Development of Band-shaped Device and Detection Algorithm of Laryngeal Elevation

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Abstract— **This study concerns a measurement device and an algorithm of the laryngeal elevation for the Mendelsohn maneuver. The measurement device is band-shaped and measures the change of the circumferential length of the neck by stretchable strain sensors. The device is lightweight of 35 g. The algorithm detects the onset and offset points in time of the laryngeal elevation by the first-order difference and the dynamic time warping distance. Twelve elderly people participated in an experiment to validate the effectiveness of the device. A clustering method separated the measurement data into two groups based on their waveforms. We defined template data from the measurement data. The algorithm detected the onset and offset time by using the template data. Although the offset time of a group had an error of about 4 s, the onset and offset time points of the other group were errors within 1 s.**

I. INTRODUCTION

Pneumonia is one of the major diseases for people over 65 old in Japan. Approximate 80% of pneumonia of elderly people is aspiration pneumonia [1], [2]. The cause of aspiration pneumonia is a less harmonious motion of muscle and organs for swallowing. To prevent elderly people from aspiration pneumonia, they need to keep the harmonious motion by a rehabilitation maneuver.

In dysphagia rehabilitation, the Mendelsohn maneuver is one of the self-initiated training to improve the harmonious swallowing motion and to reduce aspiration. A trainee stops and keeps the larynx at the highest position of its elevation in a swallowing motion. The Mendelsohn maneuver measures the time of the elevation. The prolongation of the elevation time improves the harmonious swallowing motion [3], [4]. With the Mendelsohn maneuver, Bodén found that both the pharyngeal peak contraction and contraction duration were increased [5]. The simpleness and effectiveness are the merits of the Mendelsohn maneuver. However, the Mendelsohn maneuver has also demerits. In general, it is difficult for elderly people to recognize the position of the larynx. Some people cannot see the larynx by such as a mirror because it is inside the throat. If a biofeedback device detects the position of the larynx and informs it by sound or vision, people can perform the Mendelsohn maneuver at home by themselves.

Regarding the measurement of the laryngeal elevation for the Mendelsohn maneuver, some measurement methods were reported. Ding et al. measured the activity of five muscle groups including the infrahyoid muscle group by a surface electromyogram (sEMG) [6]. The data of the sEMG showed the initiation and termination of muscle activity during both normal swallow and the Mendelsohn maneuver. Although the sEMG is suitable for the measurement of muscle activity, the sEMG electrodes need skin preparation. It is difficult for trainees to perform daily the Mendelsohn maneuver with the sEMG electrodes at home. Hayashi et al. developed a laryngeal motion detector with a photo-reflective sensor array [7]. The sensor array is mounted on the anterior region of the neck using a flexion belt and measures distance between the sensor array and the neck skin surface. The detector obtains the laryngeal position from the measurement data. The photo-reflective sensor needs an air gap between the sensor and the neck skin. Hence, the detector has a much thick structure and might interfere with a trainee's normal motion.

This study proposes a band-shaped device for the Mendelsohn maneuver. The advantages of the device are a thin structure and a lightweight. The key sensor is a stretchable strain sensor. The device measures the circumference length of the neck by the strain sensor. An algorithm that uses the first-order differential and the dynamic time warping detects the time of the onset and offset from the time-series data of the circumference length. In this paper, we explain the device and the algorithm. The effectiveness of the device is validated through an experiment of elderly people.

II. METHOD

A. Measurement device

In a swallowing motion, the larynx starts moving up at the onset time and returns to the original position at the offset time. The circumferential length of the neck changes to the motion simultaneously. Concretely, because of the absence of the larynx, the circumferential length of the neck at the original position of the larynx shortens. After swallowing, the larynx returns the original position and the circumferential length also lengthen to the original length. If we measure the circumferential length, we capture the position of the larynx.

To measure the change of the circumference length of the neck, we use a stretchable strain sensor [8], [9]. The fundamental structure of the strain sensor consists of one

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elastomer sheet and a pair of stretchable electrode sheets. The electrode sheet is made from conductive particles. The electrode sheets sandwich the elastomer sheet. Its structure makes a variable capacitor. Because the elastomer sheet and electrodes are flexible and stretchable materials, an external force stretches the strain sensor even by a small force. The capacitance of the sensor also changes based on the stretch. Hence, we can obtain the change of the length of the strain sensor from the capacitance.

The strain sensors are embedded into a measurement device shown in Fig. 1. The measurement device has two strain sensors. The size of the electrode of the strain sensor is 50 $\times$ 5 mm in length $\times$ width. The thickness of the strain sensor is about 150 μm. Both ends of the strain sensor are attached to a neckband by velcro fasteners. The neckband which is made of fabric material is soft and stretchable. We put the device around the neck by the other velcro fastener. We can easily adjust the compression pressure between the neck and the band. The strain sensors are connected to a wireless communication unit. The unit records the capacitance of the sensor as the voltage through a capacitance-to-voltage conversion circuit and an analog-to-digital conversion chip. The sampling frequency is 10 Hz. Then, a tablet PC receives the voltage data. If the sensor lengthens, the voltage is high and vise versa. Fig. 2 shows the neck with the measurement device. The height of the device is about 50 mm. The weight of the device is 35 g. The thickness of the part of the strain sensor is about 8 mm. Hence, we can perform the Mendelsohn maneuver without discomfort even if we put the device around the neck.

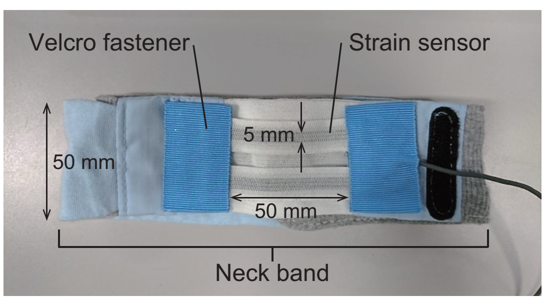


Fig. 1: Measurement device with strain sensors.

B. *Detection of swallowing*

When a trainee performs a swallowing motion, the larynx normally moves up in the front side of the neck and the circumference length of the initial position of the larynx shortens. In this study, the initial position of the center of the lower sensor shown in Fig. 2 is put on the neck skin over the larynx. In this case, when the larynx moves up at the onset time of swallowing, the voltage of the sensor becomes low. When the larynx moves down at the offset time swallowing, the voltage of the sensor becomes high. A typical illustration of the change of the voltage is shown in Fig. 3. The change of the voltage during swallowing shows a bathtub-shaped waveform. The Mendelsohn maneuver requires the time interval between the onset and offset of the swallow for the evaluation of the training. Hence, the device needs to detect the onset and offset times from the measurement data.

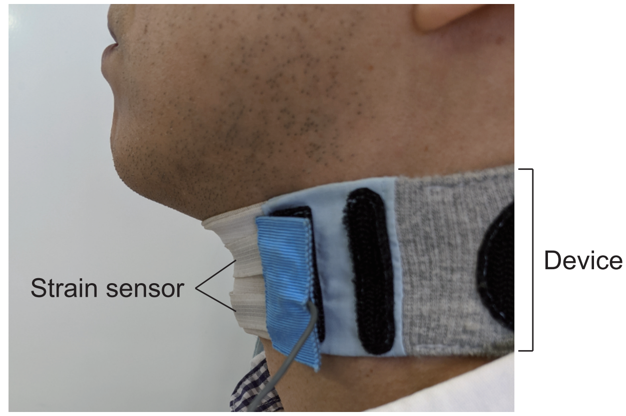


Fig. 2: Measurement device put around the neck.

We propose an algorithm as follows. First, the first-order differences of the measurement data are calculated at every sampling time. The onset time is detected by using a threshold determined based on the data without swallowing. Second, the dynamic time warping (DTW) determines the DTW distance between template data and the measurement data from the onset time to the latest time [10]. The DTW matches the template data with the measurement data optimally by partial expansion and contraction of the data. The DTW distance means dissimilarity between the two data. If we use an ideal data of the laryngeal elevation as the template data, the minimal DTW distance is expected to indicate that the latest time is the offset of the laryngeal elevation. The algorithm detects the offset time by judgment with a threshold to the DTW distance. Hence, the proposed algorithm requires the thresholds of the first-order difference and the DTW distance in advance. The range of the change of the circumferential length of the neck depends on individual differences such as the initial circumferential length of the neck, the size of the laryngeal prominence, etc. To reduce the individual difference, we obtain the range of the measurement data in normal swallowing beforehand and normalize the measurement data. Hence, a trainee has to perform normal swallowing before using the measurement device. Although the algorithm requires such the preliminary measurement, the algorithm is expected to detect the onset and offset times in realtime by the DTW.

III. Experiment

Twelve elderly and healthy individuals (1 male and 11 females, 75.8$\pm$5.7 years old) participated as subjects in the study. Before an experiment performing the Mendelsohn maneuver, all participants completed a questionnaire about their sex and age. Informed consent was obtained from all participants before the experiment. The experimental procedures were approved by the Ethics Committee of Kobe University Graduate School of System Informatics in accordance with the Helsinki declaration.

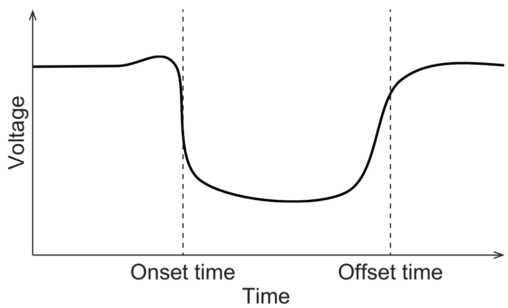


Fig. 3: Typical illustration of Measurement data and onset and offset points in time. The considered range of the time interval is from 2 to 18 s.

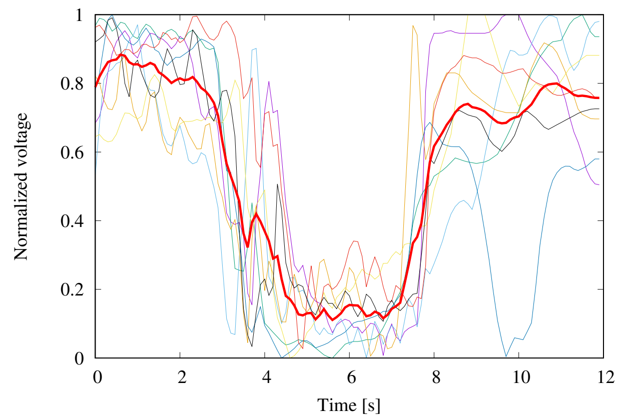
The subjects wore the device around the neck with weak pressure (approx. 100 Pa). The lower sensor was put on the laryngeal prominence as shown in Fig. 2. A speech-language-hearing therapist (ST) instructed the subject to perform the Mendelsohn maneuver for about 4 s. The device measured the change of the circumferential length of the neck. Simultaneously, the ST detected the onset and offset of the laryngeal elevation by palpation and sent the time by a push-button connected to the tablet PC. The tablet PC recorded the measurement data and the onset and offset times by the ST simultaneously.

After the measurement, the data of voltage are normalized in the range from 0 to 1. First, we analyzed the measurement data by the k-means clustering. The clustering method separated the data into two groups of 8 and 4 data. Fig. 4 (a) and (b) plot the separated data. Hereafter, they are called a bathtub-shaped data and long-v-shaped data, respectively. The bold lines in Fig. 4 (a) and (b) show average data calculated from the measurement data in each group. We used the average data as the template data in the determination of the DTW distance. Although the average data include the data before the onset and after the offset, the DTW contracts the data in the determination of the DTW distance.

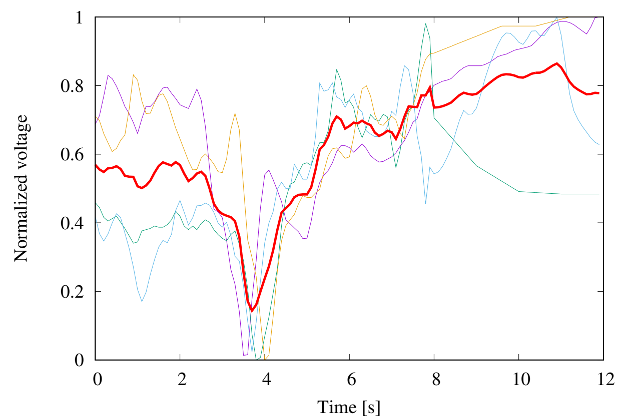
Fig. 5 shows the typical example of the onset and offset detection. The vertical red-colored line shows the detection time of the onset and offset of the laryngeal elevation. The vertical green-colored line shows the onset and offset recorded by the ST. The onset and offset of the bathtub-shaped data showed a good agreement with those by the ST in Fig. 5 (a). On the other hand, the long-v-shaped data showed the difference in the offset time as shown in Fig. 5 (b). The mean absolute error (MAE) between the device and the ST and its standard deviation (SD) are summarized in Table I and II. The MAEs of the bathtub-shaped data had a small error within 1 s. The offset of the long-v-shaped data had a large error of around 4 s.

IV. Discussion

We developed a prototype of the measurement device of the laryngeal elevation and evaluated the effectiveness of the device through the experiment. Because the supposed major

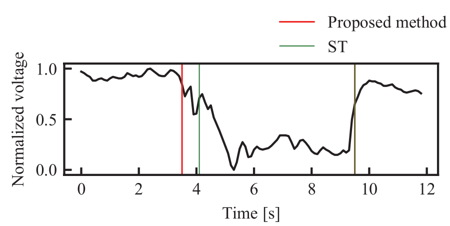


(a) Bathtub-shaped data.

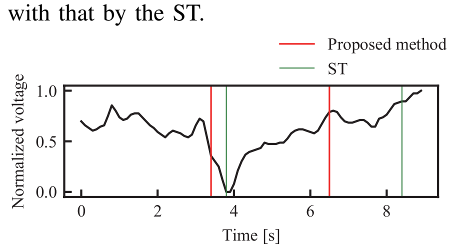


(b) Long-v-shaped data.

Fig. 4: Two groups separated by clustering method.



(a) Bathtub-shaped data. The offset time by the method corresponded with that by the ST.



(b) Long-v-shaped data.

Fig. 5: Typical measurement data and detection of onset and offset points in time.

TABLE I: Detection error and standard deviation of the bathtub-shaped group.

	Onset	Offset	Time interval
Mean absolute error s	0.81	0.23	0.76
Standard deviation s	0.31	0.22	0.39

TABLE II: Detection error and standard deviation of the long-v-shaped group.

	Onset	Offset	Time interval
Mean absolute error s	0.65	3.95	3.30
Standard deviation s	0.55	0.69	0.68

users of the device are elderly people, the twelve elderly people participated in the experiment of this study as the subjects. The measurement data of the Mendelsohn maneuver were separated into two groups as shown in Fig. 4 (a) and (b). The bathtub-shaped data showed that the subjects kept the larynx at a high position during the maneuver. The ST evaluated the bathtub-shaped data as the visualization of the correct performance of the Mendelsohn maneuver. On the other hand, the long-v-shaped waveform showed that the larynx gently moved below. The device and the clustering method visualized the difference between the two groups.

The onsets of the laryngeal elevations were detected with a small-time error by the first-order difference. The MAEs of the onset of the bathtub-shaped and the long-v-shaped data were 0.81 and 0.65, respectively. We considered that the MAE within 1 s was appropriate for the biofeedback device because normal swallowing duration is over 2 s. Hence, the MAEs were enough small to detect the onset. The MAE of the offset of the bathtub-shaped data was 0.23 and was also small. The algorithm, which uses the first-order difference and the DTW distance, performed effectively for the bathtub-shaped data.

However, the MAE of the long-v-shaped data was approximately 4 s. The detection of the offset time was too early as shown in Fig. 5 (b). The error of 4 s was not appropriate for the biofeedback device. One of the causes of the large error was the template data. Although we used the average data as the template data in the experiment, we should improve the procedure of the determination of the template data. Besides, we can add the limitation of expansion and contraction to the DTW. For example, if we prepare a set of template data with different lengths, the DTW with the limitation might detect correctly the offset time.

The limitations of the study are the following. The number of subjects was twelve and was not enough. This limitation does not allow us to evaluate the accuracy of the onset and offset detection. The validation of the accuracy of the detection needs more subjects. Also, the waveform of the measurement data depends on the neck shape of a subject. If we could collect more data, the clustering method might add the new group to the bathtub-shaped and long-v-shaped groups. The other limitation is that the subjects in the experiment were healthy and elderly people. We need to validate the effectiveness of the device for elderly people with dysphagia.

V. Conclusions

We proposed the measurement device of the laryngeal elevation for the Mendelsohn maneuver. The measurement data of the elderly subjects showed bathtub-shaped and long-v-shaped data. The algorithm, which consisted of the first-order differential and the DTW, detected the onset time within the MAE of 1 s. The DTW detected the offset of the long-v-shaped data with the error around 4 s. We confirmed that the device and algorithm perform effectively for the bathtub-shaped data at least.

In future work, we need to improve the detection method of the offset. Besides, additional data of elderly subjects with dysphagia validates the effectiveness of the device and the improved algorithm.

ACKNOWLEDGMENT

This work was supported by Kawanishi Memorial Shin-Maywa Education Foundation.

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