Increasing of Accuracy of Definition of Coordinates in Robotic Vision

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***Abstract*: In article, ways of increase of accuracy of definition of spatial coordinates to systems of computer sight intended for a robotics are considered. It is offered to use with that end in view a combination of projective and triangulable methods. In a projective method for increase in word length of a projected sinusoidal lattice structured illumination is formed of a set binary images. Keywords-interference robotics; 3D-vision; structured illumination; data processing algorithms.**

***Keywords*: Robotic vision, accuracy, image processing, data processing**

I. Introduction

Machine vision nowadays is successfully implemented more and more in the area of robotics. In systems of 3D-computer sight basically projective methods of definition of coordinates of three-dimensional objects are used. Among variety of applied methods it is possible to allocate two basic approaches a method of a triangulation and a method of the structured radiation [1, 2]. The triangulation method is based on calculation of coordinates of points of object in three-dimensional space on two (or several) to the two-dimensional pictures made under different parallax corners. A method simply enough, but accuracy of definition of coordinates is low. The projective method of the structured illumination simulates an interferential method of measurement of a relief of a surface and consists in object illumination by specially generated image of a sinusoidal lattice. Three-dimensional coordinates of object are defined on distortion of a profile of a sinusoidal lattice which is connected with the object form. The method allows defining directly spatial coordinates of object commensurable with the period of a projected lattice. For increase in a range of measured distances it is necessary to count up quantity of strips from a measured point to the chosen reference point. Accuracy of this method above, than at a triangulable method and the core is limited to word length of the devices intended for input of optical images.

We suggest to eliminate the specified lacks and to raise accuracy of measurement of coordinates, using a combination of these methods. In addition, with the aim to raise accuracy of a projective method by formation of the image of a sinusoidal a lattice from binary images is represented.

II. Proposed Methods and Solutions

A) Technology of the projection methods (3D scanning) allows recording information about object's surface (depth) with high precision and speed using the principle of structured illumination. All data are obtained by means of projection of special grating to the scene objects. Distortions of grating projection, which are created by objects' geometry, allow calculating accurate position of each point of the grating in 3D. These systems allow measuring 3D surfaces in case of video capturing.

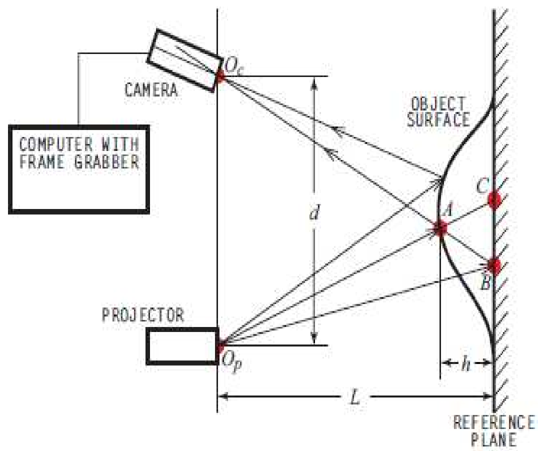

Figure 1. Geometrical representation of the experimental Setup [3]

Sinusoid patterns are projected on object as

$$I_p(x,y) = A_p + B_p \cos(2\pi f_\varphi y) \quad (1)$$

where A_p and B_p are the projection constants and (x, p) is the projector coordinates. The y dimension is in the direction of the depth distortion and is called the phase dimension. On the other hand, x dimension is perpendicular to the phase dimension, so we call it the orthogonal dimension. The frequency f_φ of the sinusoidwave is in the phase direction. Note that every point $I_p(x, y)$ is represented as an integer. The reflected intensity images from the object surface after projections are

$$I_c(x,y) = \alpha(x,y)\left(A_c + B_c\cos(2\pi f_\varphi y + \varphi(x,y)\right). \quad (2)$$

where (x, y) are the image coordinates and α(x, y) is the reflectance variation or the albedo. The pixel-wise phase distortion φ(x, y) of the sinusoid wave corresponds to the object surface depth. The depth of the object surface with respect to the reference plane is easily obtained through simple geometric algorithms [3]. As shown in Fig. 1, the distance between the projector lens center, Op, to the camera lens center, Oc, is d. Both the projector and the projectorcamera plane are a distance L from the reference plane. The height of the object at point A, h, is calculated by

$$h = \frac{BC\cdot(L/D)}{1+BC/D}. \quad (3)$$

and BC is proportional to the difference between the phase at point B, φ_B, and the phase at point C, φ_C, as

$$BC = \beta\left(\varphi_A - \varphi_B + 2\pi N\right). \quad (4)$$

The constant β, as well as other geometric parameters, L and d, are determined during the calibration procedure. The phase value calculated from Eq. (2) is wrapped in the range value of [−π, π] independent of the frequencies in phase direction. Phase unwrapping procedure retrieves the non-ambiguous phase value $2\pi N$ out of the wrapped phase [4, 5].

The given problem can be solved, using results of measurements of coordinates a triangularly method. Then, the formula (3) will become

$$BC = \beta\left(\varphi_A - \varphi_B + 2\pi\cdot\mathrm{int}\left(\frac{L_A}{T}\right)\right). \quad (5)$$

Here T - periods of a lattice, L_A - of triangularly measurements

For phase calculation used a method of phase shifts [6]

$$I_i(x,y) = \alpha(x,y)\left(A + B\cos(\varphi(x,y) + \delta\varphi_i\right) \quad (6)$$

Phase shift $\delta\varphi$ turns out by spatial shift of the image of a lattice on size proportional to the period of strips T. Lattice shift for one period is equivalent to entering of phase shift equal 2π.

At entering of phase shifts on size $\delta\varphi_1 = \frac{\pi}{4}$, $\delta\varphi_2 = \frac{5\pi}{4}$ and $\delta\varphi_1 = \frac{\pi}{4}$ also we will receive the following formula of decoding

$$\varphi = \arctan\frac{I_3 - I_2}{I_1 - I_2}. \quad (7)$$

B) In proposed method for elimination of impact brightness distortions you need to shape halftone structured image (1) as a sequence of bit (two-gradational) fields.

$$I_p = \sum_{n=0}^{N-1} 2^n \cdot I_n(x,y) \quad (8)$$

where $I_n(x,y) \in (0,1)$ and calculated from Eq. (1). When bit field is projected on the object surface than the pattern $I_n(x,y)$ on normalization factor is multiply. Normalization factor is defined projected output data format. Such, to get rejected pattern with N-binary level is necessary projected sequence consist from n fields. Decoding the brightness level of the image is calculated by

$$I_c(x,y) = \sum_{n=0}^{N-1} 2^n \cdot I'_n(x,y). \quad (9)$$

where $I'(x,y)$ - taken by the camera images which are converted to two-level image $I'(x,y) \in (0,1)$ and calculated I_c.

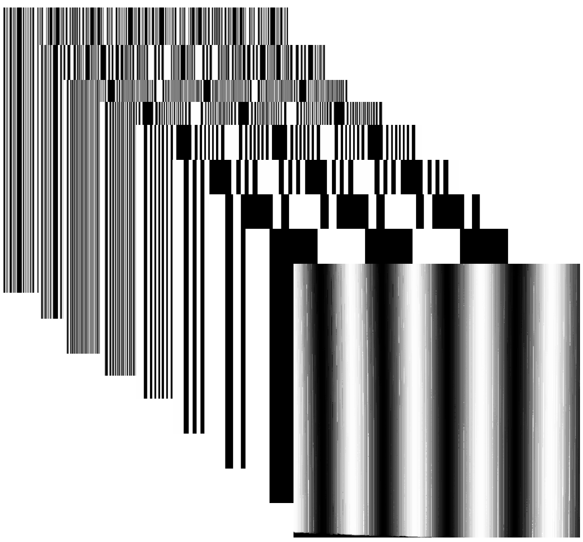

Figure 2. A technique of structured image shaping.

Figure 2 shows the calculated sinusoidal grating I (gray patterns) corresponding set of bit planes I'_n (binary pattern).

III. Experements

For practical validation of this technique there has been used the projection measuring system consisted of the generator of structured illumination – digital projector with resolution 800x600 pixels and the photo recording system – 8-bit web-camera with resolution 1600x1200 pixels. The size of projected image was 2x2 m. Sequentially 8 images of bit fields corresponding to the image of sinusoidal grating with 256 brightness levels, have been projected and recorded. After reflected from the object halftone image has been formed by means of these images. The grating grooves were perpendicular to the plane, which passed through optical axes of illumination system and recording optical system. The optical axes of recording and illumination systems intersected in one point in the object's area. The angle between axes of recording and illumination systems was 10º. The distance between the object's plane and the target's plane was 3 m. The arrangement fastened to unmovable platform.

Figure 3 shows reconstructed profile of sinusoidal fringes. Need to note that fringes profile does not have nonlinear distortions, which exist in projection "analog" sinusoid to the object's surface.

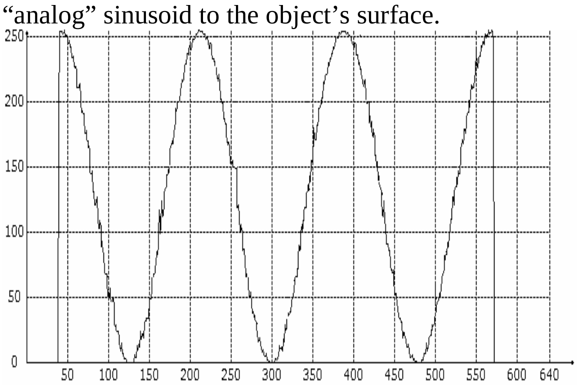

Figure 3. Reconstructed profile of sinusoidal fringes

Existence of error points is a result of inaccuracy in fixation of binary images front and may be eliminated by means of redundancy coding and additional bit images, which correspond e.g. Reed–Solomon code, Hamming code or analogue method of error-correcting coding [7]. Note that proposed principle of structured illumination shaping allows significantly improve another one the most important characteristic of projecting image – dynamic range of transmitted brightness levels.

In real digital systems this characteristic is restricted by projector's or photo recording system's capacity. As a rule 8-bit illumination devices and 8-12 bit photo recording systems are used. In our case we can form practically unrestricted dynamic range of structured illumination brightness measuring using rather cheap devices.

IV. Conclusion

We represent accuracy increase 3D-vision system having excluded necessity of performance of deployment of a phase, defining it from triangularly measurements. and a general technology to combine binary multi-frame patterns into a single half-tone pattern. In our case we can form practically unrestricted dynamic range of structured illumination brightness measuring using rather cheap devices. A new principle of structured illumination shaping, which is suitable for realization of pinpoint accuracy noncontact optical measuring systems for determination the surface coordinates of large scale objects, has been developed and tested. Pinpoint accuracy of measuring allows using such systems for robotics 3D-vision.

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