Development of a prototype simulation model for mealtime assistance and a spoon navigation application

Hirokazu Kawana
gekitetz Inc.
Digital Hollywood University Graduate School
Tokyo, Japan
access@gekitetz.com

Masumi Muramatsu
School of Nursing, Sapporo City University
Sapporo, Japan
m.muramatsu@scu.ac.jp

Atsushi Mitani
School of Design, Sapporo City University
Sapporo, Japan
a.mitani@scu.ac.jp

Abstract*—Japan has a substantial problem in regard to its rapidly aging society. To realize the goal of a "100-year life" set by the Ministry of Health, Labour and Welfare, it is crucial for older adults to maintain healthy oral functions as long as possible. Mealtime assistance helps older adults take food by mouth and is therefore essential in nursing and caregiver education. However, students have few opportunities to receive direct coaching from instructors because of low student/teacher ratios. Recently, simulation education has attracted attention as an effective process for nursing and caregiver students before clinical practice in hospitals and care facilities. With the aim of improving the educational environment in oral care and the effectiveness of simulation education, we have developed several oral care simulation models, including a prototype mealtime assistance simulation model consisting of denture and tongue models with a sensor system to detect spoon movement. Here, we describe the development of a prototype mealtime assistant simulation model showing an improved humanoid appearance with a jaw joint driven by a servo motor and an improved tongue model with a sensor board embedded with three photo reflectors. We also developed a spoon navigation algorithm for the tongue part based on our former model and a spoon movement navigation application, and evaluated the function in a series of experiments.

***Keywords*—simulation education; oral care; simulation model; mealtime assistance; sensing; interaction design**

I. Introduction

An aging society poses a significant problem for many nations such as Japan. To achieve the goal of a "100-year life", the Japanese Ministry of Health, Labour and Welfare has promoted strategies for enhancing the quality of life and maintaining the health and oral functions of older adults as long as possible. Oral functions deteriorate owing to an age-related loss of muscle strength and particular diseases that affect older adults, such as Parkinson's disease and dementia, which usually lead to dysphasia. Therefore, mealtime assistance skills are essential in nursing and caregiver education.

In clinical practice at hospitals and care facilities, students in nursing and caregiver education also have few opportunities to practice on actual patients and are limited to observing how well-trained caregivers provide care to patients with poor oral status, such as older adults with dementia.

In recent years, simulation education has been attracting increasing attention as an effective exercise process that allows students in nursing and caregiver education to learn fundamental clinical care skills and procedures in the clinical setting before clinical practice in hospitals and care facilities. Simulation education started in the US in the 1970s and has been systematized as an essential part of the curriculum for students in medical, nursing, dental hygiene, and caregiver education. In Japan, simulation education was introduced in the 2000s as an effective process to cultivate the practical abilities required of a specialist [1].

Focusing on the insufficient educational environment in educational facilities, as well as the effectiveness of simulation education, we attempted to develop oral care simulation models suitable for an education program. We then developed a prototype mealtime assistance simulation model [2] consisting of denture and tongue models with a sensor system to detect spoon movement. Next, we evaluated the sensor system in spoon detection experiments and devised a spoon navigation algorithm that enabled students to move the spoon to the target position and apply a pressing force to stimulate the hypoglossal nerve and provoke oral closure.

The present study aimed to develop a prototype simulation model for mealtime assistance. This model has an improved appearance closer to an actual human head accompanied by a jaw joint driven by a servo motor. Based on fundamental experiments and previous work, we also developed a spoon navigation algorithm on the tongue model as well as a spoon movement navigation application, the interface and function of which are introduced in this paper.

II. Related Works

Several simulation models and related research topics can be found in the simulation education area. However, examples such as a foot gait simulator [3] and a defecation simulator [4] were not designed for simulation education in nursing school. SimMan (Laerdal Medical) [5] is a robot patient simulator that simulates various body parts, but was not designed for use in oral care education. Other examples used in Japan include Seiketsu-Kun (Kyoto Kagaku Co.), a commercial oral care simulation model [6], DR-H Ni:Mo (Nissin), a practice phantom with a denture model [7] targeted for use in dental hygiene school education, and Manabot (Nissin), an oral function management training tool [8] consisting of an oral cavity with denture and tongue models that replicates an older adult. These models can be used to practice some oral care procedures, but not mealtime assistance.

Some research topics have been targeted for simulation education in nursing school. A robot simulator [9] has been used to simulate the oral care of bedridden patients, but not for mealtime assistance. Although case studies of simulation education using SimMan have been reported in nursing and medicine [10,11], no reports regarding oral care simulation education have been published. Other simulators, such as an arrhythmia simulator [12] and a remote oral diagnosis system [13], were not designed for oral care simulation.

Information technology has been integrated into simulation education and several research topics have been explored, including a computer-aided auscultation learning system [14], clinical prostate training [15], a haptic feedback system for nasotracheal suctioning [16], a virtual reality auscultation learning system [17], and a dental patient robot for dental students [18]. However, none of these systems cover oral care or mealtime assistance.

Therefore, the present study aimed to develop an appropriate oral care simulation model including mealtime assistance by applying robot and information technologies.

III. Requirement to Detect Spoon Movement in Mealtime Assistance

Mealtime assistance consists of all processes that can help older adults who cannot eat independently, such as oral training, massaging the tongue, wetting the oral mucosa, getting into a proper seating posture at a table or while in a wheelchair, and oral care with a toothbrush or sponge brush after eating. In the case of mealtime assistance using a spoon, the caregiver must move the spoon so that it stimulates nerves such as the hypoglossal nerve (left side of Figure 1) and trifacial nerve to not only place foods on the tongue, but also improve swallowing function (right side of Figure 1). Thus, the mealtime assistance simulator developed in the present study was designed to be able to evaluate whether the spoon would have stimulated the target nerves correctly [19,20]. To realize this, sensors for detecting spoon movement were installed in the tongue and the upper lip parts of the simulator. In the present work, STEP 1 can be performed as shown in Figure 1, but STEP 2 will be implemented in the future. Therefore, the present simulation model has the following functions:

1. *Detects spoon movement with sensors embedded in the tongue modelUnits*

2. *Closes the mouth via a servo motor-driven jaw joint model*

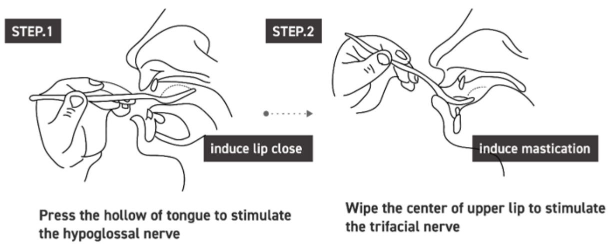


Figure 1. Spoon movement for mealtime assistance: STEP 1 can be performed as shown, whereas STEP 2 is still under development.

IV. Mealtime Assistance Simulation Model

With reference to the operating mechanism of the jaw joint, a humanoid upper body model (above the shoulder) was newly designed using three-dimensional (3D) computer-aided design software and output using a 3D printer. The chassis had an exterior part and a denture model part with a jaw joint. The model is controlled by a PC and microcomputer (Figure 2).

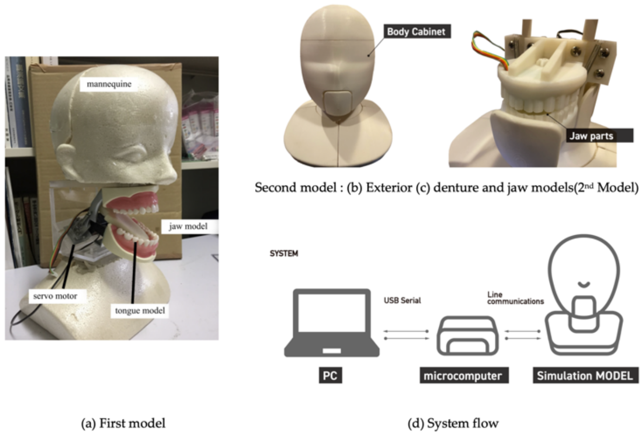


Figure 2. Prototype model And System flow.

V. Spoon Movement Detection Sensor System for Mealtime Assistance

5.1. Development of the Prototype of Tongue Model

Figure 3(a) shows our newly developed sensor board to detect spoon movement. In our previous work, the sensor board for the tongue model consisted of four sensors with two types: a force sensor to detect the pressing force on the center of the tongue, and three photo reflectors (PRs) to estimate the pressing position by detecting deformation in the tongue model [2]. In the present work, three reflection sensors were used to estimate both the pressing force and position. Figure 3(b) shows a molded tongue model covered with a soft urethane gel designed to approximate the feeling of human tissue, called "Hitohada Gel", product of Exseal Corporation.

VI. Fundamental Experiments for Spoon Movement Detection and Navigation

6.1 Spoon Identification for Mealtime Assistance

Figure 3 shows a typical spoon for mealtime assistance. Based on previous work [2], we defined the target values as follows:

1. *Detects spoon movement with sensors embedded in the tongue modelUnits*

2. *Pressing force: 100 –150 gf*

6.2 Experiments for the Tongue Model

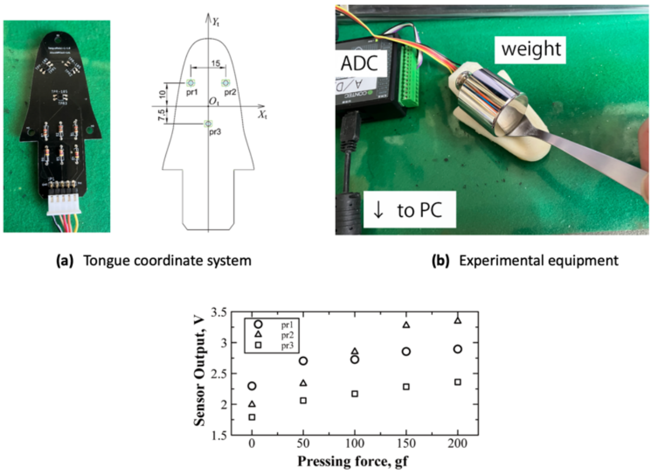
Based on the tongue coordinate system Ot-XtYt shown in Figure 3(b), we considered the relationship between the pressing force and sensor signals from the three PRs. In Figure 3(b), the origin Ot indicates the position of the hypoglossal nerve and the coordinates of each PR are the same as those in our previous work [2], denoted as follows (unit: mm): pr1 = (–7.5, 10), pr2 = (7.5, 10), and pr3 = (0, –7.5).

We prepared an analog-to-digital converter (AIO-160802AY-USB; Contec Inc., Osaka, Japan) to record output signals from the PRs via a USB interface. The pressing force was imposed using a weight on a spoon Figure 3(c).

Figure 3(c) shows the experimental results for spoon pressing forces of 0, 50, 100, 150, and 200 gf on the origin Ot. The results indicate that the sensor outputs from each PR increased with increases in the pressing force from 0 to 200 gf. Thus, the pressing force can be estimated as follows from the output of each sensor.

Smaller: pr1<2.7, pr2 <2.8, and pr3 <2.17
Appropriate: 2.7 < pr1 < 2.85, 2.85 < pr2 <3.27, and 2.17 < pr3 < 2.28
Larger: pr1 > 2.8, pr2 > 3.27, and pr3 > 2.28

Next, we considered the estimation of pressing position from the sensor signals. Based on previous work, the signal outputs from each PR are the largest when the spoon presses just above each sensor position, and become smaller as the distance from the sensor to the pressing position increases. Therefore, the spoon can be positioned close to the origin Ot along both the Xt and Yt axes. Figure3(a) shows the sensor signal trajectory of each PR when the spoon moves from negative to positive on the Yt axis with a pressing force of 100 gf. As shown in the figure, pr1 and pr2 peaked at y = 10, perpendicular to the positions of pr1 and pr2, and pr3 peaked at y = –7.5. This means that the appropriate spoon position can be indicated using the same algorithm as that in our previous work [2].



(a) Tongue coordinate system

(b) Experimental equipment

(c) Experimental results when a pressing force is imposed on the origin O_t

Figure 3. Experiments for the Tongue Model.

VII. Development of the Spoon Navigation Application

7.1. Application Interface

Based on the studies described earlier, we developed an application to enable the user to learn how to move the spoon appropriately. This application records the sensor output values sent from the sensors mounted on the simulation model and visualizes the spoon movements based on these values.

7.2. Software-Based Navigation Algorithm for Spoon Movement

Based on the details described in Section 3, the procedure necessary for mealtime assistance can be defined as comprising the following phases:

Phase 1. Move the spoon into the oral cavity and place it on the center of the tongue.

Phase 2. Maintain the position of the spoon and apply an appropriate force.

Phase 3. Remove the spoon from the oral cavity while pressing against the upper lip.

To realize this spoon navigation procedure, we developed a software-based navigation algorithm.

7.3. Validity of the Navigation Algorithm in Phase 1

The value P0 is transferred from the tongue sensor board value, while P1 is transferred from the sensor detecting the appropriate applied force value. The relationship between P0 and P1 is described in the following equation, with P_offset defined as the allocated silicon-reacted value:

$$P1 = P0 / P\_offset$$

F0 is defined as the normal condition when the spoon does not apply any force on the tongue. In the case of F0, the range of P1 can be described as follows:

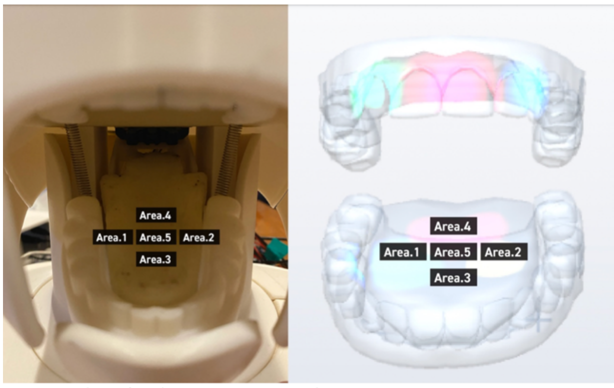
$$0.8 < P1 < 1.0f$$

By using the F0 condition equation, the software application can estimate in which area the spoon is located in the position chart. F1, F2, and F3 in the conditional expressions are the values of pr1, pr2, and pr3 on the sensor board.

A judgment is then made based on one of the following equations when the spoon is placed on the tongue sensor. If the spoon is not placed in the appropriate center position, the user is urged to move the spoon to the correct position. Figure 4 shows the navigation results when the spoon is located in each area. All navigation arrows indicate the direction to Area 5.

If the spoon is not navigated appropriately, this indicates that the spoon should be moved to the proper center position.

Left position	*Area 1 = F1 ≤ 1.0f & F2 ≥ 1.2f & F3 ≥ 1.2f*
Right position	Area 2 = F1 ≥ 1.2f & F2 ≤ 1.0f & F3 ≥ 1.2f
Front position	Area 3 = F1 ≥ 1.2f & F2 ≥ 1.2f & F3 ≤ 1.0f
Back position	Area 4 = F1 ≤ 1.0f & F2 ≤ 1.0f & F3 ≥ 1.2f
Center position	Area 5 = F1 ≥ 1.2f & F2 ≥ 1.2f & F3 ≥ 1.2f



Position chart for the navigation application

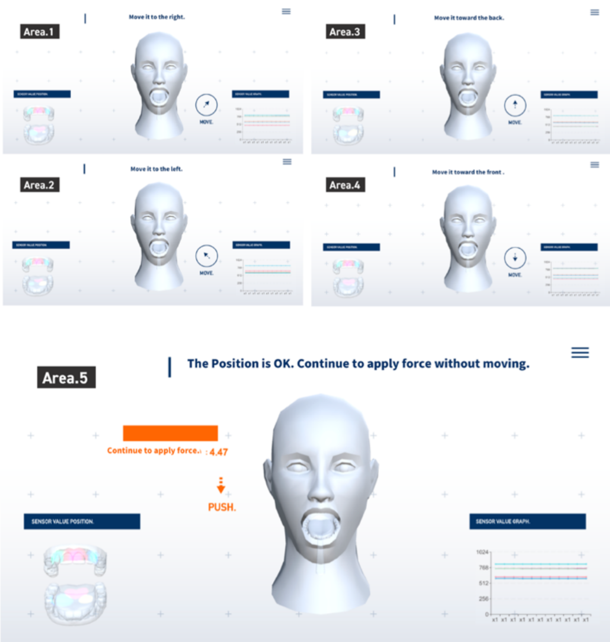


Figure 4. Position chart for the navigation application and Navigation results in each area.

7.4. Algorithm for Simulation of the Spoon Movement

The three movements listed in Section 6.2 were implemented using the following equations. The value of the movement to press the spoon on the indicated tongue position is denoted as S1. The time of the movement to press the spoon on the indicated tongue position is denoted as t1, and the designated time as t2. The movement to fix the spoon at the current position and keep pressing it until the indicated time is denoted as S2. If the value of the upper lip sensor is denoted as P3 and the movement to remove the spoon from the oral cavity with the spoon is fixed as S3, the equations are as follows:

$$1: S1 = \text{Area } 5$$

$$2: S2 = S1 \,\&\, t1 > t2$$

$$3: S3 = F0 \,\&\, P3 > 1.0f$$

When the user presses the spoon on the correct position or maintains a fixed position, the navigation indicates that the user should continue such correct movements by showing the designated time on the screen. In addition, if the user performs the procedure correctly and moves to the next screen, the application displays the term "Correct"; if the user does not perform the procedure correctly, the application urges the user to follow the correct movements by providing instruction on how to apply force properly, etc.

7.5. Algorithm to Control the Timing of the Jaw Joint

Three movements were set up to move the patient's jaw joint during dietary care. A servo motor was used for the movement of the jaw joint. The angle of the servo motor can be changed according to the navigation application, allowing the dietary movements to be controlled.

By performing the movements of the jaw joint in conjunction with the 3D model of the oral cavity in the software, the system makes it possible for the user to understand the timing of dietary care and the flow of movements (e.g., mastication) in a way that corroborates with both actual and simulated learning environments.

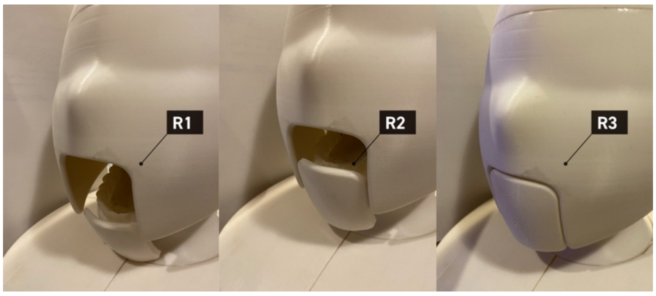


Figure 5. Opening and closing of the jaw

VIII. Preliminary Experiments

Before the experiments were conducted, we obtained the approval of the ethics committee of Sapporo City University (No. 2022-01). However, under the circumstances produced by the coronavirus disease 2019 pandemic, we had difficulty finding agreement between the experiments in nursing school and care facilities, and we could not obtain a sufficient number of examinees to analyze the simulation model statistically. Therefore, this section provides the following comments from six experts who were working in the rehabilitation section of a hospital:

"Visualization is an essential function of the simulator."

"The simulation model showed reactions according to spoon movements."

"Patients sometimes refuse to open their mouth, and some have tongue paralysis or cancer, or missing teeth and dentures. The simulation model should include functions appropriate for such clinical situations."

IX. Discussion

Based on the comments in Section 8 obtained after conducting examinee experiments targeted for students, the simulation model appears to be adequate for learning fundamental mealtime assistance skills and procedures using a spoon. On the other hand, further improvements are needed to improve its effectiveness. Although the present oral cavity model is similar to a healthy actual one, a certain proportion of patients are expected to have some disorders. Therefore, various types of oral cavities, such as those with tongue paralysis, tongue cancer, choking, and tooth pain, which inhibit chewing and swallowing function, should be developed to replicate clinical situations more accurately.

X. CONCLUSION

In the present study, we developed and described the details of a prototype simulation model for mealtime assistance for nursing students and caregivers, including an upper lip model and improved tongue model, a spoon navigation application, and a navigation algorithm. To assess the developed simulation model, we conducted experiments targeting caregiving experts. The results suggested that the simulator is effective for teaching fundamental mealtime assistance skills and procedures.

In the future, we plan to conduct further examinee experiments targeting students and experts in various facilities to assess the simulation model. We also plan to improve the simulation model and its application based on the advice and comments obtained in the experiments, and to develop a mealtime assistance simulation education program.

Acknowledgements: This work was supported in part by JSPS KAKENHI (18H03114) and the Collaborative Research Fund, Sapporo City University, Japan.

Acknowledgements:

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