Hands-free man-machine interface device using tooth-touch sound for disabled persons

K Kuzume and T Morimoto

Department of Information Engineering, Yuge National College of Technology
1000 Yuge, Kamishima-cho, Ochi-gun, Ehime Ken, JAPAN

kuzume@info.yuge.ac.jp, ap05007@yuge.ac.jp

ABSTRACT

This paper presents the realization of a hands-free man-machine interface using tooth-touch sound. The proposed device has several advantages, including low price, ease of handling, and reliability. It may be used as an Environmental Control System (ECS) and communication aid for disabled persons. We analyzed the characteristics of the tooth-touch sound, obtained using a bone conduction microphone. We then designed the device using VHDL (Hardware Description Language) and a simulation of the FPGA (Field Programmable Device) in practice. We applied our device to the ECS to demonstrate its usefulness and evaluate its performance. The results confirmed that the proposed device had superior features to comparable devices, such as those utilizing voice control or eye blinks, chin operated control sticks, mouth sticks, or a brain computer interface (BCI) for severely disable persons.

1. INTRODUCTION

Severely disabled persons have proven to be at risk of negative life indicators, such as a high risk of depression and anxiety (P. MacIsaac, Ashley Craing, et. al. 2002). Effective aids are necessary to improve their quality of life and lower risks. Viable therapies include psychological, medical or pharmacological, physical and occupational therapies. None-the-less, reducing dependency is a desirable move towards improving the quality of life of the disabled. This may be achieved through the development of technological aids to enhance their ability to control devices in the environment.

Environmental Control Systems (ECS) enable disabled persons to activate and control their environment. ECS devices should improve the quality of life for disabled persons and lessen the burden on helpers. In the last ten years, thanks to progress in information technology, many types of ECS devices have been developed. Some resemble the remote control units used with television sets, making use of finger movements for operation. Unfortunately, many disabled persons have limited or no such control from the neck down. A number of devices have been developed to meet the needs of the severely disabled. These include devices utilizing suck-puff techniques, voice control, eye blinks, chin operated control sticks and mouth sticks (M. P. Barnes 1994).

In recent years, a new ECS, called the Mind Switch (MS), has been developed. It makes use of variations in the electroencephalograph (EEG) patterns formed when people intend to control the environment. The MS is mounted in a plastic housing and attached to a moisture repellent cap. To make contact with the head, commercially available electrode gel or paste is used. The disabled must spend considerable time learning how to control their EEG in order to communicate or activate devices (A. Craing, P. MaIsaac, et. al. 1997). Moreover, as the EEG signal is very small, the amplitude is easily disrupted by background noises. As such, sophisticated noise suppression techniques are necessary. (L. Kirkup, A. Searle, A. Craig, et. al. 1997)

In this paper, we propose a "hands-free man-machine interface device utilizing the tooth-touch sound". The tooth-touch sound signal is detected by a bone conduction microphone, after which it can be easily processed. The proposed device is superior to conventional devices in the following ways:

- Low price
- Fitness
- Ease of handling
- Reliability

This paper is organized as follows. In Section 2, we analyze the characteristics of tooth-touch sounds. Section 3 is devoted to design of the interface's device architecture and evaluation of its performance through computer simulation. Section 4 applies our device in the environmental control system of disabled persons. Section 5 outlines our conclusions and potential development.

2. ANALYSIS OF TOOTH-TOUCH SOUND SIGNAL

2.1 Measurement of the tooth-touch sound signal

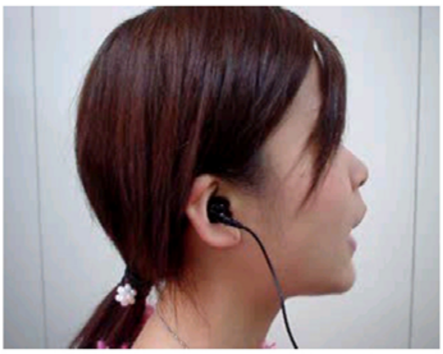
We used a bone conduction microphone to collect the tooth-touch sound signal. The bone conduction microphone cords used a highly sensitive vibration sensor, to collect vibrations that reached the skull from the site of the tooth-touch and convert this vibratory motion into audio signals. These devices could be worn all over the head to pick up vibrations, provided they were mounted on a relatively solid section of the head. Two types of bone conduction microphone could be utilized: an "ear microphone" that picks up vibrations in the auditory canal or a headset that captures vibrations on the head. In this research, we adopted the ear microphone. The bone conduction microphone had several qualities, including excellent noise tolerance (not affected by external noise) and flexibility when fitting. Figure 1(a) shows the way in which the ear microphone was fitted. In our experiment, we utilized a two-way communication device, EM7B-06, as the bone conduction microphone, developed by Temco Japan Co. The sound signal resulting from the tooth-touch was collected by the bone conduction microphone and amplified prior to low pass filtering and AD conversion. The signal was sampled at 10 [KHz] and processed for realization of the ECS. Figure 1(b) shows an example of the tooth-touch sound signal.

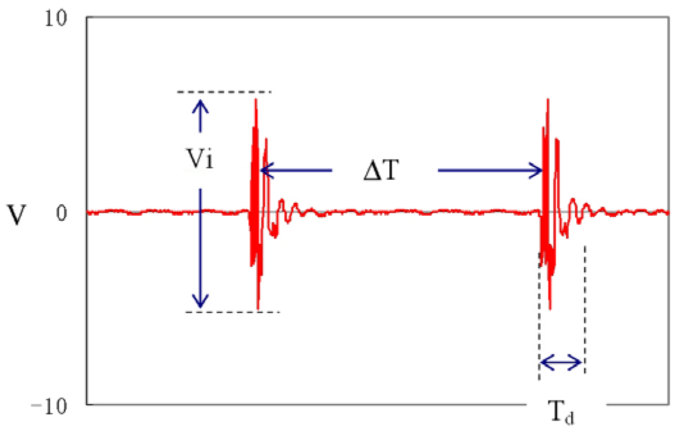
2.2 Characterization of tooth-touch sound signal

The characteristics of the tooth-touch sound signal varied between people. It was necessary to understand these characteristics in order to develop a man-machine interface using tooth-touch sound. In this section, we try to characterize the tooth-touch signal measured above. The characterization parameters shown in Figure 1(b) are defined as follows:

- Vi : Amplitude of tooth-touch sound
- Fc : Central frequency of tooth-touch sound using Fast Fourier Transform.
- T : The period between tooth-touch sound signals.
- T_d : Signal duration.

We collected the tooth-touch sound data from 17 adult volunteers aged 20 years old (9 males and 8 females). We asked them to generate 5 successive tooth-touch sounds in as consistent an interval as possible. Figure 1(b) shows an example of the tooth-sound signal. Table 1 summarizes the analyzed results of the above-mentioned characteristic parameters.





(a) *(b)*

Figure 1. *(a) Fitting the bone conduction microphone. (b) Example of measured tooth-touch sound signal.*

©2006 ICDVRAT/University of Reading, UK; ISBN 07 049 98 65 3

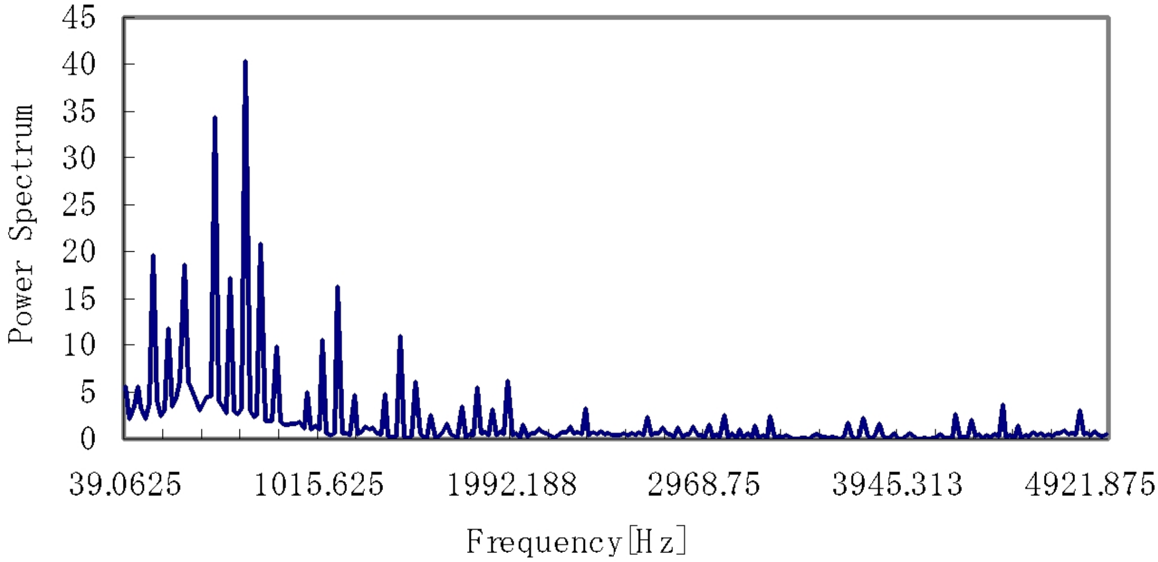


Figure 2. *Frequency spectrum of tooth-touch sound by FFT.*

The center frequency of the tooth-touch sound was about 600 [Hz] and its individual variation was very small. The duration of signals was less than 5 [msec]. It was, therefore, easy to process the signals and apply the data in controlling the ECS. Deviation in the amplitude and interval time of the 5 successive tooth-touch sounds was relatively small. In the next section, we outline how to learn about the mechanism involved in individuals' tooth-touch sound characteristics.

Table 1. *Resulting measurements of tooth-sound characteristics.*

Central Frequency Fc	Signal duration T_d	Deviation of tooth-sound amplitude Vi	Deviation of interval time between the tooth-touch sounds, ΔT
600 Hz	< 5msec	< 30%	< 20%

3. DEVICE ARCHITECTURE

In this section, we propose a learning method for individuals' characteristic tooth-touch sounds. We then present a voice elimination algorithm and results from its simulation. Finally, we realize a "hands-free man-machine interface using the tooth-touch sound" and an FPGA chip.

3.1 Learning the characteristics of the tooth-touch sound

The characteristics of the tooth-touch sound have individual variations and vary with time, as shown in Section 2. To manage such variation, a device must learn and memorize changes. We proposed the learning algorithm as shown in Figure 3.5. Successive tooth-touch sounds, called "preamble code," were added prior to inputting the control code. In this example, the control code was [1101], which contained one start-bit "1" (the MSB of the control code) and one stop-bit "1" (the LSB of the control code). The mark, when the signal existed, was represented by "1". The space, when the signal did not exist, was represented by "0". Using the preamble code, the average amplitude (Va) and average period between signals (Ta) were calculated and stored in the memory, called the tooth-touch sound database unit. Setting the proper threshold levels for Va and Ta enabled us to distinguish the mark signal "1" and the space signal "0" from the tooth-touch sound signal. This learning process should be executed every time a user begins using the interface device and be updated, to adapt to changes in the user's physical conditions.

3.2 Voice elimination algorithm

Several kinds of noise, such as voice and ham noise, interfered with tooth-touch sound detection, the most serious being voice noise. The bone conduction microphone picked up not only the tooth-touch sound, but also the user's voice. Development of the voice elimination method was required to eliminate faults

©2006 ICDVRAT/University of Reading, UK; ISBN 07 049 98 65 3

originating from background noise. Figure 4 depicts the signal containing both the voice and tooth-touch sound. The tooth-touch sound and voice were rarely generated at the same time. The tooth touch sound clearly resembled an impulse signal, having higher frequency components comparing with the voice signal and a distinct pattern. The voice eliminating method involved calculating the average of the absolute value of the signal. The average time was about 10 times longer than the duration of the tooth touch sound (from section 2 we set the time to 50 [msec]). Next, a threshold level to detect only tooth-touch signals had to be set. If the signal was larger than the threshold level, it could be regarded as the tooth-touch sound. The threshold level was set at a value ten times higher than the average of the voice signal.

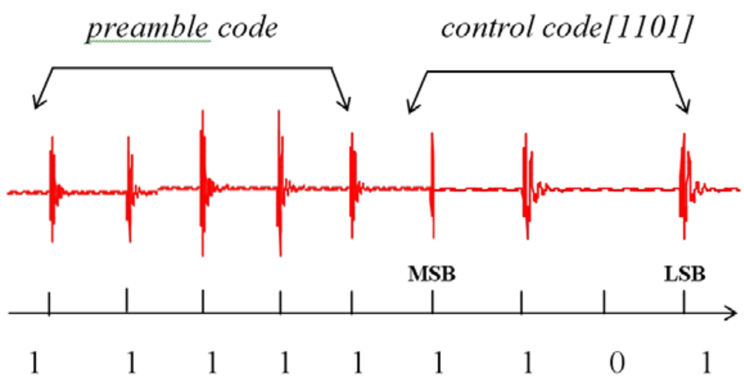


Figure 3. *Composition of preamble and control codes.*

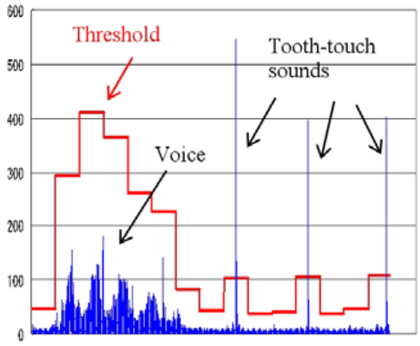


Figure 4. *Voice elimination.*

3.3 Realization of man-machine interface using an FPGA chip

Figure 5 shows the FPGA based man-machine interface, with the above mentioned functions. The FPGA chip was operated at 3v-D.C. The tooth-touch sound detector and voice elimination unit eliminated noise from the digitized signal, leaving only the tooth-touch sound signal. The function of the learning unit was to learn and store characteristic parameters of individual's tooth-touch sound signals in the tooth-touch sound database. From the succession of tooth-touch sound signals in the database, the control codes for the ECS were generated and outputted from the chip.

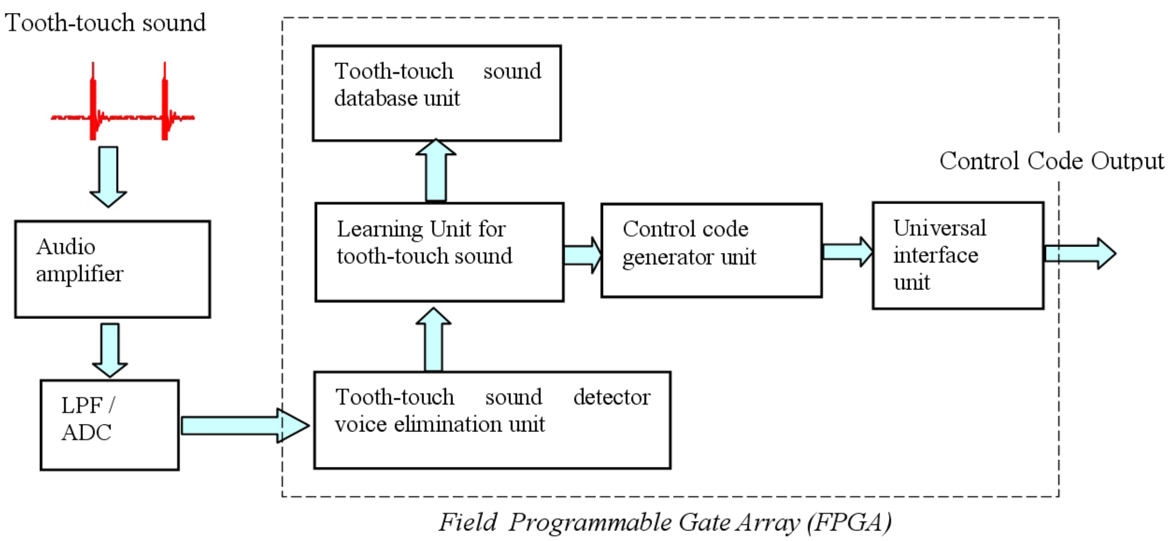


Figure 5. *Schematic diagram of an interface using tooth-touch sound.*

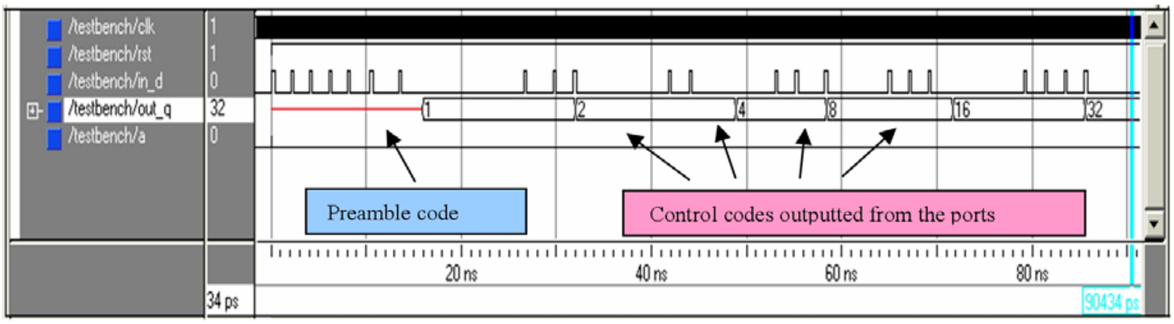


Figure 6. *Simulation result.*

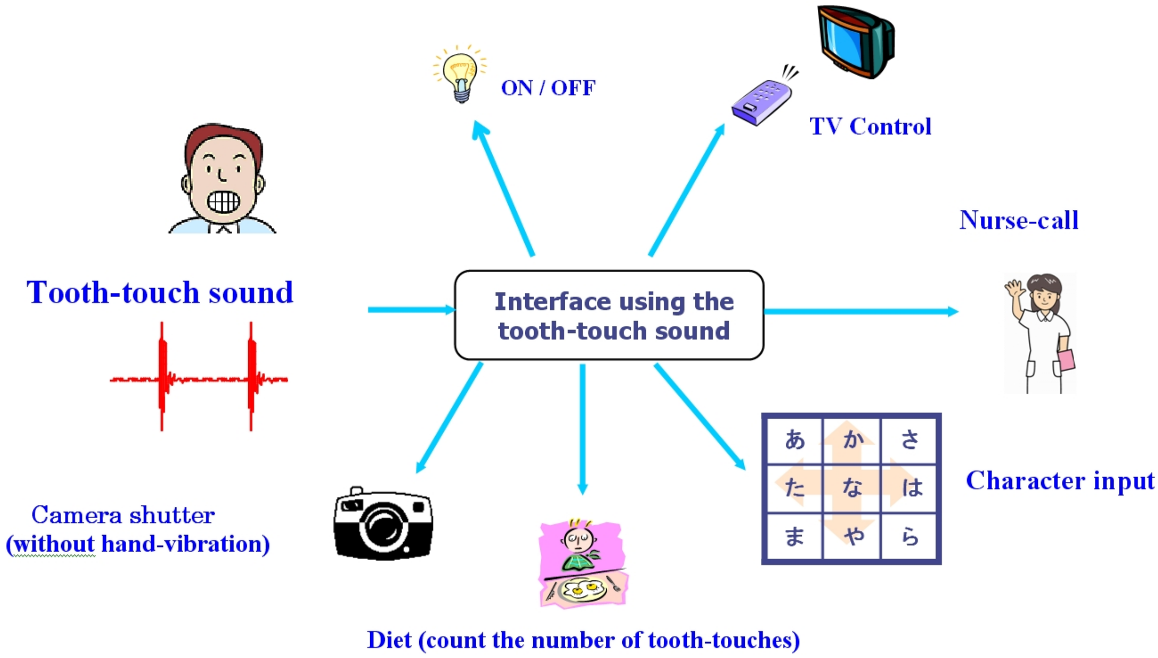


Figure 7. *Various applications of an interface using tooth-touch sound.*

3.4 Simulation results

To confirm the effectiveness of our system, we executed a timing simulation using logic simulation software, ModelSim. Figure 6 depicts the results of this timing simulation. The preamble code (5-successive pulses) and the following control code can be observed. The system could operate properly.

4. APPLICATIONS

A hand-free type, man-machine interface using tooth-touch sound, has several applications, as depicted in Figure 7. One obvious application is in an ECS, used to control consumer electronic appliances or to call a nurse in a hospital. Another type of application is as a character input device for communication aids.

In this research, we demonstrated a simple example of an ECS in which the interface was used to control an electric fan. We chose an electric fan because it could easily be controlled with only a few codes. Figure 8 shows an example having a 4-output control code system. Prior to inputting the control codes, users generated a preamble code consisting of the 5-successive tooth-touch sounds. This was to enable the device to learn the individual’s characteristic tooth-touch sounds.

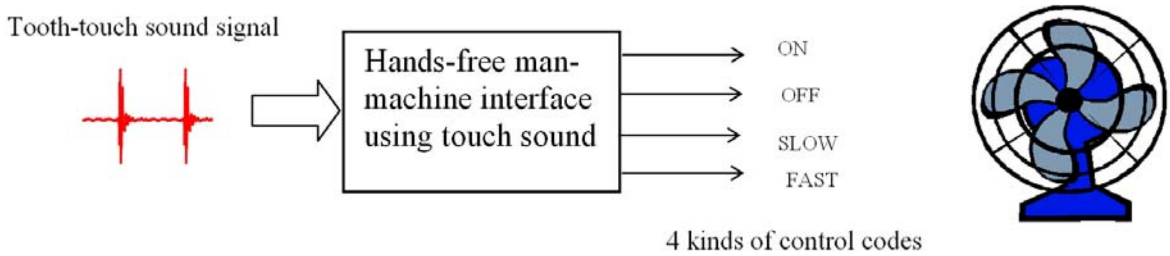


Figure 8. *Example of Simple ECS.*

5. CONCLUSIONS AND POTENTIAL IMPROVEMENTS

In this paper, we proposed a "hands-free man-machine interface device using tooth-touch sound". This device, which consisted of a bone conduction microphone, an audio amplifier, and an FPGA chip, had several advantages over existing technologies, including low cost and ease of handling. We analyzed the characteristics of the tooth-touch sound and showed that the tooth-touch sound was suitable for application in an ECS as a control signal. We then developed a learning method to allow for individual variations and a noise suppression algorithm. Parameters defining the amplitude and average time period between tooth-touch sound signals were used in the learning method. We tested our circuits using VHDL and developed a working FPGA chip. The prototype device was evaluated as an ECS, with the following shortcomings awaiting resolution: (1) insufficient suppression of noise caused by body movement, (2) extension of the device to other applications, (3) detailed evaluation of its usefulness for disabled persons.

6. REFERENCES

P. MacIsaac, A. Craing et. al. (2002), The mind switch environmental control system: Remote hands free control for the severely disabled, Technology and Disability 14, IOS Press, pp. 15-20.

D. J. Welling and J. Unsworth (1997), Fortnightly review: Environmental control systems for people with a disability: an update, British Medical Journal 315, pp. 409-412.

M. P. Barnes (1994), Switching devices and independence of disabled people, British Medical Journal 309 pp. 1181-1182.

A. Crag, P. MaIsaac et.al. (1997), Mind over matter: Brain signals and control of electrical devices, Today's Life Science 9, pp. 12-15.

L. Kirkup, A. Searle, A. Craig et. al. (1997), EEG system for rapid on-off switching without prior learning, Medical and Biological Engineering and Computing 35 pp. 504-509.