Chapter 3

Range Image Acquisition

3.1 Introduction

A range camera is a device that can acquire a dense grid (an “image”) of distance measurements. Range imaging sensors may be classified as being either active or passive [4]. Active sensors project energy onto a scene and measure the portion of energy that is reflected. Radar, sonar, and laser ranging systems are examples of active sensors. Passive sensors operate using existing environmental conditions. Stereo imaging systems are examples of passive sensors.

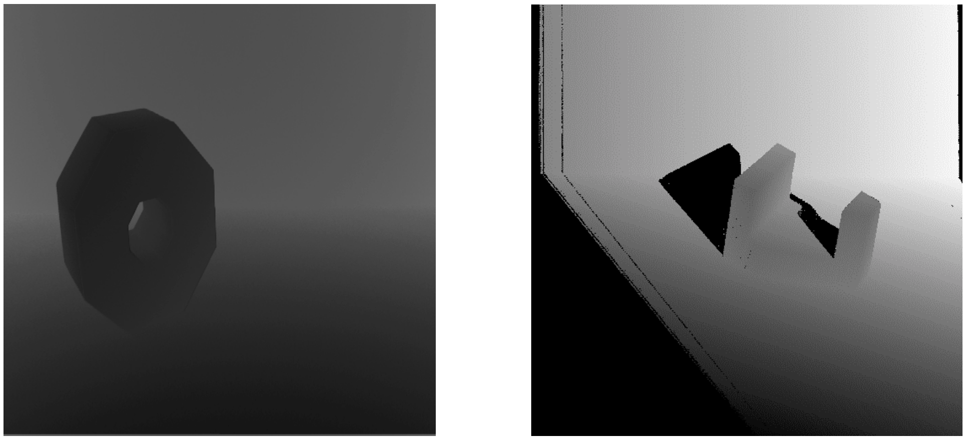
In range images, the distances from the sensor to the points on the images are recorded over a quantized interval. For instance, range value 0 means a distance of 0 - 2.5 cm, range value 1 means a distance of 2.5 - 5.0 cm, and range value 255 means a distance of 637.5 - 638 cm. In an intensity image, the grayscale or color of imaged points is recorded, but the depths of the points are not known. For display purposes in range images, the depth values are often converted to shades of gray, such that the darker a pixel is, the closer it is to the camera. The data acquired by a range camera is often referred to as 2½D in nature.

Commercially, there are two major types of range camera [42,43,44]. The first one is called a laser range finder (LRF), or laser radar camera, and uses a single optical path. The LRF computes depth via the phase shift or time delay of a reflected laser beam. Perceptron and Odetics are two companies that produce popular laser range scanners. Figure 3.1(a) shows an example of a range image taken by the Perceptron scanner.

The second type of range camera is called a structured light scanner that uses two optical paths. One of them is for a CCD camera and the other is for some form of projected light. The structured light system computes depth via triangulation. ABW and K2T are two companies that produce structured light scanners. Figure 3.1(b) shows an example of a range image taken by the ABW scanner. The existence of two optical paths for a structured light system may yield the shadow problem, where parts of the scene are visible to the

CCD and may not be visible to the light projector. The resulting pixels in the range image, called shadow pixels, do not have valid range measurements.

Both laser range finders and structured light cameras are generally capable of producing both range and intensity data, and they are well suited for vision applications in robotics and industrial automation. In fact, the cameras may consist of several separate components (such as a CCD and light projector, or two CCDs, or laser and optics and power supply, etc.), but collectively the components make up a single range camera.



(a) (b)

Figure 3.1 Examples of range images obtained using laser range finder and structure light scanner. (a) An image of size 512×512 obtained using a Perceptron laser range finder. (b) An image of size 512×512 obtained using an ABW structured light scanner.

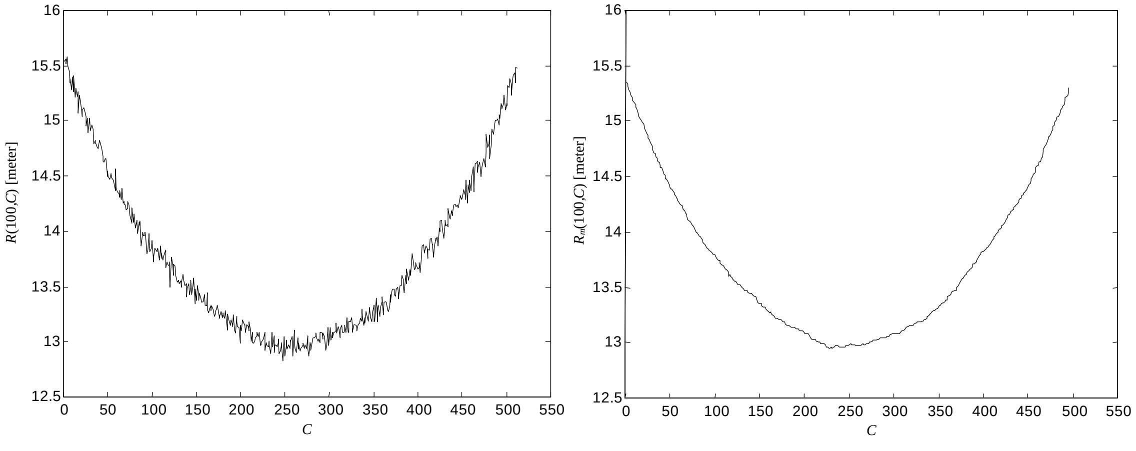
The LRF typically can acquire a range image in less than one second for an image that is 512×512 pixels, while a structured-light camera can take as much as five to ten seconds for an image of the same size. During image acquisition, both of these types of cameras must remain motionless and be imaging motionless objects. This is because the raster of range measurements is not measured simultaneously [42].

There have been some obvious tradeoffs between laser range finders and structured light scanners. The former costs more, while the latter operates more slowly and suffers from possible occlusion due to its two optical paths [42]. Regarding the quality of data, the contest is almost equal. Both types of camera rely on receiving reflections of projected energy. Given the variety of surface reflective properties in the world, both types of camera have the same opportunities to work equally poorly, or equally well.

3.2 Measuring the Depth for the Range Images

The Perceptron laser range finder scanner produces 512×512 images while the Odetics scanner produces 128×128 images. The ABW structured light scanner produces 512×512 images while the K2T scanner produces 640×480 images. The Perceptron scanner quantizes the phase shift measured at each pixel in the image into 4092 depth values covering its 9.4 meter ambiguity. This 9.4 meter ambiguity interval is considered to be the distance that the modulated wave travels and returns to make one complete phase. These distance values include the minimum distance that the camera can measure. The Odetics scanner quantizes the phase shift measured at each pixel in the image into one of 256 depth values. Because the Perceptron scanner, which uses 12 bits, has better precision than Odetics scanner, uses 8 bits, it is considered in the experimental results [25,43].

Figure 3.2 shows the profiles of row number 100 in the range image shown in Figure 3.1(a) after smoothing with a median filter. This graph implies that the laser source is closer to the middle of the scene than to the sides.



(a) (b)

Figure 3.2 Examples of profiles for the real range image of Figure 3.1(a) at row 100. The symbol *c* represents column number in the range image. (a) Raw range image. (b) Smoothed range image.

The data acquired by a range camera are stored as depth values in a 2D-array. Each pixel can also be converted to a 3D Cartesian coordinate. A conversion between the image and Cartesian systems is accomplished by applying a set of transformation as,

$$(x, y, z) = f\left(r, c, R(r,c)\right) \tag{3.1}$$

This conversion must be performed each time the image is processed. The values *x*, *y*, *z* are the Cartesian coordinates while *r*, *c*, and $R(r,c)$ are row and column indices, and depth value respectively. The Perceptron and Odetics laser range finder scanners use perspective projection, so that the image coordinate system is spherical. The ABW and K2T structured light scanners use orthographic projection, so that the image coordinate system is, in fact, equivalent to a Cartesian coordinate system. The following section will discuss the transformations used for the Perceptron laser range finder scanner.

3.3 Perceptron Laser Range Finder

Each pixel in the range image $R(r,c)$, for $0 \le r, c \le 511$, is converted to Cartesian coordinates (in centimeters) as follows [25,42]:

$$\begin{aligned} x(r,c) &= \Delta x + r_3 \sin(\alpha) \\ y(r,c) &= \Delta y + r_3 \cos(\alpha)\sin(\beta) \\ z(r,c) &= \Delta z + r_3 \cos(\alpha)\cos(\beta) \end{aligned} \tag{3.2}$$

$$\begin{aligned} \alpha &= \alpha_0 + \frac{H \cdot (255.5 - c)}{512} \\ \beta &= \beta_0 + \frac{V \cdot (255.5 - r)}{512} \end{aligned} \tag{3.3}$$

$$\begin{aligned} r_1 &= \frac{\Delta z - h_2}{\delta} \\ r_2 &= \sqrt{(dx)^2 + \frac{(h_2 + dy)^2}{\delta}} \\ r_3 &= \left(R(r,c) + r_0 - (r_1 + r_2)\right)\delta \end{aligned} \tag{3.4}$$

$$\Delta x = (h_2 + dy)\tan(\alpha) \tag{3.5}$$

$$\Delta y = dz \tan\left(\theta + \frac{1}{2}\beta\right)$$

$$\Delta z = \frac{-h_1(1.0 - \cos(\alpha))}{\tan(\gamma)}$$

The specific values of h_1, h_2, γ, θ, α_0, β_0, H, V, r_0, and δ are obtained through calibration before imaging. More details about the Perceprton LRF are presented in Appendix A.