# A Lightweight Method to Detect the Insufficient Brushing Regions Using a Six-Axis Inertial Sensor

Lei Jing
School of Computer Science and Engineering
University of Aizu
Aizu-Wakamatsu, Japan 965-8580
Email: leijing@u-aizu.ac.jp

*Abstract*—**In this research, we present a practical method to detect the insufficient brushing points. The system consists of a sensor node and a visual interface. The sensor node can be clipped onto the handler of a toothbrush while brushing the teeth and the brushed regions will be realtime displayed on the visual interface. A six-axis inertial sensor inside the node is used to detect the scrubbed areas, so that the user can realize the insufficient scrubbed areas in an intuitive way. All teeth are divided into 16 regions to evaluate the detection accuracy. The user dependent accuracy is 88%, and user independent accuracy is 72% across five users. Moreover, Two users took part in a learning effect experiment. After one-week usage, their insufficient toothbrushing points reduced by 80% and 77% perspectively.**

## I. Introduction

Oral hygiene is not only related with the mouth clean, but also related with the overall health. And to keep the oral hygiene, it is important to brush the teeth not only in a regular, but also in a right way.

According to a survey in 2011 by Japan Ministry of Health, Labor and Welfare, the percentage of Japanese who brush their teeth more than twice has increased from 17% in 1969 to 75% in 2011. But there are still about 80% adults ($\geq$ 35 years old) suffering from periodontal disease. Moreover, another data in the same survey shows that even among the people with self-confidence on their tooth brushing, the test data shows that about 70% of them with more than 20% miss brushing regions. Therefore, most of people do not acquire a right tooth brushing method.

Such situation attributes to the inadequate of tooth-brushing education. We can verify this claim by asking ourselves that what is the right tooth-brushing method. And then compare with the method given in this paper. In the elementary schools of Japan, approximately every half a year, a dental checkup is done by a dentist. However, it is hard to say that adequate tooth-brushing education has been conducted only from once or twice short checkups per year.

Like any skills, to learn it, people need to do it with timely feedback. But currently, they can not get professional feedback on the tooth brushing unless go to the dental clinics or hospitals. And even in such places, the brushing method is difficult to be rectified since it is invisible from out side of the mouth.

To this end, in the research, we propose a method to detect the brushed regions using a wireless inertial sensor node clipped on the handle of a tooth brush. Moreover, we show that such tools can improve the tooth-brushing effect through a controlled comparison experiment.

## II. Related Works

The main topic of this research is on automatic detection of brushing regions using inertial sensor and the educational effect by providing timely visual feedback.

In paper [1], a visual interface is designed to guide the brushing sequence and duration. Such an educational system shows continuous effect even after six weeks. In paper [2], a toothbrush is used as the game controller to interact with a visual game, which shows the game can enhance the brushing efficiency and duration. But, in above research, no method is proposed for brushing region detection. In research [3], the magnetic sensor is adopted to detect the relative translation from a predefined start point of the teeth with the millimeter accuracy. But the sensing device is bulky for home usage. In research [4], three kinds of sensors including accelerometer, gyroscope, and magnetic sensors are adopted to detect the attitude of the toothbrush. It can discriminate totally 16 regions. But it still needs the external sensor in the environment as the marker of the global coordination to reduce the errors caused by head movement. In research [5], two kinds of sensors including accelerometer and magnetic sensors are adopted, which can detect 15 regions. It is self-contained and much compact for daily usage. But it relies on the magnetic sensor to infer the heading, which is error prone and introduce complex filter and head estimation method like Kalmen Filter.

As a summary, most of the proposed method relies on the environmental factors, like sound, light, electromagnetic field, etc., which limit the usage in the daily life. In view of the above issues, we propose an inertial sensor based detection method. The system is independent from the environment to avoid the complicated hardware and software structure.

## III. Model and Method

A tooth model is defined to explain the method. From the top view (Figure 1.A), the teeth in the mouth is in the shape of a curve. And from the side view (Figure 1.B), each tooth has two or three surfaces. Therefore, we propose a method to the horizontal region at first, then to detect the brushing surface.

Formal definition of the tooth-brushing model is given as below.
Top View (Figure 1.A):
(1) The teeth is in the shape of a curve which is a part of circle represent as, $C_h = \{p_0, \cdots, p_i, \cdots, p_n\}$ , which $p_0$ is a point on the circle. The center of $C_h$ denoted as $O$. The tooth-brush is represented as a line segment, denoted as b. Thus, at any time $t_i$, the brush orientation is $b_i$.
(2) Each time, the toothbrush starts from the same location, denoted as $S$. $S$ can be any points on the $C_h$, so we can define $S = p_0$.
(3) Since $\forall t_i, b_i \perp Op_i$, the angle between $b_0$ and $b_i$, denoted as $\alpha_i$, is equal with the angle between $Op_0$ and $Op_i$, denoted as $\theta_i$.
Side View (Figure 1.B):
(4) From the side view, a pair of upper and lower bite teeth can be represent in a upside down way so that the tooth brush trajectory construct a circle, denoted as $C_v = \{q_0, \cdots, q_j, \cdots, q_m\}$. The center is $O$, $q_j$ is a point on the circle.
(5) The start point is denoted as $q_0$, the angle between $q_0$ and $q_j$ is denoted as $\beta_j$.
From the model, the brushing region can be located as long as given the start point, horizontal angle $\theta_i$, vertical angle $\beta_j$. We presume that, each time the user starts to brush from a known point. Therefore, we can locate the brushing region with angular sensor, which can get the $\theta_i$ and $\beta_j$. Furthermore, we can define a range in terms of $\theta_i$ and $\beta_j$ for each region so that we can track the brushing region.

978-1-5090-4045-2/17/$31.00 ©2017 IEEE

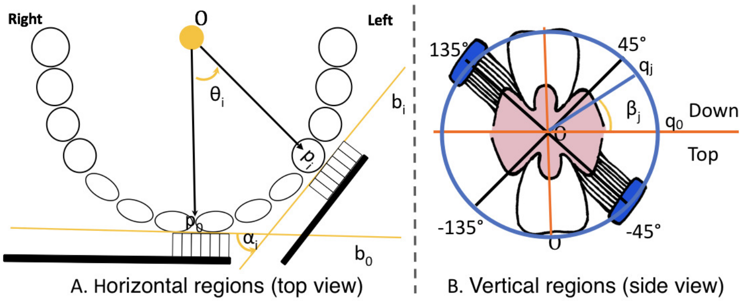


Fig. 1: Teeth model for recognition.

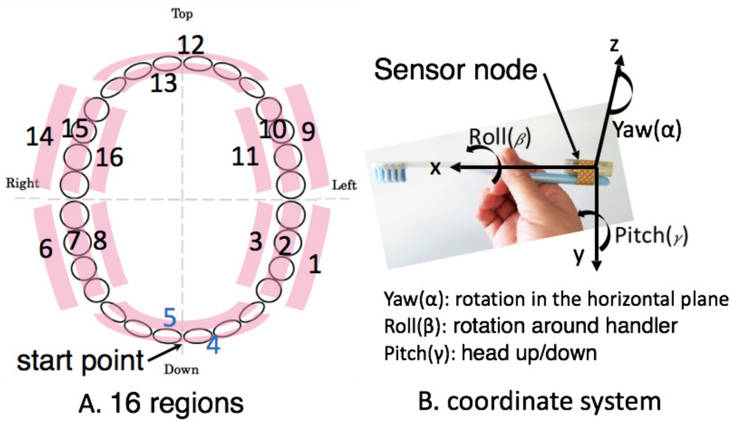


Fig. 2: Sixteen regions of teeth and sensor coordinate system.

# IV. Evaluation

## A. Experiment System

The teeth is divided into 16 regions as shown in Figure 2.A to conduct the evaluation experiment.

A sensor node prototype is developed to verify the proposed method. The sensor node consists of ARM cortex M0 process, nine-axis motion sensor (only accelerate and angular sensor adopted in this research), BLE 4.1 wireless interface, and rechargeable battery with a 15x15x30mm dimensions. The placement of the sensor is shown in Figure 2.B. According to the right hand rule, the spacial coordinate system is defined including three rotation angles: yaw($\alpha_i$), roll($\beta_j$), and pitch.

The user interface in the experiment is shown in Figure 3. The sensor control panel is in the middle. Sensor status and sensing data are displayed on the left. And the tooth brushing status is displayed on the right. When a region is not sufficiently scrubbed, it is in pink color. Otherwise, it is in white color. Therefore, user can get intuitive feedback on there tooth brushing behavior.

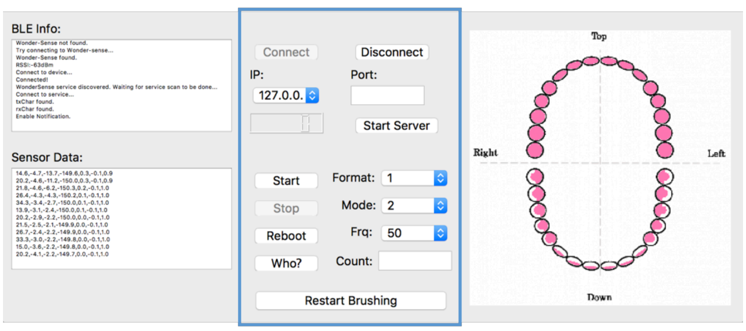


Fig. 3: Visual feedback interface.

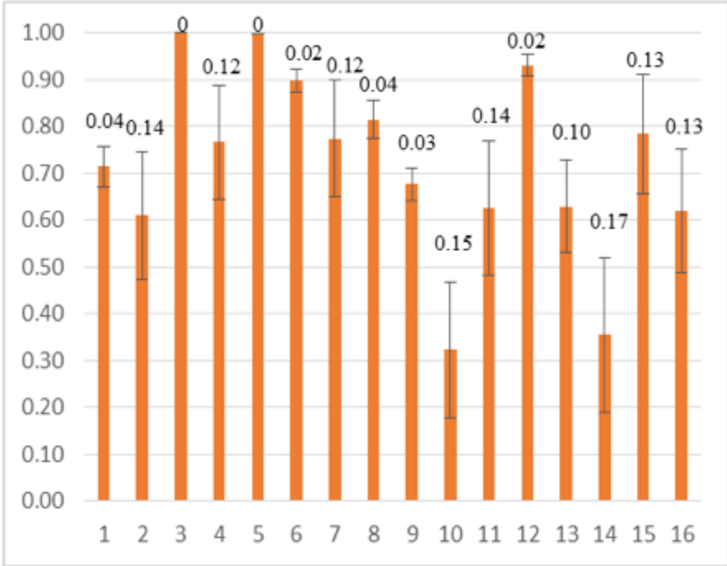


Fig. 4: User Independent Data (5 users) Average Accuracy = 72%. SD = 23%

## B. Accuracy Evaluation

Five subjects (avergae age 21, 4 female 1 male) took part in the experiment to verify the accuracy of detection. The experiment process:
- The subject is asked to take part in the experiment one by one
- A mirror is put in front of the subject to help s/he to confirm their action
- A picture of Figure 2.A is put under the mirror to remind the brushing order.
- Explain the correct brushing method, but not conduct prior exercises.
- Start each test from the initial position.
- Brushing in the same order as shown in Figure 2.A.

For the user independent experiment, the average rate is 72% (sd 23%)(Figure 4), while for the user dependent case, the average accuracy is 88% (sd 6%)(Figure 5) . The different of the result is attributed to the different range definition protocol. For user independent experiment, the same set of upper and lower limits were defined for all five users. While in the user dependent experiment, a set of upper and lower limits were defined for each user through individual measurement. Since the teeth shape has individual different, therefore, the user-independent experiment gets lower accuracy and bigger standard deviation. Meanwhile, it shows pretty high and stable accuracy.

## C. Educational Effect Evaluation

Two subjects took part in the experiment to verify the educational effect. The experiment lasted for one week. The subjects were required to use our system once a day. And on the first and last day, plaque staining method (scoring method in Figure 6) was adopted to quantitatively evaluate their tooth brushing scores. Therefore, the educational effect is reflected on the difference of the two scores.

On the 1st day, subject A score is 80 points, B score is 87 points. On the 7th day, A score is 96 points, B score is 96 points as shown in Figure 7 and Figure 8 respectively. Their insufficient brushing points reduced by more than 80% and 77% respectively after 5 times continuous usage of our system. Therefore, it can be said that there is an obvious educational effect for our system.

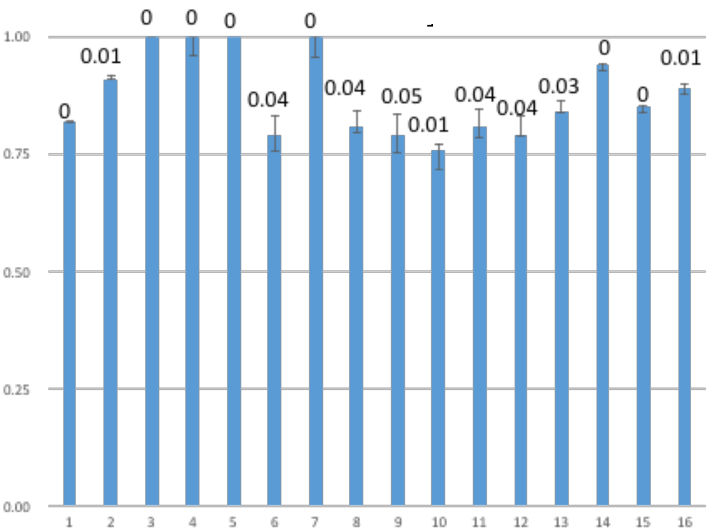


Fig. 5: User Dependent Data (5 users) Average Accuracy = 88%. SD = 6%

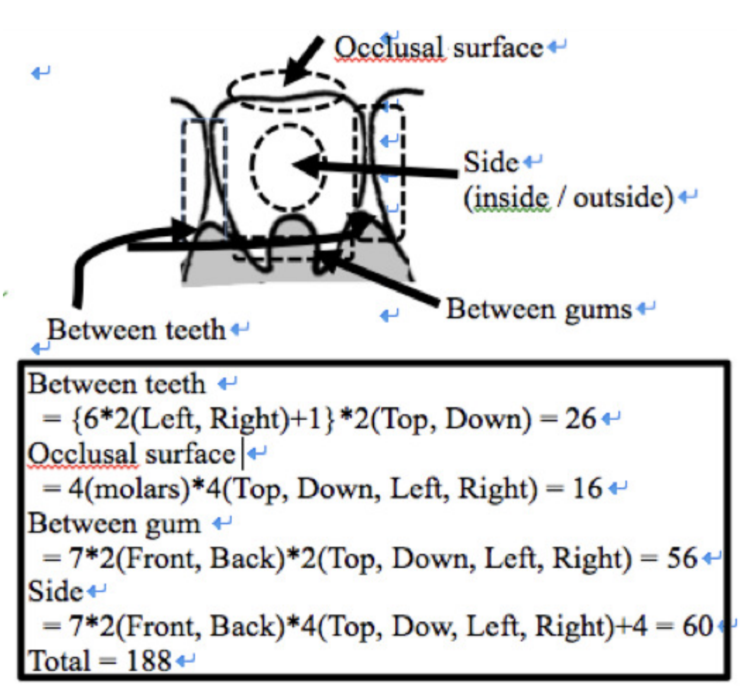


Fig. 6: The scoring method in the educational effect evaluation.

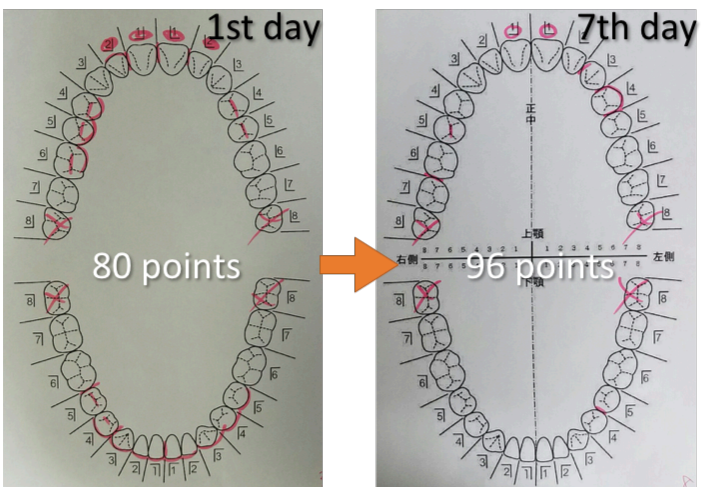


Fig. 7: A before/after comparison of the score for user A.

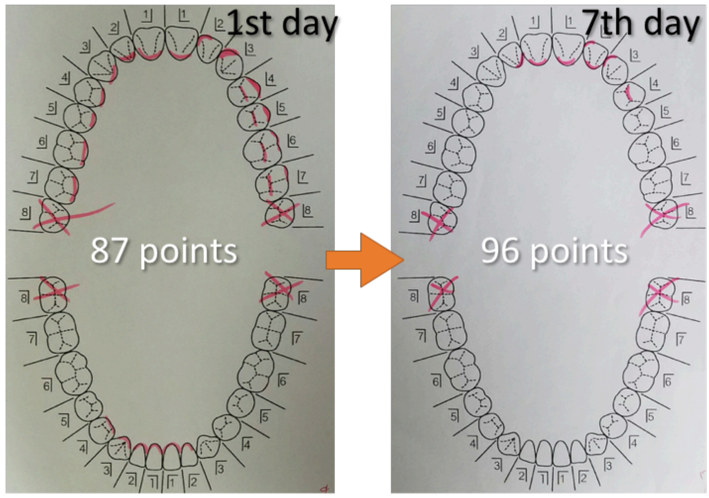


Fig. 8: A before/after comparison of the score for user B.

## V. Conclusion

We proposed a lightweight method to detect the insufficient tooth brushing regions. Such a method shows stable accuracy in user dependent experiment. And the system shows outstanding educational effect in a one-week experiment. The educational effect should be verify through long-term experiment with more subjects.

## References

[1] C. Graetz, J. Bielfeldt, L. Wolff, C. Springer, K. M. F. El-Sayed, S. Sälzer, S. Badri-Höher, and C. E. Dörfer, "Toothbrushing education via a smart software visualization system." *J. Periodontol.*, vol. 84, no. 2, pp. 186–95, 2013.

[2] K. Shao, J. Huang, H. Song, R. Li, and J. Wu, "DAYA: a system for monitoring and enhancing children's oral hygiene," *CHI'14 Ext. Abstr. Hum. Factors Comput. Syst.*, pp. 251–256, 2014.

[3] R. L. T. Derek Guy Savill, "Toothbrush usage monitoring system," 2002.

[4] H. Jin-Sang, "Tooth Brushing Pattern Analyzing/Modifying Device, Method and System for Interactively Modifying Tooth Brushing Behavior," 2006.

[5] Y. J. Lee, P. J. Lee, K. S. Kim, W. Park, K. D. Kim, D. Hwang, and J. W. Lee, "Toothbrushing region detection using three-axis accelerometer and magnetic sensor," *IEEE Trans. Biomed. Eng.*, vol. 59, no. 3, pp. 872–881, 2012.