3D OBJECT MEASUREMENT BY SHADOW MOIRÉ

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Abstract: In order to get the 3 dimensional data of an object, this research applied a shadow Moiré method to build an optical measurement system without touching the object to measure the contour for getting a 3D data. A digital camera was used to capture the Moiré images through an image processing to get the texture of each contour line. After calculated the texture of each contour line, the correspondence values are then filled. Each correspondence value will make smooth contour interpolation and then three-dimensional image of the object was plotted. This method for 3D measurement is simple and does not need an expensive measurement device to get precisely image information for a 3D rebuilt implementation.

1 NON-TOUCHING 3-DIMENSIONAL MEASUREMENT METHOD

Non-touching measurement method is to use a laser or light interference measuring the objects. There will be no touching wear or contact vibration to cause bias. This method is very suitable to measure the soft materials. In addition, its application domain is wide, such as industrial model design process, reverse engineering, medical engineering, surgery simulation, 3D animation and so on. The followings are some common non-touching three-dimensional profile measurement methods (Fu, 1997).

Shadow Moiré is the method applied in this study, shown in Figure 1. The experimental devices include a reference grating, light source and digital camera. The light source projects on the grating with a specific angle. This grating is called as the reference grating. The shadow of straight-line projected onto the testing object called as the shadow grating which overlapped with original reference grating and generated the circular textures. Applying the image extracting equipment to obtain images shall be the interception of two grating lines forming the moiré image, which can be the most cost-saving, but also the easiest way to set up. In order to allow the observers intuitively understand the ups and downs of surface with contour lines. The measurement resolution could be changed by setting the light angle or the grating pitch.

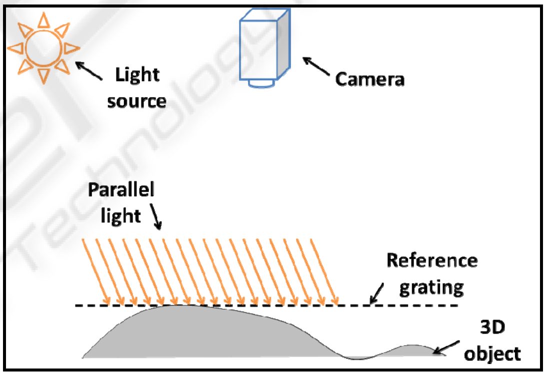

Figure 1: Shadow Moiré Measurement.

2 METHOD

2.1 Shadow Moiré

Moiré grating is forming by two overlapped grating with low spatial frequency textures (Batouche, 1992). Shadow Moiré is only using a single grating as the reference grating placed on the front of object. After the light projection on the reference grating through the test object which generates a distorted shadow called shadow grating. The shadow grating overlaps with the reference grating formed a shadow moiré. Figure 2 is the framework of shadow Moiré measurement. The shadow moiré is composed of the original grating and the grating shadow. The grating

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size can't too thin or dense to produce diffraction effects (Glassner, 1999).

From the observation, the overlapped Moiré of two gratings of AC and AD were recognized simultaneously. The number of AB straight stripes has m lines and AD has n lines, then

$$AC = mp\,,\, AB = np$$
$$BC = AC - AB = (m-n)p = Np$$
$$BC = d(\tan\theta_1 + \tan\theta_2)$$

N: the number of Moiré fringe within the scope of AC.
p: pitch of grating.
θ_1: incidence of light.
θ_2:Observation angle of image.

$$d = \frac{Np}{\tan\theta_1 + \tan\theta_2} = \frac{Np \times o}{m} \qquad (1)$$

d: Distance of a testing object and reference grating.

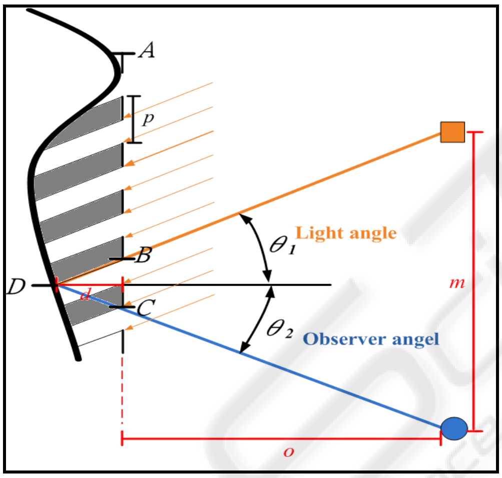


Figure 2: Enlargement of Shadow Moiré measurement framework (Tran etc., 1996).

From the equation 2.1, each moiré fringe can be calculated. It can be seen that each Moiré is a contour, in which we can label each moiré fringe in order to facilitate the depth calculation of the measurement surface.

2.2 The Image Processing Methods

2.2.1 Remove the Reference Grating Stripes

In the Moiré image, if the reference grating pitch is too large then the reference grating stripes will be very obvious, which is not the required information. The impact of stripes on the images are comprehensive and can be seen as a periodical signal in the whole image. It must use a low pass filter to remove (Batouche, 1992).

Suppose the original matrix is f (x , y), x and y are matrix elements. Through Fourier transformed, the output matrix is F(u ,v). Suppose index the matrix is M×N, the x-index ranges are from 0 to M-1 and the y-index ranges are from 0 to N-1. Equations 2.2 and 2.3 are the two-dimensional discrete Fourier transformation formula:

$$F(u,v) = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\exp\left[-2\pi i\left(\frac{xu}{M}+\frac{yu}{N}\right)\right] \qquad (2)$$

the reversed transformation is

$$f(x,y) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} F(u,v)\exp\left[2\pi i\left(\frac{xu}{M}+\frac{yu}{N}\right)\right] \qquad (3)$$

Figure 3 (a) is a stripe of its Fourier transformed images shown in Figure 3 (b), which could be observed out of several star shapes. The more close of the distance represents more thin and dense of straight line, that is the frequency is more higher. Reversely, the far of the distance represents the frequency is low and the pitch of straight stripes is larger. is shown in Figure 3 (c) is the image after processing by a notch filter . The straight-line stripes have been removed, shown in Figure 3 (d).

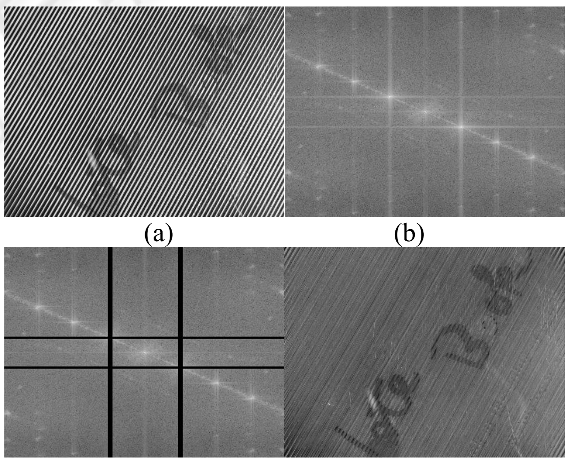


Figure 3: Fourier transformed with the notch filter image processing.

A template mask scanning on the image with the adjacent grayscale calculates the new grayscale value. If it uses a linear function to obtain the mask, this mask can also be called as a linear filter (McAndrew, 2004).

Too much detail of images in the computer vision on some specific pattern recognition will affect its results. To solve this problem, a low-pass filter on the image will produce fuzzy results and also can reduce the noise.

2.2.2 Enhance the Image Contrast

The contrast of a non-obviously image can be enhanced through the expansion of gray-scale distributions.

Using histogram equalization, assuming a gray-scale image has L gray levels, in the histogram of the i layer has n pixels, and assuming that all the number of pixels are $N = n_0 + n_1 + \ldots + n_{L-1}$ the gray-level i can be replaced by Equation 2.4 (Lin, 2001):

$$\left(\frac{n_0 + n_1 + \ldots + n_i}{N}\right)(L-1) \qquad (4)$$

A clear contrasted black and white images will be obtained.

2.2.3 Binarization

After the step of the image contrast enhancement, the next step is the binary image process. The required stripes and unnecessary image need to be split. The change of gray-scale image will be converted into black and white binary images. A common method is to set a threshold value of gray-scale images T to judge the grayscale value of each pixel, shown as follows.

$$g(x,y) = \begin{cases} 255 & , g(x,y) \geq T \\ 0 & , g(x,y) < T \end{cases}$$

Sometimes, the brightness of image is not consistent. A single threshold may not be fully extracted the images. The images can be cut to different blocks and each image block can have different setting of threshold value.

2.2.4 Thinning

The Zhang-Suen iterative algorithm was used to process the thinning (Zhang & Fu, 1984).

1. Odd-iteration was used to remove the right, bottom and upper-left corner pixels.
2. Even-iteration was used to remove the left, top and bottom right corner pixels.

However, there is certain condition should be considered. There is one neighboring pixel which may be the endpoint of framework and can't be removed. if there are 7 or more neighboring pixels, then it should remove the image object which probably can destroy the shape of image.

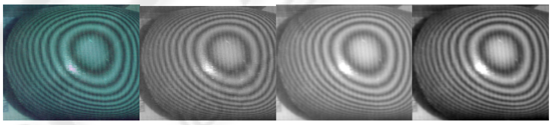
After the thinning step, it should remove the four-side line to get a contour line graph. The next section will be the actual measurement results and establish the three-dimensional graphic.

3 EXPERIMENTAL RESULTS

The pitch of reference grating is 1mm (p = 1mm), light source is from θ_1= 45 ° to project, and the observation is from θ_2 = 0 ° to observe, shown in Figure 4 which is the extracting image of the Moiré. Through Equation 3.1 calculating the d=1N(mm), it represents that there is a depth change of 1 mm in each pixel. The image area was cut appropriately and the color image was converted into grayscale for each pixel RGB (www.mathworks.com, 2009).

$$Gray = 0.299 \times R + 0.587 \times G + 0.114 \times B \qquad (5)$$

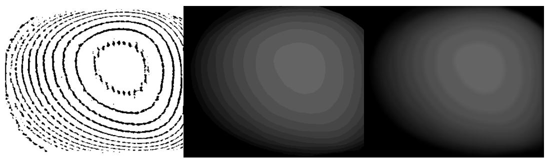
Cutting the region of interest image and filtering the reference grating stripes, shown in Figure 4.



(a) (b) (c) (d)

Figure 4: Capture images (a) original image (b) 8-bit grayscale (c) filtering the grating stripes (d) contrast enhancement.

After binarization of the image, the unneeded parts were cut or manual removed, shown as Figure 5(a) Marking on the Moiré lines, Figure 5(b) fill in the different gray values.



(a) (b) (c)

Figure 5: Remove the unwanted unneeded parts and fill in the gray-scale value.

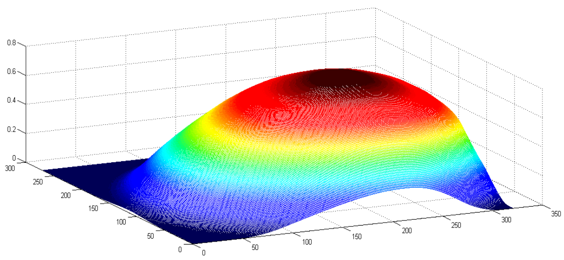


Figure 6: Three-dimensional graphic rebuit.

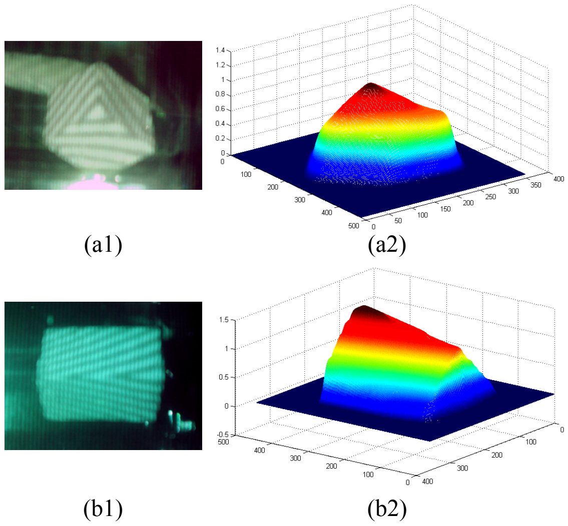


Figure 7: (a1) (b1) original photos (a2) (b2) three-dimensional measurement results.

4 CONCLUSIONS

This research applies shadow Moiré to measure the shape of the mouth. It can freely adjust the different grating pitch, light sources and different image grabbing angle to get different resolutions. The more the density of the grating is, the higher the resolution is. However, when the shadow stripe on the object is not obvious, it will increase the difficulty to process. If the light is not uniform while projecting, aperture and shutter exposure are not all the same. The images can't be processed by a fixed step of the camera operation. Sometimes it requires manual adjustment and handling. In the future, in order to increase its feasibility of projection Moiré in the experiment, it can also build more samples of the moving objects. The further study also needs to use the measured information matching with the 3D graphic design software to create animation models.

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Convert RGB image or colormap to grayscale. http://www.mathworks.com/access/helpdesk/help/toolbox/images/rgb2gray.html (retrieved date 07-19-2009)