A DIGITAL CLOSE-RANGE PHOTOGRAMMETRIC SYSTEM USED FOR TEXTURE-LACKING OBJECTS IN MEDICINE

Wenhao FENG, Xin LI and Xueliang MEI
Wuhan Technical University of Surveying and Mapping
39 Luoyu Road , Wuhan, 430079
E-mail: whfeng@wtusm. edu. cn
Guangxiang HONG, Yunting WANG and Qishun HUANG
Wuhan TongJi Medical University
CHINA

Commission V, Working Group V/4

Key Words: DLT , Degree of coincidence, hand bone, CCD Camera

Abstract

A digital close range photogrammetric system used for determining the surface shape of hand bone and geometric coincidence between two bones was presented. The system hardware consists of a single CCD camera , a light source with a specially made infrared ray, a spinning platform carrying a tiny control system frame, and a PC computer with image card Video Blaster. With the help of software, the left and right images of a stereopair can be displayed on the screen simultaneously. Screen coordinates of points are measured through average grey. Space coordinates are solved by using algorithm of DLT (Direct Linear Transformation). Performing imitation of two bone surfaces with a general quadratic surface and the overlapping of the main orientations of both surfaces, it is possible to determine the degree of coincidence between the two bone surfaces dynamically.

The system can also be used to determine the appearances of other texture-lacking objects quickly.

1. Introduction

From far away, the wrist of the hand composed of three bones: distal carpale (first part), wrist joint (second part) and proximal carpale (third part). When the second part has to be excised, the surgical operation, which links the first part third part directly in order to reconstruct the wirst joint, has an important medical meaning. This paper is part of the achievement of research between Wuhan Technical university of Surveying and Mapping and Wuhan Tongji Medical University.

The main research content is to select a practical surveying system, so that the degree of coincidence of both bones (1st and 3th) can be accurately surveyed and determined quickly, and so that a scientific basis can be provided for the feasibility of these kinds of operations.

The authors hope that the system can also be used to determine 3-D space coordinates of other similar objects.

2. Hardware Components of the System

2.1 Designed index of the system

- Form a digital close-range photogrammetric system for raising measurement speed;
- Using a single CCD camera in order to reduce hardware investment;
- Form sub-binary image of texture-lacking objects on the screen in order to simplify the procedure of image processing and photogrammetric processing.

2.2 Hardware components

The system hardware shown in Figure 1 consists of a single CCD camera 1, a light source with infrared ray near the main optical axis of the CCD 2, power source 3, a tiny 3-D coordinate control system 4, a tiny spinning platform with horizontal degrees 5, and a personal computer with video Blaster software 6. Retro-reflective targets (RRT) are used in the surveying procedure.

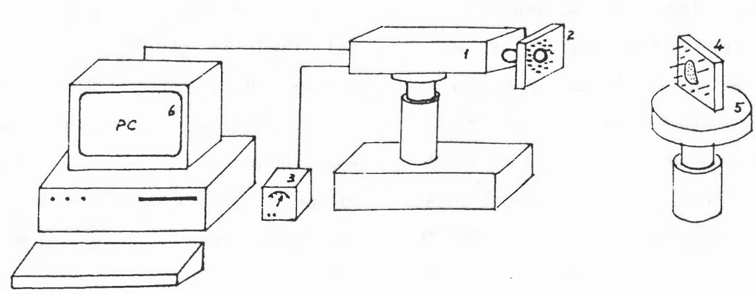

Figure 1

The Black-and-white CCD camera is appropriate for the low illuminance environment and low price

According to the actual size [80mm×80mm×30mm] of the object space control frame, the space resolution power fitting in every pixel is ±0.16mm , RMS in object space is assumed to be ±0.3mm, so it is not necessary to consider mechanical errors of the CCD camera, but only lens distortions.

The light source with infrared ray near the main optical axis is used in order to form sub-binary image and work under the condition of normal illuminance indoors . The light source with infrared ray made by ourselves consists of 56 infrared ray diodes. The power distribution of diodes is from 1.5 to 3.5 mw. The total power the light source attains is 110 mw, and the direct current voltage is 10 V.

The tiny control frame consists of 12mm thick square made of cast iron and several bolts of different lengths affixed on it. Fifteen RRT of 1mm diameter are pasted on the top of those bolts and the surface of cast iron. By using the two surveying piers which locate in the close-range photogrammetric laboratory of WTUSM and the Topcon-GTS-6 Total Station connected to computer, the 3-D space coordinates of control points on the tiny control frame are solved with forward intersection and their accuracy reaches ±0.1mm.

The tiny spinning platform is actually the sample platform of an optical microscope with a diameter of 12 cm. The tiny control frame can be conveniently put on the glass sample platform of the microscope .

The 386/DX computer supplied with multimedia video Blaster could be connected with 3 CCD cameras.

3. Digital Close-Range Photogrammetric Processing

3.1 Image acquisition

Images are recorded by the following steps:

★ A bone with 30~40 quadrilateral RRT , the size of which is 0.2mm,is put inside the tiny control frame system.

★ The relative position between the CCD camera and the control system is adjusted in order to get the clearest and maximum size picture of the control system on the screen.

The photographic distance is about 0.7m.

3.2 Image processing

Attention should be paid to select grey threshold in the image processing in order to form a high quality sub-binary image on the screen.

3.3 Determination of space coordinates of RRT on surface of hand bone

Space coordinates of the RRT on the surface of the hand bone are solved according to the DLT method:

$$
\begin{aligned}
x+\Delta x + \frac{L_1X+L_2Y+L_3Z+L_4}{L_9X+L_{10}Y+L_{11}Z+1} &= 0 \\
y+\Delta y + \frac{L_5X+L_6Y+L_7Z+L_8}{L_9X+L_{10}Y+L_{11}Z+1} &= 0
\end{aligned}
\qquad (1)
$$

where:

x, y —— pixel number of image point on the screen coordinate system;

Δx, Δy —— correctness for optical distortion;

X, Y, Z —— object space coordinates of RRT in tiny control coordinate system;

(L_1, L_2 ...... L_{11}) —— coefficients of interior and exterior elements of image and ds , $d\beta$.

and:

ds — coefficient of non-equal scale along axis of x and y;

$d\beta$ — coefficient of non-perpendicularity between axis of x and y:

The reasons why DLT is adopted in the research are :

★ The complex procedure of calibration of the CCD camera could be omitted under middle and low accuracy;

★ DLT fits the calibration of the CCD camera, spaces of pixels along x and y of which are not equal.

In order to measure the number of pixels of image points by using the mouse, the programme used has following abilities:

★ Two convergent images can be displayed on the left and right parts of screen so the correspounding image points could be identified and measured easily;

★ Measured point image can be enlarged on the corner of the screen so that it is easy to improve measuring accuracy.

★ Measured point position can be marked with a red symbol right away.

According to the experiment, the total procedure for taking a pair of images and photogrammetric proccesing uses about ten minutes .

4. The Determination of The Degree of Coincidence Between Two Contact Surfaces of Two Hand Bones

4.1 The degree of coincidence between contact surfaces of hand bones is determined according to the following ideas:

A. The surface of the hand bone is presumed to be a quadratic surface with a centre;

B. The coefficient of the quadratic equation is determined solely through determination of space coordinates of several tens of RRT pasted on the hand bone surface;

C. The purpose of changing the general equation to a standard equation is to creat a situation in which the contact surfaces of the two hand bones are in a comparative position;

D. The determination of dynamic degree of coincidence of two contact surfaces of the hand bones is performed through translation and spinning of a hand bone to another.

4.2 The shape of hand bone surface is assumed as following general quadratic equation:

$$\Sigma:\ F(X, Y, Z) \equiv a_{11}X^2+a_{22}Y^2+a_{33}Z^2 +2a_{12}XY+2a_{13}XZ+2a_{23}YZ +2a_{14}X+2a_{24}Y+2a_{34}Z+a_{44}=0 \qquad (2)$$

Even if a_{44} is simplified , it requires at least nine points whose space coordinates are already known on the contact surface to define every coefficient a_{ij} of the general equation. Moreover, the quadratic equation is assumed as a quadratic equation with a centre.

It means that there are points on the quadratic curved surface and symmetrically located relating to the centre.

Equation (2) can also be expressed as following:

$$\Sigma:\ F(X, Y, Z) \equiv (a_{11}a+a_{12}Y+a_{13}Z+a_{14})X+ (a_{21}X+a_{22}Y+a_{23}Z+a_{24})+Y+ (a_{31}X+a_{32}Y+a_{33}Z+a_{34})Z+ (a_{41}X+a_{42}Y+a_{43}Z+a_{44}) \qquad (3)$$

so there is a matrix expression:

$$F(X, Y, Z) \equiv [\,X\ Y\ Z\ 1\,]\ A \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \qquad (4)$$

where A is a symmetrical matrix($a_{ij} = a_{ji}$):

$$A= \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \qquad (5)$$

The part of the second term of the above matrix is :

$$\varphi(X, Y, Z) \equiv [X\ Y\ Z]\ A_{44} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \qquad (6)$$

where :

$$A_{44} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \qquad (7)$$

Any quadratic surface has three main directions, they are conjugate and perpendicular to each other. Moreover, the main diameter having main direction is the symmetrical axis of camber with centre. So to find out the main directions of the cambers is the key step in determining the degree of coincidence between the two cambers.

The main direction V(X : Y : Z)and its corresponding eigenvalue λ can be derived from following formula:

$$A_{44} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \lambda \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \qquad (8)$$

where upon :

$$\begin{vmatrix} a_{11}-\lambda & a_{12} & a_{13} \\ a_{21} & a_{22}-\lambda & a_{23} \\ a_{31} & a_{32} & a_{33}-\lambda \end{vmatrix} =0 \qquad (9)$$

So , the eigenvalue equation is

$$-\lambda^3+I_1\lambda^2-I_2\lambda+I_3=0 \qquad (10)$$

and

$$I_1=a_{11}+a_{12}+a_{13}$$

$$I_2= \begin{vmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{vmatrix} + \begin{vmatrix} a_{11} & a_{13} \\ a_{31} & a_{33} \end{vmatrix} + \begin{vmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{vmatrix} \qquad (11)$$

$$I_3= \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} =|A_{44}|$$

All eigenvalues have relationship as follows :

$$I_1=\lambda_1+\lambda_2+\lambda_3$$
$$I_2=\lambda_1\lambda_2+\lambda_1\lambda_3+\lambda_2\lambda_3 \qquad (12)$$
$$I_3=\lambda_1\lambda_2\lambda_3$$

According to the eigenvalues mentioned above three main directions of curved surface are derived , and their directions are regarded as coordinateaxes of a new coordinate system o' - x'y'z' , so the equation of the quadratic surface is expressed as follows :

$$\lambda_1X'^2+\lambda_2Y'^2+\lambda_3Z'^2+2a'_{14}X'+2a'_{24}Y'+2a'_{34}Z'+a'_{44}=0 \qquad (13)$$

After a translation of the origin of coordinate system, equation(13) can be simplified as follows :

$$\lambda_1X''^2+\lambda_2Y''^2+\lambda_3Z''^2+a''_{44}=0 \qquad (14)$$

According to the numeral value symbols of λ_1 , λ_2, λ_3, a''_{44} and whether a''_{44} equals zero or not , the quadratic surface can be judged as a kind of ellipsoid 、pseudoellipsoid 、hyperboloid 、 of one sheet 、 hyperboloid of two sheets or cone . Under special conditions, the curved surface may be a simple spin curved surface.

5. Tests

Test 1

A cylinder lump made of aluminium with known shape are taken as the examination target. Thirty

RRT, 0.2mm^2 size ,are pasted on the surface of the cylinder generatrix. By using the CCD camera a convergent stereo-pair was taken and the screen coordinates of the control points on the tiny control frame and of unknown points are measured. Then the space coordinates of unknown points are solved through DLT , and then come to a standard equation as follows.

$$X^2+Y^2-R^2=0 \qquad (15)$$

The radius of the aluminium cylinder through solving is 20.20mm, and by comparing it with radius 20.30mm through direct measurement by using surveying callipers, so the difference is 0.1mm.

The experiment proves the correctness of the system algorithm.

Test 2

After getting the standard equations of two hand bone surfaces I and II, the two hand bones are piled as shown in Figure 2. On the same coordinate system , the coincidence difference dZ of the two bones surfaces at one position :

$$dZ=Z_1-Z_2 \qquad (16)$$

According to the formula mentioned above data are counted including the degree of coincidence in different positions (x,y) on two bones , the maximum coincidence difference and the average coincidence difference.

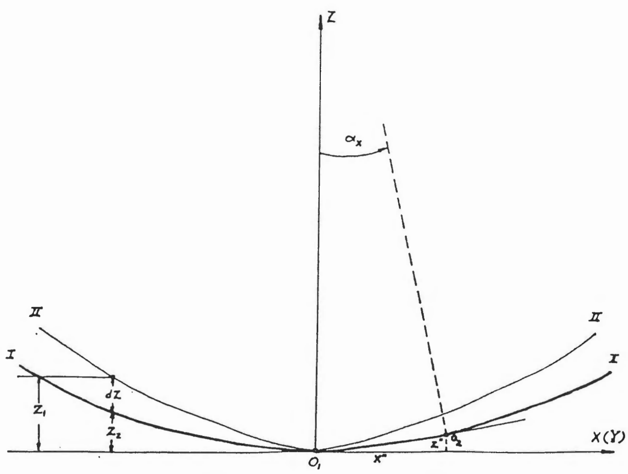

Figure 2

When the bone surface II was moved with relation to bone surface I , the position change can be considered as the bone surface translation X"(or Y") and Z" from O_1 to O_2 and the bone surface spinning as angle α_x (or α_y) at point O_2 Taking α_x as an example, presuming Y" as constant, having :

$$\lambda_3 Z''^2+\lambda_1 X''^2+C=0 \qquad (17)$$

$$tg\alpha_x=\frac{dZ''}{dX''}=-\frac{\lambda_1 X''}{\lambda_3 Z''} \qquad (18)$$

After the bone surface II has been translated and spun , the dynamic coincidence degree determination of the two bone surfaces is counted.

The surveying example is shown in table 1.

Table 1

-------------------------Zuoyou xuan zhuang jiaodu-------------------------

0

----------------------------------ge dian li cha----------------------------------

	-5	-4	-3	-2	-1	0	1	2	3	4	5
-5	0.65	0.61	0.58	0.56	0.54	0.54	0.54	0.56	0.58	0.61	0.65
-4	0.40	0.37	0.35	0.33	0.32	0.32	0.32	0.33	0.35	0.37	0.40
-3	0.24	0.21	0.19	0.18	0.17	0.17	0.17	0.18	0.19	0.21	0.24
-2	0.14	0.11	0.09	0.08	0.07	0.07	0.07	0.08	0.09	0.11	0.14
-1	0.08	0.06	0.04	0.03	0.02	0.02	0.02	0.03	0.04	0.06	0.08
0	0.06	0.04	0.02	0.01	0.00	0.00	0.00	0.01	0.02	0.04	0.06
1	0.08	0.06	0.04	0.03	0.02	0.02	0.02	0.03	0.04	0.06	0.08
2	0.14	0.11	0.09	0.08	0.07	0.07	0.07	0.08	0.09	0.11	0.14
3	0.24	0.21	0.19	0.18	0.17	0.17	0.17	0.18	0.19	0.21	0.24
4	0.40	0.37	0.35	0.33	0.32	0.32	0.32	0.33	0.35	0.37	0.40
5	0.65	0.61	0.58	0.56	0.54	0.54	0.54	0.56	0.58	0.61	0.65

--------zhui da li cha-------li cha zhong he------ping jun li cha-----

maxq2=0.653 q3=28.152 q4=0.233

6. Conclusion

1. In the research of determination of degree of coincidence of two hand bones, because the object is texture - lacking , and because of the large number of samples , lower determination accuracy and small size, the system designed has been tailor - made with rigorous theory, practical function and limited investmest.

2. The system can also be used in the research of other texture - lacking objects such as the design of new types of helmets.