Original

3D Assessment of Facial Symmetry for Quantitative Diagnosis of Facial Paralysis

Ken Sudo, School of Science and Technology, Keio University
Toshiyuki Tanaka*, School of Science and Technology, Keio University

Abstract

Objective: Facial paralysis is most commonly assessed using a 10-item, 40-point method, with a facial nerve grading system. It has been highlighted that while it is easy for inspectors to be subjective when using these methods, there are problems with objectivity and reproducibility. Furthermore, detailed evaluations using these methods are limited. This study aims to propose a novel objective method for evaluating facial paralysis, considering changes in the depth direction of the face.

Method: 3D shape data of the face are acquired using a Kinect sensor, and facial paralysis is evaluated using 3D shape assessment.

Results: Faces were photographed at rest and when performing facial exercises, such as inflating one cheek, tightly closing both eyes, and closing only one eye. The symmetry of facial movements was calculated using the distance between corresponding points, captured in the shape data point cloud, while at rest and during the facial exercises.

Conclusions: This study proposes a novel objective method to assess facial paralysis that considers changes in the depth direction of the face. The calculations of the symmetry of facial movements using a 3D shape data point cloud, obtained using a Kinect sensor to photograph eight varieties of facial exercises, confirmed that the proposed method objectively and quantitatively evaluates left-right motions.

Keywords: Facial paralysis, Yanagihara method, 3D quantitative evaluation method, Kinect sensor, ICP algorithm

Introduction

Currently, in the diagnosis of facial nerve paralysis, an examiner evaluates the degree of paralysis by comparing the laterality of the facial movements with the naked eye. The 10 items-40 points method (Yanagihara method) (Yanagihara, 1977) is widely used in Japan. However, the facial nerve grading system (House, 1985) reported by House et al. is common in Europe and the United States. Additionally, the Sunnybrook method (Ross, 1992) is an evaluation method that focuses on the sequelae after recovery from paralysis.

Because the examiner evaluates the subject by visual examination, the subjectivity of the examiner is likely to be included, which may lead to problems in terms of objectivity and reproducibility (Murakami, 2015). It has also been pointed out that it is difficult to understand the recovery from symptoms (Murakami, 2015). Therefore, with the development of computers and digital devices in recent years, an objective evaluation method that emphasizes objectivity and reproducibility using image processing has been proposed. The moiré method (Iguchi, 1993), marker method (Tanaka H. 1994), subtraction method (Takakita, 1993), objective evaluation method by optical flow (Minamitani, 2003), the method by feature value extraction (Barbosa, 2016), etc., are cited as well-known objective evaluation methods. In these evaluation methods, there are burdens on the patient when installing equipment and preparing for photographing as well as photographing constraints. Additionally, there are few objective evaluation methods that consider the depth direction.

However, it has become possible to easily acquire the three-dimensional shape of an object with the development of three-dimensional shape measuring devices capable of high-density and high-speed measurement. Recently, Microsoft's Kinect sensor

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*: Corresponding Author

(Microsoft, 2018) has become popular as a device that can operate games by gestures, voice recognition, etc.

This study proposes a three-dimensional evaluation facial symmetry method considering changes in the depth direction for the objective evaluation of facial nerve paralysis. We propose an evaluation index that shows the degree of facial symmetry based on shape data by acquiring the three-dimensional shape data of the face using the Kinect sensor.

Subjects and Methods

1. Subjects and Imaging Environment

In this study, eight types, among 10 facial expression movement items used in the Yanagihara method, are photographed for six healthy subjects (A to F); they include resting, weakly closed eyes, strongly closed eyes (both sides, right side, left side), and movement that inflates cheeks (both sides, right side, left side). Figure. 1 shows the facial expression movements used by the Yanagihara method and those used in this study. The facial expression movements in this study are indicated by a red frame in the figure.

Table1: Specifications of Kinect sensor

Kinect v2		
Viewing angle	Vertical	43°
	Horizontal	43°
Frame rate		30 fpd
Depth camera resolution		512×424
RGB camera resolution		1920×1080
Depth acquisition range		0.5–0.8 m

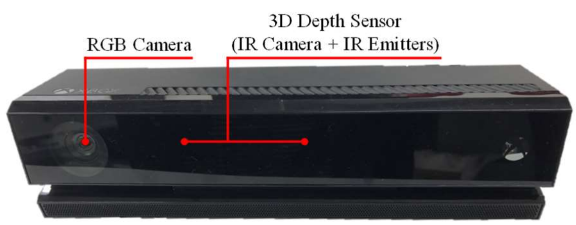

Figure 2: Kinect sensor

The Kinect v2 sensor was used for imaging, and the 3D shape data of the face was acquired using Kinect Fusion software (Newcombe, 2011; Izadi, 2011). Table 1 lists the technical specifications of the Kinect v2 sensor.

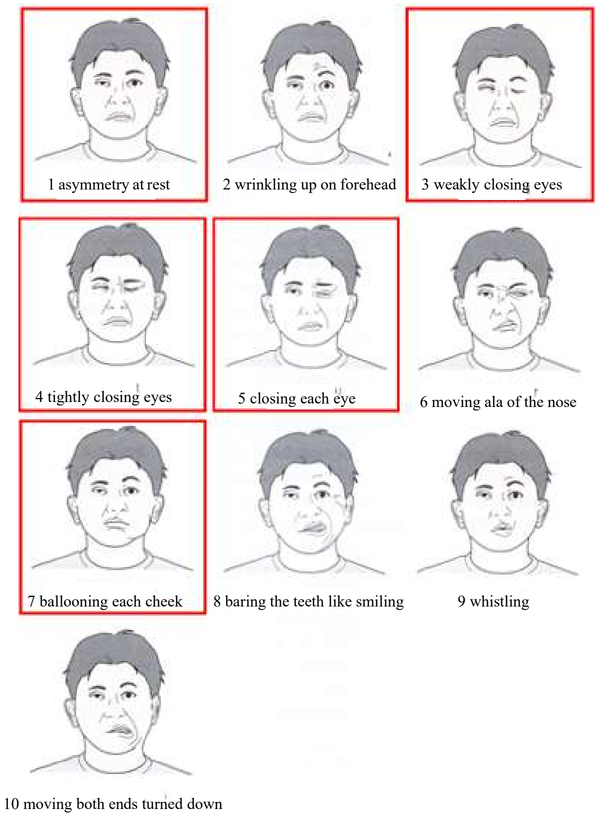

Figure 1: Facial expression movements in Yanagihara method and facial expression movements used in this study
Yanagihara 40 point method: https://www.st-medica.com/2012/ 12/ yanagihara40tenhou.html (July 9th, 2020)

2. Extraction of face area

The 3D shape data obtained by the Kinect Fusion sensor include the face area and the areas that are not necessary for symmetry evaluation, such as the hair and neck; hence, only the face area relevant for evaluation is extracted. In this study, the apex of the nose is detected from the 3D shape data obtained by the Kinect Fusion sensor, and the face area is extracted around that point.

3. Alignment

After acquiring the 3D shape data of the face, the iterative closest point (ICP) algorithm is applied during resting and during each facial expression movement for alignment. The ICP algorithm automatically aligns two point clouds given as inputs (Chen, 1992; Besl, 1992; Rusinkiewicz, 2001). Each point constitutes one point cloud; the nearest neighbor points in the other point cloud are searched, and used as tentative correspondence points. The amount of movement of the data point cloud that minimizes the distance between these correspondence points is estimated. These two point clouds are aligned by repeating the search for the correspondence points, and estimating the amount of object movement.

4. Calculation of distance between correspondence points

The two point clouds are aligned by repeating the search for the correspondence points and rigid transformation estimation in the ICP algorithm. The point cloud that serves as a reference for alignment is referred to as the model point cloud, and that which undergoes rigid transformation to overlap the model point cloud is referred to as the data point cloud. The model and data point clouds are represented by sets Q of n_q points and P of n_p points, respectively. Additionally, the points included in Q and P are written as $\boldsymbol{q}$ and $\boldsymbol{p}$, respectively. The distance to a point $\boldsymbol{q}$ on Q is obtained for a point $\boldsymbol{p}$ on P, and the set $(\boldsymbol{q}, \boldsymbol{p})$ with the minimum distance between the two points q and p is obtained for all n_p points on P. The set of nearest neighbor points obtained using this method are used as tentative correspondence points in the alignment.

Specifically, the l^{th} set in the n_p set of points is taken as $(\boldsymbol{q}_l, \boldsymbol{p}_l)$, and the nearest point $\boldsymbol{q}_l$ of $\boldsymbol{p}_l$ is obtained. If $\boldsymbol{T}$ is the transformation applied to $\boldsymbol{p}_l$ to get closer to $\boldsymbol{q}_l$, then $\boldsymbol{q}_l$ becomes

$$\boldsymbol{q}_l = \arg\min_{q \in Q} \|\boldsymbol{q} - \boldsymbol{T}\boldsymbol{p}_l\| \qquad (1)$$

Based on the transformation $\boldsymbol{T}$, the sum D of the distances between the nearest neighbor points of the n_p set becomes

$$D = \sum_{l=1}^{n_p} \|\boldsymbol{q}_l - \boldsymbol{T}\boldsymbol{p}_l\| \qquad (2)$$

After aligning the 3D shape data, the distance between the correspondence points on the shape data during resting and the facial expression movements is calculated. The distance d_l between the correspondence points in the l^{th} set $(\boldsymbol{q}_l, \boldsymbol{p}_l)$ of the n_p set of data is calculated by the following equation:

$$d_l = \|\boldsymbol{q}_l - \boldsymbol{T}\boldsymbol{p}_l\| \qquad (3)$$

The distance between the correspondence points increases where the change in the face shape is large. The distance between correspondence points of the same size is calculated at the left and right symmetrical locations during a symmetrical facial expression movement. The distance between the correspondence points of one increases, whereas the distance between the points of the other decreases during an asymmetrical facial expression movement. Thus, the area where the distance between the correspondence points has a large value is concentrated on one side of the face. Therefore, it is possible to evaluate the symmetry of facial expression movements in three-dimensions by comparing the distance between the correspondence points during facial expression movements on the left and right sides of the face.

5. Evaluation of symmetry

In this study, we compare the root mean square deviation (RMSD) of the distance between the correspondence points on the left and right sides of the face. The position information at each point is not stored when comparing the RMSD values. In cases where the distance between the correspondence points increases at different parts on the left and right, the face may be symmetrical. Therefore, the position information is stored as a block unit by dividing the face vertically and horizontally as shown in Figure 3.

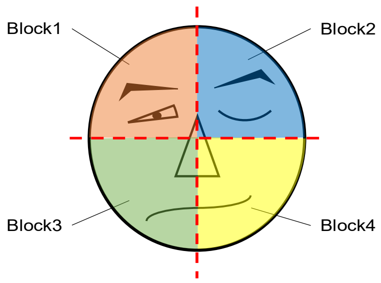

Figure 3: Block division of face area

In each area where the face is divided into four areas, n points are extracted in order from the one with the largest distance between the correspondence points, and their RMSD is compared. The RMSD is represented by the following equation using the distance between the correspondence points $d_i(i = 1, \ldots, n)$:

$$\mathrm{RMSD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} {d_i}^2} \qquad (4)$$

The smaller the RMSD value, the smaller the misalignment, which indicates that the two data cloud structures are very similar. Conversely, a larger RMSD value leads to a larger point deviation, which indicates that the two data cloud structures are different. By calculating the RMSD from the shapes during resting and the facial expression movements using this method, it is possible to quantify the movement. The symmetry of the facial expression movements is then evaluated in three-dimensions by comparing the RMSD calculated for each divided area on the left and right sides. The final symmetry score is calculated by the following equation:

$$\mathrm{Score} = \begin{cases} \dfrac{\mathrm{RMSD}_R}{\mathrm{RMSD}_L} & (\mathrm{RMSD}_R \le \mathrm{RMSD}_L) \\ \dfrac{\mathrm{RMSD}_L}{\mathrm{RMSD}_R} & (\mathrm{RMSD}_L < \mathrm{RMSD}_R) \end{cases} \qquad (5)$$

In the above equation, RMSD_R and RMSD_L represent the RMSD on the right and left sides of the face, respectively. The score is a numerical value in the range of 0 to 1. From Equation (3), the score is 1 when the RMSD_R and RMSD_L are equal. That is, the score takes a value close to 1 if the facial expression movement is symmetrical. However, the score is close to 0 if there is a large difference between the RMSD_R and RMSD_L.

Results

1. Acquisition of facial 3D shape data

Figure 4 shows an example of the results of acquiring the 3D shape data of the face using the Kinect Fusion sensor and pre-processing. In Figure 4, the upper left figure shows the data obtained from

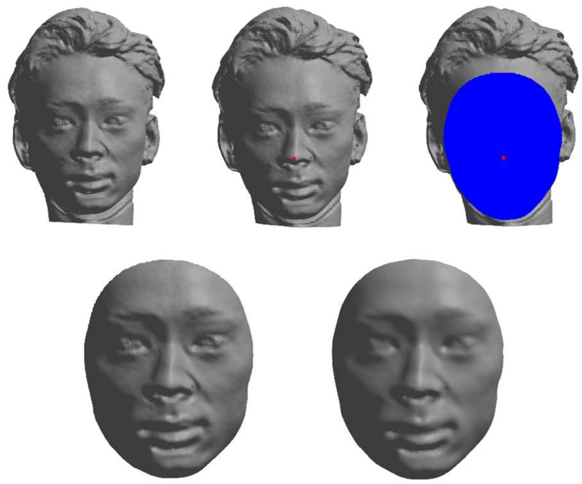

Figure 4: Example of 3D shapes of face and pre-processing results

the Kinect Fusion sensor; the upper center figure shows the result of extracting the apex position of the nose from the data point cloud; and the upper right figure shows the result of cutting out the face with a sphere centered on the apex of the nose. Further, the lower left figure shows the result of extracting the face part to be analyzed from the data point cloud of the Kinect Fusion sensor and the lower right figure shows the result of applying Laplacian smoothing to the 3D shape data of the face part and smoothing the mesh surface, respectively.

The data format obtained from the Kinect Fusion sensor is a PLY file. The PLY file is a format for handling polygon models, and is recorded by vertex coordinate value data, vertex normal vector data, polygon plane data, etc. The vertex coordinate value data and vertex normal vector data are each recorded with the X, Y, and Z components. The polygon plane data is recorded as an array of indices of the vertex coordinate value data list. Although the number of vertices of the data obtained from the Kinect Fusion sensor are several millions, they were pre-processed and eventually reduced to approximately several tens of thousands.

2. Calculation of distance between correspondence points in each facial expression movement

(a) Weakly closed eyes

Figure 5 shows the results of calculating the distance between the correspondence points when the eyes are weakly closed. From the figure, the entire face becomes blue and only the part around the eyes is light blue. That is, the distance between the correspondence points is slightly large in the area around the eyes, but the area other than that has a value close to 0. Many areas in the weakly closed eyes movement exhibit a small change from the resting state; movement is only around the eyes.

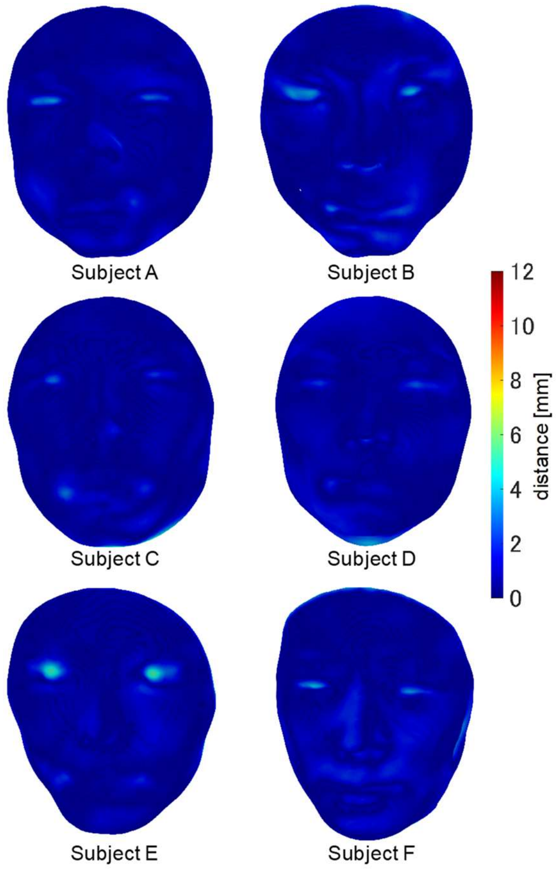

Figure 5: Results of calculating the distance between correspondence points using facial shape data when eyes are weakly closed and during rest

(b) Strongly closed eyes (both eyes)

Figure 6 shows the results of calculating the distance between the correspondence points when the eyes are strongly closed. It can be confirmed that the distance between the correspondence points in the area around the eyes is common to all subjects when both eyes are strongly closed. The distance between the correspondence points increases on the cheeks and around the mouth for four subjects. However, it has a value close to 0 in the cheek area for two subjects. This may be because when the eyes are strongly closed, the area other than around the eyes may or may not move depending on the subject.

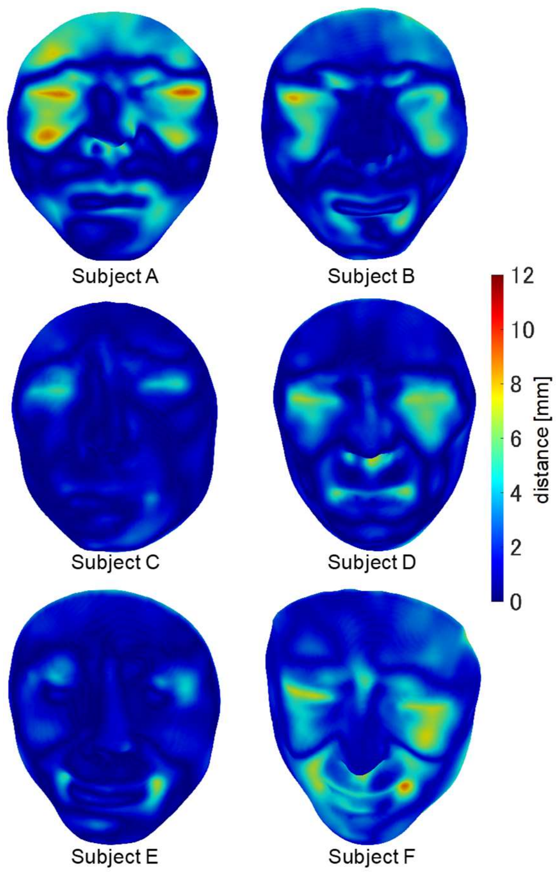

Figure 6: Results of calculating the distance between correspondence points using facial shape data when eyes are strongly closed and during rest

(c) Strongly closed eye (right eye)

It was confirmed that the distance between the correspondence points has a large value in the area around the eyes for all the subjects when the right eye is strongly closed, similar to the case where both eyes are strongly closed. Additionally, the distance between the correspondence points is large on the cheeks and around the mouth for four subjects, but is close to 0 on the cheek area for two subjects. The area with a large value was concentrated on the right side of the face because the left side of the face does not move in the case of the strongly closed right eye.

(d) Strongly closed eye (left eye)

It was confirmed that the distance between the correspondence points has a value in the area around the eyes common to all subjects when the left eye is strongly closed. Additionally, the distance between the correspondence points is large on the cheeks and around the mouth for four subjects, but is close to 0 on the cheek area for two subjects. The area where the distance between the correspondence points was large was concentrated on the left side of the face because the right side of the face did not move in the case of the strongly closed left eye.

(e) Movement that inflates cheeks (both cheeks)

Figure 7 shows the results of calculating the distance between the correspondence points in the case of movement that inflates both cheeks. The distance between the correspondence points is a large value because there is more movement on both cheeks compared to the resting state. Additionally, the distance between the correspondence points is smaller than that of the lower part because there was less movement from the resting state in the upper part of the face. It can be confirmed that the distance is similar on both cheeks for all the subjects because both cheeks are inflated.

(f) Movement that inflates one cheek (right cheek)

The distance between the correspondence points was large because the movement from the resting state was more on the right cheek in the case of movement that inflates the right cheek. Additionally, the area where the distance between the correspondence points was large was concentrated at the lower part of the right side of the face because the left side of the face was not moved.

(g) Movement that inflates one cheek (left cheek)

The distance between the correspondence points was large because the movement from the resting state was more on the left cheek in the case of movement that inflates the left cheek. Additionally, the area where the distance between the correspondence points was large was concentrated at the lower part of the left side of the face because the right side of the face was not moved.

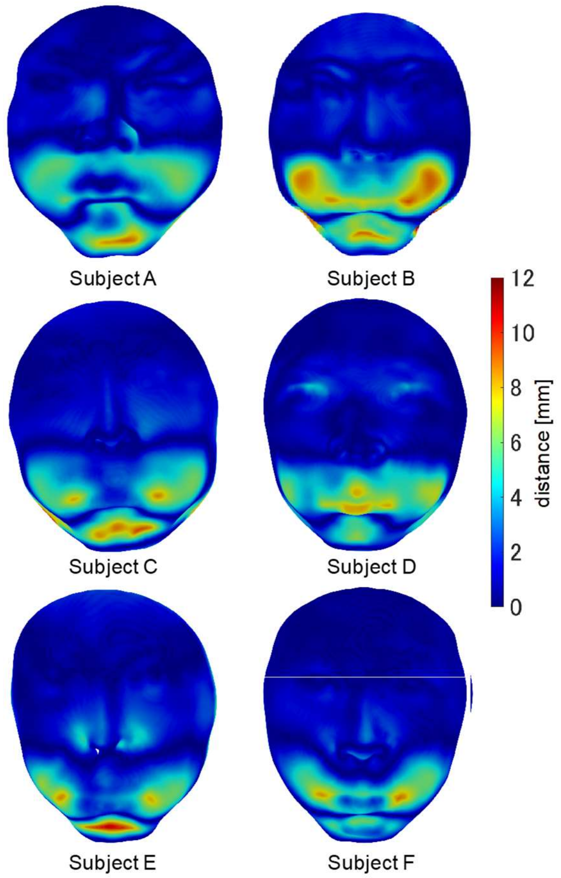

Figure 7: Results of calculating the distance between correspondence points using facial shape data during movement that inflates both cheeks and rest

Discussion

1. Examination of number of ICP adaptations

In this study, the ICP algorithm was applied twice to prevent the distance between the correspondence points from increasing in the area where there was little movement during the facial expression movements. The area where the change from the resting state was more during the facial expression movements was aligned in the 1st processing, whereas the area where the change from the resting state was less was aligned in the 2nd processing. Figure 8 shows an example of the calculation results when the ICP algorithm was applied once and twice when the face was aligned during the resting state, and with the left eye strongly closed. By applying the ICP twice, the distance between the correspondence points was smaller on the forehead area, and the distance between the correspondence points was larger around the left eye and on the left cheek. When the variance value of the distance between the correspondence points was calculated by performing the same processing on the data of six subjects, similar results were obtained for all the subjects.

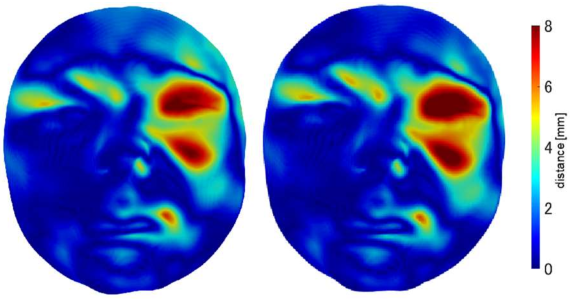

Figure 8: Difference in distance between correspondence points by ICP algorithm

2. Examination of scores used for RMSD calculation

In this study, the symmetry of the face was evaluated by selecting n points in order from the one with the largest distance between the correspondence points in each area where the face was divided into four, and comparing the RMSD of those distances. The symmetry of the left and right movements was examined by obtaining the absolute value of the difference between the RMSD_R in the right facial area and the RMSD_L in the left facial area, and the ratio of the RMSD_R to RMSD_L. The absolute values of the difference between the RMSD_R and RMSD_L on the upper part of the face when the number of points n used when calculating RMSD was changed were calculated for each facial expression movement of the six subjects, A to F, and compared. Here, n varies from 100 to 2900 in increments of 100. $|\mathrm{RMSD}_R - \mathrm{RMSD}_L|$ is stable at a value close to 0 in the symmetrical facial expression movements such as both eyes weakly closed , both eyes strongly closed, and movement that inflates both cheeks. Furthermore, $|\mathrm{RMSD}_R - \mathrm{RMSD}_L|$ is stable at a value close to 0 because the upper part of the face does not change considerably from the resting state in the movement that inflates the cheeks. However, $|\mathrm{RMSD}_R - \mathrm{RMSD}_L|$ tends to decrease as n increases in the case of the strongly closed right eye and strongly closed left eye, which are asymmetrical facial movements in the upper part of the face. There are a few areas where the change from the resting state is significant in the facial expression movements, and most of the areas are not changed from the resting state. As the number of points increases, the difference decreases because the point cloud of the area where the change from the resting state is small is used for the RMSD calculation. $|\mathrm{RMSD}_R - \mathrm{RMSD}_L|$ is found to be stable at a value close to 0 in the symmetrical facial expression movements such as when both eyes are weakly closed, both eyes are strongly closed, and during movement that inflates both cheeks, similar to the lower part of the face. $|\mathrm{RMSD}_R - \mathrm{RMSD}_L|$ tends to decrease as n increases in the case of the movement that inflates the right and left cheeks, which are asymmetrical facial movements in the lower part of the face. It is considered appropriate to maintain the number of points used when calculating the RMSD as small as possible with regards to the difference in the RMSD. This is because it is preferable for the difference in the RMSD between the right and left side of the face, that is, the difference in movement because of facial movements between the right and the left side of the face to be large. Additionally, in the calculation of the ratio of the RMSD_R to RMSD_L of the six subjects, the values were not stable with a small number of points in both the upper and lower face areas, and the score tended to stabilize as the number of points increased. This may be because an outlier, when n is small, will be strongly affected by that. Therefore, it is appropriate to set the number of points n used in the calculation to a somewhat large value from the viewpoint of the RMSD ratio. Empirically, n of 1000 or more is considered appropriate. In this study, we set the number of points used for the RMSD calculation to $n = 1500$, and examined the method to calculate the left-right symmetry, based on the two viewpoints mentioned above.

3. Evaluation of facial symmetry

Figures 9 and 13 show the calculation results of

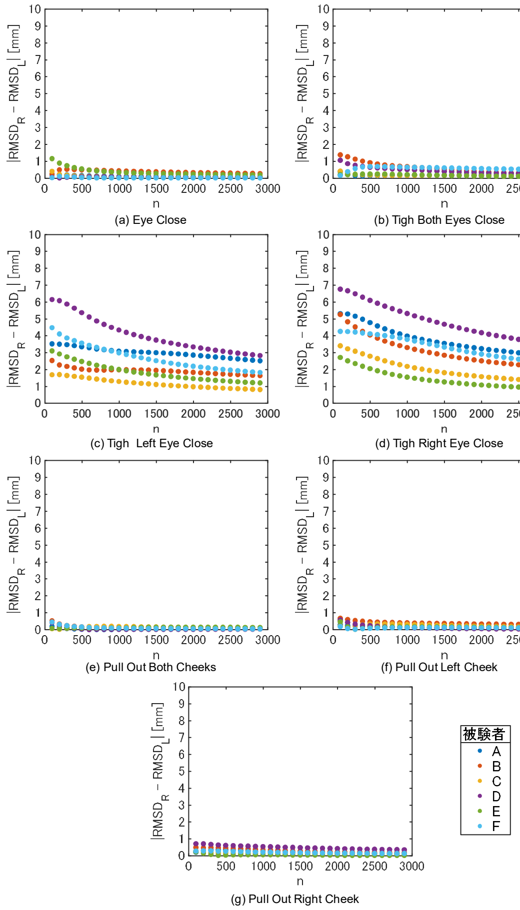

Figure 9: Absolute difference between RMSD_R and RMSD_L according to the change in n (Upper face)

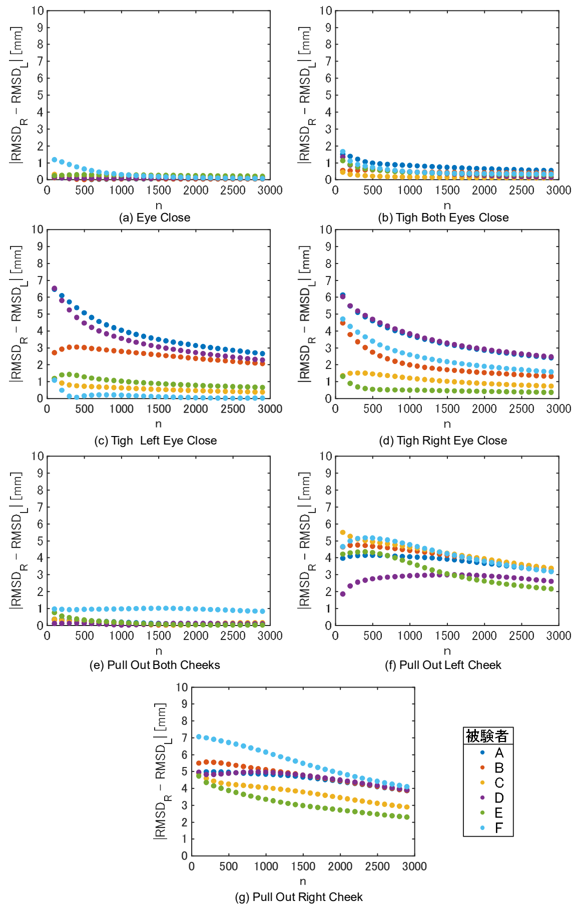

Figure 10: Absolute difference between RMSD_R and RMSD_L according to the change in n (Lower face)

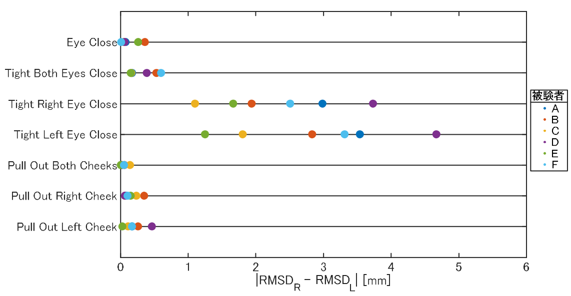

Figure 13: Absolute difference between RMSD_R and RMSD_L (Upper face)

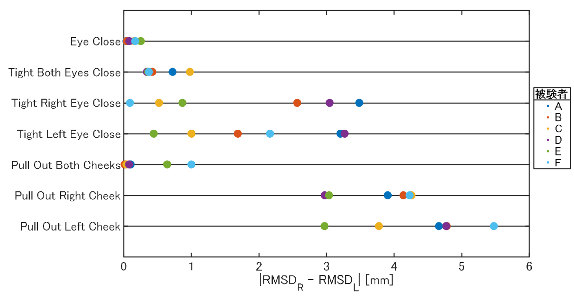

Figure 14: Absolute difference between RMSD_R and RMSD_L (Lower face)

the absolute value of the difference between the RMSD_R and RMSD_L at the upper part of the face when $n = 1500$ for each facial expression movement of the six subjects, A to F, and Figures 10 and 14 show the results at the lower part of the face. From both figures, the difference in the RMSD between the right and left sides of the face is approximately 1 mm or smaller in the symmetrical facial expression movements including both eyes weakly closed, both eyes strongly closed, and movement that inflates both cheeks. Additionally, the difference in the RMSD is small because the change in the upper half of the face from the resting state is small; this is also the case when the movement that inflates the cheek on one side, which is an asymmetrical movement, is performed.

However, the difference in the RMSD is 1 mm or more in the asymmetrical facial expression movements such as the upper part of the face in the strongly closed right and left eye states, and the lower part of the face in the movement that inflates the right and left cheeks, which is a value larger than the case where the symmetrical facial expression movements are performed. In addition, the difference in the RMSD during the asymmetric facial expression movements has a large variation. This may be because of individual differences in the size of the facial movements. The difference in the RMSD varies between 0 and 4 mm at the lower part of the face when the eye is strongly closed on one side. This is because the cheek area on this side may or may not move in conjunction with the closed eye, and it is considered that the difference in the RMSD on the lower side of the face increases when there is movement, whereas that on the lower side of the face decreases when there is no movement.

Figures 11 and 15 shows the calculation results of the facial symmetry score in the upper part of the face when $n = 1500$ for each facial expression movement of the six subjects, A to F, and Figures 12 and 1624 shows the results in the lower part of the face. From the figures, the score is close to 1 for the symmetrical facial expression movements such as when both eyes are weakly closed, both eyes are strongly closed, and both cheeks are inflated. However, the score in the asymmetrical facial expression movements such as the upper part of the face for the strongly closed right and left eyes, and the lower part of the face when the left and right cheek are inflated is smaller than the score during the symmetrical facial expression movements. The score is also large when the movement that inflates the cheek on one side, which is an asymmetrical movement, is performed, similar to the case of the difference in the RMSD between the left and right sides of the face; this is because the change in the upper half of the face from the resting state is small.

In this study, the ratio of the RMSD between the right and left sides of the face was adopted as the evaluation score of the target degree of the face. The value is close to 1 if the right and left sides of the face are moving in the same degree, and is close to

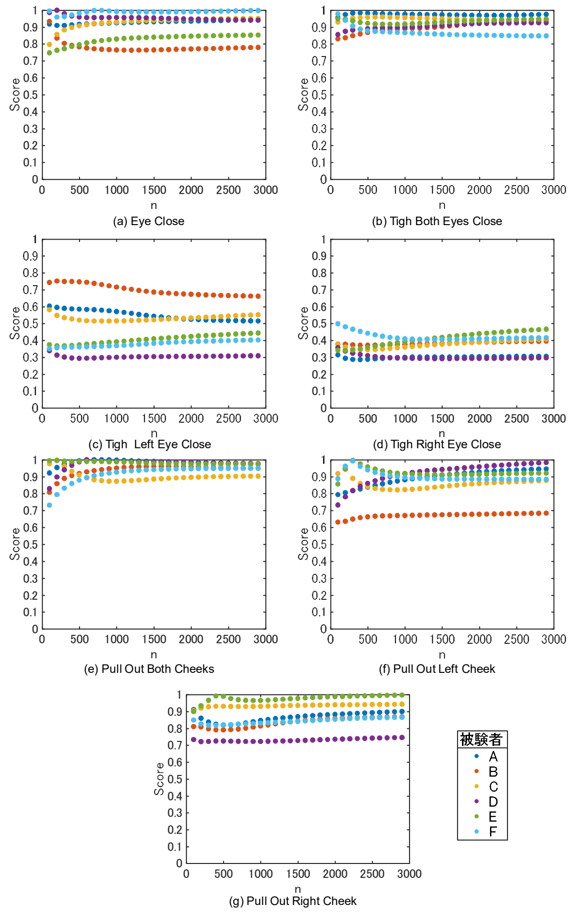

Figure 11: Symmetry score of face according to the change in n (Upper face)

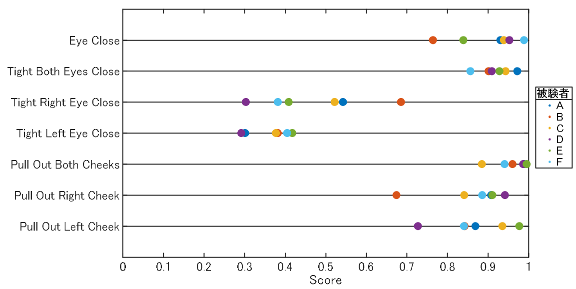

Figure 15: Symmetry score of face (Upper face)

0 if the movement of the face, because of the facial expression movements, is only on one side. In the present experiment, it was confirmed that the value was close to 1 when the face was moved symmetrically, and became smaller than that when the face was moved asymmetrically. This indicates the possibility of using this method to evaluate the degree of facial nerve paralysis in three-dimensionally and objectively, by assessing the degree of symmetry of the facial movement because

of facial expression movements.

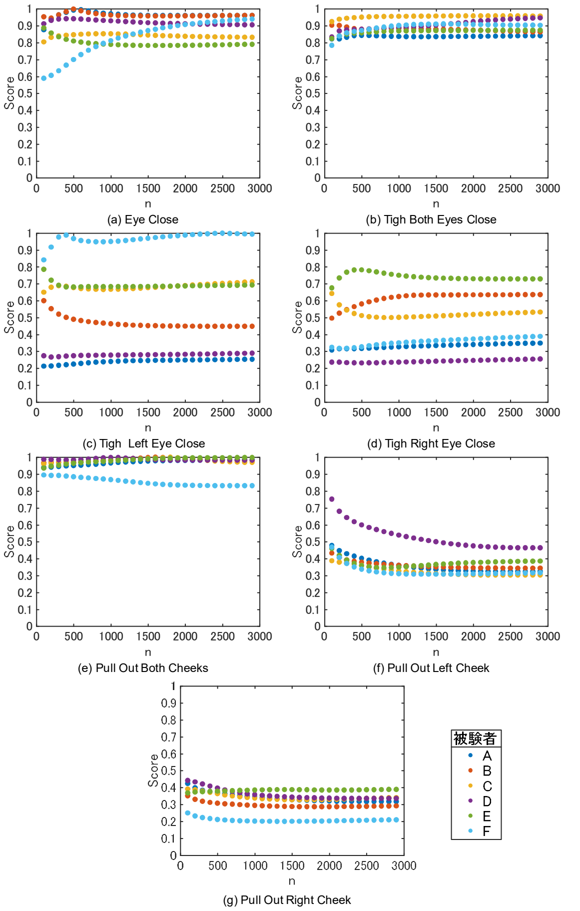

Fig. 12 Symmetry score of face according to the change in n (Lower face)

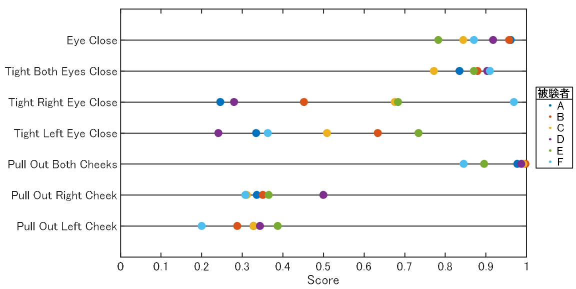

Fig. 16 Symmetry score of face (Lower face)

In the present experiment, the symmetry score was not 0 when the face was moved asymmetrically. This may be because it is impossible for a healthy person to exclusively move one side of the face, even when they try to. It is deduced that this can be improved by using the data of patients with facial paralysis.

In this study, the ratio of the RMSD between the left and right sides of the face was adopted as the evaluation score of facial symmetry. In the experiment, it was confirmed that a value close to 1 was obtained for the facial expression movement that moved symmetrically, and a small value was obtained in the asymmetrical movement. Ideally, the symmetry score is 0 for the left-right asymmetric movement; however, the result in this study is not 0. In the experiment, healthy people were used as the subjects; it was inferred that the result was caused by movement on both sides even when the person tried to move only one side of the face. It is expected that the value will be closer to 0 if the subject is a patient with facial paralysis.

Conclusion

In this study, we proposed a method for evaluating the left-right symmetry during facial expression movements to objectively evaluate facial nerve paralysis in 3D. We acquired three-dimensional shape data of the face in the resting state and during facial expression movements using the Kinect Fusion sensor, calculated the distance between the correspondence points of the two data point clouds, and evaluated the left-right symmetry of the movement during the facial expression movements.

Faces were photographed during eight types of facial expression movements for six subjects, and the distance between the correspondence points in the data point cloud was calculated. It was confirmed that the area where the distance between the correspondence points was large corresponded to the area where there was movement during each facial expression movement. Additionally, it was possible to visualize the movement of the skin from the data point cloud during the facial expression movements and resting state. Until now, the symmetry evaluation of the left-right movement has been performed subjectively; however, using this method has made it possible to numerically express the degree of movement of the face from the resting state and the difference in movement between the left and right sides of the face. Additionally, the method made it possible to make an evaluation closer to the examiner compared to the objective evaluation method using images; this is because three-dimensional movement was considered for the distance between the correspondence points.

From the results of calculating the symmetry score for each facial expression movement of six subjects, A to F, it was confirmed that the score is close to 1 during symmetrical facial expression movements, and decreases during asymmetrical facial expression movements. These results demonstrated the possibility of evaluating the facial nerve paralysis level three-dimensionally and objectively by assessing the symmetry during facial expression movements. Furthermore, it was possible to cancel the left-right asymmetry in the resting state on each subject's face by expressing the difference during the facial expression movements and in the resting state as an index referred to as the distance between correspondence points.

The improvement of the right and left division accuracy of the facial data, and practical application to the paralysis evaluation of patients with facial nerve paralysis are possible future topics.

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