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Phase unwrapping simulation of dual-frequency combined analog encoding structured light

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ABSTRACT

In order to improve the measurement accuracy of phase shift method, we present a novel dual-frequency combined analog encoding phase unwrapping model and 3D measurement method. This engineered phase unwrapping model is built based on two phase principal values of one pixel from two different periodic fringe images. By calculating analytic solution from remainder formula, this model has simple and fast advantages; and by adding one rounding process, measurement error can be limited in some extent. Furthermore, based on cosine phase shift, 3D measurement method of dual-frequency combined analog encoding phase unwrapping is presented. Then theoretical analysis, simulation and actual experiment are used to verify the proposed model and method in this paper.

1. Introduction

Structured light vision measurement is the most effective way for obtaining objects three-dimensions (3D) information [1,2], It can realize 3D measurement on the human body in the industry of medicine, clothing, sculpture and archaeological etc [3,4]. In the 3D vision measurement technology, coded structure light can greatly improve measurement speed by projection patterns, and have more widely applications [6–8].

Temporal coded structured light have many advantages, such as high sampling density and measurement accuracy, development potential and more practicality, such as manufacturing [9,10], reverse engineering [11,12], and product inspection [13,14]. Temporal coding structured light can be divided into digital coding and analog coding. Analog code has high sampling rate and high resolution, but if the whole the measurement space is covered by one a variation period, the result will have low noise immunity. In order to improve the anti-noise performance, repeat cycle projection pattern are usually used, but this method can bring insurmountable unwrapped phase problem.

Phase unwrapping is a challenging problem. Therefore, various solutions are emerging, and from principal, temporal phase method [15–17] can avoid error spread, and can measure the discontinuous surface. Therefore, combination of the two analog codes has become the trend of development and research [18,19]. However, this method also exist phase jump problem, phase expansion limitation and algorithm complex problem [20].

Therefore, this paper studies for the dual analog code light 3D measurement method, and proposes an engineered dual-frequency combined analog encoding phase unwrapping model. Then the cosine phase shift method is used to build dual-

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0030-4026/

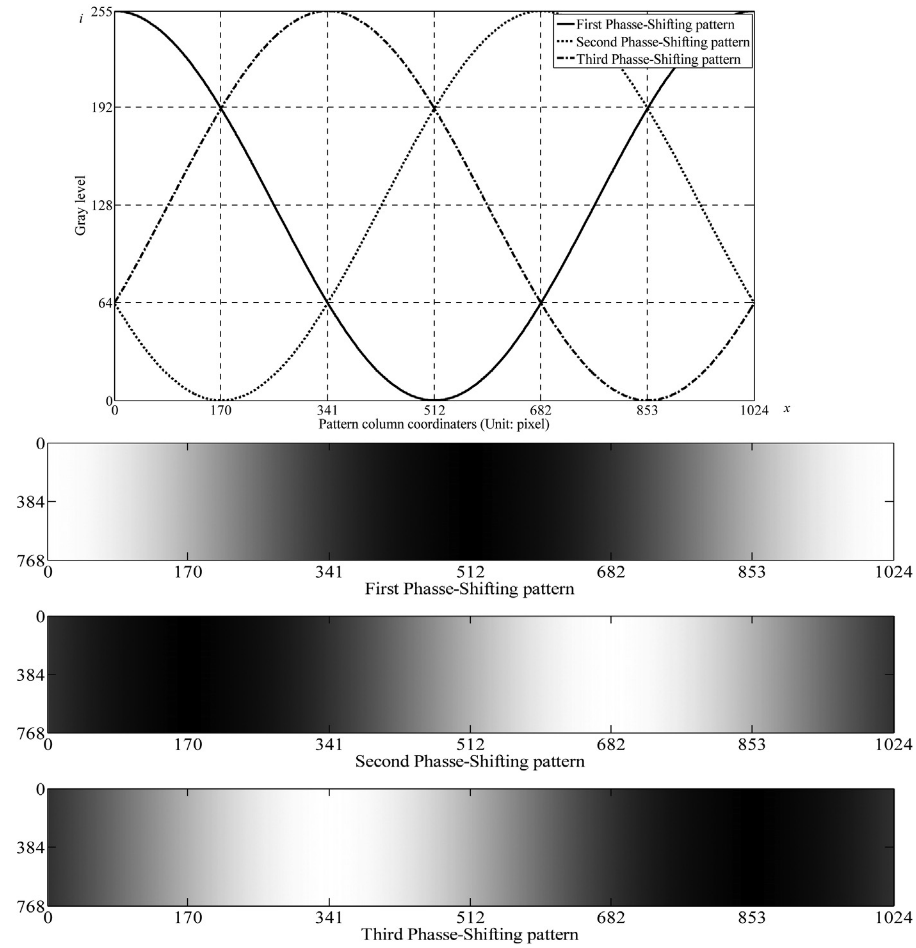

Fig. 1. The patterns of three-steps cosine phase shifting.

frequency combination measurement. The proposed method has the advantages of easy implementation, high measuring efficiency, and small measurement error.

2. Single-frequency single-cycle cosine phase-shift method and its evaluation

Single-frequency and single cycle three step cosine phase-shift method is often used in 3D measurement area. This method project three stripe pattern with cosine distribution along the abscissa axis repeatedly, and then move the stripe pattern$2\pi/3$along the abscissa axis, as shown in Fig. 1. The grayscale of image point (x, y) are as follows:

$$i_1(x,y) = F(x'', y'')\left[I_0(x',y') + I(x',y')\cos(2\pi f_0 x' - \frac{2\pi}{3})\right] \quad (1)$$

$$i_2(x,y) = F(x'', y'')\left[I_0(x',y') + I(x',y')\cos(2\pi f_0 x')\right] \quad (2)$$

$$i_3(x,y) = F(x'', y'')\left[I_0(x',y') + I(x',y')\cos(2\pi f_0 x' + \frac{2\pi}{3})\right] \quad (3)$$

where x, y are the horizontal and vertical coordinates of the pattern projector. $I_0\,(x', y')$ is the average gray. $I\,(x', y')$ is grayscale modulation range. $f_0$is cosine striped pattern frequency. $F\,(x'', y'')$is a modulus which is decided by transmitter capacity, point (x'', y'')reflective properties, space energy loss and collector capacity when light $i\,(x', y')$ irradiate from (x', y') to (x'', y'') and reflect to image point (x, y).

The phase of point (x, y) in the 2nd image can be denoted as $\varphi(x, y)$, which is named as the phase main value of three-step phase shift method. From Formulas (1)–(3), $\varphi(x, y)$can be represented as follows:

$$\varphi(x,y) = \left\{\arctan\frac{\sqrt{3}[i_1(x,y) - i_2(x,y)]}{i_1(x,y) + i_2(x,y) - 2i_3(x,y)}\right\} \bmod (2\pi) 0 \le \varphi < 2\pi \quad (4)$$