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# Development of Smart Toothbrush Monitoring System for Ubiquitous Healthcare

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*Abstract*— **The design of an intelligent toothbrush, capable of monitoring brushing motion, orientation through the grip axis, during toothbrushing is described. Inappropriate Tooth-brushing styles, even in adults, sometimes cause dental problems, cavities, gingivitis, etc. This smart system provides user to monitor his or her brushing pattern using accelerometer and magnetic sensors for evaluation of toothbrushing style. Directional information of toothbrush with respect to the earth's magnetic field and activity data were measured by a miniaturized low-power micro- controller, MSP430 and transmitted to personal computer by 2.4GHz radio transmitter, nRF2401. A personal computer provides an on-line display of activity and orientation measurements during toothbrushing. The signal trace is then analyzed to extract clinically relevant information. This preliminary study showed that the proposed monitoring system was conceived to aid dental care personnel in patient education and instruction in oral hygiene regarding brushing style.**

## I. INTRODUCTION

RECENTLY, ubiquitous or pervasive healthcare [1] is recognized as a solution to the current crisis of healthcare industries, including skyrocketing costs, a growing incidents of medical errors, and lack of coverage in rural and underserved urban areas. Now, most healthcare industries are under increasing pressure to provide better service to more people using limited financial and human resources. Regarding this trends in healthcare industries, healthcare technologies is now evolving to reduce long-term healthcare costs and improve quality of life [2].

Generally, it would be economical and beneficial to our community if we could prevent form getting in worse conditions in early stage. Then, it would reduce healthcare costs and provide healthy life. Among various diseases depending on life-style, dental health is one of such diseases which requiring preventive methods and techniques. Cavities, generally occurs as a result of tooth decay. Tooth decay occurs when foods containing carbohydrates such as breads, cereals, milk, soda, fruits, cakes, or candy are left on the tooth. In order to prevent tooth decay, dentists suggested brushing one's teeth at least twice a day, especially after each meal and before going to bed. So, it's a generally good idea to get in the habit of brushing one's teeth as soon as they emerge. But sometimes, even in adults, bad brushing style causes some dental problems. There have been many convenient and automatic electronic toothbrushes in the market. But now, there are some skeptical points regarding efficacy and safety of electronic toothbrushes [3]. Recent investigation regarding tooth brushing forces [4-8] did not provide effective and qualitative ways of evaluating brushing styles such as motion of brush and minimum duration of brushing, and so on. So, with the help of modern surface-mounted microelectronics technology, we could implement a miniaturized toothbrush monitoring system which is capable of tracing brush movement and location through the grip axis in order to improve dental health (Fig.1).

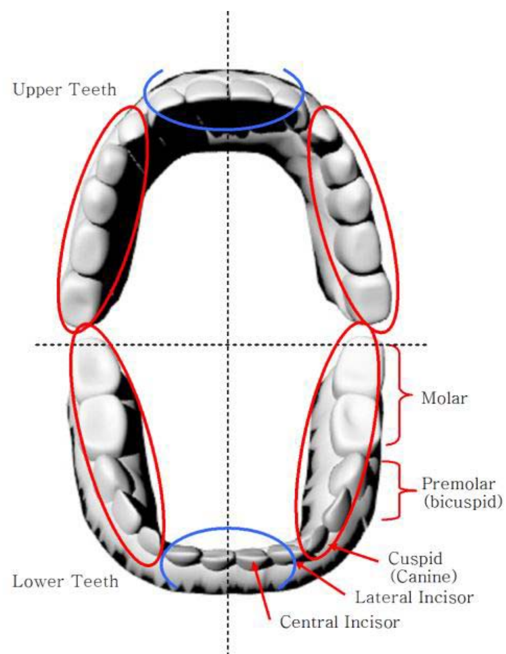


Fig.1. Permanent teeth of dental arch, looking into a person's mouth with the jaws open. Four wisdom teeth are omitted. Adult humans have 32 teeth (including wisdom teeth) evenly distributed across the quadrants.

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## II. IMPLEMENTATION OF A SMART TOOTHBRUSH

### *A. Direction and Position of Toothbrush*

Orientation of toothbrush could be measured by magnetic field sensors. Candidate sensor which we considered was anisotropic magnetoresistive (AMR) sensor. The AMR sensor is one type that lends itself well to the earth's magnetic field sensing range. AMR sensors can sense dc static fields as well as the strength and direction of the field. For AMR sensors, the sensor resistive elements are oriented as a resistive "wheastone bridge" that varies resistance slightly as the magnetic field changes upon each element. By integrating AMR sensor into smart toothbrush prototype, as toothbrush moves around tooth, directional information of toothbrush relative to the earth's magnetic pole could be obtained.

When brushing teeth, one of important factors affecting the dental health is the duration of brushing which means how long a bristle stays at a certain location of teeth. In order to recognize a duration time, we need to know in which parts of teeth, a bristle is located while brushing. This information is obtained using orientation of toothbrush. Also, it is possible to measure inclination of toothbrush with respect to ground plane using accelerometer sensors which are easily available in the market. But these kinds of sensors based on micro-electro-mechanical systems (MEMS) could not differentiate when brush is upside-down. In order to overcome this drawback, we added one more magnetic axis in z direction.

### *B. Motion of Toothbrush and Telemetry System*

Back and forth movements of bristle were measured by 3-axis accelerometer (MMA7260, Freescale, TX). The sensitivity of accelerometer is set to 800 mV/g, empirically. Because of small-package size (6mm x 6mm x 1.45mm; QFN-16) and low power consumption, smart toothbrush prototype could be powered by a single 3V coin-cell battery.

Various movements comprising rotation of toothbrush through the bristle axis were measured by piezoelectric vibrating gyroscope (ENC-03MA, maximum angular velocity: ±300 deg./sec., Murata, Japan). Another gyroscope to monitor extra angular motion was integrated through x-axis as shown in Fig. 3.

Regarding direction of toothbrush, as we have mentioned in the previous section, we used magnetic sensor based on AMR. There are several types of magnetic sensors, fluxgate, magnetoresistive, and magnetoinductive. A common type of magnetic sensor for navigation system is the fluxgate sensor. But, this sensor tends to be bulky, somewhat fragile, and have a slow response time, 2~3 seconds. AMR based sensor (HMC1055, Honeywell, MN) has a well defined axis of sensitivity and is massively produced in a small solid state package, and has a response time less than 1 μs.

Fig.2 shows the system configuration of the smart toothbrush prototype and Fig. 3 indicates sensor coordinates there by integrating 3 different types of inertia sensors, accelerometer, magnetic sensor, and gyroscope. The main specifications of the smart toothbrush prototype are summarized in Table I.

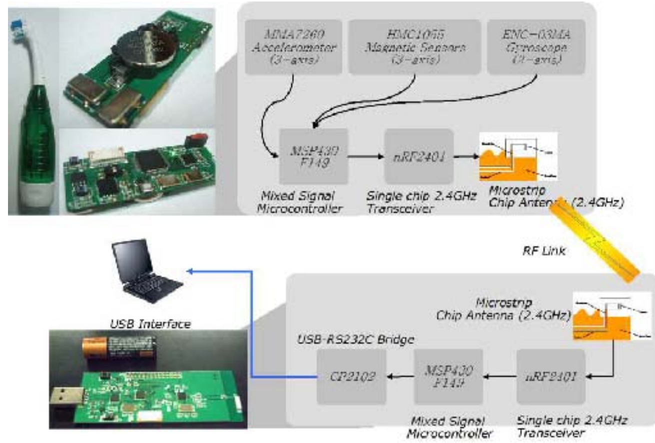


Fig.2. System configuration of the smart toothbrush prototype.

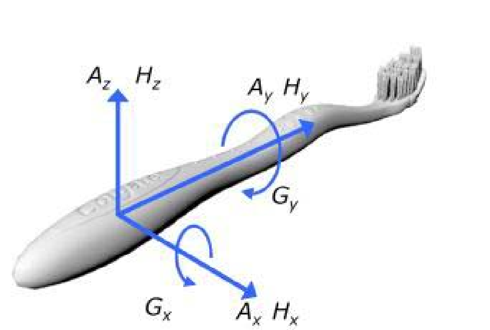


Fig.3. Sensor coordinates of the smart toothbrush prototype.

Table I. Specification of the smart toothbrush prototype.

| | | Specification |
|---|---|---|
| Degree of Freedom (DOF) | | 8 |
| Accelerometer (MMA7260, Freescale) | | 3-axis (800 mV/g) |
| Gyroscope (ENC-03MA, Murata) | | 2-axis (± 300 deg./sec.) |
| Magnetic Sensor (HMC1055) | | 3-axis ( 1.0 mV/V/gauss) |
| A/D converter (embedded with MSP430F149) | Resolution | 12 bits |
| | Sampling rate | 50Hz |
| Wireless Comm. (nRF2401, Nordic, Norway) | Carrier Freq. | 2.4 GHz |
| | Modulation | GFSK |
| | Date Tx/Rx rate | 1Mbps (Shock-Burst) |
| Power | Battery-powered | Coin cell (3.3V) |
| Physical Characteristics | Size (W x H x D) | 25x160x25,mm |
| | Weight | 50 g |
| Current consumption | | < 5 mA at 3.3V |

## III. RESULTS

Fig. 4 shows output of magnetic sensors integrated in the smart toothbrush as rotating horizontally in the earth's magnetic field. Output of two orthogonal magnetic sensors rotated horizontally in the earth's magnetic field showing Sine and Cosine relationships. A minimum of two magnetic sensors arranged mutually perpendicular would eliminate the ambiguity in electrical output with respect to heading direction as seen in Fig. 4. These 90°phase-shifted signals can be used to calculate the heading direction of a toothbrush, even though the heading direction in an absolute sense is unknown.

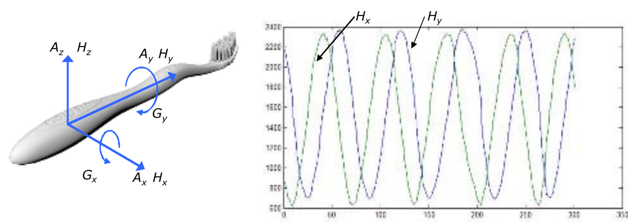


Fig.4. 360°sensing waveform of smart toothbrush. x-axis is sample number and y-axis is arbitrary AD values. Z-axis is rotating axis.

With the relative directional information with respect to the earth's magnetic dipole, we speculated the necessity of gyros which provides angular movement information of a bristle. Fig. 5 and 6 shows signal traces of angular movement through x-axis and y-axis. Angular movement of toothbrush is clearly shown in $G_x$ and $G_y$. Also changes of magnetic field in y-axis and z-axis (in Fig. 5), x-axis and y-axis (in Fig.6) could be observed.

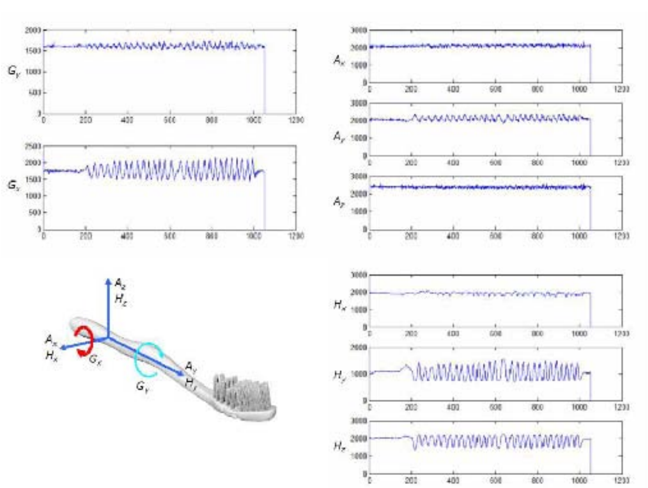


Fig.5. Simulated angular movement on x-axis and signals traces. X-axis is sample number and y-axis is arbitrary AD value.

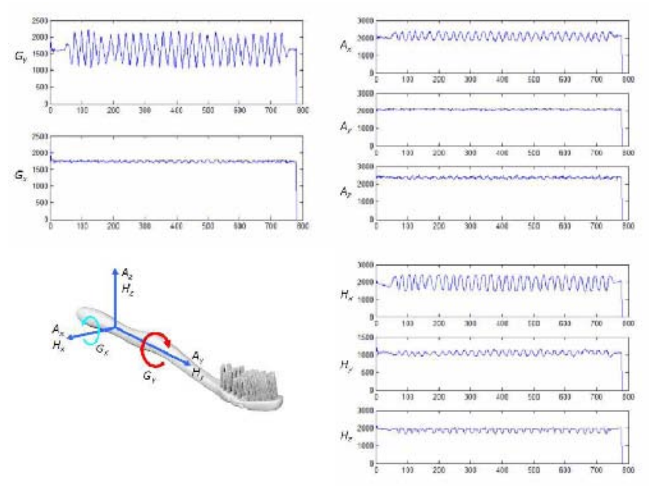


Fig.6. Simulated angular movement on y-axis and signals traces. X-axis is sample number and y-axis is arbitrary AD value.

Fig. 7 shows output waveforms of accelerometer and magnetic sensor during restricted motion of brushing upper and lower left molars. A DC component of accelerometer also provides information regarding inclination of toothbrush. Especially, in z-axis, accelerometer and magnetic sensor provide same information about direction of the bristle, upward or downward positions. But, as shown in Fig. 8, it is difficult to recognize whether toothbrush is positioned in left side or right side of molar using only accelerometer output. If we considered output of magnetic sensors, we could clearly distinguish whether left side or right side of molar tooth is brushed. Also, if we extend this directional information to all position of toothbrush, we could recognize direction and position information of toothbrush while brushing.

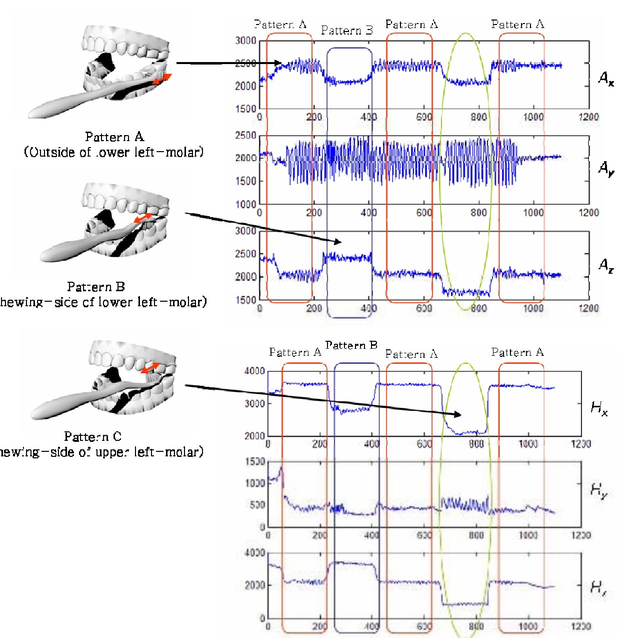


Fig.7. Accelerometer and magnetic sensor signal traces during simulated brushing of left-molar. Back-and-forth movement of the bristle is performed. X-axis is sample number and y-axis is arbitrary AD value.

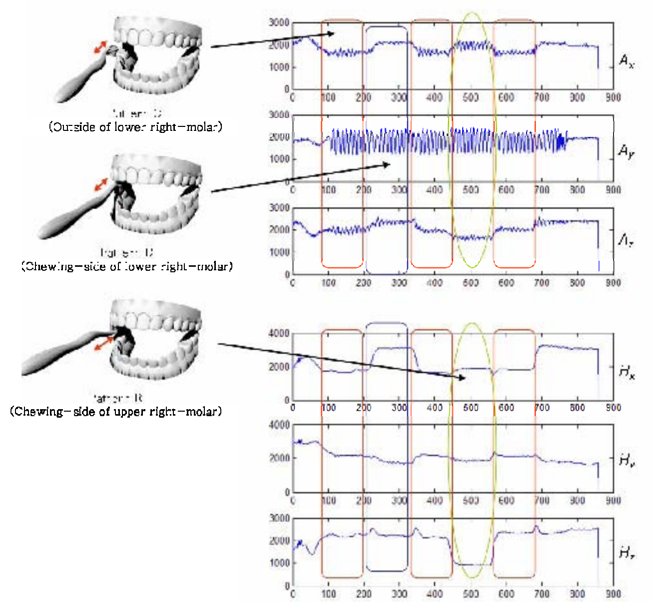


Fig.8. Accelerometer and magnetic sensor signal traces during simulated brushing of right-molar. Back-and-forth movement of the bristle is performed. X-axis is sample number and y-axis is arbitrary AD value

## IV. DISCUSSION

From this preliminary study, we could found the followings: (i) the relationship between angular movements and orientation of toothbrush is highly correlated with each others, we did not need to take gyro sensors into the smart toothbrush system. (ii) the orientation of toothbrush provides more distinguishable direction and position information of toothbrush, so we could devise more efficient and reliable position tracking algorithms for evaluating quality of toothbrushing.

But, there are many problems and issues to be solved, calibration of each sensor, clinical implication of toothbrush position, clinical field test, and so on. Also, in order to provide persuasive motives for modification of one's life-style, we must consider more user-orientated, condensable feedback information during daily life. So, we believe that preventing chronic disease in early stages by certain form of daily checkup is an efficient and economical way of reducing medical costs, and there by, realization of ubiquitous or pervasive healthcare in our daily life could be advanced.

## REFERENCES

[1] U. Varshney, "Pervasive Healthcare," *IEEE Computer*, vol.36, no.12, pp.138-140, Dec. 2003.

[2] P. Bonato, "Wearable Sensors/Systems and their impact on biomedical engineering," *IEEE Engineering in Medicine and Biology Magazine,* vol.22, no.3, pp. 18–20, May/June 2003.

[3] M.J. Cronin, W.Z. Dembling, M.A. Cugini, M.C. Thompson, and P.R. Warren, "Three-month assessment of safety and efficacy of two electric toothbrushes," J. Dentistry, vol.33, Suppl.1, pp.23-28, 2005.

[4] S.L. Yankel, and R.C. Emling, "Laboratory interproximal access efficacy comparison of bi-level and flat bristled toothbrushes," *J. Clinical Dentistry*, vol.4, no.4, pp. 128~130, 1994.

[5] D.W. Volpenhein, M.E. Walsh, P.A. Dellerman, and T.A. Burkett, "A new method for in-vitro evaluation of the interproximal penetration of manual toothbrushes," *J. Clinical Dentistry*, vol.5, no.1, pp.27-33, 1994.

[6] H.R. Rawls, D.L. Lentz, G.W. Cobb, M.S. Bailey, J. Spencer, D.A. Williams, D. Walley, and J. Vidra, "Interproximal penetration of commercial toothbrushes as determined by static and dynamic tests using recommended brushing techniques," *J. Clinical Dentistry*, vol.4, pp.88-95, 1993.

[7] C.R. Allen, I.C. Leggett, and I.D.M. Macgregor, "Remote measurement of in-vivo toothbrushing forces as a clinical tool for dental hygenine purposes," in *Proc IEEE Instrumentation and Measurement Technology Conf.*, Minnesota, 1998, pp.854-857

[8] C.R. Allen, N.K. Hunsley, and I.D.M. Macgregor, "Development of a force-sensing toothbrush instrument using PIC micro-controller technology for dental hygiene," *Mechatronics*, vol.6, no.2, pp.125-140, 1996.

[9] C. Poche, H. McCubbrey, and T. Munn, "The development of correct toothbrushing technique in preschool children," *J. Appl. Behav. Anal.*, vol.15, no.2, pp.315-320, 1982.