A Low Cost Structured Light System

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ABSTRACT

The aim of this paper is to present the current development status of a low cost system for surface reconstruction with structured light. The acquisition system is composed of a single off-the-shelf digital camera and a pattern projector. A pattern codification strategy was developed to allow the pattern recognition automatically and a calibration methodology ensures the determination of the direction vector of each pattern. The experiments indicated that an accuracy of 0.5mm in depth could be achieved for typical applications.

Keywords

Structured light, 3D imaging, calibration, low cost.

1. INTRODUCTION

Reconstruction with structured light system is still a topic of interest in Photogrammetry and Computational Vision due to its effectiveness for close range object reconstruction. Basically, 3D reconstruction with structured light consists in projecting a light pattern (line, grid, or shape) onto an object, and recovering the shape of object using the projection geometry. The technique can be based on the projection of a spot (a laser beam) or a frame pattern, which is reflected by the object and recorded by a digital camera [Bal82a]. Three key problems can be mentioned: geometry of the projection; identification and precise location of the projected pattern in the digital image and; system calibration [Dun89a]. There are several different approaches to solve the issues concerning the camera and projector calibration, reconstruction, codification of patterns and precise measurement of patterns, and some of them can be found in: [Tom98a], [Bat98a], [Zha02a], [Sal04a].

A system called 3DScanSL (3D Scanner by Structured Light) has been developed based on an off-the-shelf digital camera, a pattern projector and software components, mainly for system calibration processing and surface reconstruction. This paper presents the current status of system development. A brief derivation of the mathematical models, the prototype configuration and experiments with real data will be presented in this paper.

2. THE 3DScanSL

The 3D reconstruction system is composed by an acquisition system (Figure 1), a calibration plate, and computer software implemented in C++ language. All the software components were in house developed and the prototype was in house projected and mounted by an external private company (AVR Instrumental).

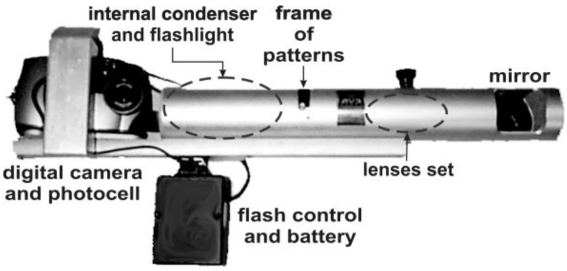


Figure 1. The system prototype.

The developed prototype uses a Kodak DX 3500 digital camera, with a maximum resolution of 1800x1200 pixels, fixed focal length (38 mm) and a pixel size of 19.44 μm (35mm equiv.). The digital camera is tightly attached to the projector ensuring the geometric conditions for reconstruction that are mathematically modeled. The reconstruction is achieved through the parametric equation of the projected ray (pattern) combined with the well-known collinearity equations [Tom98a]:

$$X_{i,t} = X_{\mathbf{p}} + \lambda_{i,t} \cdot l_t,\ Y_{i,t} = Y_{\mathbf{p}} + \lambda_{i,t} \cdot m_t,\ Z_{i,t} = Z_{\mathbf{p}} + \lambda_{i,t} \cdot n_t \quad (1)$$

Considering the projective equations:

$$x_{i,t} = -f\frac{X_{\mathbf{p}} + \lambda_{i,t} \cdot l_t}{Z_{\mathbf{p}} + \lambda_{i,t} \cdot n_t},\ y_{i,t} = -f\frac{Y_{\mathbf{p}} + \lambda_{i,t} \cdot m_t}{Z_{\mathbf{p}} + \lambda_{i,t} \cdot n_t} \quad (2)$$

where: $x_{i,t}, y_{i,t}$ are the image coordinates of the t^{th} projected point in the i^{th} image; f is the camera focal length; $\lambda_{i,t}$ is a scale factor; $X_{i,t}, Y_{i,t}, Z_{i,t}$ are 3D coordinates of the projected point in the camera reference system; (X_P, Y_P, Z_P) are the coordinates of projector center, and (l_t, m_t, n_t) the direction cosines of the projected ray.

The first step is the projector calibration aiming the determination of the projector center and the direction cosines of each projected pattern. To achieve this, the patterns are projected onto a flat surface; assuming $Z_{i,t}$ as a constant, Equations (1) can be rewritten as:

$$X_{i,t} = l_t \cdot (Z_{i,t} + Z_P) - X_P,\ Y_{i,t} = m_t \cdot (Z_{i,t} + Z_P) - Y_P \quad (3)$$

All the elements of Equation (3) are related to the camera reference system. Using this equation, the coordinates of the projector center and the components of the direction vectors can be estimated in an iterative simultaneous adjustment of observations and parameters. The XY coordinates of the projected points in the camera reference system are considered as pseudo-observations, whilst $Z_{i,t}$ is set as a constant. At least two images with a minimum of four projected points over the reference plane at different distances are required. The components l_t and m_t of the direction vector are computed considering n_t as negative unit value (-1); a normalization can be carried out later for each direction vector.

A pattern codification strategy was developed to allow the recognition of the patterns automatically (Fig. 2)

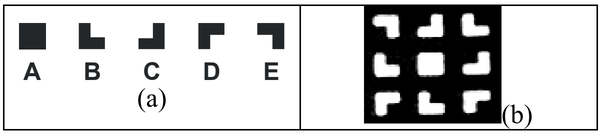
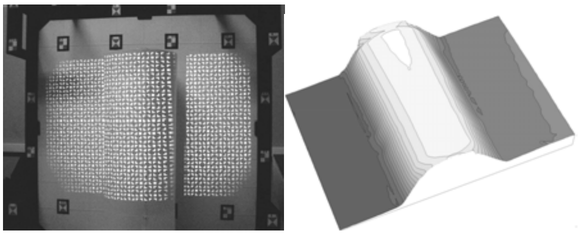


Figure 2. Projected patterns: (a) The five primitive patterns; (b) An example of a group of nine patterns from a collected image.

The 5 primitives L-shaped (Fig. 2) targets were grouped to enable recognition of incomplete patterns and quality control. A matrix of 54x36 targets (1944 targets) was generated and reproduced by photographic process in a slide that is insert in the pattern projector.

3. EXPERIMENTS WITH REAL DATA

In order to access the accuracy and the potential of the methodology, the prototype was tested with simulated and real data. The camera was firstly calibrated using a bundle adjustment with convergent cameras. After, the projector parameters were computed using the developed methodology. Several tests were performed to evaluate the accuracy of 3D reconstruction achieved by the system. The experiments demonstrated that 0.5mm in depth and 0.2mm in XY are the typical accuracies with the current configuration. The prototype was then tested with a solid cylindrical object, resulting in the 3D model shown in Fig 3.



(a) (b)

Figure 3. (a) Acquired image and, (b) 3D surface model of a cylinder.

4. CONCLUSIONS

The presented results show that an accuracy within 0.5mm can be achieved and this is considered suitable for the intended applications, with a cost less than US$ 3000. The system performance and accuracies can be significantly improved by introducing a high resolution digital camera and using subpixel point measurement technique, like least squares template matching.

5. ACKNOWLEDGMENTS

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