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A high-sensitivity 3-D shape measurement method with microscope

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Abstract: An optical microscope commonly has the magnification from tens times to thousands times, and is often used for the observation of a micro specimen. The three-dimensional (3-D) form measurement of the specimen surface is broadly demanded of fields, such as medical treatment, pharmacy, life science, and materials science. On the conventional methods, the focus distance is regulated with great precision or the system is complex and the operation and observation is simply by the skilled personnel. In order to solve these problems, we propose a high-sensitivity 3-D shape measurement method with microscope. The measurement system is consisted of a normal microscope, a line laser, and a computer can obtain the high precision of target. The method is unnecessary to regulate the focus distance with great precision, simply project the laser source onto the surface of target and obtain the reflection image with the camera of microscope, and by using the image processing to obtain the center point of waveform of the intensity distribution of reflection image, finally calculate the 3-D shape information based on the triangulation method. The experimental results show the proposal method is available.

Keywords: Laser, 3-D measurement, Microscope.

1 INTRODUCTION

An optical microscope commonly has the magnification from tens times to thousands times, and is often used for the observation of a micro specimen. The three-dimensional (3-D) shape measurement of the specimen surface is broadly demanded of fields, such as medical treatment, pharmacy, life science, and materials science and so on.

The methods of 3-D shape measurement with microscope are various. For instance, laser-scanning confocal optical microscopy[9], strength is spatial resolution is high; weakness is the focus distance is regulated with great precision, and it cost time and observation is simply by the skilled personnel. AOD-based two-photon microscopy[10], strength is high-speed in vivo; weakness is the system is complex and the operation and observation is simply by the skilled personnel. Laser-induced fluorescence (LIF) detection system[5], strength is to provide effective high-throughput flow cytometry measurements; weakness is simply available for the direction. Shape from focus[1], strength is the system is simple and inexpensive; weakness is not available for the non-uniform spatial resolution, and the observation view is limited and performance affected by ambient light. And holographic optical element[6], strength is the calculation method is simple; weakness is the system is complex that the various mirror and microscope are used, the operation is difficult.

In order to solve these problems described on above methods, we propose a high-sensitivity 3-D shape measurement method with microscope.

The papers are formed with 5 sections as the following:

Section 2 introduces the composition, principle and methods of the 3-D measurement system we presented.

Section 3 shows the experimental results by using the method we proposed.

Section 4 introduces the conclusion for the method we proposed.

2 COMPOSITION, PRINCIPLE AND METHODS

The composition, principle and methods of the 3-D measurement system we presented is shown as following.

2.1 System composition

The measurement system on our proposal method is consisted of a microscope, a line laser, and a computer. It is shown as Figure. 1.

The operation of the method we proposed is as the following. At first, the line laser source is projected onto the surface of the micro target by the line laser. And next,

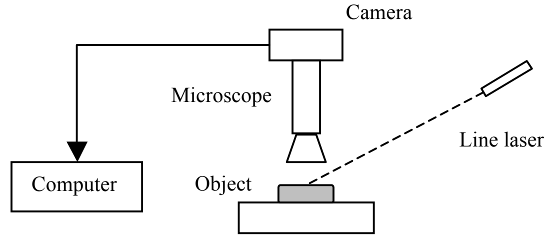


Fig. 1 Microscope 3-D measurement system

we regulate the microscope to observe the reflection image of target, and then, the camera of the microscope photographs the reflection image, and the image is inputted into the computer. Finally, the measurement image is obtained through the image processing on the computer, and the 3-D shape information of the target is calculated from the measurement image by using the triangulation.

2.2 Measurement principle

The measurement method is based on an optical principle - the intensity distribution of a reflection light likes a cosine waveform. For the cosine waveform, we can simply detect the top point of it. (On our research "Accuracy Improvement for Projection Patterns in 3-D Measurement" (Ref. [4], [5]), the top-point analysis method is introduced on detail.)

On the basis of the principle, when the microscope observes the reflection image, the focus distance can be regulated within great precision. It means the observation time and operation degree are reduced. It's the prominent strength of proposal method.

The cause is for the reflection image at any station, we can use the image processing to process the image, and obtain the ideal the cosine waveform of the intensity distribution of it. For the cosine waveform, we can easily detect the top point – the real center point of the waveform. And then, we can calculate the correct 3-D shape information of the observation point.

2.3 Measurement methods

2.3.1 Microscope observation

At first, in order to observe the target clearly, we put the specimen on the microscope stage, and move location of the stage to make the target on the center of the visual field of the microscope. And then, we regulate the focal distance of the objective of microscope to obtain the distinct image of the target, and regulate the light source of the microscope to obtain the primitive image of the target.

2.3.2 Laser projection

Second, we regulate the distance and rotation angle of the laser to make the line laser project onto the surface of the target and the reflection image on the visual field of the microscope. And then, we can obtain the reflection image intermix with the reflection light of laser source and light source of the microscope. The image is called the laser and light source image.

2.3.3 Camera photographs

And then, we close the light source of the microscope, and obtain the reflection image of the laser source by using the camera of the microscope. The image is called the laser source image.

2.3.4 Image processing

Be aimed at the laser source image, we will use the image processing to obtain the measurement image.

In order to obtain the channel had the maximum value of R, G, B, we use the method choose the measurement channel and generate a measurement image (Ref. [2], [3]).

In every pixel of the extracted object image, the color and intensity distributions are detected. The channel of the initial observation pattern image intensity maximum is chosen to be the measurement channel of the pixel by

$$\bar{I}(x,y) = \max\{\bar{I}_R(x,y), \bar{I}_G(x,y), \bar{I}_B(x,y)\} \quad (1)$$

where the (x,y) is the image coordinate of current pixel, $\bar{I}(x,y)$ is intensity of the (x,y), $\bar{I}_R(x,y)$, $\bar{I}_G(x,y)$, $\bar{I}_B(x,y)$ is respectively intensity of the Red, Green channel of the (x,y), Blue of (x,y).

The result image is called the monochrome image.

2.3.5 Center point detection

Through using the moving average method, we can obtain the cosine waveform of the intensity distribution of the reflection light.

For the cosine waveform, we can easily detect the top point of it. The result is shown as Fig. 2.

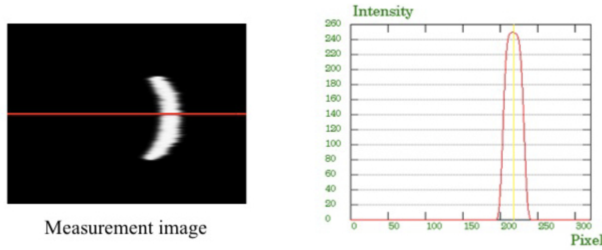
Where the yellow line on the Intensity distribution figure is the top point position of reflection light on the red line of the measurement light.

2.3.6 3-D information calculation

Fig. 3 is the diagram used the proposal method based on the triangulation method. On the basis of the diagram, we obtain the equations calculated the 3-D information of the target, they are shown as the (2), (3) and (4)

$$X = Z \times \frac{x}{f} \quad (2)$$

$$Y = X \times \frac{y}{x} \quad (3)$$



Measurement image

Intensity distribution figure

Fig. 2 Detection results of the object

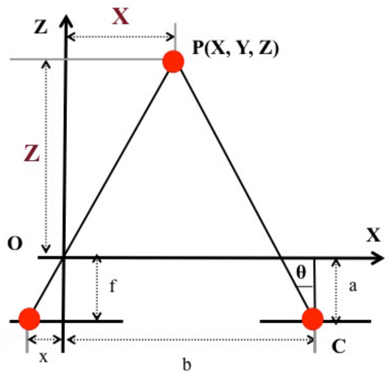


Fig. 3 The principle of triangulation method

$$Z = \frac{b - a\tan\theta}{\tan\theta \pm x/f} \qquad (4)$$

Where P is the observation point on the target, C is the projection point from the laser, and P1 is the reflection point of the projection point from the target to the camera. X is the horizontal distance from P to the mid-perpendicular line of camera. Y is the vertical distance from P to the mid-perpendicular line of camera. Z is the depth distance from P to the image plane of camera. x is the horizontal distance from P1 to the mid-perpendicular line of camera. y is the vertical distance from P1 to the mid-perpendicular line of camera. b is the distance between the laser and camera. a is the distance from the laser to the lens of the microscope. tan θ is the angle between the projection laser source and the vertical line. f is the focal distance of camera.

By using the equations (2), (3) and (4), we can calculate the 3-D information of each top point on the reflection light.

3 EXPERIMENTAL RESULTS

The experimental conditions: The microscope is the pinhole confocal optical system; the magnification is from 25 to 175. The spatial resolution of the camera of the microscope is 320 × 240, the CCD is the ½ type 900,000 pixel CCD series. The laser is the semiconductor line laser.

For test the proposal method, we make a series experiments for various specimens. The experimental results are shown as following. (Because the time is not enough on the deadline of the manuscript, the experiment from 3.2 to 3.4, we only obtain the analysis result and can't calculate the depth distance.)

3.1 Pine needle

The experiment is on the pine needle; the specimen is the section of a pine needle. For the case, the magnification of microscope is 175. The result is shown as the Fig. 4.

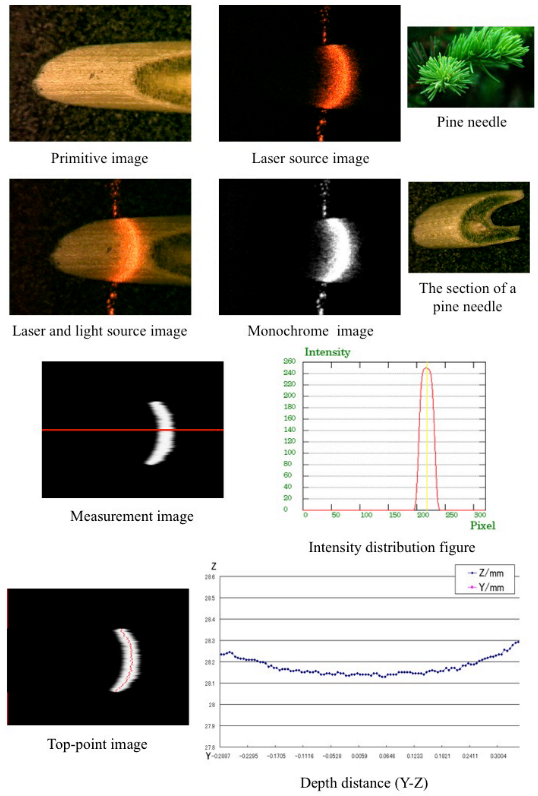


Fig. 4 Measurement results of a Pine needle

Where, the red point on the Top-point image is the top point position of each line of the reflection light.

3.2. Drawing pin

The experiment is on the pine needle; the size of the specimen is shown as the "Drawing pin". For the case, the magnification of microscope is 25. The result is shown as

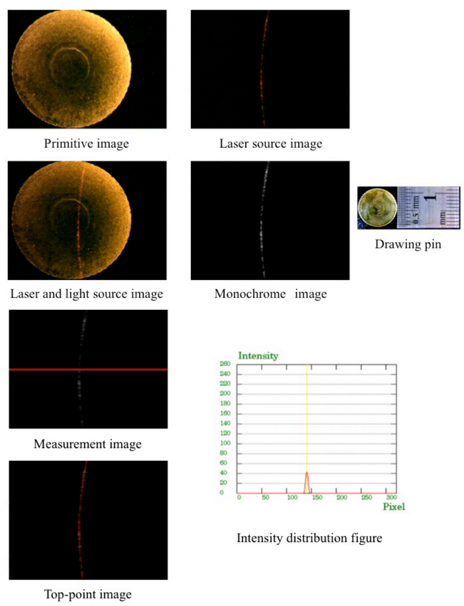


Fig. 5 Measurement results of a Drawing pin

the Fig. 5.

On the case, for the smooth surface of target, the results are very well.

3.3 Flat head tapping screw

The experiment is on the flat head tapping screw; the size of the specimen is shown as the "Flat head tapping screw". For the case, the magnification of microscope is 25. The result is shown as the Fig. 6.

On the "Section image", we can see the problem for the concave surface, the reflection light has the loss, and the 3-D information of the loss can be not measured in reality.

3.4 Self-tapping screw

The experiment is on the self-tapping screw; the size of the specimen is shown as the "Self tapping screw". For the case, the magnification of microscope is 25. The result is shown as the Fig. 7.

On the "Analysis image", we can see the problem for the concave-convex surface, the reflection light not only has the loss, but also has the two waveform, the case become more complex, to calculate the 3-D information is too difficult in reality.

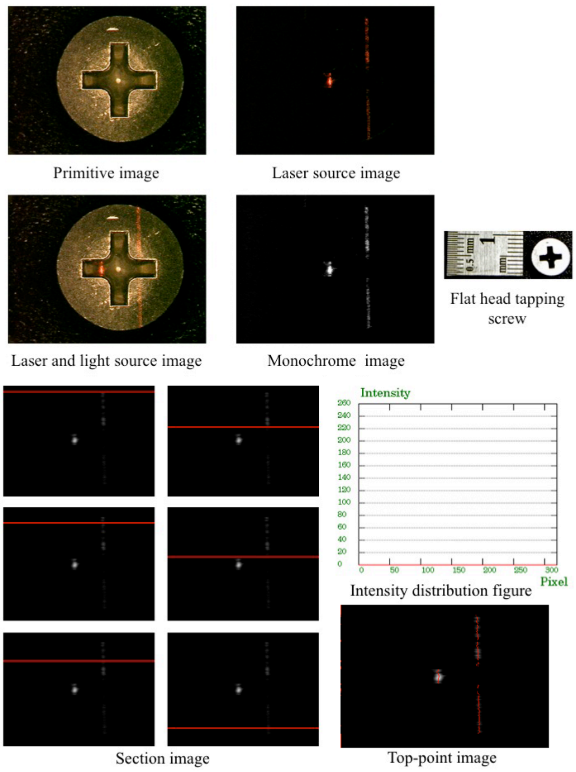


Fig. 6 Measurement results of a Flat head tapping screw

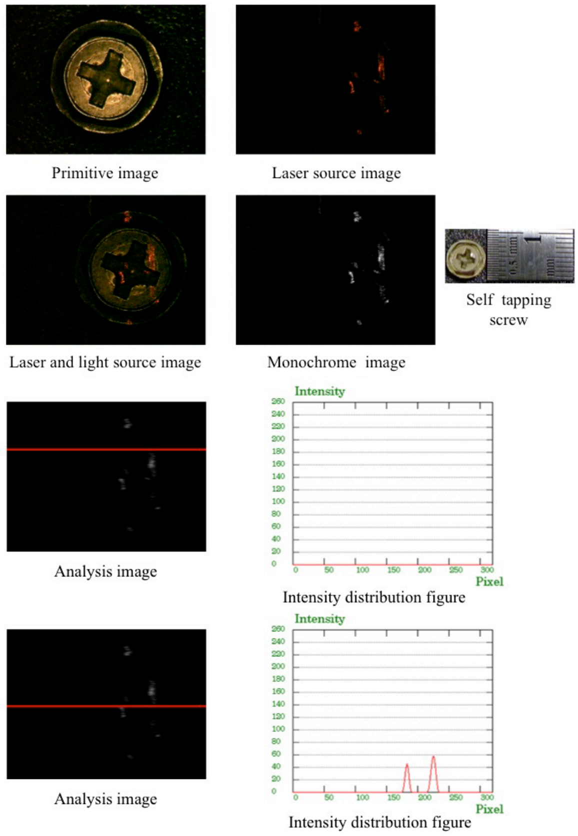


Fig. 7 Measurement results of a Self-tapping screw

4 CONCLUSION

On the research, we combine a simple, inexpensive and easy operation system, and lead the top-point analysis method for the system.

At present, through a series experiments, we can prove the method is available for the system. And from the experiment 3.2, 3.3 and 3.4, we can see: for the uniform, smooth surface shape, the method is well. For the free-form shapes, the reflection light has loss. For the complex shapes, the reflection light becomes too complex to detect the top-point of the intensity distribution.

And at the further, we will be aimed at these problems to perfect the proposal method.

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