TOOTH-TOUCH SOUND AND EXPIRATION SIGNAL DETECTION AND ITS APPLICATION IN A MOUSE INTERFACE DEVICE FOR DISABLED PERSONS

Realization of a Mouse Interface Device Driven by Biomedical Signals

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Abstract: Presented is a mouse interface device for disabled persons using tooth-touch sound and expiration signals. It enables disabled persons to operate a personal computer easily using a mouse driven by their tooth-touch and expiration. A bone conduction microphone was used to detect the tooth-touch sound and the piezo film sensors to sense the expiration. Both sensors had superior features including being easy to handle, light weight, user-friendly, and inexpensive making the device practical as a mouse interface for disabled persons. First, we describe the novel method for detecting the tooth-touch sound in conjunction with Dyadic Wavelet Transform to improve the performance of tooth-touch sound detection. The device consists of sensor units that can sense the tooth-touch sound and the expiration signals, an individual adaptive circuit, and an output interface to connect directly with a mouse and Environmental Control System (ECS). Next, we designed the device using Hardware Description Language (VHDL) and realized a prototype of mouse interface with a Field Programmable Gate Array (FPGA) in practice. Finally, we confirmed the basic operation of the mouse.

1 INTRODUCTION

Thanks to advances in electronics and information technology, everybody can use a personal computer easily. This includes disabled persons who are interested in using the Internet and multimedia. A mouse is usually used as a computer interface to select the icons on a display and execute program by clicking the mouse button. As a result, it has become essential for disabled persons to use a mouse. However, as hand operation is needed to control a mouse, disabled persons may not be able to use a mouse easily, making development of alternative input devices necessary.

Several types of mouse for disabled persons have been devised. For example, Dimitry et. al. developed a mouse device using vision-based technology (Dimitry, 2004). The mouse cursor position could be controlled by multiple eye blinks and nose movement used for clicking operations. However, it was sensitive to external disturbance such as the brightness of the room and users' movement.

Recently, we proposed a hands-free man-machine interface device, utilizing the expiration in conjunction with the tooth-touch sound signal, which we have been researching for realization (K. Kuzume, 2006, 2008, 2010). This device utilized the bone conduction signal collected by a bone-conduction microphone, which is utilized for clicking operation of the mouse and the expiration signal gathered by piezo-film sensors to control the mouse cursor position. The proposed device met conditions required by disabled persons namely low price, fitness, and ease of handling. We constructed a prototype device and tested its usefulness as an input device for a character input system (K. Kuzume, 2008). However, there are some remained problems with issues, such as the reliability of the input operation by the tooth-touch sound signal and the realization of the other applications, such as in an ECS with better usability by means of our input device. In practical application, since the amplitude of the tooth-touch sound signal varies between people, detecting even small signals as accurately as possible is required along with elimination of the voice signal. The input operation for the disabled

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persons to control the ECS smoothly is desired to be as intuitive as possible.

In this paper, we propose a novel method for eliminating the voice and white noise suppression by dyadic wavelet transform in conjunction with the signal adaptive threshold technique and show that our method has excellent performance. Next, to improve the usability of the input device, we modified the control method to adjust the mouse cursor position more intuitively, adapting to the amplitude of the expiration signal. Finally, we designed the tooth-touch sound and the expiration-based mouse device system using VHDL and realized the system on an FPGA chip in practice.

This paper is organized as follows: In section 2, we detailed the novel method for detecting the tooth-touch sound using a dyadic wavelet based noise suppression method and review the expiration signal detection method briefly. In Section 3 we present the device architecture of a mouse driven by the tooth-touch sound and expiration signals. We are then devoted to the design of the mouse interface device and realization of it by an FPGA chip. In Section 4, we apply our device to control of mouse cursor position by expiration signal and confirmed its basic operation. Section 5 outlines our conclusions and potential development.

2 SIGNAL DETECTION

2.1 Review of Tooth Touch Sound Signal Detection Technique

Several kinds of noises, such as voice and ham noise, interfere with tooth-touch sound detection, the most serious being voice noise and white 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 is required to eliminate faults originating from background noise.

Our analysis on the tooth-touch sound signal has shown that the frequency spectrum of tooth-touch sound is overlapped with that of voice signal. Therefore it is difficult to detect only the tooth-touch sound in the measured signal by the conventional band pass filters. Moreover, the magnitude of the tooth-touch sound signal varies between people. If the amplitude of the tooth-touch sound signal is too small, it is necessary to amplify the signal. As results, the tooth-touch sound signal may be corrupted by white noise.

In this section, we propose the novel method for eliminating voice signal, which is very simple and easy to realize by simple circuit. Moreover, we also present dyadic wavelet transform for the white noise suppression.

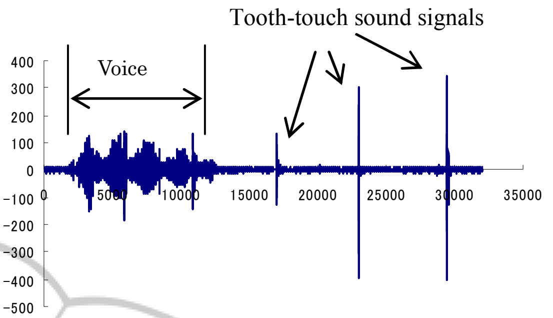


Figure 1: The bone-conduction signal containing voice, tooth-touch sound, and white noise.

2.1.1 Voice Elimination Method

Figure 1 shows 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.

We depict the distribution of the amplitude of the voice signal in Figure 2(a) and also distribution of its absolute value in Figure 2(b). According the previous researches on the voice signal, it is known that its distribution function follows to normal distribution. The statistics theory tells that in the normal distribution function, sampled data without $\bar{x} \pm 8\sigma$ occupies less than $6.7\times10^{-14}[\%]$, where $\bar{x}$ is average value of the voice signal and σ is standard deviation of the distribution shown in Figure 2(a). Now we set a threshold level adapting to the signal for eliminating the voice signal. If the threshold level set to 8σ, most of the voice signal can be eliminated. However, to compute the standard deviation, multipliers circuits and a large amount of computation are needed. We surveyed the relationship between the standard deviation σ and the average $\bar{\mu}$ of the absolute value of the voice signal. We then confirmed there is nearly linear relationship between them in (1).

$$\sigma \cong 1.5\bar{\mu} \qquad (1)$$

By using (1), we can easily calculate the standard deviation by the average value of the absolute value. In the actual system we choose sampling frequency at 4 KHz, and average interval time T in 0.128sec (512 samples), then $\overline{\mu}$ is calculated by (2),

$$\overline{\mu} = \frac{\sum_{i=0}^{511} |V_i|}{512} \tag{2}$$

where V_i denotes the bone-conduction signal at the time i .

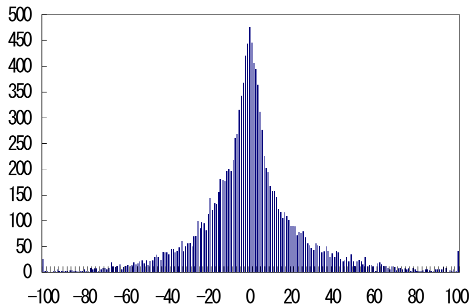
Now, if we set the threshold level to 8σ, we can get the following equation (3).

$$V_{th} = 8\sigma \cong 8 \times 1.5\overline{\mu} = 12\overline{\mu} \tag{3}$$

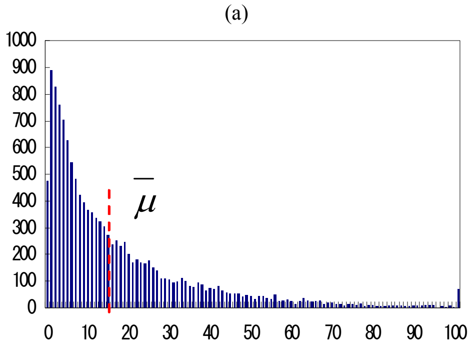
Considering the margin and simple calculation, we set V_{th} to $16\overline{\mu}$, finally signal adaptive threshold level can be given by (4).

$$V_{th} = \sum_{i=0}^{2^{9-1}} |V_i| \times 2^{-5} \tag{4}$$

The threshold level can be obtained by calculating sum of 2^9 samples and then shifting the sum by 5-bit toward to the right. Figure 3 (a), (b) show the threshold level and the result of the tooth-touch sound signal detection by computer simulations. The simulation results show that the only the tooth-touch sound signals can be detected correctly.

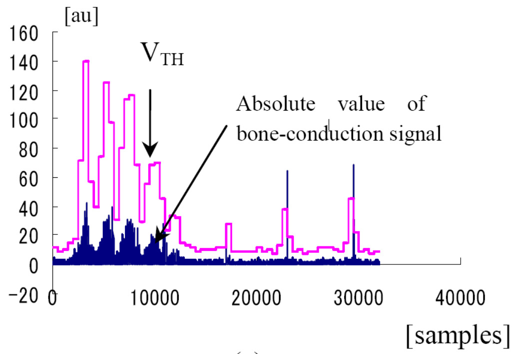


(a)

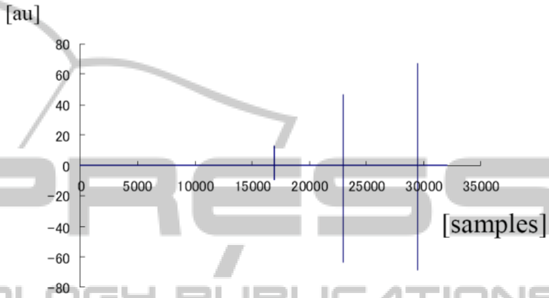


(b)

Figure 2: (a) Distribution of the amplitude of the voice signal. (b) Distribution of the absolute value of Figure 2 (a).



(a)



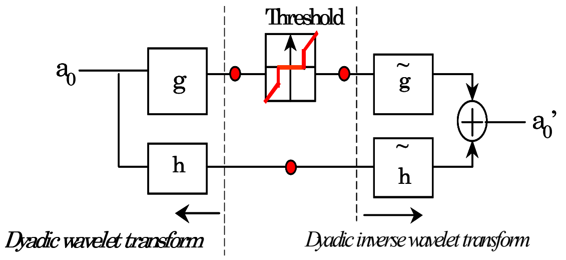
(b)

Figure 3: (a) Signal adaptive threshold (b) Result of tooth-touch sound signal detection.

2.1.2 White Noise Suppression by the DWT

The magnitude of the tooth-touch sound signal varied with individual characteristics, including age, sex, and continuous operating time. It was necessary for the system to detect even small tooth-touch sounds as accurately as possible. When the amplitude of the tooth-touch sound matched that of the white noise, the bone conduction signal needed to be amplified. White noise made it difficult to detect the tooth-touch sounds signal correctly using the earlier method in 2.1.1. Figure 4 shows a block diagram of the DWT, threshold processing, and inverse dyadic wavelet transform. It was desirable for filter length to be as short as possible to reduce computation time. We employed the Haar wavelet filter, with a filter length of 2.The threshold level can be set shown in (5), where σ^2 is deviation of the white noise and N is the number of data (D.L.Donoho,1995). The lowpass decomposition signals within $\pm V_{TH}$ can be regarded as the white noise and be set to zero. As the results of this signal processing the white noise could be suppressed and tooth-touch sound signal is remained.

$$V_{TH} = \sqrt{\sigma^2 2\log_e N} \tag{5}$$



a_0 : Bone conduction signal (original signal)

a_0' : Denoised signal,

g : Highpass decomposition filter,

$\tilde{g}$: Highpass reconstruction filter,

h : Lowpass decomposition filter,

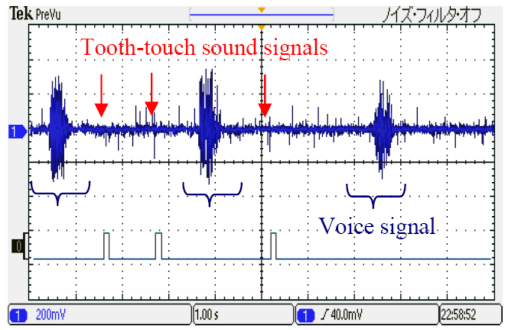
$\tilde{h}$: Lowpass reconstruction filer.

Figure 4: White noise suppression by the dyadic wavelet transform.

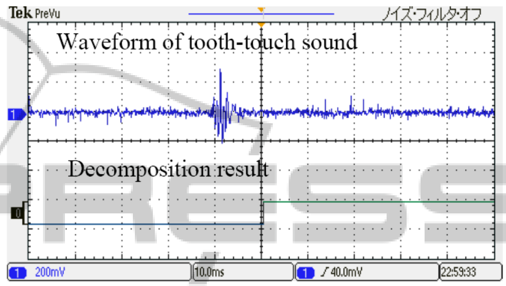
Figure 5 shows the FPGA-based tooth-touch sound detector with the above-mentioned noise suppression functions. The tooth-touch sound detector contains the white noise suppression and voice elimination unit, outputting pulse signal at the time, when only the tooth-touch sound signals are input as shown in Figure 6. And also, even the small tooth-touch sounds can be detected.

2.1.3 Evaluation of Detection Performance

To evaluate the effectiveness of white noise suppression by the DWT, we implemented practical use test. We asked 4 persons (healthy, 20 year-old males) to touch their teeth together 50 times. The duration and strength were arbitrary. All tooth-touch sound signals were stored by a data recorder. Using the recorded data, we compared detection accuracy between non-white noise suppression and white noise suppression. Table 1 shows the experimental results of performance of tooth-touch sound signal detection based on the experimental results. The results show that the number of positive faults decreased and detection performance was improved.



(a)



(b)

Figure 6: (a) Result of the tooth-touch sound signal detection from the bone-conduction signal corrupted by the voice signal, (b) Tooth-touch sound signal detailing.

Table 1: Comparison of detection performance.

	Error Detection Ratio (in case of not using DWT)		Error Detection Ratio (in case of using DWT)	
User	Positive Fault	Negative Fault	Positive Fault	Negative Fault
A	6%	2%	2%	2%
B	8%	2%	2%	2%
C	4%	4%	0%	2%
D	2%	0%	0%	0%

2.2 Review of Expiration Signal Detection by Piezo Film Sensors

The details of the expiration signal detection were described in our previous paper (K. Kuzume, 2010).

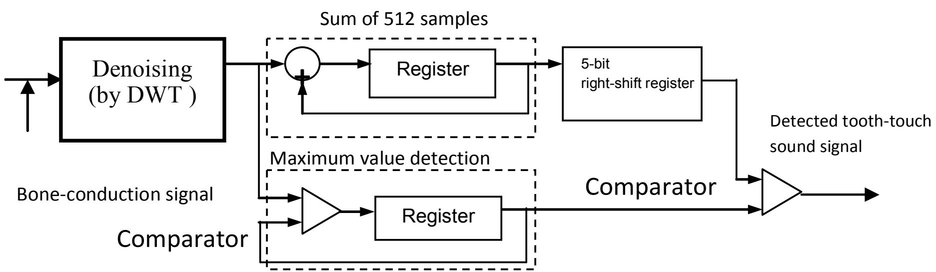
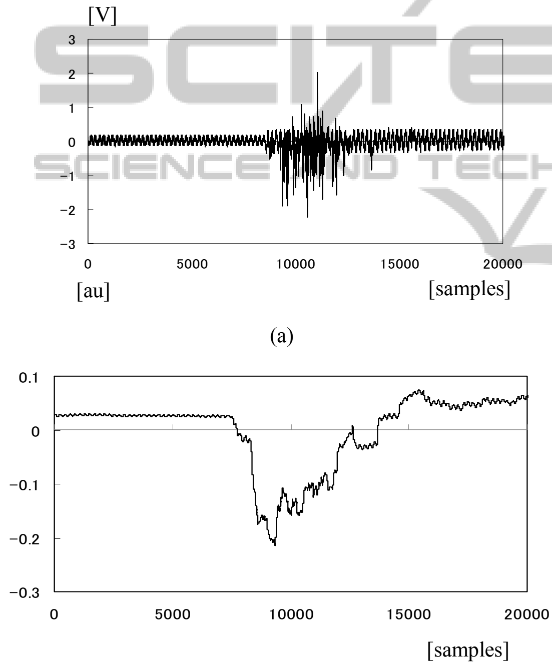


Figure 5: Circuit diagram for detecting the tooth-touch sound signal.

We review it briefly in this section.

We set the piezo film sensors in the form of a sensor array to detect the expiration signal. The film had an area of about $13 \times 25mm^2$, suitable hardness to sense the expiration and weighed less than 1g (http//:www.t-sensor.co.jp). To detect the user's direction of expiration, three piezo film sensors were set about 6cm from the user's mouth, to the left, center and right. Each sensor had two functions, one being to detect the piezoelectric signal (vibration), and the other to sense the pyroelectric signal (temperature variation). A user fitted with 3-ch piezo film sensors to detect the expiration signals from three directions, right, center, and left. Expiration could be accurately detected using both the piezoelectric and pyroelectric signals to reduce



(a)

(b)

Figure 7: (a) Vibration component (piezoelectric) (b) Temperature variation component (pyroelectric).

outside disturbance. This enabled us to dramatically improve input efficiency by changing the direction and duration of a user's expiration. It was necessary to accurately separate the piezoelectric and pyroelectric signals from the original. Here we present a novel method for signal separation. In addition to the expiration signal, the signal obtained by the sensors contained the DC offset and ham noise. Only after eliminating these noises by dyadic wavelet transform did we obtain the higher frequency component of the expiration signal. Figure 7 shows the waveform of vibration component and temperature variation component processed by the DWT. These figures show that the pyroelectric signal could be separated accurately from the original signal.

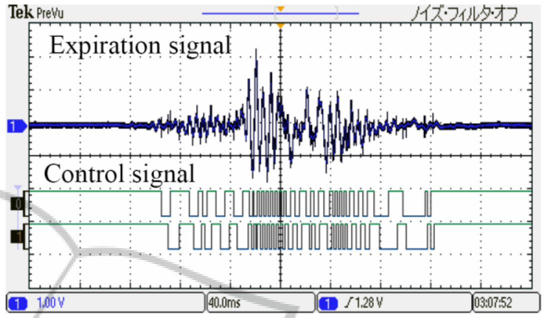


Figure 8: Example of the expiration signal and Control signals for moving the mouse cursor.

2.3 Control of Mouse Cursor Position by Expiration Signal

We connected the proposed device to a personal computer via a wheel-type mouse with a USB interface. Two pairs of signals, moving the mouse cursor in horizontal and vertical directions respectively, were generated in the FPGA chip. Figure 8 shows an example of the expiration signal and a pair of signals for moving the mouse cursor. The distance which a cursor is moved by the expiration signal is dependent upon the strength and duration of the expiration signal. When stronger expiration is applied to the sensor, the more pulses are output and as a result, the cursor moves quickly. The phase deference between pair signals is 90 degrees.

3 DEVICE ARCHITECTURE

Architecture of our device is shown in Figure 9. The device consists of a sensor unit, amplifiers, lowpass filter, individual adaptive circuit, and output interface for connecting with the ECS and a mouse driver circuit. The sensor unit contains piezo film sensors to detect the expiration and a bone conduction microphone for detection of the expiration and tooth-touch sound signals respectively and ADC (Analog to Digital Converter). The 3 piezo film sensors were set at the positions of right, center, and left sides far from a user's mouse to detect not only the directions of a user's expiration but also the temperature variations by the

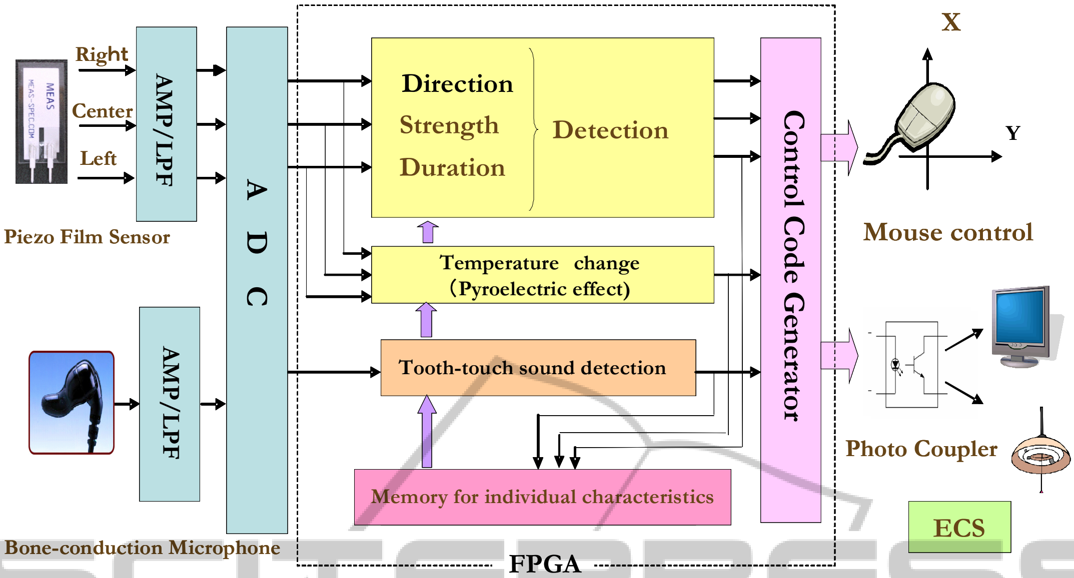


Figure 9: Schematic diagram of the tooth-touch sound and expiration based mouse interface.

pyroelectric effect. The mouse cursor position and its speed may be controlled by the expiration direction and the magnitude. Tooth-touch sound is utilized for clicking of the mouse. The individual adaptive circuit functions to learn the individual characteristics of users such as the magnitude of the expiration and tooth-touch sound and memorizes the variation between users. The main signal processing unit surrounding by a dotted line in this figure, is constructed on a FPGA chip, SPARTAN-3, produced by XILINX INC., which was operated at 3V-DC (www.xilinx.com).

4 APPLICATION AS MOUSE CURSOR POSITION CONTROLLOR

In this section we applied our device to a mouse controller called an “Expiration and tooth-touch sound based mouse”. Figure 10 shows a user fitting the bone conduction microphone for the tooth-touch sound and 3-ch piezo film sensors to detect the expiration signals from three directions, right, center, and left. We set two targets on a display to use in the pointing task experiment as shown in Figure 12(a). After clicking the target A by a tooth-touch, we moved a mouse cursor from the target A to target B by our expiration and finally clicked the target B to finish the trial. The typical characteristic of the velocity of a mouse cursor is shown in Figure 12 (b). A peak velocity was observed between the target A and B. We confirmed that the velocity of a cursor could be controlled well by the expiration.

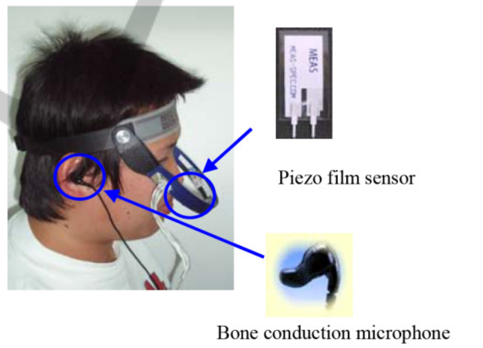


Figure 10: Fitting the device.

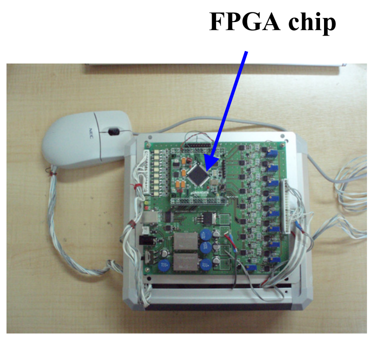


Figure 11: FPGA based mouse interface.

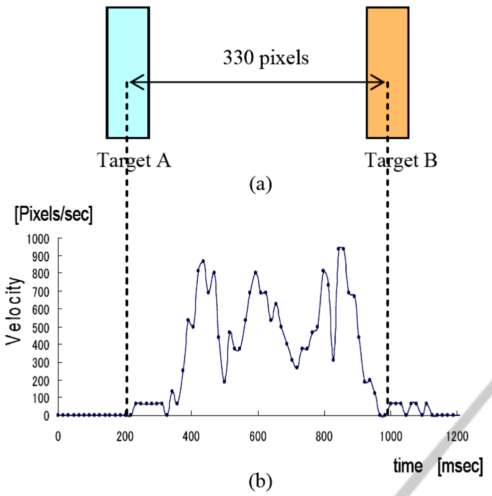


Figure 12: (a) Two target setting on a display (b) Typical characteristics of the cursor's velocity.

5 CONCLUSIONS AND POTENTIAL IMPROVEMENTS

We proposed a novel method for eliminating the voice and white noise suppression by dyadic wavelet transform in conjunction with signal adaptive threshold technique. We showed that our method has excellent performance at detecting the tooth-touch sound signal. Next, to improve the usability of positioning the mouse cursor by the expiration signal, we modified the control method to adjust the mouse cursor position more intuitively adapting to the amplitude of the expiration signal. Finally, we designed a tooth-touch sound and the expiration based mouse device circuit using Hardware Description Language (VHDL) and realized the system on an FPGA chip in practice.

However, we should further investigate the details of the expiration operation for the mouse cursor positioning using the Fitts' Law, which describes the relationship between the time to move the target, the movement distance from the starting position to the target center, and the target width (Thompson, 2004). We will confirm whether the expiration-based mouse pointing follows to the Fitts' Law and we will design the optimal target size. Finally, we hope evaluate the usefulness for disabled persons in more detail.

ACKNOWLEDGEMENTS

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