New principle of the shaping the nonline illumination in optical measuring systems

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***Abstract*—A new principle of the shaping the nonline illumination is given. It is suitable for realization of noncontact high-precision optical measuring systems for determination the surface profile of large scale objects.**

Optical measuring system; structured illumination; error-correcting code

I. INTRODUCTION

In modern aerospace manufacturing there is necessity of controlling products with pinpoint accuracy in work and production processes. Along with conventional contact methods for the surface profile measuring, optical control methods are widely used. In these methods the object is not loaded and thus is not changed own characteristics in measuring process, besides, in most cases, measured surface do not fasten relative to measuring device.

In spite of significant progress, which was achieved last years in the area of interference and holographic systems, using of these systems for the stress-strain state control of large scale objects remains a problem, because for the capturing the holograms of diffuse objects you need resolution of the photo recording system about 1000-2000 lines per mm. Therefore the task of the creation simple, reliable and efficient measuring systems is rather topical.

The process of the moiré patterns decoding is greatly similar with the decoding of interferograms. In that case it is possible to use mathematical techniques for the interference patterns decoding. Using of the phase-shifting method produces the pinpoint accuracy [1, 2]. To control of the fringes phases in that case, one of gratings which form sinusoidal pattern is shifted by a part of the period. However, creation of systems, which are able to accurately project sinusoidal grating to the controlled object surface, is a rather difficult metrological task. Low precision of projection systems does not allow solving research tasks of the stress-strain state of the objects.

We have proposed a new method of the shaping the layerwise structured (nonline) illumination, which allows to create measuring systems with error which isn't yield holographic and speckle interferometry.

II. PROPOSED METHODS AND SOLUTIONS

The 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 the projection of special grating on the scene objects. Distortions of the grating projection, which are created by the geometry of the objects, allow calculating accurate position of each point of the grating in 3D. These systems allow measuring 3D surfaces in case of video capturing.

The application of the projection methods shows that the main cause of measuring error is the distortion of the structured illumination profile as a result of nonlinear processes: the object's lighting (nonlinearity of projector's brightness), reflection the illumination from the object (nonlinearity of reflection factor) and registration of the illumination (nonlinearity of photo or video camera brightness).

Fig. 1 shows geometrical representation of the experimental setup [3].

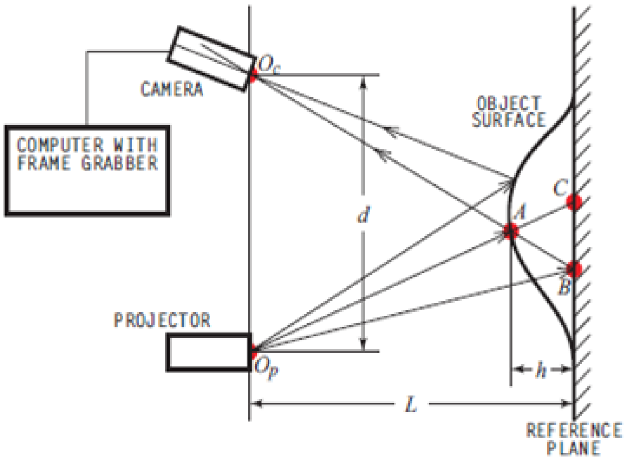

Figure 1. Geometrical representation of the experimental setup.

Sinusoid patterns are projected on object as

$$I(x, y) = A + B\cos(2\pi f_\varphi y), \quad (1)$$

where A and B are the projection constants. 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 sinusoid wave is in the phase direction. The reflected intensity images from the object surface after successive projections are

$$I(x, y) = (\alpha(x, y))(A + B \cos(2\pi f_\phi y) + \varphi(x, y)), \qquad (2)$$

where (x, y) are the image coordinates and $\alpha(x, y)$ is the reflectance variation or the albedo. The pixel-wise phase distortion $\varphi(x, y)$ 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 [4]. As shown in Fig. 1, the distance between the projector lens center, O_p, to the camera lens center, O_c, is d. Both the projector and the projector camera plane are a distance L from the reference plane. The height of the object at point A, h, is calculated by

$$h = BC\,(L/D) / (1 + BC/D), \qquad (3)$$

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

$$BC = \beta\,(\varphi_A - \varphi_B). \qquad (4)$$

The constant β, as well as other geometric parameters, L and d, are determined during the calibration procedure. The phase value calculated from (2) is wrapped in the range value of $[-\pi, \pi]$ independent of the frequencies in phase direction. Phase unwrapping procedure retrieves the non-ambiguous phase value out of the wrapped phase [5, 6].

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

$$I(x, y) = \Sigma\, 2^n I_n(x, y), \qquad (5)$$

where $I_n(x, y)$ calculated as (1).

Fig. 2 shows the formed sinusoidal grating (gray patterns) corresponding set of bit planes (binary pattern).

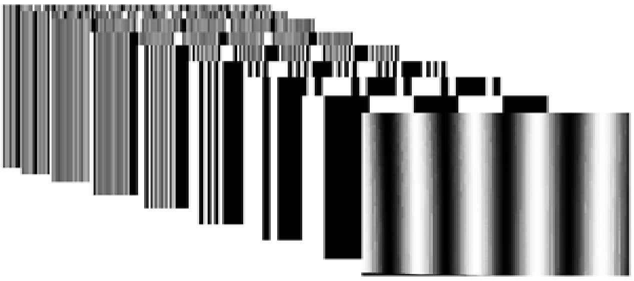

Figure 2. A technique of structured image shaping.

III. EXPERIMENTS

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

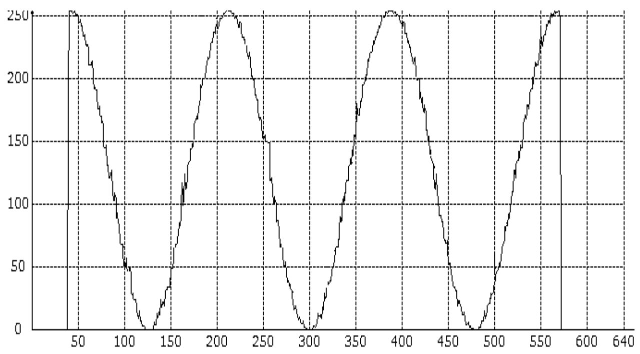

Figure 3. The reconstructed profile of sinusoidal fringes.

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 the shaping the structured illumination allows to significantly improve one of 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 the structured illumination brightness measuring using rather cheap devices.

CONCLUSIONS

A new principle of the shaping the structured (nonline) illumination, which is suitable for realization of high-precision noncontact optical measuring systems for determination the surface profile of large scale objects, has been developed and tested.

By means of experimental system which consists of common, widely-used components we have reconstructed the profile of sinusoidal fringes. This profile did not have nonlinear distortions which are usual for the projection of “analog” sinusoid. Pinpoint accuracy of measuring allows using such systems for analysis of the stress-strain state of the objects in aerospace manufacturing and other areas.

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