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Markerless Registration for Intracerebral Hemorrhage Surgical System using Weighted Iterative Closest Point (ICP)

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Abstract— **It is required to use a stereotactic frame on a patient's cranial surface to access an intracerebral hematoma in conventional ICH (Intracerebral Hemorrhage) removal surgery. Since ICH using a stereotactic frame is an invasive procedure and also takes a long time, we attempt to develop a robotic ICH removal procedure with a markerless registration system using an optical 3-D scanner. Preoperative planning is performed using a patient's CT (Computed Tomography) images, which include the patient's 3-D geometrical information on the hematoma and internal structures of brain. To register the preplanned data and the intraoperative patient's data, the patient's facial surface is scanned by an optical 3-D scanner on the bed in the operating room. The intraoperatively scanned facial surface is registered to the pose of the patient's preoperative facial surface. The conventional ICP (Iterative Closest Point) algorithm can be used for the registration. In this paper, we propose a weighted ICP in order to improve the accuracy of the registration results. We investigated facial regions that can be used as anatomical landmarks. The facial regions for the landmarks in the preoperative 3-D model are weighted for more accurate registration. We increase weights at the relatively undeformed facial regions, and decrease weights at the other regions. As a result, more accurate and robust registration can be achieved from the preoperative data even with local facial shape changes.**

I. Introduction

The principal medical treatment of ICH (Intracerebral Hemorrhages) uses a drainage tube mounted on a stereotactic frame. The stereotactic frame is fixed on the skull through the skin. Therefore, this procedure is invasive. In addition, it takes a long time to mount a stereotactic frame on a patient's head. In order to determine the location of a hematoma in the stereotactic frame, the patient should take CT scan one more time with the stereotactic frame. This increases the radiation dose of the patient. Even during an emergency situation, the processes from diagnosis to treatment require a long time.

In this paper, a surface registration method is used to determine the target location within the patient instead of using the stereotactic frame.

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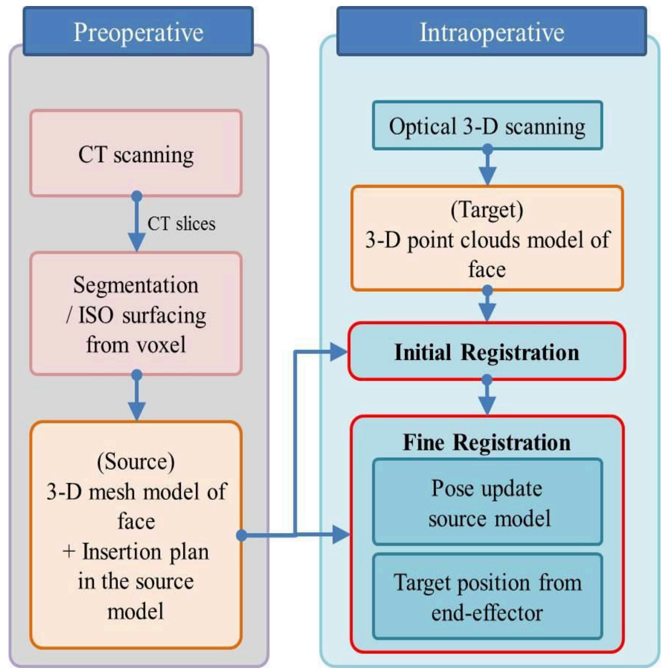

Figure 1. Patient-image registration in robotic ICH operation

The proposed method of hematoma localization has the following advantages compared to the conventional method.

- It is non-invasive because it does not use a stereotactic frame.
- Patients do not have to take one more CT scan with the stereotactic frame.
- As the registration process is simplified, total operation time can be shortened.

The patient-image registration processes of the robotic ICH surgical system are divided into the preoperative part and the intraoperative part, as shown in Fig. 1. The processes of the preoperative part are CT scanning, face segmentation, and 3-D mesh modeling of the surface (source), in that order. In the intraoperative part, a 3-D point clouds model (target) of the patient's face is obtained using the optical scanner. Then, the 3-D mesh model and the 3-D point clouds model are aligned with each other. Now the preoperative CT image is registered to the patient.

In many studies [2][3][4], surface registration methods have been used for patient-image registration with optical scanners. After scanning the entire face shape, the head of the preoperative CT images obtained from the 3-D surface model is matched. Fiducial markers detection of the registration method, compared to the point-based matching method based

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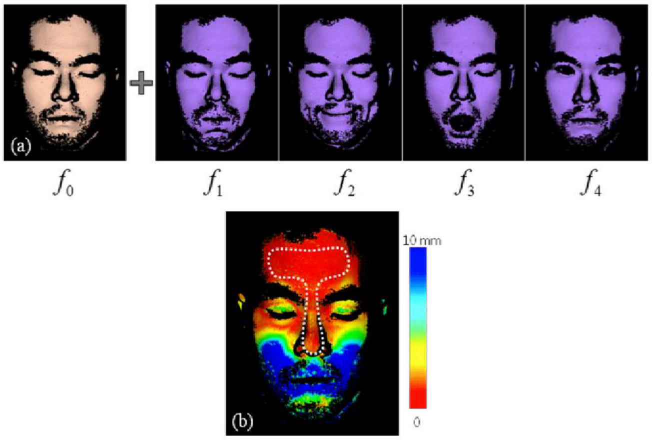

Figure 2. Finding weighted region of the face shape

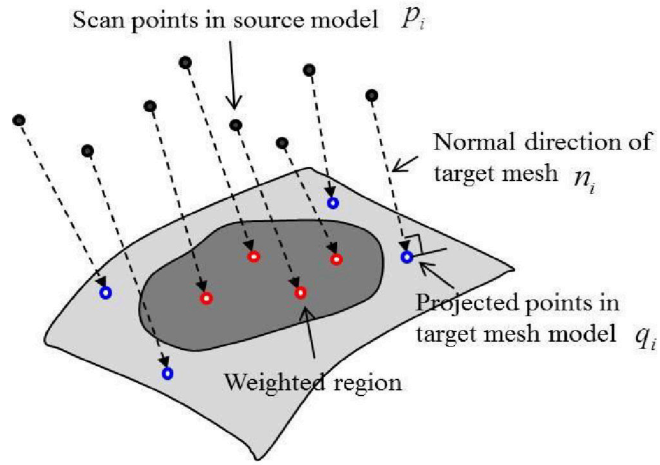

Figure 3. Weighted point-plane ICP registration

on facial surface scanning through the matching method, has proved more accurate. ICP (Iterative Closest Point), the 3-D target-source model, in order to minimize the global error, is the matching method. CT image geometry of the patient's face during preoperative should be the same as obtained by scanning the face image during surgery.

II. Weighted Region Registration of Face Shape

A. *Finding the weighted region of the face for ICH surgery*

In diagnosis and surgery for ICH, images resulting from the 3-D model of the patient obtained from the preoperative CT images and the 3-D model acquired through an optical scanner during surgery is different according to the patient's pose and facial expression. Therefore, facial feature regions of face shape should be weighted so that they will not change significantly. Variation of the patient's face in the floating face region was carried out in order to predict the final shape. As shown in Fig. 2(a), after securing the patient's head, an optical scanner that uses a standard face shape is defined as f_0. Arbitrary shapes of the face are defined as f_1, f_2, f_3 and f_4. The cumulate difference between the face based model (f_0) and the other face model (f_1, f_2, f_3 and f_4) is found using Eq. (1)

$$\sum_{i=1}^{4} \| f_0 - f_i \| \quad (1)$$

As shown in Fig. 2(b), it is possible to produce color mapping of the cumulate points. The blue region shows a lot of differences between the face based model and the other face model. The red region shows only a little difference between the face based model and the other face model. Although there are changed facial expressions, only a little change of the shape region of the entire face can be found. This region is weighted and the region is named *T-Zone* (Fig. 2(b)).

B. *Weighted Iterative Closest Points*

In 3-D model registration for ICP, rigid body translation (T) or rotation (R) to minimize the error from the source model to the target model is used to calculate the metrics. A source model of N points (p_i) is randomly chosen and then the closest corresponding points (q_i) are obtained out of the target model. Before surgery, the source model is obtained from the optical scanning points. A preoperative 3-D mesh model of the CT image is the target model. The mesh model using normal information (n_i) can be used in the point-plane closest surface registration method [6].

The weighted-ICP is used in the same way as the above method. However, correspondence for the pairs of importance is weighted (w_i). The global registration error of the two models is minimized and is expressed as Eq. (2).

$$E = \sum_{i=1}^{N} w_i [(Rp_i + T - q_i) \cdot n_i]^2 \quad (2)$$

As shown in Fig. 3, each point of the neighbor target model is projected on the source mesh model. If (p_i, q_i) is projected on the weighted region, $w_i > 1$. If we do not project this on the weighted region, $w_i = 1$. According to Eq. (2), $x(R, T)$, almost all of the corresponding points are defined as

$$x(R,T) = \arg\min_x \sum \| Ax - b \|^2 \quad (3)$$

Eq. (3) is a linear least-square equation to be solved. As shown in Fig 3., we find a triangle (t_i) that is the closest target mesh model from the source point (p_i), and then find the projected point (q_i) and the normal vector (n_i) of the triangle. If the region projection of the triangle is set to the point of the source model, the weighted (p_i, q_i, n_i) of redundant Eq. (3) can be approximated by A_{6x6} and b_{6x1}.

III. Experiments and Results

A. *Experimental Environment*

Optical scanners for the experiments were the Rexcan III, produced by the Solutionics Company. The experimental environment is similar to that of the actual ICH surgery room for a patient lying with a fixed head. The surface of the patient's facial surface model at the top of the head is obtained using the optical 3-D scanner. A preoperative CT scan image of the state is assumed. Considering the situation changes during surgery, a wide range of expression should be scanned for any given face. We must use a combination between the CT image and the changed surface image experiments for the

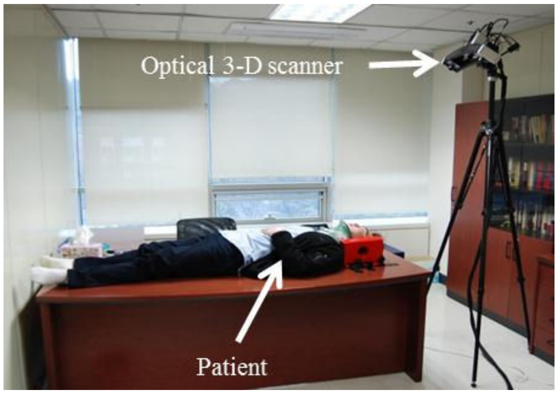

Figure 4. Subject of Environment for ICH registration

registration of ICP and Weighted ICP (Fig. 4). The ICP algorithm is implemented using Visualization Tool Kit (VTK). The software environment consists of Windows 7 and Visual C++.

B. Face Shape Data Set Up and Weighted Region Selection

A preoperative 3-D model of the head and face using a diagnostic CT image is assumed to have been obtained. Face shape and brain of the patient with the hematoma should be modeled. The 3-D location of the hematoma and the brain in the head, with a defined approach path and operative planning, should be included. Instead of the 3-D model using the diagnostic CT model, a preoperative CT scan image of the state is assumed. To set up the weighted region in the 3D face model, we click it with the mouse.

C. Compared Results to Registration of ICP and Weighted ICP

After obtaining 3-D face shaped from 3 persons, ICP and weighted ICP experiments were conducted to compare them. As shown in Fig. 5, the left line is the ICP registration and the middle line is the T-Zone; and right line is the weighted ICP. Registration error is expressed by color. Red indicates 0 mm and blue indicates 3 mm. ICP registration minimizes the errors of the two models for the entire matching process, and so the distribution of the registration error does not shift in any particular region.

TABLE I. RESULTS OF ICP AND WEIGHTED ICP

Model	ICP(mm)		Weighted ICP(mm)	
	All Regions	*Feature Region*	*All Regions*	*Feature Region*
#1	45.68	1.31	42.32	0.84
	37.42	0.89	30.56	0.91
	39.97	0.69	26.12	0.53
#2	29.34	1.87	21.34	1.41
	27.48	1.65	27.61	0.99
	26.74	0.25	21.31	0.22
#3	41.26	1.29	38.00	0.94
	38.11	1.59	46.02	1.13
	47.52	1.48	41.20	1.05

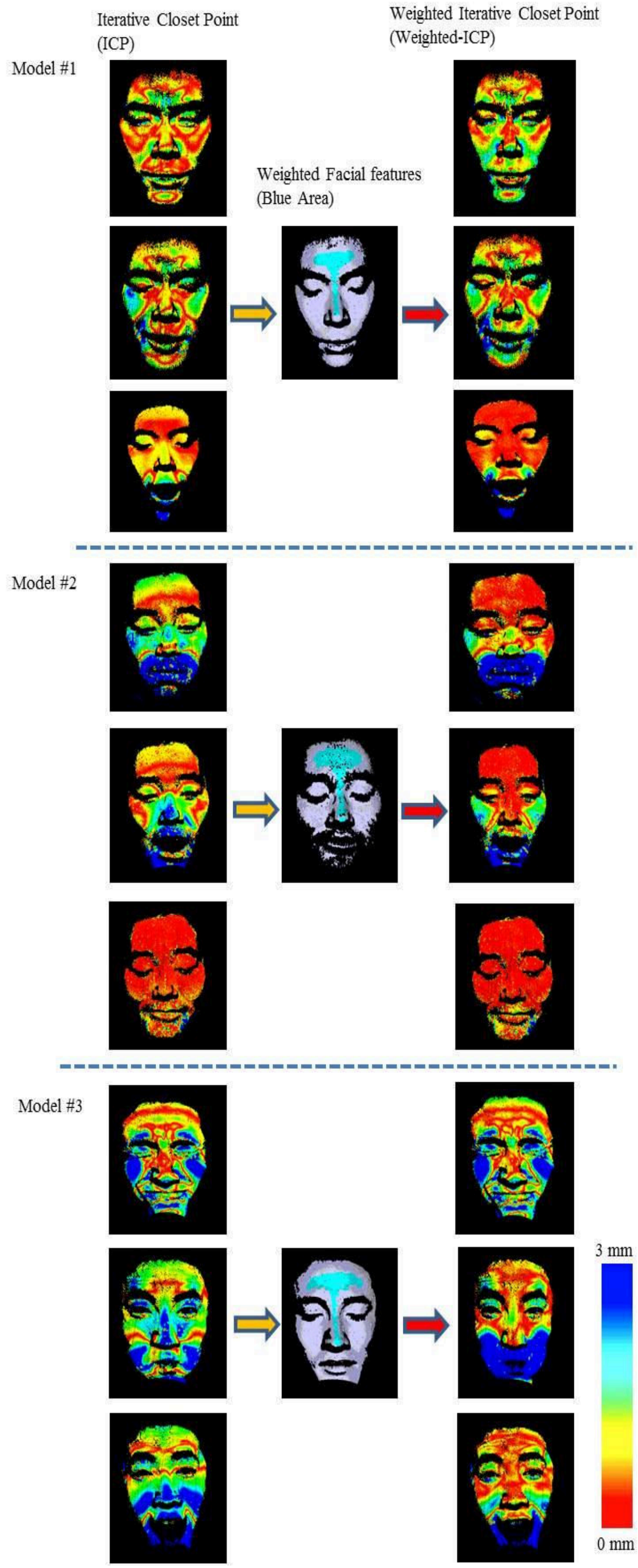

Figure 5. Results of ICP and Weighted ICP

Weighted ICP registration error results based on weighted regions are marked in red. Based on weight region is registered as a small error that is shown in Fig. 5.

Table I provides lists of the average of the registration error. The calculated average of the registration error is measured by the distance of the projection points. Registration error of the entire face region has nothing to do with the weighted regions. We know that weighted ICP registration involves a quantity of error that is less than that of the ICP registration process. If the location of a hematoma relative to the facial features is located, we can expect that the patient's face shape deformation as determined by the weighted ICP registration method will be more accurate than it would be if determined by the conventional ICP registration method for the target location.

IV. Conclusion

Instead of using a stereotactic frame for conventional ICH surgery, a registration method without markers for a preoperative 3-D face model using an optical 3-D scanner determines the hematoma location. Compared to the amount of conventional registration error that occurs between preoperative CT images and intraoperative ones, the patient images acquired using the 3-D scanner with weighted ICP registration method have reduced registration error, which is the source of the originality of this study.

The proposed method for the evaluation of the preoperative 3-D face model is that these images should be obtained using a 3-D optical scanner. However, configurations of the 3-D model according to the actual CT image resolution may differ. Therefore, future work on registration error should be considered. Weighting of the face regions is limited to the *T-Zone* and is set up only once. According to the facial features of patients, divided into multiple regions depending on the degree of deformation, weights of different regions can be set up.

Feature regions for preoperative 3-D face imaging have been manually set. However, we are required to automatically detect feature regions through the analysis of preoperative CT images. We need to be compared the location of the hematoma using the face registration method based on the surface with the location of the hematoma using the face registration method with attached markers or stereotactic devices. While these are certainly challenges, the non-invasive nature and reduced time of operation preparation are strong benefits that will be derived from the success of this new method.

Finally, the proposed method, when it is fully available, will be used not only for conventional surgical drainage of the brain but also for other brain target navigation.

Acknowledgments

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