Chapter 25
3D Imaging for Mapping and Inspection Applications in Outdoor Environments

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ABSTRACT

This chapter is aimed at introducing the fundamentals of three-dimensional (3D) imaging to scientists, students, and practitioners while also documenting recent developments in the ability to rapidly digitize real-world environments. We begin with a survey of popular 3D sensing options and list factors that challenge 3D imaging in outdoor environments. The survey guides the reader towards the choice of a 3D sensor for his or her application of interest. Then, we describe 3D data acquisition strategies and integration methodologies for multi-view range data from laser scanners, multi-view image data from cameras mounted on a mobile platform and multi-sensor localization based 3D mapping. We explain the steps involved in creating 3D models from raw sensor data for each of these data acquisition strategies. Finally, we document research results obtained in the Imaging, Robotics and Intelligent Systems Laboratory at the University of Tennessee, Knoxville from 3D imaging prototypes developed for automated pavement runway inspection and urban mapping.

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INTRODUCTION

Over the last decade, many research efforts have focused on the development of 3D imaging solutions for photo-realistic 3D scene building, 3D scene description, and 3D data visualization. The efforts broadly fall into three categories:

1. building ready-to-deploy system prototypes with easy-to-use acquisition interfaces;
2. formulating and implementing algorithms for processing and integration of acquired datasets;
3. demonstrating the advantages of 3D sensing-based innovations over existing methodologies.

As researchers following and contributing to the literature in the area of 3D sensing for mapping and inspection applications, this chapter draws upon our experience from several projects including 3D under-vehicle inspection (Sukumar et al., 2007), reverse-engineering of automotive components (Page et al., 2009), road surface inspection (Yu et al., 2007), terrain modeling (Sukumar et al., 2006) and mapping of hazardous environments (Grinstead et al., 2006). The breadth of applications that we addressed in the last decade helped us realize that 3D imaging system design, especially in outdoor environments, can be a challenging problem with a steep learning curve. We hope to document some of the lessons learned in operating 3D sensors outside of controlled laboratory environments in large-scale outdoor environments. Our anticipation is that with augmented reality concepts and three-dimensional television making the foray into the consumer markets, we will soon be witnessing an increased demand for generating photo-realistic 3D immersive environments for these new devices. This chapter, we hope, will act as a knowledge dissemination source for entrepreneurs and early researchers who wish to learn the challenge and solution space with 3D sensing in outdoor environments.

With this motivation, we begin by introducing the fundamentals of 3D sensing and mapping in the background section. We will address questions like - What sensing methods are available? What accuracy can one expect from these sensors? Is a particular sensing methodology too slow? Is a sensing technique illumination sensitive? We present a brief overview of the underlying principles of active and passive 3D sensing methods and explain why some sensors are better suited than others to outdoor mapping applications. This section briefly explains concepts of 3D shape extraction using principles of stereoscopy, triangulation, time-of-flight etc. and provides appropriate reference links for detailed descriptions. We then expand upon the particular challenges and requirements of 3D sensing in outdoor environments. Based on these requirements, we argue that very few sensing methods are suitable for real-world deployment challenges. We pick laser-scanner (both triangulation-based and time-of-flight) based systems and image-based 3D reconstruction systems as potential sensors for outdoor mapping applications and discuss them in greater detail.

In the section following the background, we describe data integration strategies for multi-view range data, multi-view image data and mobile scanning using line profile scanners. We explain the range data integration approach as that of imaging a scene of interest from different viewpoints and registering the multi-view scans into one common co-ordinate system. Such methods have already been used in applications for site verification (Sequiera et al., 2007), building information models for energy efficiency simulations (Okorn et al., 2010) etc. We then contrast the range data integration approach with mobile scanning, where the concept is to mount 3D sensors on a manned/unmanned or remotely operated mobile platform equipped with a suite of different localization sensors. The line-profiles from the 3D sensors, after further processing and alignment based on localization information, deliver geometrically accurate, geographically meaningful photo-realistic

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