing a collision between the robot and the glass. The original map must be modified to ensure that the map is consistent with the actual environment, but this will reduce the positioning accuracy of the robot.

Classical navigation framework uses a single map for robot self-localization and path planning [16], which cannot guarantee the accuracy of robot self-localization and path planning. We propose a new navigation framework to solve this problem, using localization map to locate robots and planning map to complete robot path planning. Planning map is a subset of localization, the robot gets a precise position by localization map and planning a safe and efficient path in the planning map. The new navigation framework ensures safe operation of robots in glassy environments.

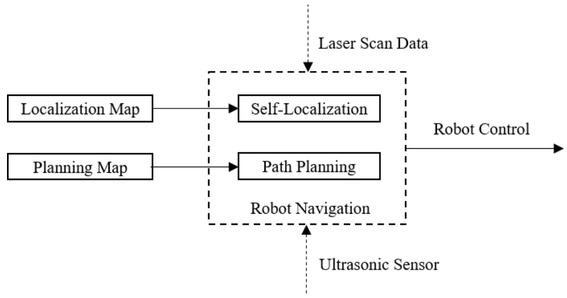


Figure 5. Improved Robot Navigation Frame.

IV. EXPERIMENTS

The robot platform is equipped with laser rangefinders, IMU and four ultrasonic sensors. Laser rangefinders fixed in the top center of the robot, it can stable provides range and intensity data at 7 scans per second, each scan emits 720 data points. Three ultrasound sensors are fixed in the front of the robot and the other one is directly behind. In the front ultrasonic sensors, one of them is fixed in the directly front, and the other two are respectively at an angle of 30°with the directly front one.

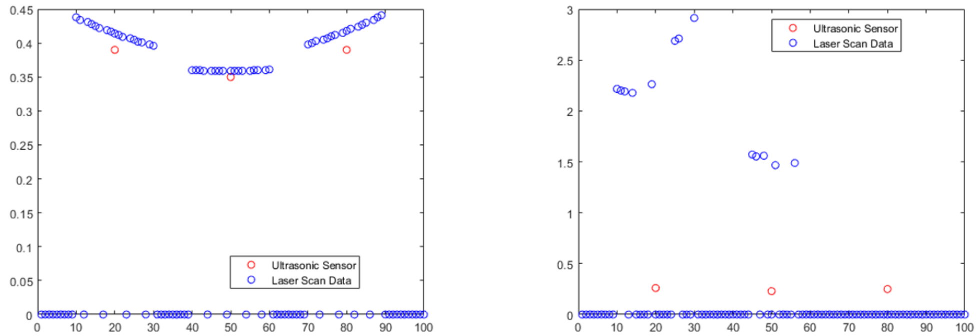
A. Glass Detection Experiments

(a) Wall. (b) Glass.

Figure 6. Experiment environment.

We chose a corridor as our experimental site, where about 50% of the glass (Fig. 6). We chose a wall and a glass as typical scenes and collected robot sensor data. The beam angle of ultrasonic sensors we used is 30 degree, so we selected laser lidar data in the range of the beam angle. Measurement shows that the real data is the same as the ultrasonic sensor data.

From the figure (Fig. 7), the red cycle indicates ultrasonic sensor data and the blue cycle indicates laser lidar data.



(a) Sensor data in the front of wall. (b) Sensor data in the front of glass.

Figure 7. Sensor data in different environment.

When the robot was in front of a normal wall (Fig.7 a), the measurement results are almost the same, which means both laser rangefinders and the ultrasonic wave have measured the correct obstacle distance. When there is a glass plane in front of the robot (Fig.6 b), from the figure (Fig. 7 b), in the direction of the left and middle sensors, laser scan data is much bigger than the ultrasonic sensor data. In the direction of the right sensor, laser scan data is zero, which indicates the laser scan detected nothing. We can measure the correct distance between the robot and the glass by ultrasonic sensor, but laser rangefinders data significant bigger than actual situation. Experiments shows that we can detect the position of the glass panel by using the different between the two sensor measurements.

B. Improved SLAM with Glass Detection Experiments

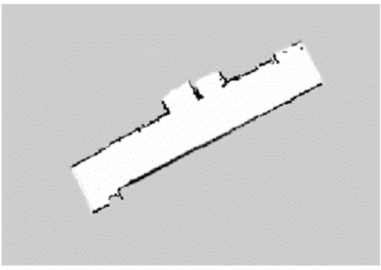
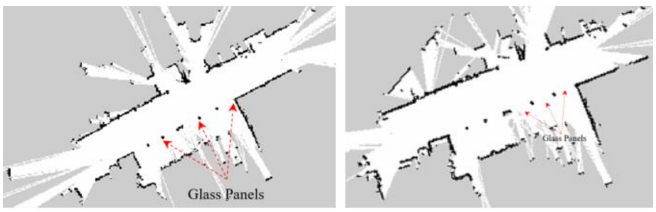


Figure 8. Standard map of the experiment environment.

Our robot platform uses ROS, first, we provide a standard environment map and use it as a reference standard (Fig. 8).



(a) Gmapping. (b) Hector SLAM.

Figure 9. Map generated by classical SLAM algorithms.

Second, we apply gmapping and hector slam to build a map of the environment (Fig. 9). From the figure, neither algorithm can identify the glass panel, because both algorithms use laser rangefinders data only. As seen in (Fig. 1 b), robot may cause collisions with the glass panel based on those maps.

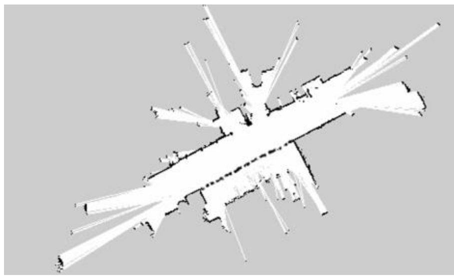


Figure 10. Map generated by improved SLAM algorithm.

Last, we test ours improved SLAM algorithm with glass detection. The robot walks along the glass wall during the building process due to the limited measuring range of ultrasonic sensors. When the robot detects the glass, the robot will calculate the coordinates and save the position of the glass. The algorithm cannot merge glass position into the map now, so we did it by hand. From (Fig. 10), most of the glass area were identified by the algorithm. The experimental result shows that our algorithm can build an accurate map in a glass environment.

C. Improved Navigation Frame

ROS amcl package gets the robot position by sensor data and map matching. When the map is obtained map far from the actual environment, the map needs to be properly adjusted, which will reduce the positioning accuracy of the robot. We use map matching to characterize this effect.

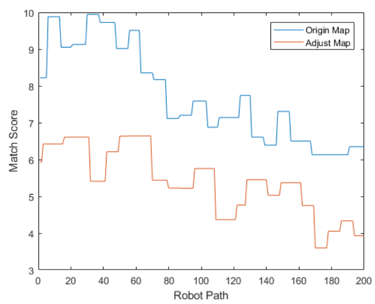


Figure 11. Map matching in two different obtained maps.

In Fig.11, let the robot run from the starting point to the end point in the two maps. We collected the map matching data in the process. As can be seen from the figure, the map matching accuracy will be significantly reduced after modification.

Our algorithm generates two maps at the same time, one same as the map generated by gmapping SLAM algorithm, and the other one overlays the detected glass information on the map generated by gmapping. Localization use the one generated by gmapping and planning map use the other one overlays the detected glass information. We randomly chose four target points in the environment as test points and measured the performance of an algorithm by robot's runtime to reach the target point under different frames.

TABLE I. RUNTIME OF ROBOT NAVIGATION TO TARGET

Runtime	Target1	Target2	Target3	Target4
Classical Frame	**27.9**	**42.0**	**39.8**	**46.2**
Improved Frame	**26.4**	**39.6**	**32.7**	**40.7**

Due to the presence of glass, the robot may not reach the target point using the traditional navigation framework, we only selected the data that robot reached the target point successfully. From the TABLE 1, compare with the classical navigation frame, target to the same point, the new frame proposed spends less time, calculation shows that the new navigation frame increased robot navigation efficiency by 11% in glass environment.

V. CONCLUSION

In this paper, we propose an efficient and robust method to detect glass panels based on sensor fusion of ultrasound and laser rangefinders data. By integrating the glass detection with SLAM, we have improved an existing SLAM algorithm to provide more accurate mapping and localization results. Due to the limitation of the measurement range of the ultrasonic sensor, if the robot is far from the glass during the map construction, the glass detection algorithm will fail, this is another issue that we need to solve in the future. We propose a new navigation framework that improves the original navigation framework, the experiments show that the new navigation frame increased robot navigation efficiency by 11% in glass environment. The improved frame can also be used to limit the robot movement area artificially.

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