INTEGRATION OF SUCCESSIVE RANGE IMAGES FOR ROBOT VISION

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ABSTRACT

Most conventional approaches to integrate range images from plural view points utilize range images obtained under some artificial restrictions set on movement of the target or measurement system by predetermined scheme, so as to skip determining process of mutual position relationship between range images.
This paper presents a method for integration of range images obtained from plural view points under non-restricted condition.
In this regards, we try to extract linearly independent four corresponding points automatically from 3D shape data of the same part of the target existing in successive two range images obtained under free condition by our high speed and continuous 3D measurement system [1], then, from those, derive 4x4 affine transformation matrix which gives mutual position relationship between the two range images and finally integrate them automatically in quest of thus determined affine transformation matrix.

1   INTRODUCTION

It is very important to obtain 3D shape data of an object in recognition and understanding of it for the robot vision etc. Conventionally, 3D shape data have been input manually, but the possibility of automatic data input has become prospective with the improvement of range finders in recent years.

However, in the measurement from one view point by range finder, they enable us to obtain only a part of the whole shape data of the target, because, generally, there is a part of the target which is not seen from the view point of range finder. So, we must integrate range images obtained from plural view points, using mutual position relationship as a clue, to get whole shape data of the target. Most conventional approaches to integrate range images from plural view points utilize range images obtained under some artificial restrictions set on movement of the target or measurement system by predetermined scheme, so as to skip troublesome determining process of mutual position relationship between range images. Although, in many field such as robot vision etc, it is desirable to integrate range images obtained under the condition free from such artificial restriction and such approaches are few and remain offering poor level of result.

In this regards, we try to solve the problem mentioned above by using our high speed and continuous 3D measurement system that enables us to acquire range images continuously at video rate with an error within ±0.3%. Successive two range images obtained our system have many shape data that are from the same part of the target because of short time interval between them. If we can determine linearly independent four corresponding points from them, we can derive the 4x4 affine transformation matrix which gives the mutual position relationship between two range images.

So, in this paper, we try to extract linearly independent four corresponding points automatically from the shape data of the same part of the target existing between successive two range images obtained by our system under the condition free from any artificial restriction, then, from those, derive the 4x4 affine transformation matrix which gives mutual position relationship between those two range images and finally integrate them automatically in quest of thus determined 4x4 affine transformation matrix.

2   HIGH SPEED AND CONTINUOUS 3D MEASUREMENT SYSTEM

Schematic diagram of our high speed and continuous 3D measurement system is illustrated in Figure.1. It is based on slit-ray projection method. Its key component is the non-scan-type image plane that developed in our laboratory Owing

to it, our system enables us to continuously acquire 3D shape data of the target in spatial resolution of 128x128 at video rate with an error within ±0.3%. Details of our system are available in elsewhere(K. Araki et al., 1992)(K. Araki et al., 1991)(K. Araki et al., 1995).
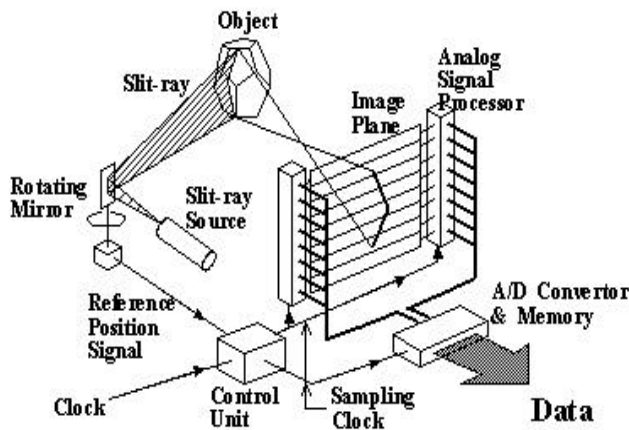

Figure 1. Schematic diagram of high speed and Continuous 3D measurement system

3 METHOD

3.1 Outline of Integration Method

If we can determine linearly independent four corresponding points between successive two range images, we can derive the 4x4 affine transformation matrix which gives the mutual position relationship between them and we can integrate successive two range images by it.

So, firstly, we measure the target by our system from plural view points under the condition free from any artificial restriction as shown in Figure 2. Successive range images obtained from plural view points by our system have many shape data that are from the same part of the target because of short time interval between them.

Therefore, secondly, we determine four linearly independent corresponding points between our successive two range images from them. In extracting four linearly independent corresponding points, we determine suitable four points from the first range image and then select four points in the second range image corresponding to the first ones, automatically. Details will be described in section 3.2.

Finally, we integrate all successive range images into first range image by concatenation of each 4x4 affine transformation matrix in order. Thus, we automatically integrate successive range images obtained under the condition free from artificial restriction. Details will be described in section 3.3.
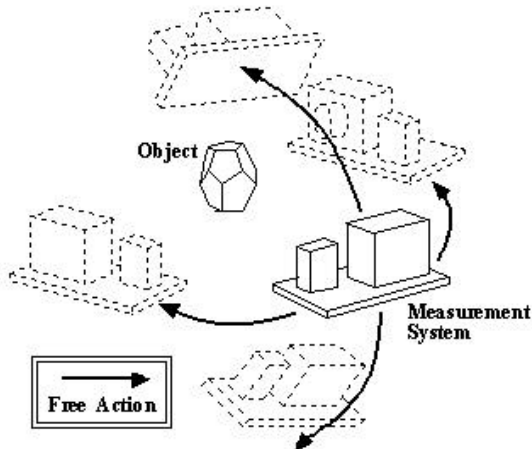

Figure 2. Measurement under the condition free from artificial restriction

3.2 Extracting Four Corresponding Points

Each range data obtained by our system is stored into two-dimensional array of 128x128 and each element of it is composed of 3D range, brightness and color data as shown in Figure 3. In extracting four linearly independent corresponding points between successive two range images, firstly we determine suitable four points from the first range image and then select four points in the second range image corresponding to the first ones in quest of above two-dimensional array.
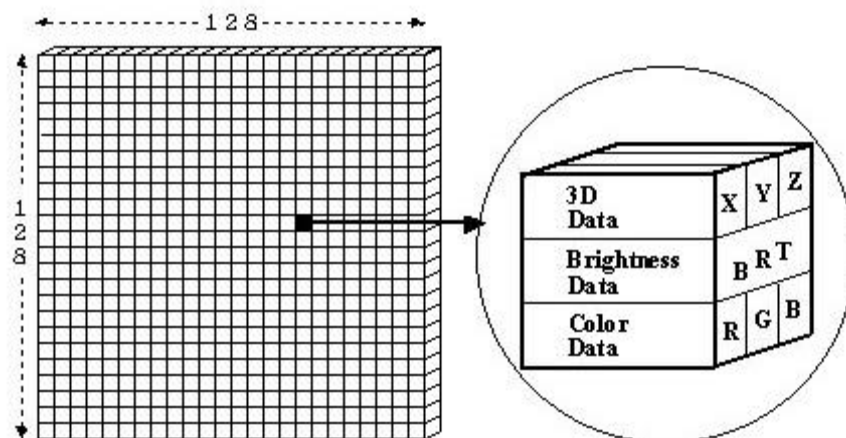

Figure 3. Two-dimensional array storing range image

When we determine four points from two-dimensional array of first range image, those must be linearly independent and four points corresponding to them must exist in two-dimensional array of second range image. It may happen that corresponding points from the edge of range data in the first range image don't exist in second one and vice versa. Also if we determine them in the closer region, they may not be linearly independent.

So, in this paper, we divide effective data array into four areas as shown Figures 4(a), then, we search the point in each area at which change in coordinate and brightness is the least and determine them as the above mentioned four points. By means of this method, thus determined four points are separated enough in distance. And, so, it may be probable for them to be linearly independent and not to be extracted at the edge of range image.
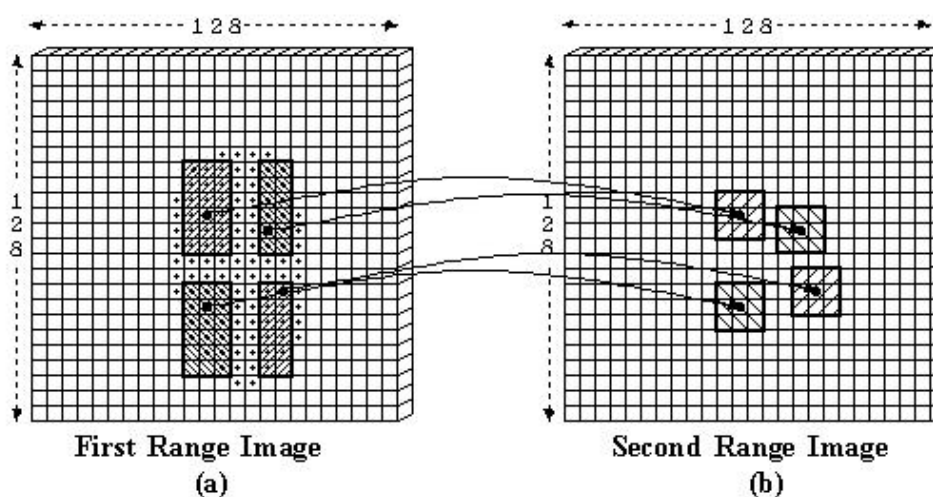
Figures 4. Extracting four corresponding points

Next, we describe how to determine four points from the second range image corresponding to the first one. Four corresponding points must be extracted very exactly, because result of integration may be strongly distorted even if only one point in corresponding points slightly deviate from exact corresponding points. In this paper, we overcome the problem by means of the following method.

Tentatively, four points in the second range image having the same array position as these extracted form first range image are adopted as provisional corresponding points. And, using these four pair of corresponding points, tentative 4x4 affine transformation matrix that gives the mutual position relationship between successive range images is determined from Equation.1.

$$\begin{bmatrix} a & b & c & 0 \\ d & e & f & 0 \\ g & h & i & 0 \\ j & k & l & 1 \end{bmatrix} = \begin{bmatrix} x_{21} & y_{21} & z_{21} & 1 \\ x_{22} & y_{22} & z_{22} & 1 \\ x_{23} & y_{23} & z_{23} & 1 \\ x_{24} & y_{24} & z_{24} & 1 \end{bmatrix}^{-1} \times \begin{bmatrix} x_{11} & y_{11} & z_{11} & 1 \\ x_{12} & y_{12} & z_{12} & 1 \\ x_{13} & y_{13} & z_{13} & 1 \\ x_{14} & y_{14} & z_{14} & 1 \end{bmatrix} \tag{1}$$

Where, $P_{11}(x_{11},y_{11},z_{11})$, $P_{12}(x_{12},y_{12},z_{12})$, $P_{13}(x_{13},y_{13},z_{13})$, $P_{14}(x_{14},y_{14},z_{14})$ are four points in the first range images and $P_{21}(x_{21},y_{21},z_{21})$, $P_{22}(x_{22},y_{22},z_{22})$, $P_{23}(x_{23},y_{23},z_{23})$, $P_{24}(x_{24},y_{24},z_{24})$ are four points in the second range images. And then, we transform all range data of second range image by them and we tentatively integrate them into the first range image.

Finally, if more than 30% of range data in the first range image agree with thus transformed range data in the second range image, that is, if Equation.2 are satisfied, we regard provisional corresponding points as desired ones.

$$\frac{C}{A} \times 100.0 \geq 30.0(\%) \tag{2}$$

Where, A is total number of effective data in the first range image and C is number of data in the first range image which agree with transformed data of the second one. The reason why we adopt Equation.2 as a criterion will be shown later.

If Equation.2 isn't satisfied at this stage, we repeat same procedure by regarding neighboring points as provisional corresponding points in order (Figures 4(b)) until Equation.2 is satisfied. Nevertheless, when Equation.2 isn't satisfied, we repeat the same procedure by returning to the first range image because, in this case, we can judge four points corresponding to ones in the first range image not to exist in the second range image.

Figure 5 shows rate of agreement between range data in the first range image and transformed data of the second one at the neighboring array point. Rate of agreement sharply increases at one neighboring array point. Therefore, we consider this point as exact corresponding point. Generally, rate of agreement sharply exceeds 30% at the corresponding points and becomes less than 10% at other points as shown in Figure 5. So, we adopt Equation.2 as a criterion for correspondence.
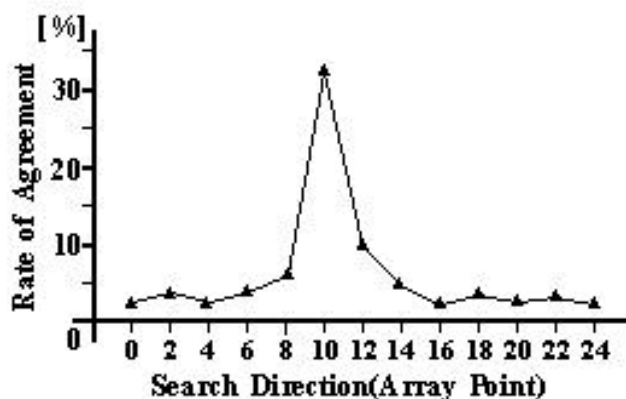

Figure 5. Rate of agreement

3.3 Integration of All Successive Range Images

By the method mentioned above, 4x4 affine transformation matrices are obtained between each pair of successive two range image. Then we can integrate range data of second range image into that of first one by using 4x4 affine transformation matrix between first range image and second one as shown in Figure 6. Now we represent 4x4 affine transformation matrix between kth range image and $(k+1)$th range image by $T_{k,k+1}$. Then we can integrate the second range image into the firsrt one by using 4x4 affine transformation matrix $T_{1,2}$ as shown in Figure 6. Similarly, the third range image into first one by using concatenation of $T_{1,2}$ and $T_{2,3}$. Generalizing this procedure, we can integrate the Nth range image into the first one by using concatenation of $T_{1,2}$, $T_{2,3}$, ...$T_{N-1,N}$ as shown in Figure 6. Thus we can automatically integrate all successive range images obtained from plural view points into the first range image.
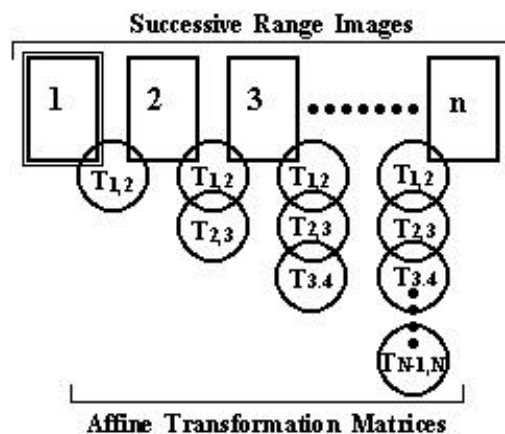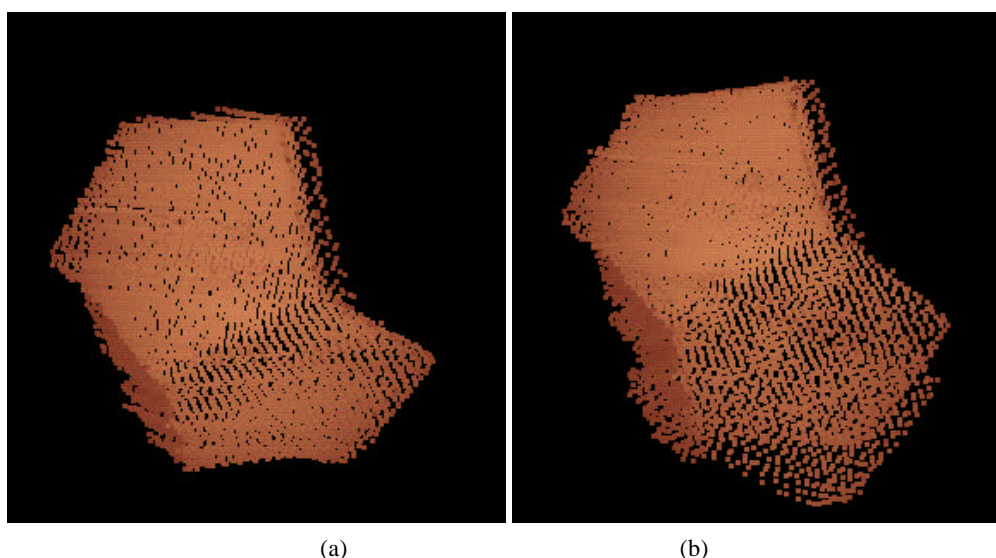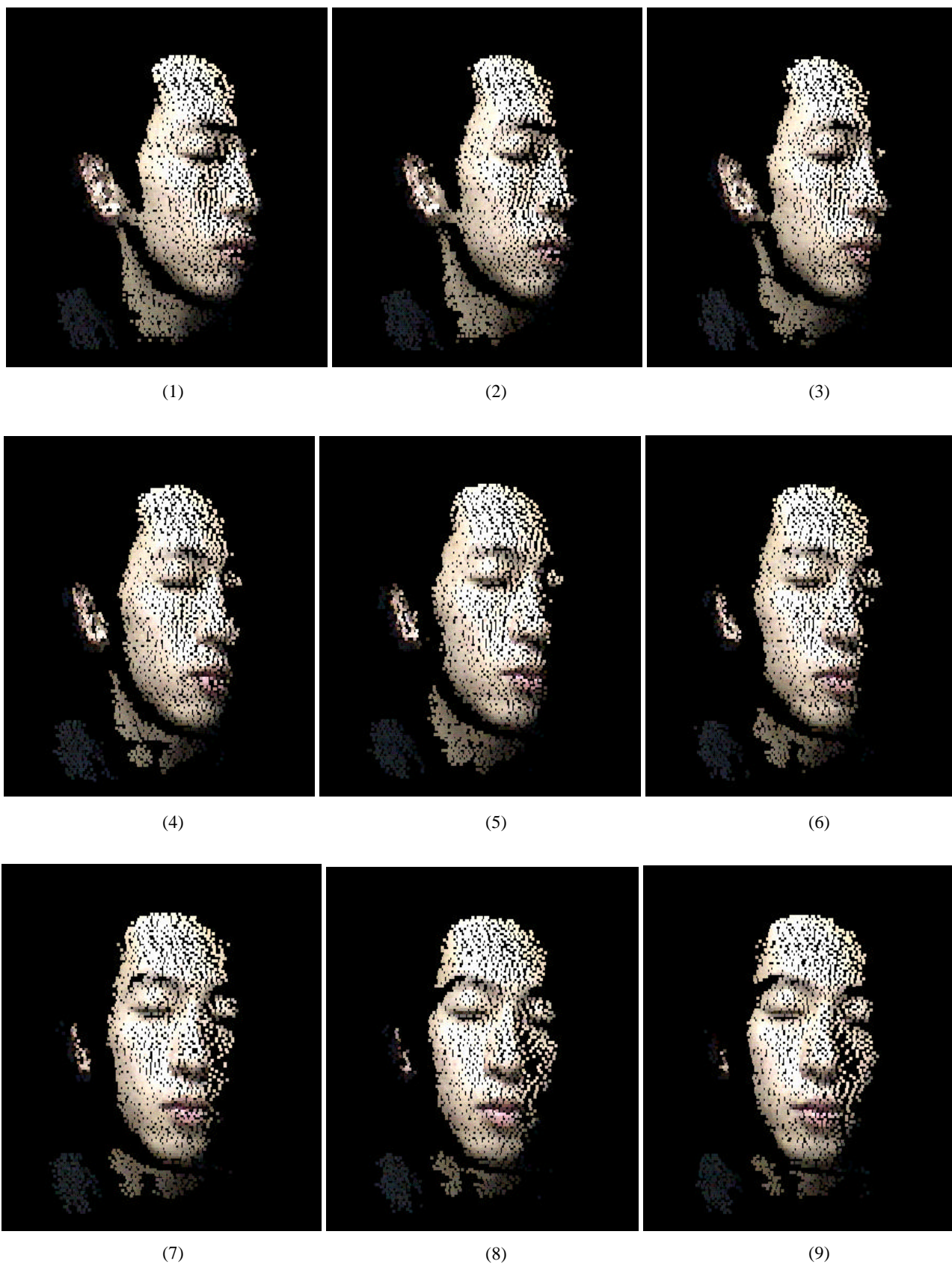

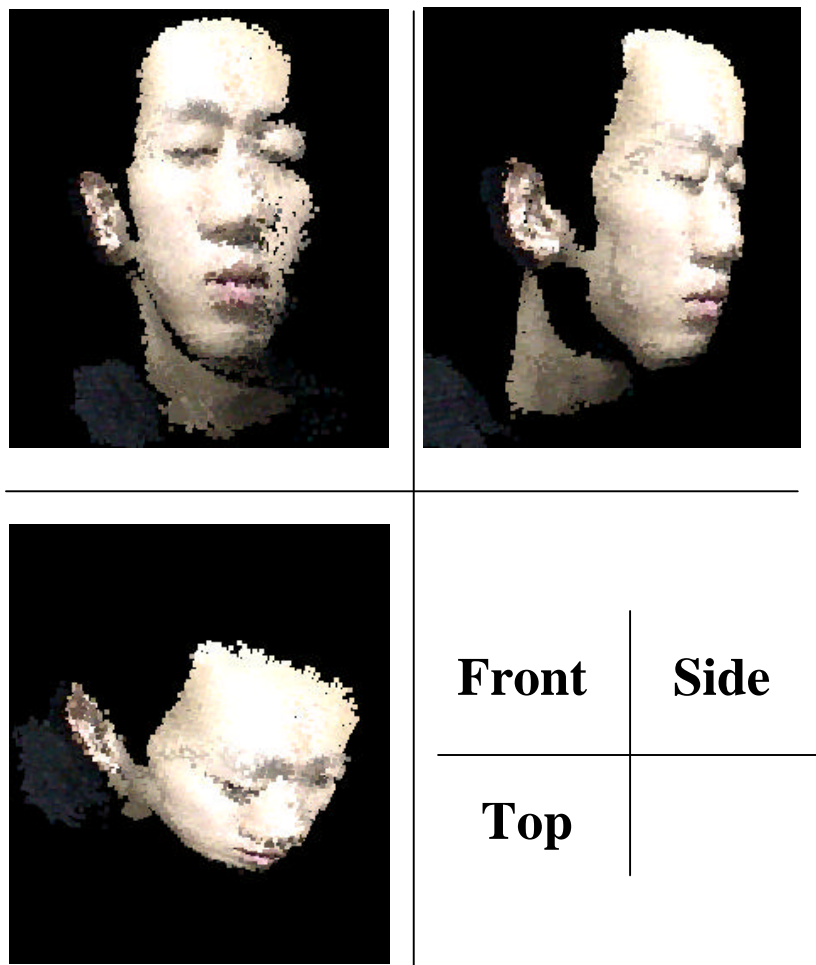Figure 6. Integration of all successive range images

4   RESULT

Figures 7(a) show result of integration between two range images by using 4x4 affine transformation matrix obtained by exact four corresponding points and Figures 7(b) show that between two range images by using 4x4 affine transformation matrix obtained by shifting one point slightly from exact corresponding points. As it is obvious from the Figures, even if we choose a little incorrect four corresponding points, the result of integration strongly distorted. Figures 8 show nine range images of human face obtained under condition free from any artificial restriction. Figures 9 show the integrated result of them, through the method proposed in this paper.

(a)   (b)

Figures 7. Result of integration by (a)exact and (b)incorrect corresponding points

Figures 8. Nine successive range images

Figures 9. Result of integration

5   CONCLUSIONS

In this paper, we describe the method for integration of successive range images obtained from plural view points under non-restricted condition by our high speed and continuous 3D measurement system. We can automatically integrate all successive range images by paying attention to range data of the same part of the target existing in successive two range images.

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REFERENCES

A. Li and G. Crebbin., 1991. Octree encoding of objects from range images. Pattern Recognition, 27(5):727-739.

Besl, Paul J. and Neil D. Mckey.,1992. A Method of Registration of 3-D Shapes. IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol.14, No.2, pp.239-256.

Chen, Yang and Gerard Medioni.,1992. Object Modeling by Registration of Multiple Range Images. Image and Vision Computing. Vol. 10, No. 3, pp.145-155.

Greg Turk and Marc Levoy.,1994. Zippered Polygon Meshes from Range Images Proc. SIGGRAPH.

G. Succi, G. Sandini, E Gresso, and M. Tistarelli.,1990. 3D feature extraction form sequences of range data. In Rovotics research. Fifth International Symposium, pages 117-127.

K. Araki, M. Shimizu, T. Noda, Y. Chiba, Y. Tsuda, K. Ikegaya, K. Sannomiya and M. Gomi.,1992. HIGH SPEED AND CONTINUOUS 3-D MEASUREMENT SYSTEM. 11th IAPR International Conference on Pattern Recognition, The Hague, The Netherlands August 30-Spetember 3, pages 62-69.

K. Araki, M. Sato, T. Noda, Y. Chiba and M. Shimizu.,1991. High-speed and continuous range finding system. Trans Institute of Electronics, Information and Communication Engineerings E74:3400-3406.

K. Araki, M. Shimizu, T. Noda, Y. Chiba, Y. Tsuda, K. Ikegaya, K. Sannnomiya and M. Gomi.,1995. A High-speed and continuous 3D measurement system, Machine Vision and Applications 8:79-84.

K. Kawai, T. Ueshiba, T. Yoshimi and M. Oshima.,1992. Reconstruction of 3D Objects by Integration of Multiple Range Data. Proc The Institute of Electronics, Information and Communication Engineers D-2 Vol.J75-D-2 No.4 pp737-748.

M. Soucy and D. Laurendeau.,1995. A general surface approach to the integration of a set of range views. IEEE Transactions on Pattern Analysis and Machine Intelligence, 17(4):344-358.

R. Szeliski.,1993. Raped octree construction from image sequences. CVGIP:Image Understanding, 58(1):23-32.

V. Krishnamurthy and M. Levoy. Fitting smooth surfaces to dense polygonmeshes. In these proceedings.