Chapter 3

Three-Dimensional Laser Radar Recognition Approaches

Gregory Arnold\textsuperscript{1}, Timothy J. Klausutis\textsuperscript{2}, and Kirk Sturtz\textsuperscript{3}

\textsuperscript{1} Air Force Research Lab, AFRL/SNAT, Bldg. 620, 2241 Avionics Circle, Dayton, Ohio 45433 Gregory.Arnold@wpafb.af.mil

\textsuperscript{2} Air Force Research Lab, AFRL/MNGI, Bldg. 13, 101 West Eglin Blvd., Eglin AFB, FL 32542 Timothy.Klausutis@eglin.af.mil

\textsuperscript{3} Veridian Incorporated, 5200 Springfield Pike, Suite 200, Dayton, Ohio 45431 ksturtz@mbvlab.wpafb.af.mil

Summary. Three-dimensional laser radars measure the geometric shape of objects. The shape of an object is a geometric quality that is more intuitively understood than intensity-based sensors, and consequently laser radars are easier to interpret. While the shape contains more salient (and less variable) information, the computational difficulties are similar to those of other common sensor systems. A discussion of common approaches to 3D object recognition, and the technical issues (called operating conditions), are presented. A novel method that provides a straightforward approach to handling articulating object components and multiscale decomposition of complex objects is also presented. Invariants (or more precisely covariants) are a key element of this method. The presented approach is appealing since detection and segmentation processes need not be done beforehand, the object recognition system is robust to articulation and obscuration, and it is conducive to incorporating shape metrics.

3.1 Introduction

Lasers provide many advantages for the object recognition problem, especially when compared to passive electro-optical (video) sensors. For robust object recognition, it is desirable for the sensor to provide measurements of the object that are stable under many viewing and environmental conditions. Furthermore, these sensor measurements, or signatures, should be easily exploitable and provide enough richness to allow object-to-object separability. Specifically, 3D imaging laser radar (ladar) greatly simplifies the object recognition problem by accurately measuring the geometric shape of an object in 3D (preserving scale). In contrast many other sensing techniques inherently suffer a loss of information by projecting 3D objects onto 2D or 1D images. Another advantage of ladar shape measurements for object recognition is that the object signature is far less variable than other sensing modalities (e.g., the shape
of the object does not vary due to lighting, diurnal affects, thermal loading, range, etc.). However, there is still difficulty since the ladar effectively samples an object’s surface slightly differently each time. Another complicating factor is that ladar does not sample a scene on a uniform sampling lattice. Furthermore, a general complication for recognition is the lack of a general theory of discrimination (i.e., how to tell objects apart). This chapter will present the fundamentals of generic ladar systems, and detail a method for handling the differences in images due to articulation and viewpoint changes.

Generically, ladars can be thought of as an orthographic projection of the world onto the sensor (see Figure 3.1). Many 3D imaging ladars provide a range and intensity measurement at every point in the sampling lattice. Direct detection and coherent detection are two common ladar detection techniques. A complete treatise of ladar detection techniques is beyond the scope of this chapter [1]. The intensity value is a measurement of the amount of energy reflected from the appropriate region of the sampling lattice. This measurement is directly related to the monostatic bidirectional reflectance distribution function (mBRDF) of the material illuminated by the laser pulse. The intensity image is effectively a narrow-band, actively illuminated 2D image. This chapter focuses on the range measurement. The inherent data coordinate system for 3D ladar is \{angle, angle, range\}=\{θ, φ, ρ\}, where θ is the depression angle and φ is the azimuth angle from which the transmitted laser energy propagates from the sensor for each point in the sampling lattice. This is a polar coordinate system that can be transformed into a rectilinear \{x, y, z\} coordinate system. Many different types of ladars exist, but for simplicity a flash ladar constructed with a focal plane array (FPA) of detectors will be assumed as the standard in this chapter. The term flash implies that the whole range and intensity image is measured at one time by spotlight illuminating the entire scene with one laser pulse. Alternately, a scanning 3D ladar images a scene by scanning one or several Laser beams over the entire sampling lattice. Although scanning ladars will be briefly described, the assumption is that appropriate motion compensation for platform motion has been done such that the resulting range image from the scanning ladar is equivalent to a (3-D) flash ladar. This assumes that the scanning mechanism operates in a linear fashion.

Operating conditions [2] have been discussed in many papers since their inauguration during the DARPA Moving and Stationary Target Acquisition and Recognition (MSTAR) program. Essentially the operating conditions are an attempt to describe everything that can affect the sensed image. They include sensor, target, and environmental parameters. Understanding all the standard and extended operating conditions is a first step to the development of an object recognition system. For the purposes of this chapter, they are categorized as (i) conditions whose effect on the image can be modeled (i.e., by a group action), (ii) conditions that obscure the image of the object (but are not easily modeled), or (iii) conditions that do not affect the part of the image corresponding to the object (i.e., changes in background). The goal is to