Chapter 4
Algorithms for 3D Map Segment Registration

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ABSTRACT

Many applications require dimensionally accurate and detailed maps of the environment. Mobile mapping devices with laser ranging devices can generate highly detailed and dimensionally accurate coordinate data in the form of point clouds. Point clouds represent scenes with numerous discrete coordinate samples obtained about a relative reference frame defined by the location and orientation of the sensor. Color information from the environment obtained from cameras can be mapped to the coordinates to generate color point clouds. Point clouds obtained from a single static vantage point are generally incomplete because neither coordinate nor color information exists in occluded areas. Changing the vantage point implies movement of the coordinate frame and the need for sensor position and orientation information. Merging multiple point cloud segments generated from different vantage points using features of the scene enables construction of 3D maps of large areas and filling in gaps left from occlusions. Map registration algorithms identify areas with common features in overlapping point clouds and determine optimal coordinate transformations that can register or merge one point cloud into another point cloud's coordinate system. Algorithms can also match the attributes other than coordinates, such as optical reflection intensity and color properties, for more efficient common point identification. The extra attributes help resolve ambiguities, reduce the time, and increase precision for point cloud registration. This chapter describes a comprehensive parametric study on the performance of a specialized Iterative Closest Point (ICP) algorithm that uses color information. This Hue-assisted ICP algorithm, a variant developed by the authors, registers point clouds in a 4D (x, y, z, hue) space. A mobile robot with integrated 3D sensor generated color point cloud used for verification and performance measurement of various map registration techniques. The chapter also identifies various algorithms required to accomplish complete map generation using mobile robots.

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INTRODUCTION

Complete and dimensionally accurate maps of the environments are of interest to many domains including surveying, search and rescue, security, defense and construction. Laser based scanning devices (Light Detection And Ranging-LIDAR) are generally used to generate point clouds that describe spatial information in the form of numerous discrete point coordinate measurements. Point data are acquired by measuring time of flight of scattered light or phase shift between incident and reflected light to find the distance between the object surface and the scanning device (Blais, 2004). The speed of scanning discrete points can be enhanced by pulse and phase based measurement technologies (Blais, 2004). Precise rotation mechanisms with high-resolution encoders spin a 2D LIDAR device to generate a 3D point cloud. Point cloud scanners have been mounted on airplanes (Browell et. al. 1990) and ground vehicles (Gebre, et al. 2009) to create large area terrain maps. When vision sensors are integrated with the laser ranging systems, point clouds can also contain the color information of the scene. Optical imagery from the camera is associated with point coordinates to produce color point clouds (Andresson, 2007).

A 3D point cloud obtained from a single vantage point is seldom adequate to construct a complete map. Generation of a complete map of an environment requires merging or registration of map segments taken from various vantage points. The registration enables construction of large-scale global 3D maps (Thrun, 2003). Registering the map segments is trivial if precise position and orientation of the sensor are accurately known about a global reference frame. Position sensors such as inertial measurement units or those relying on global positioning systems are prone to errors and can be highly inaccurate under certain conditions. The map registration process determines the rigid body translation and rotation of the sensor as its output (Thrun, 1993, 2003). The map registration quality varies depending upon the sensor resolution and the extent of overlap between the map segments. Different techniques exist for merging 3D maps by exploiting geometric features and measuring surfaces. The most popular registration algorithm for point cloud registration is the iterative closest point (ICP) algorithm (Thrun, 2003). In ICP, the corresponding closest points in different point clouds are associated and optimal rigid transformation required to minimize a mean-square error of separation between the associated points (Bsel, 1992) is iteratively found. The color attributes of the sampled point can be utilized in ICP progress to increase computational speed and provide higher accuracy. Anderson (2007) filtered the point set data based on hue before conducting traditional ICP. Houng et al., (2009) processed images to extract corresponding visual features that are used in registration process.

In this chapter, we examine the algorithms required for a mobile robot to generate a dimensionally accurate and complete map of an area without prior information about the area. We focus particularly on the techniques for registration of map segments taken from various vantage points. The chapter also describes a mobile robotic system with a color point cloud scanner and various algorithms required for accomplishing the mission of generating a complete and dimensionally accurate map of an area.

MOBILE MAPPING WITH COLOR POINT CLOUD SCANNERS

Color point clouds are created by synchronizing range sensors such as the LIDAR with video/still cameras. LIDAR devices discretely measure the distance between a light source and a reflection target at a high frequency. By changing the path of the light through mirrors and actuators, a point cloud of a 3D space is produced. A calibrated vision sensor maps the color information to the sampled points. Installing such a scanning sensor