

CHAPTER I

INTRODUCTION

1.1 Background

Mobile robots increasingly rely on three-dimensional (3 D) perception to understand and interact with their environments. One of the most common representations used for 3D perception is the point cloud, which provides a spatial description of surrounding objects and structures by representing them as collections of points in three-dimensional space. Point clouds are widely used in robotics applications such as environment understanding, obstacle detection, scene analysis, and navigation support. The quality and reliability of point cloud data directly affect the performance and robustness of higher-level robotic systems.

RGB-D cameras have become a popular sensing modality for point cloud generation due to their ability to provide both color (RGB) and depth information at relatively low cost. RGB-D sensors enable dense point cloud generation with rich visual information. These sensors are widely adopted in indoor robotics, and autonomous systems. However, despite their advantages, RGB-D cameras suffer from well-known limitations that significantly degrade depth data quality under certain environmental conditions.

Depth cameras are highly sensitive to factors such as lighting variation, reflective or transparent surfaces, outdoor sunlight interference, motion blur, and sensor noise. In low-texture environments, depth estimation becomes unstable, while in high-glare or reflective scenes, depth measurements may be missing or severely distorted. These issues are especially pronounced in dynamic or challenging environments, where the depth camera may fail to produce consistent and reliable depth information.

In contrast, LiDAR sensors provide accurate and robust distance measurements independent of ambient lighting conditions. LiDAR systems actively emit laser pulses and measure the time of flight to compute distances, allowing them to operate reliably

in low-light, high-glare environments where RGB-D sensors struggle. While LiDAR sensors typically produce sparser point clouds compared to RGB-D cameras, their geometric accuracy and consistency make them well suited for localization and pose estimation tasks. Consequently, LiDAR-based odometry and localization systems are often more reliable than vision-based alternatives in adverse sensing conditions.

However, LiDAR sensors alone may not always provide sufficiently dense spatial information for detailed scene representation. Their limited vertical resolution and angular sampling can result in incomplete or sparse point clouds. As a result, relying solely on LiDAR data may be insufficient for applications that require dense point cloud representations. This limitation motivates the integration of RGB-D and LiDAR sensors, allowing each sensor to compensate for the weaknesses of the other.

Sensor fusion approaches that combine RGB-D cameras and LiDAR sensors have been explored to improve robustness in robotic perception systems. In such systems, LiDAR data is often used to provide reliable motion estimation or pose information, while RGB-D sensors contribute dense depth measurements for point cloud generation. By decoupling pose estimation from depth sensing, the system can remain operational even when the RGB-D camera experiences degraded depth quality.

Simultaneous Localization and Mapping (SLAM) is a foundational capability in mobile robotics that enables a robot to estimate its own pose while incrementally building a representation of the surrounding environment. Traditionally, SLAM systems aim to produce a globally consistent map while simultaneously tracking the robot's trajectory within that map. Over the past two decades, SLAM has evolved from purely geometric approaches using range sensors to more complex multi-sensor systems integrating vision, inertial measurements, and LiDAR data.

LiDAR-based SLAM provides a more robust alternative for localization, as it relies on geometric structure rather than visual appearance. LiDAR sensors are less sensitive to lighting variations and can maintain reliable pose estimation even when RGB-D sensors fail to deliver accurate depth information. As a result, LiDAR-based SLAM is frequently used as a dependable source of localization in challenging environments.

LiDAR-based SLAM can provide stable and accurate localization even when RGB-D sensing conditions are poor. By using LiDAR-based SLAM only for localization, the robot can still estimate its pose correctly while collecting depth data from an RGB-

D camera. This allows point clouds to be generated in a consistent coordinate frame, even when the quality of depth measurements is reduced. Therefore, combining LiDAR-based localization with RGB-D sensing is a practical approach to maintain point cloud generation under challenging depth sensor conditions

1.2 Objectives

1.2.1 To develop an indoor localization system using a loosely-coupled multi-sensor SLAM framework that integrates 2D LiDAR and depth camera data

1.2.2 To compare the resilience and localization performance of the proposed system with the single base sensor system

1.3 Scope

1.3.1 The proposed system consider only planer (2D) localization and does not estimate vertical (Z-axis)

1.3.2 Outdoor operation, GNSS integration, and large-scale environments are outside the scope

1.3.3 The system uses a 2D LiDAR for localization and RGB-D camera for dense point cloud generation other sensors such as stereo cameras, 3D LiDAR, cameras are not considered

1.3.4 The system is evaluated under degraded lighting conditions that negatively affect RGB-D sensing

1.3.5 The generated point cloud maps are intended for visualization and analysis purposes only

1.3.6 Path planning, navigation, and autonomous decision-making using the generated maps are not within the scope

1.3.7 The evaluation focuses on localization robustness, consistency of point cloud generation.

1.4 Expected benefits

1.4.1 The proposed system is expected to improve localization reliability in indoor environments where visual sensing performance is degraded. By relying on LiDAR-based SLAM for localization, the system can maintain stable pose estimation even under poor lighting conditions that negatively affect RGB-D cameras. This increases the robustness of the overall system compared to vision-based SLAM alone.

1.4.2 The proposed framework demonstrates a practical solution for multi-sensor SLAM deployment using commonly available sensors, such as 2D LiDARs and RGB-D cameras. This lowers system cost compared to solutions that rely on high-end 3D LiDAR sensors while still achieving reliable localization and dense environmental representation.

1.4.3 The outcomes of this research can serve as a reference framework for future studies involving multi-sensor robotic systems operating under challenging sensing conditions. The results may support further development in areas such as indoor inspection, environment monitoring, and robotic perception research.