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Structured-Light Based on Shaped Depth-image Capturing System

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ABSTRACT

At first, this paper introduces the structure of the depth-image capturing system using the single-stripe pattern. . At second, its operating principle is introduced, its mathematical model is established and the calibrating method for it is put forward. At last, its prototype is produced and calibrated.

Keywords: Structured-light, Depth-image

1. INTRODUCTION

It is not unique to recover the 3D shape of objects from their usual intensity images because information of depth is lost. But the depth-images have 3D information of object surfaces, so they are used not only to measure 3D shape of object surfaces but also to provide a new approach to pattern recognition.

This paper puts forward a kind of depth-image capturing system based on structured-light. As known, its distortion can be transformed into the height change in the direction of the stripe if a single-stripe light is emitted and observed sideways. So a generator emitting a single-stripe light and a camera can make up of a depth-image capturing system. It can obtain the depth-image of the detected object section. If the object is shafted by definite step along a fixed beeline direction(x), the depth-image of full object surface is achieved when the system repeats the above said operation[1].

2. THE BUILDUP OF OUR SYSTEM

The buildup of the depth-image capturing system based on structured-light this paper is shown in Fig.1. It includes semiconductor laser and its optical system, CCD camera, image collecting card, computer and its software.

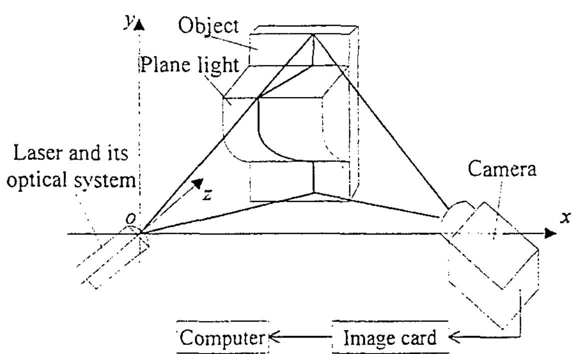

Fig.1 buildup of the depth-image capturing system

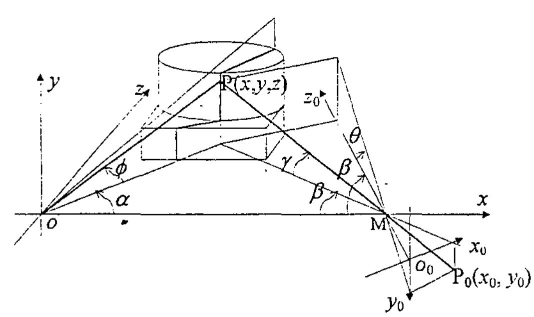

Fig.2 Principle of the system

3. MATHEMATICAL OF OUR SYSTEM

The operating principle of our system is shown in Fig.2. The center of the camera len is the point(M). The light emitted from the laser is becomes a sector plane light through the optical system, which is vertical to the plane(xoz). Its vertex is is located at the origin(o) of the world coordinate system($xyzo$), and $oM=B$. The plane light forms a strip on the measured object. Any object point $P(x, y, z)$ on the strip produces its image point $P_0(x, y)$ on the image plane($x_0o_0z_0$) in the camera coordinate system($x_0y_0z_0o_0$). The plane($x_0o_0z_0$) coincides with the plane(xoz). The ray(oP) is at an angle of ϕ to the plane(xoz), its projection on the plane(xoz) is at an angle of α to the axis(ox). In this paper, α is made to equal 90°. The optical axis(o_0x_0) of

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the camera is at an angle of β_0 to Mo. The focus of the camera is equal to o_0M. The ray(MP) is at an angle of γ to the plane(xoz), the projection of γ onto the plane($y_0o_0z_0$) is θ. The projections of the ray(MP) onto the plane(xoz) is at an angle of β to Mo. The visual angle of the camera is $2\beta_1$. The pixel sequence numbers of camera along the horizontal direction(x_0) and the vertical direction(y_0) are respectively n and m, where n is from $-N$ to N and m from $-M$ to M.

According to Fig.2, we have from the camera geometry[2]

$$z = \frac{B}{ctg\alpha + \dfrac{ctg\beta_0 + \left(\dfrac{tg\beta_1}{N}\right)n}{1-\left(\dfrac{ctg\beta_0 tg\beta_1}{N}\right)n}} = B\frac{1-\left(\dfrac{ctg\beta_0 tg\beta_1}{N}\right)n}{ctg\beta_0 + \left(\dfrac{tg\beta_1}{N}\right)n} \tag{1}$$

$$x = z \cdot ctg\alpha = 0 \tag{2}$$

$$y = \frac{z\left(\dfrac{tg\beta_1}{M}\right)m}{\sin\beta_0 - \cos\beta_0\left(\dfrac{tg\beta_1}{N}\right)n} \tag{3}$$

where n and m are obtained from the image; the parameters of β_0, β_1, B are constants to be calibrated.

4. METHOD OF OUR SYSTEM CALIBRATING

4.1. Calibrating Model of Our System

The calibrating principle of our system is shown in Fig.3. Fig.3 is the projection of Fig.1(Fig.2) on the plane of xoz. In Fig.3, The reference plane is parallel to the plane of xoy and the distance between them is equal to A; the distances from object points of Z_1, Z_2 and Z_3 to the reference plane are z_1, z_2 and z_3, their image points are separately on the right side column, the middle column and the left side column of the camera image plane.

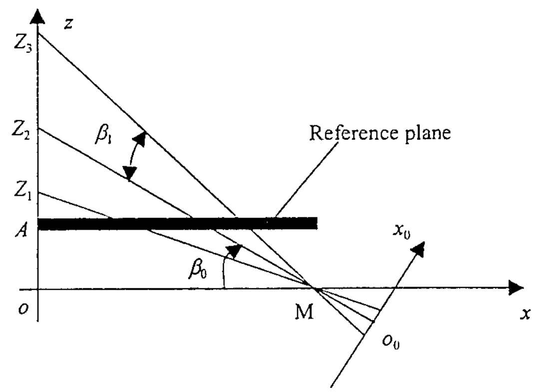


Fig.3 Projection of our system on the plane of xoz

According to the geometrical relation in Fig.3, we have

$$z_1 + A = B \cdot \tan(\beta_0 - \beta_1) \tag{4}$$

$$z_2 + A = B \cdot \tan\beta_0 \tag{5}$$

$$z_3 + A = B \cdot \tan(\beta_0 - \beta_1) \tag{6}$$

From formula (4), (5) and (6), the following formula is deduced.

$$B^2 = \frac{(z_1 + z_3 + 2A)(z_2 + A)^2 - 2(z_1 + A)(z_2 + A)(z_3 + A)}{z_1 + z_3 - 2z_2} \tag{7}$$

It is clear that B can be obtained if a reading of A is given. Formula (7) is the calibrating model of B.

From formula (4), (5) and (6), the following formulas are deduced again.

$$\beta_0 = \arctan\frac{z_2 + A}{B} \tag{8}$$

$$\beta_1 = -\arctan\frac{z_1 + A}{B} + \beta_0 \tag{9}$$

or

$$\beta_1 = \arctan\frac{z_3 + A}{B} - \beta_0 \tag{10}$$

Formula (8) and (9) or (10) is the calibrating model of β_0 and β_1.

From formula (3), we have

$$y = \frac{m}{M} \cdot \tan \beta_2 (B \cdot \cos \beta_0 + z \sin \beta_0)$$

When column number of n is changeless, we have

$$\cot \beta_2 = \frac{m_1 - m_2}{y_1 - y_2} \cdot \frac{B \cdot \cos \beta_0 + z \cdot \sin \beta_0}{M} \quad (11)$$

It is clear that β_2 can be obtained if readings of (m_1-m_2) and (y_1-y_2) are given. Formula (11) is the calibrating model of β_2.

4.2. Calibrating Process of Our System

The calibrating equipment includes a guide with a scale, placed along the lines of oz, and a standard plane parallel to the reference plane, placed on the moving part of the guide. At firat, z_1, z_2 and z_3 are calibrated across experiment. And then. B, β_0, β_1 and A are calibrated. At last, β_2 is calibrated. The concrete process is as the following:

1) The standard plane is shifted until the single-stripe image appears on the right slide column of image plane. Here the standard depth z_1 is 111mm according to the scale of the guide.
2) The standard plane is shifted until the single-stripe image appears on the middle slide column of image plane. Here the standard depth z_2 is 320mm according to the scale of the guide.
3) The standard plane is shifted until the single-stripe image appears on the left slide column of image plane. Here the standard depth z_3 is 910mm according to the scale of the guide.
4) The designed value of A(A=95mm), z_1, z_2 and z_3 are substituted into formula (7), (8), (9) or (10). Then the values of B, β_0 and β_1 are calculated.
5) The standard plane is shifted until the single-stripe image appears on some column of image plane. Here the standard depth z_i is obtained from the scale of the guide and the reading of n_i is given by the camera image plane.
6) Many groups of (z_i, n_i) are obtained when repeating process 5).
7) According to n_i, the depth calculated value of z'_i is obtained from formula (1).
8) Calculate least square error of $\sum_{i=1}^{I} \left(z_i - z'_i\right)^2$.
9) Correct the value of A to make the least square error reduce.
10) Repeat process4)~9) until the least square error becomes least. Here the value of A is best and used as calibrated value.

The calibration result is as the following: B=311.916mm, β_0=52.7372°, β_1=19.9293°, A=90mm.

Row numbers of two images of the same column of m_1 and m_2 can directly be obtained from the image. Then the value of β_2 can be calibrated according to formula (11), if the height difference of (y_1-y_2) is known, where the object point height corresponding to image point row number m_1 is expressed as y_1 and m_2 expressed as y_2. The concrete process is as the following:

1) The standard measuring block is placed in the view field of the system, perpendicular to the plane of xoz and parallel to the reference plane, shown as in Fig.4.
2) The upper surface height of the standard measuring block is expressed as y_1, the lower surface height expressed as y_2. Then the standard value of the measuring block(100mm) is used as the height difference (y_1-y_2) in formula (11).
3) The intensity image of the block is shown in Fig.5. The row numbers of m_1 and m_2 are made sure by image processing. The tow-valued fringe image of the block is shown in Fig.6. From its grey data, m_1 and m_2 can directly be obtained
4) The calibrated value of β_2 can be calculated when substituting (y_1-y_2) and (m_1-m_2) into formula (11).

The calibration result is that β_2=15.0703°.

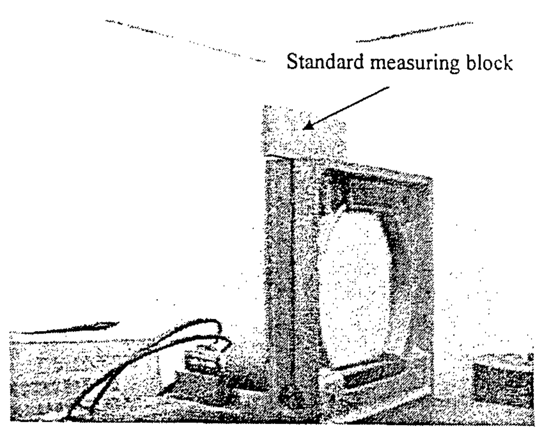


Fig.4 Placement of the standard measuring block

5. EXPERIMENT RESULTS

As shown in Fig.7, the bright stripe is the section outline of a plaster head portrait figure, and its depth image is shown in Fig.8.

The depth image experiment of a water heater model is shown in Fig.9. The stripe image of the model is as shown in a, and the depth image of the model is as shown in b.

Fig.5 Grey image of blocl

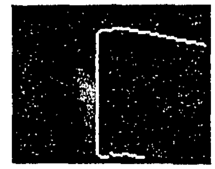


Fig.6 Two-valued fringe image of block

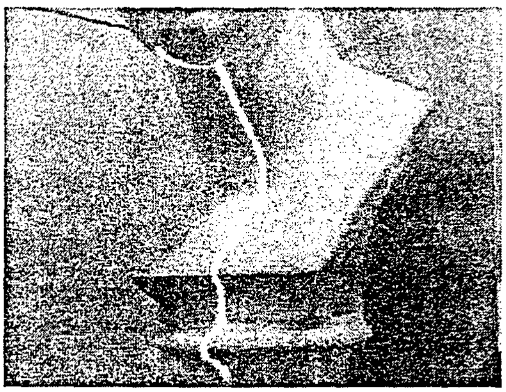


Fig.7 Stripe image of the plaster head portrait

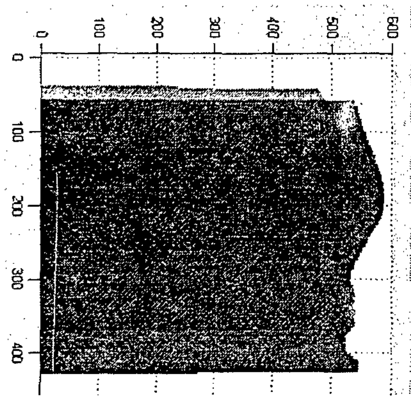
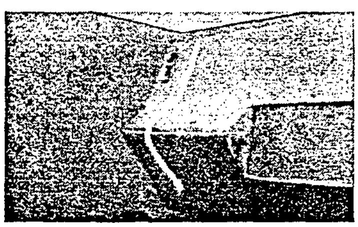
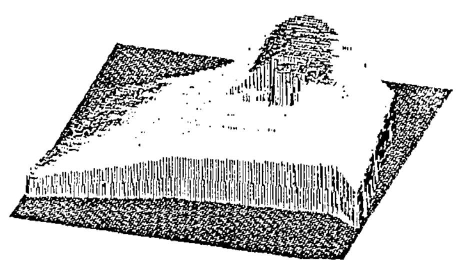


Fig.8 Depth image of section of the plaster head portrait



a. Stripe image of the water header model



b. Depth image of the water header model

Fig.9 Depth image experiment result of the water header model

6. CONCLUSION

This paper introduces the depth image capturing system based on structured-light and proposes the calibration method for our system. The experiment results show that our system prototype has the measuring scale of 300mm(y)×300mm(z), the resolving power of 0.5mm(y)×0.5mm(z) and the precision of 1.5mm(y)×1.5mm(z).

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