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3-D Face Recognition Method Based on Optimum 3-D Image Measurement Technology

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*Abstract***:** We propose a 3-D face recognition method using the iterative closest point (ICP) algorithm. So far, the reported 2-D face recognition methods have weak points by source of light, make-up and facial positioning. A using 3-D shape measurement system includes a technique for optimizing the intensity-modulation pattern projection. Therefore, we propose 3-D face recognition system which is robustness in the color change. The face recognition method is possible for facial registrations. This method estimate rotations and translations for different positions and directions. Consequently, experimental results obtained the high accuracy that the rate of face recognition is 96%.

Keywords: *3-D shape measurement, 3-D image, face recognition, iterative closest point, registration*

I. INTRODUCTION

The biometrics is the security technology used for access control. The two main types of biometrics are behavioral method and physiological method. The examples of behavioral method are voice, gait and handwriting. This method's problem is influenced by the condition of person. The examples of physiological method are fingerprint, iris and face recognition. This method is more highly accurate than behavioral method. However, fingerprint and iris recognition are difficult to get people's approval. Many people become unpleasant feelings because of measurement. Face recognition is easy to measure biometric information. Therefore, face recognition has a lot of researches. Past face recognition uses the two-dimensional image. The biometric system extracts a feature from the facial image. The first time a feature data is stored. In subsequent uses, the feature data is compared. However, face recognition does not work well under conditions of lighting and make-up. The matching of feature data fails by appearance changes of the facial image. To deal with this problem, the three-dimensional face recognition attracts attention. This technique uses 3-D shape measurement system to capture information about the shape of a face. One advantage of 3-D face recognition is that it is not affected by changes in lighting like other techniques. Popular 3-D recognition algorithm is the matching of z-range images. The z-range image is 2.5-D information. The problem of this information is the changes of facial position with rotation and translation. We proposed the practicable 3-D image measurement system based on optimal intensity-modulation projection technique. This system is possible to obtain 3-D facial images in high-speed and high-accurate. The registration of 3-D facial image is easy under changes with rotation and translation. We propose technique of recognition using 3-D facial image.

II. 3-D SHAPE MEASUREMENT

The method of triangulation is the radical principle of 3-D shape measurement based on the pattern light projection. The pattern light is projected to the target object from the source of light, and the camera captures images of the appearance from a different angle.

Formula (1) is used to measure a depth distance of target point by the triangulation principle.

$$z = \frac{b}{\tan\alpha + \tan\beta} \tag{1}$$

Here, z is a depth distance of the measurement point; b is a base length (the distance between source of light and the center of lens of camera); α is stripes projection angle; β is an observation angle degree; β is computable by stripes coordinates on the observation image.

When the strength modulation pattern light is used as shown in Fig 1, stripes projection angle could be calculated by a single piece of picture theoretically. However, this pattern is influenced by the surface color of the measurement object and reflection. The intensity value of the projection stripes in the observation image

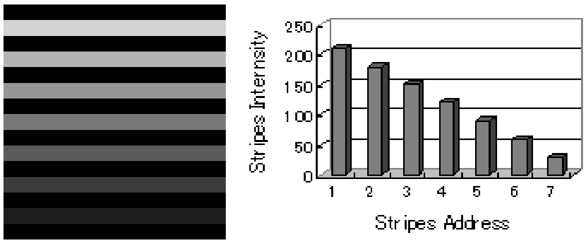


Fig.1. Intensity modulated pattern

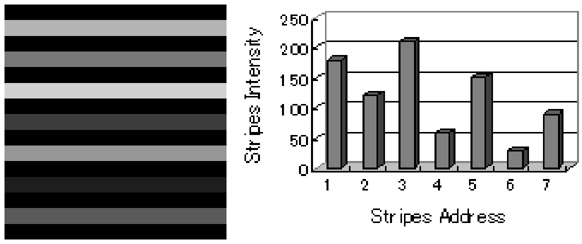


Fig.2. Optimal intensity modulated pattern

(a) Initial observation (b) Projection pattern (c) Observation

Fig. 3. Projection pattern and capture images

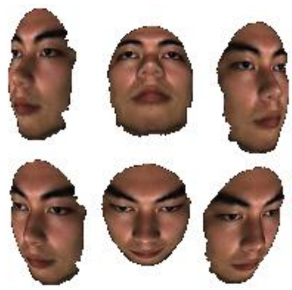


Fig. 4. 3DCG of face

changed and the correspondence to the projection angle collapsed. There is an optimum strength combination pattern light projection method to solve such a problem. It is a technique to optimize projection pattern and to seek for regulation of variations in intensity at a maximum about intensity difference of projection between adjacent stripes[1].

In a set of stripes addresses $\{1,2,\ldots,N\}$, when the intensity order of the address $p_i \in \{1,2,\ldots,N\}$, the projection light intensity of the stripes strength order is defined as the following magnitude correlations.

$$I_{\min} \leq I_{p_1} \leq I_{p_2} \leq \cdots \leq I_{p_N} \leq I_{\max} \quad (2)$$

Here, I_{p_i} is the projection light intensity of stripe address, $I_{\min}$ and $I_{\max}$ are minimum value and maximum value of the projection light intensity respectively. The function is defined when the projection light intensity difference of the stripes strength distribution combination $(I_1, I_2, \ldots I_N)$ is at the maximum, evaluation function $d(I_1, I_2, \ldots I_N)$ is also at the maximum.

$$d(I_1, I_2, \ldots I_N) = \sum_{i=M+1}^{N} \sum_{j=1}^{M} k_j \left| I_i - I_{i-j} \right| \quad (3)$$

Here, *kj* is a weight factor. *M* is width of the filter on which evaluation function has been set. As the relation of formula (2), when $d(I_1, I_2, \ldots I_N)$ is at the maximum, $d(p_1, p_2, \ldots p_N)$ amounted to the same thing. Thus, it can be said that $d(p_1, p_2, \ldots p_N)$ seek combination $(p_1, p_2, \ldots p_N)$ at the maximum as its optimum combination. Projection pattern shown in Fig 2 is replaced by the stripes order of projection pattern in Fig 1. We know that the strength difference between adjacent stripes has been increasing as graph. As a result, stripes projection angle should be computable accurately as long as the strength change rule is maintained even if the error margin is included in the detection of stripes projection light intensity.

III. 3-D FACE RECOGNITION

We obtain 3-D facial images by proposed 3-D shape measurement system. A using projection pattern and captured images show in Fig 3 (a) (b) (c). The obtained 3-D image can be displayed as 3DCG (Fig 4). The 3-D face recognition needs registration of 3-D facial images. The registration algorithm is used as an aligning two 3-D shape data. A propose recognition method uses the Iterative Closest Point (ICP) algorithm[2]. We mounted ICP for 3-D face recognition on the system. ICP is comprised of four steps.

1. Selection ; select 3-D point cloud
2. Matching ; detect correspondence point-pairs
3. Rejecting ; reject illegal point-pairs
4. Minimizing ; minimize error between shapes

(a) Model texture (b) Scene texture

Fig. 5. Camera captured images

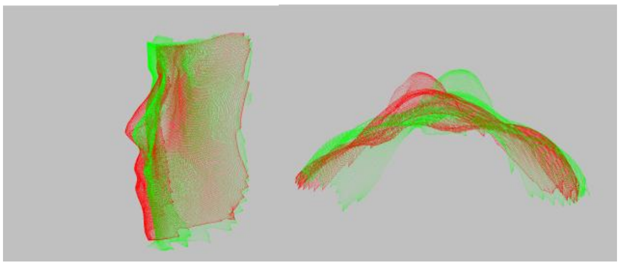
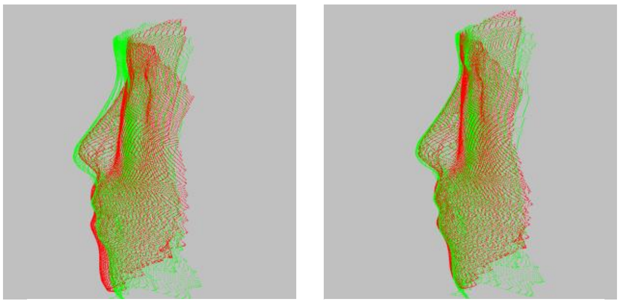


Fig. 6. Initial position of two faces

(a) Measurement-area (b) Boundary-area

Fig. 7. Mask images for rejecting



(a) Before minimizing (b) After minimizing

Fig. 8. Registration of two faces

A concrete steps are shown in the following.

1. Selection

The first time a system obtains the 3-D point cloud from 3-D facial images. 3-D point cloud is comprised of many three-dimensional coordinates. 3-D point cloud in enrollment time is called *Model*, 3-D point cloud in unknown input time is called *Scene*. However, *Model* is measurement data of frontal faces. Images that 3-D measurement system captured are shown in Fig 5. Fig 5 (a) and Fig 5 (b) are texture color images of *Model* and *Scene*. At first, two facial positions are different. 3DCG of *Model* and *Scene* shows in Fig 6.

2. Matching

System finds a point-to-point correspondence between *Model* and *Scene*. The corresponding point of *Scene* is the closest point in *Model*. We usually takes long time of $O(N)$ that search a corresponding point of one query point. Here, N is number of 3-D points in *Model*. We use k-dimensional tree (k-d tree) structure to make the search processing faster[4]. We take time of $O(\log N)$ for searching with k-d tree. This algorithm finds the corresponding points of all 3-D points in *Scene*. The point-to-point pair between *Scene* and *Model* is $(\boldsymbol{p}_i, \boldsymbol{q}_i)$ $i = 0,1,2,\cdots M-1$. Here, M is number of 3-D points in *Scene*, $\boldsymbol{p}$ is 3-D point in *Scene*, $\boldsymbol{q}$ is 3-D point in *Model*.

3. Rejecting

The purpose of this is to eliminate outliers. The corresponding point-to-point pairs include the illegal point-pairs. This method eliminates pairs containing points on mesh boundaries. Mask images used for rejecting are shown in Fig 6. Fig 6 (a) is 3-D measurement-area. Fig 6 (b) is boundary-area. The corresponding pairs are eliminated on boundary-area.

4. Minimizing

The purpose of this is to minimize error of corresponding point-to-point. This method finds the rigid transformation that minimizes a weighted least-squared distance between the pairs of points. The transformation is comprised of rotation and translation.

$$\sum_{i=0}^{M-1} \left\| \boldsymbol{q}_i - \boldsymbol{R}\boldsymbol{p}_i - \boldsymbol{t} \right\|^2 \to \min \tag{4}$$

Here, $\boldsymbol{R}$ is rotation matrix, $\boldsymbol{t}$ is translation vector. $\boldsymbol{t}$ is obtained using center of gravity.

$$\boldsymbol{t} = \overline{\boldsymbol{q}} - \boldsymbol{R}\overline{\boldsymbol{p}} \tag{5}$$

Here, $\overline{\boldsymbol{p}}$ is center of gravity in *Scene*. $\overline{\boldsymbol{q}}$ is center of gravity in *Model*.

$$\begin{aligned} \boldsymbol{p}'_i &= \boldsymbol{p}_i - \overline{\boldsymbol{p}} \\ \boldsymbol{q}'_i &= \boldsymbol{q}_i - \overline{\boldsymbol{q}} \end{aligned} \tag{6}$$

$\boldsymbol{p}$ and $\boldsymbol{q}$ is translated using center of gravity. Formula (4) is changed to formula (7).

$$\sum_{i=0}^{M-1} \left\| \boldsymbol{q}'_i - \boldsymbol{R}\boldsymbol{p}'_i \right\|^2 \rightarrow \min \qquad (7)$$

Formula (7) and formula (8) are the same meanings.

$$\mathrm{Tr}\left[\boldsymbol{R}^{\mathrm{T}} \boldsymbol{N}\right] \rightarrow \max \qquad (8)$$

Formul (8) can be solved by the eigen problem of correlation coefficient matrix. ***R*** can be calculated out from formula (8). Then ***t*** can be found from formula (5) with ***R***. 3-D points in *Scene* are transformed into 3-D points in *Model* using rotation and translation. *Model* and *Scene* shows in Fig 7.

5. Verification

Scene and *Model* are aligned using iteration of four steps. At the last step, we verify identities of 3-D facial images of personal person. The distance of *Model* and *Scene* is distinguished with the threshold. The recognition system accepts Scene when the distance is smaller than the threshold. The recognition system rejects Scene when the distance is larger than the threshold.

IV. EXPERIMENT AND DISCUSSION

This section describes experiment steps and results. The first time, we measure *Model*s of 15 persons. *Model* is 3-D measurement data of frontal face. They move face when measure *Scene*. A number of 3-D measurement data is 105 samples. We recognize all samples by an application using proposed method. We measures rate of misidentification about false rejection rate (FRR) and false acceptance rate (FAR). The threshold is variable parameter in verification step. FAR and FRR shows in Fig 9. The receiver operating characteristic (ROC) plot is a visual characterization of the trade-off between the FAR and the FRR. In this experiment, FAR = 0.038, FRR = 0.047. The rate of false is small when a person moves a face. This method using registration is effective face recognition with moving. The lighting and make-up does not influence this method because without facial color information. However, this method is used for a one to one comparison of a 3-D facial image. The stored template data is individual person's *Model*. This method takes long time when it is used for a one to many comparison. Therefore, 3-D face recognition system using this method is in conjunction with an ID card or username. And, we are necessary to shorten the processing time. It is depended on the improvement of hardware and refactoring of software.

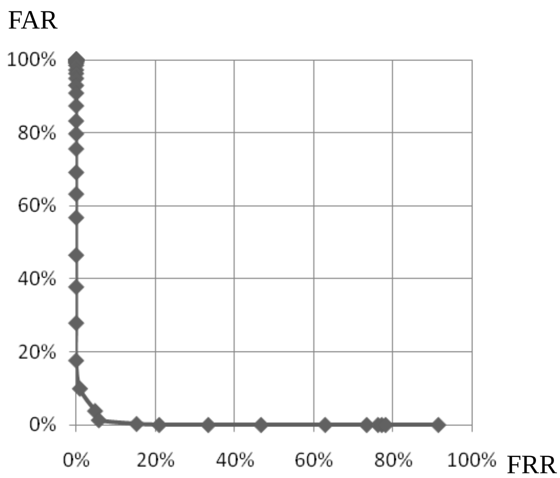


Fig. 9. ROC of 3-D face recognition

V. CONCLUSION

In this paper we proposed a face measurement and face recognition method, our system is possible to measure 3-D facial shape with moving. This recognition method is possible to verify personal persons with make-up and lighting. The 3-D face recognition system aligns 3-D facial images when a person moves a face. This method calculates the distance between two faces. The verification step compares a face to stored face. The rate of false is small when a person moves a face. Serious disadvantage is that our system is less effective if the facial expressions vary. A weakness of registration is the changes of 3-D shape. Therefore, our system now allows only neutral facial expressions. The future work is to deal with facial expressions and facial accessory problem.

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