Simple Gamma Correction for Fringe Projection Profilometry System

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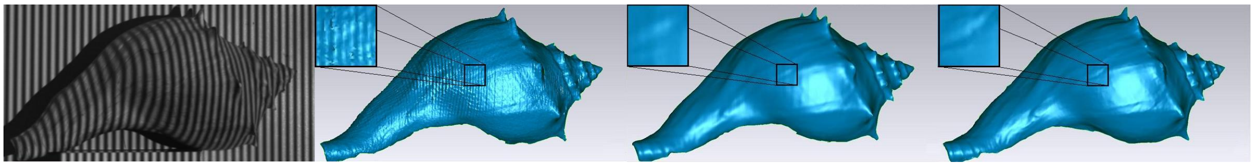

Figure 1: *From left to right:a captured shell model,shape measurement results obtained by the 3-, 7-step phase-shifting schemes without gamma correction, and the 3-step phase-shifting scheme with proposed gamma correction method*

1 Introduction

Fringe projection profilometry (FPP) is one of the most commonly used non-contact methods for retrieving the three-dimensional (3D) shape information of objects. In reality, the nonlinearity mostly caused by the gamma effect of digital otpic system, includes both projector and camera, gives inevitable intensity changes, which dramatically reduce the measurement accuracy. In this poster, a robust and simple scheme to eliminate the intensity nonlinearity induced by gamma effect. Firstly, by using phase shifting techniques, the gamma value involved in the measurement system can be detected accurately. Then, a gamma encoding process is applied to the system for future actual 3D shape measurements. With the proposed technique, high accuracy of measurement can be achieved with the traditional three-step phase-shifting algorithm.

2 Gamma Correction

In practice, the nonlinear luminance distortion in the FPP system brings high-order harmonics to the actual fringe interferograms. Hence, the intensity of the captured fringe image can be mathematically expressed as follows:

$$I(x,y) = I_0(x,y) + \sum_{j=1}^{p} I_j(x,y)\cos\{j\,[\phi(x,y)+\delta]\} \tag{1}$$

where $(x;y)$ denotes an any point in the image, I_0 is the mean intensity, I_j is the modulation amplitude, ϕ is the fringe phase, δ is the phase-shift amount, and p is the highest significant harmonic order of the captured fringes. Using the least square approach, the phase distribution in Equation (1) can be retrieved correctly:

$$\phi = tan^{-1}\frac{-\sum_{i=1}^{p+2}\sin(\delta_i)I_i}{\sum_{i=1}^{p+2}\cos(\delta_i)I_i} \tag{2}$$

The equation indicates that $(p+2)$-step uniform phase-shifting scheme can be applied to retrieve phase accurately from fringe patterns with nonlinear harmonics up to the p-th order.

The traditional phase-shifting algorithm with large step is very simple and effective for extracting correct phase from real FPP images. In order to have high speed measurement, however, taking more than three phase-shifted frames is usually unpreferable.To deal with this issue, a novel gamma correction scheme is described as follows.

In theory, the gamma effect of the projector and camera system can be described as:

$$I = I_0^{\gamma'} \tag{3}$$

where I is the caputured intensity, I_0 is the intensity of the ideal sinusoidal pattern, and γ' is the gamma value of the entire system including projector and camera.

To detect γ' in equation (3) for the three-step phase shifting algorithm, the following equation can be used:

$$\tan^{-1}\left\{\frac{-\left[I_2^{\gamma'}\sin(\frac{\pi}{3})+I_3^{\gamma'}\sin(\frac{2\pi}{3})\right]}{I_1^{\gamma'}+I_2^{\gamma'}\cos(\frac{\pi}{3})+I_3^{\gamma'}\cos(\frac{2\pi}{3})}\right\} - \phi^c = 0 \tag{4}$$

where ϕ^c is the correct phase value obtained in Equation (2), which in practice is determined by using the conventional large step phase-shifting algorithm presented previously. It is noted that the previous equation is for a single pixel only; to solve for γ' for the entire image to ensure high accuracy, a least-square approach is highly recommended.

3 Results

To verify the validity of the proposed approach, an experiment of measuring the 3D shape of a sea shell is conducted. It is confirmed that the phase error of proposed method is only around 0.01 radian, and the encoded gamma is calculated with errors averaging only 0.1 %, which is significantly better than previous method's result, 7.5 % [Farid et al.2001]. Using this technique, accuracy with fast three-stepping phase shifting algorithm can be yielded up to 1/10000 . The above figure demonstrates 3D imaging reconstruction from three different schemes. It shows that the three-step phase-shifting algorithm with proposed gamma encoding method can achieve accuracy even higher than the one provided by the larger-step phase-shifting algorithm. The experiments thus demonstrate when high speed is desired, the proposed gamma encoding scheme can be applied with the conventional three-step phase-shifting algorithm to achieve high measurement accuracy.

References

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