Enhanced LiDAR-based Robot Navigation System in Transparent Obstacle-Rich Environments

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Abstract

This paper proposes an enhanced LiDAR-based robot navigation system in transparent obstacle-rich environments. The system incorporates transparent obstacle detection and perception correction on LiDAR point cloud data to improve the navigation capability of robots that often collide with unmapped transparent structures such as glass doors and glass walls, which are inherently difficult for LiDAR to detect. The system was tested on a mobile robot in various case studies, including search and rescue scenarios, and demonstrated promising results with a 100% success rate in fully autonomous navigation tasks.

Keywords: transparent, obstacle, LiDAR, robot, navigation

I. Introduction

The use of LiDAR and cameras as environmental perception sensors in robotics has become a standard practice and has been implemented across various use cases. These include robots operating in fulfillment centers, search and rescue missions, autonomous vehicles, and many others. These sensors play a critical role in enabling robots to perform autonomous navigation. However, in certain environments and specific scenarios, these sensors often struggle to provide reliable perception data to the robot.

For instance, in indoor search and rescue operations, there is no guarantee that ambient light intensity will always be sufficient for the camera to produce reliable data. In such conditions, LiDAR becomes a favorable alternative as it does not depend on ambient light levels. However, in many modern buildings, certain transparent materials such as glass, transparent plastics, or acrylics pose significant challenges for robots relying on LiDAR for autonomous navigation.

LiDAR operates by emitting laser beams to gather environmental perception data. However, it often fails to detect transparent objects because the laser beams are not reflected back to the sensor, but instead refracted through the transparent material. This results in the object going undetected, which can critically impair a robot's performance during emergency indoor search and rescue missions.

Therefore, this paper proposes a reliable system designed for search and rescue missions in indoor emergency environments. The system integrates transparent object detection [1] and perception correction approaches [2], [3] on LiDAR data, which are then utilized within the robot's navigation system.

II. Methodology

The proposed system in this paper adopts a transparent obstacle detection method [1]. This method leverages the characteristic behavior of transparent obstacles, where LiDAR points located near the normal angle of such obstacles tend to exhibit higher intensity values compared to points reflected from other types of objects. Based on this characteristic, a thresholding approach is employed to determine whether a point in the LiDAR point cloud originates from a transparent obstacle.

Subsequently, the point cloud labeled by the detection method is further processed to perform perception correction using the approaches proposed in [2] and [3]. In [2], points labeled as glass points are used as reference anchors for generating virtual points that estimate the actual glass surface profile. Then, following the approach in [3], the estimated width of the glass profile is determined based on the robot's body radius.

The corrected point cloud resulting from this perception correction process is then passed to the navigation module to support the robot's path planner, enabling it to avoid collisions with previously unseen transparent obstacles in the environment. As a result, the robot is able to perform safe autonomous navigation without colliding with any obstacles.

III. Experiment and Results

To evaluate the performance of the proposed navigation system, a series of tests were conducted using a TurtleBot platform equipped with a 2D LiDAR sensor and a Lattepanda Sigma as the onboard computer. A glass panel was placed between the robot's initial state and its designated goal position.

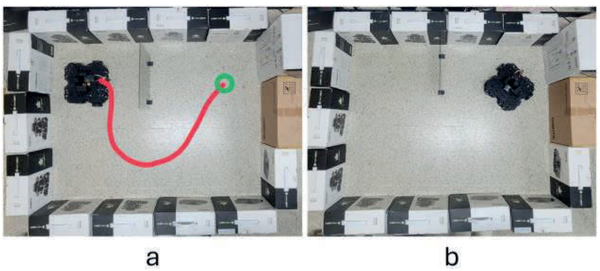

Figure 1. Navigation system test with a glass obstacle. (a) The robot's initial state, planned trajectory, and goal position. (b) The robot successfully reaching the goal position without collision.

As shown in Figure 1, the robot consistently succeeded in avoiding the glass obstacle without any collisions in all trials when the glass detection and perception correction system was enabled. In contrast, when the system was not used, the robot consistently failed to reach the goal position and collided with the glass obstacle in every attempt.

IV. Conclusion

In this paper, a LiDAR-based robot navigation system has been implemented for emergency situations in indoor environments, specifically for search and rescue missions. The current system utilizes a 2D LiDAR sensor, which limits its application to ground robots. In future work, the implementation of this system using 3D LiDAR, aiming to expand its usability and general applicability across a wider range of robotic platforms, is planned.

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