Information Processing Letters 115 (2015) 285–291

Contents lists available at ScienceDirect

Information Processing Letters

www.elsevier.com/locate/ipl

3D depth information extraction with omni-directional camera

Tong Jia [a,*], Yan Shi [b], ZhongXuan Zhou [a], DongYue Chen [a]

[a] *College of Information Science and Engineering, Northeastern University, Shenyang 110819, China*
[b] *Robotics and Automation Lab, Michigan State University, East Lansing, USA*

ARTICLE INFO

Article history:
Received 6 February 2014
Received in revised form 29 September 2014
Accepted 29 September 2014
Available online 17 October 2014
Communicated by Jinhui Xu

Keywords:
Depth measurement
Omni-directional image
Structured light
Infrared laser
Real-time systems

ABSTRACT

This paper presents a novel 3D depth information extraction method without calibration. Firstly, this paper develops an omni-directional 3D camera system, which consists of a CCD camera, hyperbolic mirror, infrared laser diodes and diffractive of element (DOE). Secondly, a depth measurement model is proposed to obtain the 3D depth information. Finally, in order to calculate the speckle shift accurately between the reference image and the object image, a dot matrix pattern and sequence coding algorithm are designed to find the corresponding speckles in the two images. Experimental results show that the reconstructed depth data have a good correlation with the actual distance. The accuracy of the data is also found to be influenced by the distance between the object and the camera.

1. Introduction

3D depth information extraction is one of the most challenging problems in robotics autonomous navigation, 3D scene reconstruction, vision measurement and industrial automation etc. [1–3]. There are two key parts in 3D depth information extraction, one is the omni-directional image acquisition, and the other one is the structured light method.

Basically there are two ways to acquire omni-directional images [4,5]. The first method is to generate the omni-directional images through the image mosaic method. The method either employs multiple cameras viewing different directions or utilizes one rotating camera [6] to obtain multiple images of the environment. The final omni-directional image is a combination of those images using the mosaic method. Such a method could not build all the 3D information at the same time and the mechanic rotation can also influence the accuracy of the result. The second method is to use an omni-direction camera [7–9] to obtain panoramic vision. An omni-directional camera system usually consists of a convex shape mirror, such as a hyperbolic, parabolic, conic or sphere mirror, and a normal camera. By viewing the reflected image of the mirror at a time, a panoramic vision can be obtained.

The structured light method has gained increasing attention due to its high speed and accuracy [10]. Compared with the stereo vision method, the structured light method replaces one of the cameras with a projector. The projector emits certain light pattern which includes single-point pattern, single-line pattern, and coded pattern, to the objects. The pattern reflection is captured by the camera. Depth information can be calculated based on the triangulation. Calibration is the key issue in the structured light method. In this method, the projectors are difficult to calibrate because they cannot capture the image actively [11].

Some studies considered the projector as an inverse camera [12], while others focused on estimating the equation of light-stripes planes emitted by the projector [13]. However, both issues depend on determining the camera

* Corresponding author.
E-mail address: jiatong@ise.neu.edu.cn (T. Jia).

http://dx.doi.org/10.1016/j.ipl.2014.09.029

parameters. Therefore, the main drawback of the structured light method is the coupling of errors in projector and camera calibration.

The single-point pattern method obtains depth information by point scanning the entire image. Thus, the computational complexity increases dramatically with the increase in the size of measured object. This method demonstrates the practicability of depth measurement based on structured light method.

Compared with the single-point pattern structured light method, single-line pattern structured light method can obtain depth information only by scanning one-dimensional object [14]. Therefore, the processing time and computational complexity are reduced significantly. However, the single-line method requires scanning the object many times to obtain the depth information.

The coded pattern structured light method has been proposed to reduce measurement time. This method can obtain the depth data in one shot. Moreover, the method has been studied extensively in recent years because of its high accuracy. Cheng proposed an arrangement coding method [15] using six colors that are arranged to produce a projection pattern. However, this method projects a colored light stripe to the object, which easily fades to the scene. Thus, the method is applicable only to objects which have neutral colors and low robustness.

Kawasaki proposed a grid pattern to obtain the depth information of the object [16]. The grid pattern is used in distinctive colors on horizontal and vertical directions. This method utilizes the peak detection to determine the intersection. The decoding algorithm only needs to identify the vertical and horizontal curves. However, this method is time consuming and not sensitive to the texture of the object surface.

Koninckx [17] proposed an adaptive depth measurement method based on the epipolar constraint. The pattern can be adjusted automatically based on the noise and color of the object. The disadvantage of this method is the effect of scene noise on the pattern.

In this paper, we propose a method to acquire 3D depth information of the environment by using the omni-directional camera and the infrared laser dot matrix structured light. This method can be used for real-time 3D reconstruction and without calibration. The remainder of this paper is organized as follows.

Section 2 describes the framework of omni-directional camera. The depth measurement model is proposed in Section 3, and proposes a new projection pattern as dot matrix and a sequence coding algorithm for the pattern. Then Section 4 presents depth information extraction results that demonstrate the validity of the proposed algorithm. Finally, Section 5 describes the experiments that are used to test the accuracy of extracted 3D depth information. Experimental results show that the reconstructed depth data have a good correlation with the actual distance.

2. The framework of omni-directional camera

The constructed omni-directional 3D camera consists of a CCD camera, a hyperbolic mirror, four infrared laser diodes and diffractive of element (DOE). Fig. 1 shows the

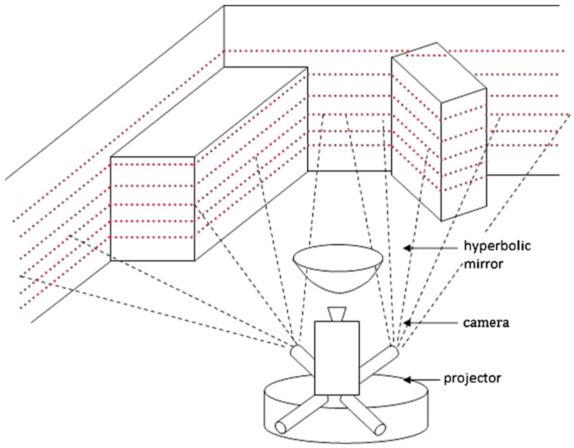

Fig. 1. Omni-directional camera setup.

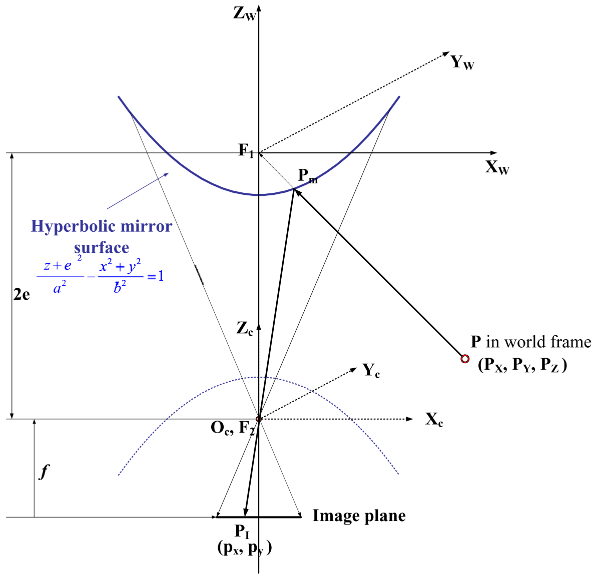

Fig. 2. Omni-directional camera model.

external camera setup. The diodes emit infrared light to the surroundings. When the light through the DOE, it is formed into the point cloud. The hyperbolic mirror is installed on the top of the camera. The surrounding structured light around the camera is reflected into the hyperbolic mirror and captured by the CCD camera. The catadioptric model is shown in Fig. 2 and the equation of the hyperbolic mirror is shown as following:

$$\frac{(z+e)^2}{a^2}-\frac{x^2+y^2}{b^2}=1 \tag{1}$$

Where a and b are the semi-major and semi-minor axis of the hyperboloid curve respectively. F_1 and F_2 are the two focal points of the hyperboloid curve. The origin point of the world frame is located at F_1. $F_2(0,0,-2e)$ denotes the origin point of the camera frame. The implementation error of the sensor is assumed as 0, which means that the rotation matrix R_{c-w} between the world frame and camera frame is considered as one identity matrix.