Handwriting Transmission System Using Noncontact Tactile Display

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ABSTRACT

This paper introduces a system which supports text-based online communication by providing non-verbal information. The handwriting motion is transmitted in addition to the appearance of characters and graphics. Our research product, a noncontact tactile display, is used to stimulate the palm from a distance with a fine spatial resolution. The tactile stimulation is a spot of pressure generated by focused airborne ultrasound. The diameter of the spot is 13 mm and the maximum output force is 18 mN. It is combined with a graphic tablet, and the handwritten characters and graphics are displayed by moving the pressure spot according to the pen strokes.

KEYWORDS: Online communication, Non-verbal information, Handwriting, Noncontact tactile display, Airborne ultrasound, Radiation pressure.

INDEX TERMS: K.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O

1 INTRODUCTION

Recently, it is common for people to communicate with each other online. Such communication is usually text-based (e.g., text chatting, e-mail, SNS, and so on) and it is not easy for them to express their emotion. They usually communicate in non-verbal manner as much as verbal manner in face-to-face communication [1]. It is preferable that non-verbal information is also conveyed in online communication to enrich it.

There are some previous researches focused on providing text chatting with non-verbal information. TangibleChat [2] vibrates the chair according to the vibration caused by key strokes. Expressive typing [3] represents the strength of key strokes as the size or font of characters. The animated chat system [4] changes the size, color, and motion of characters based on emotional states estimated from skin conductivity and blood volume pressure.

Our proposal is to transmit handwriting motion of all or selected characters to be emphasized. Then the characters are accompanied by non-verbal information (the direction, speed, and order of pen strokes, the pen pressure, the interval time between characters, and so on). The handwriting motion is influenced by two types of information: The personality and the emotional state of the writer. In addition to seeing the appearance of characters, the reader can feel the personality and/or estimate the emotional state of the writer based on the handwriting motion.

We aim to reproduce the handwriting motion as tactile stimulation. That approach has been explored in the field of tactile-visual substitution. Shimizu optimized the duration of vibratory stimulation and inter-stroke interval with a 7×9 pin array on the palm [5]. Yanagita et al. displayed letters on the back with a 3×3 vibrator array [6]. While their researches focused on the accuracy of letter recognition with the tactile sense, we intend to utilize it as a channel of the non-verbal aspects of handwritten characters in addition to the visual sense.

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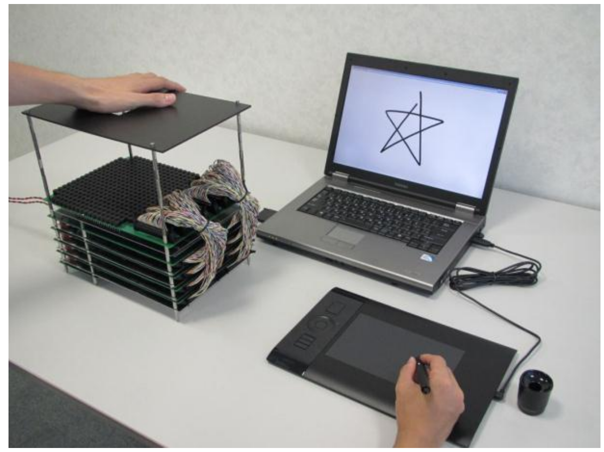

Figure 1. Handwriting transmission system.

The palm is selected as the target area of tactile stimulation in our research, for simplicity and usability in our daily life. As far as we surveyed, there are few kinds of tactile displays focusing on the palm have been reported other than the pin array. For example, Makino and Shinoda proposed a stimulation method based on suction pressure [7]. They focused on reproducing realistic touch feelings rather than movement of stimulation. Minamizawa et al. developed a wearable device which produces normal and shear forces with motor-driven belts [8]. Hashimoto and Kajimoto utilized a loudspeaker to present a wide variety of touch feelings [9]. In these two researches, the palm is stimulated at a fixed position. Mizukami and Sawada conducted experiments on transmission of characters utilizing the apparent movement phenomenon with a 3×3 array of shape-memory alloy strings [10]. While the method is suitable for characters consisting of only straight strokes, characters consisting of curved strokes are also included in the target of our research.

The Airborne Ultrasound Tactile Display [11] is used in our research to reproduce the handwriting motion on the palm. It utilizes focused ultrasound to stimulate human skin from a distance. That non-contact feature makes the reader free from placing his hand on the tactile display. He can feel tactile stimulation at an arbitrary position in midair. The stimulation is concentrated at a point and its position can be moved three-dimensionally. The tactile display was previously used to add noncontact tactile feedback to an aerial image display [12] and an aerial interface [13]. The resolution of the position of the stimulation point was relatively rough (10 mm and 5 mm, respectively) because the main purpose was targeting the hand within a several-dozen cm^3 workspace. In this research, the stimulation point moves more finely (1 mm) within the palm.

This paper introduces the developed handwriting transmission system (Fig. 1). Firstly, the principles of the ultrasound-based noncontact tactile display are outlined in Section 2. Secondly, the developed system is shown with the experimental results in Section 3. Finally, Section 4 concludes this paper.

2 Airborne Ultrasound Tactile Display

The principles of noncontact tactile display are described; Acoustic radiation pressure and phased array focusing.

2.1 Acoustic Radiation Pressure

The noncontact tactile display [11] is based on a nonlinear phenomenon of ultrasound: Acoustic radiation pressure. When the ultrasound beam is reflected vertically at an object surface, the surface is subjected to the constant vertical force in the direction of the incident beam.

Assuming a plane wave, the acoustic radiation pressure P [Pa] is described as

$$P = \alpha E = \alpha \frac{p^2}{\rho c^2} \quad (1)$$

where E [J/m^3] is the energy density of ultrasound, c [m/s] is the sound speed, p [Pa] is the RMS sound pressure of ultrasound, and ρ [kg/m^3] is the density of medium. α is the constant ranging from 1 to 2 depending on the amplitude reflection coefficient R at the object surface; $\alpha \equiv 1+R^2$. Eq. (1) suggests that the spatial distribution of the radiation pressure P can be controlled by synthesizing the spatial distribution of the ultrasound p.

2.2 Phased Array Focusing

The phased array focusing technique is used to produce the radiation pressure perceivable by human skin. The focal point of ultrasound is generated by setting adequate phase delays of multiple transducers. In addition, the focal point can be moved to an arbitrary position by controlling the phase delays.

It is theoretically derived that the spatial distribution of ultrasound generated from a square transducer array is nearly sinc-function shaped [11]. The width of the main lobe w [m] is written as

$$w = \frac{2\lambda R}{D} \quad (2)$$

where λ [m] is the wavelength of ultrasound, R [m] is the focal length, and D [m] is the side length of the square array. Eq. (2) indicates that the spatial resolution and the array size are in the relationship of trade-off.

In the current setup, the ultrasound transducers are arranged in a square area whose side length D is 20 cm. The resonant frequency of the transducers is 40 kHz (i.e. λ = 8.5 mm). Then, the width of the focal point w is 13 mm when the focal length R is set at 15 cm. The force of 18 mN is produced at the maximum with 384 transducers.

3 Handwriting Transmission System

The developed system is introduced. Experiments and results are also reported.

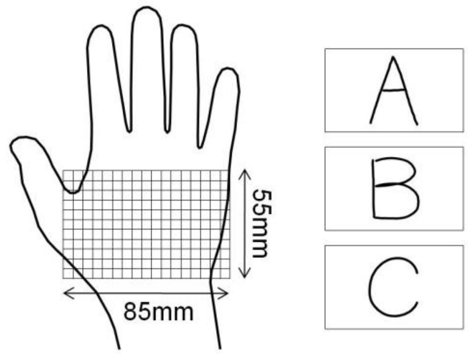

Figure 2. Stimulation area and examples of presented letters.

3.1 Overview

A handwriting transmission system (Fig. 1) was developed by using the airborne ultrasound tactile display. The system consists of a laptop PC, a graphic tablet, and the noncontact tactile display.

The graphic tablet is a commercially-available one (intuos 4 PTK-640, Wacom). It samples the position of the pen on the tablet at a rate of 200 points per second and an accuracy of 0.5 mm. The pen pressure is also measured and digitized into 10 bit data.

At the present stage, the stimulation area is limited to an 85×55 mm^2 horizontal plane at 15 cm above the transducer array. A plate which has a rectangular hole on it is tentatively arranged over the stimulation area to show where the stimulation area is. This plate will be removed in future by employing a hand-tracking technology and then users will be able to use this system at an arbitrary hand position. The resolution of the position of the focal point is 1 mm. The focal point moves within the stimulation area according to the movement of the pen. The amplitude of the output force is changed according to the pen pressure by a 3-bit PWM of the 40-kHz rectangular wave applied into the ultrasound transducers. The maximum value of the output force is 18 mN with a 50 percent duty ratio. The refresh rate of the tactile display is 65 Hz.

3.2 Experiment

Experiments were conducted to compare the performance of our ultrasound-based tactile display and a conventional pin array. The pin array [14] (DotView DV-2, KGS Corporation) has 32×48 pins aligned at intervals of 2.4 mm and a refresh rate of 10 Hz. The pins do not vibrate at a high frequency but just change between two (up and down) states.

Four subjects (22-23 years old, male, sighted, and right-handed) took part in the experiments. The subject was told to place his right hand over the stimulation area of the ultrasound-based tactile display (as shown in Fig. 2). The capital letters of 26 alphabets were presented in a random order and then he was asked to answer which letter was presented. The letters were presented based on the handwriting data recorded in advance. All the letters were written within 4 sec. Each letter was presented 5 times per subject (i.e. 130 trials in total per subject). The subject tried the identification task several times before the experiment. The visual information was shut off by closing his eyes and the auditory information was blocked off by hearing a white noise with headphones. The output force was fixed at the maximum value (18 mN). After all the trials with the ultrasound-based tactile display, the same was conducted with the pin array. The moving point was rectangular and its side length was set as 6.7 mm which is comparable to the half-value width of the ultrasound focal point.

Table 1. Results on identification of letters displayed by focused ultrasound. The percentage of correct answers is 44 percent.

Letter displayed by focused ultrasound \ Answer	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	3			2	1		2	1					1	1			1	5		1					1	1
B		12			2	1								1		1		1					1			1
C			10	1			1		2						3		1	1			1					
D	1			10	1	1				1	1					2		1			1	1				
E	1	1			7	1	1	2			1							1		1			1	1		2
F					3	4										2	1		2						2	6
G		1	2			1	10			1		1	1				2						1			
H	1				1	1	2	8			1		2	1								1	1	1		
I			1						15	2		1				1										
J		1	1						1	14		1								1		1				
K		1						1			6		3	1				7			1					
L			3									14		1							1	1				
M							1	1			3		5	1			3	2					2		1	1
N				1			1	2			1	1	1	6			1	2				1	2	1		
O			2							1		3			6	1				7						
P				3				1						3		9		1			2				1	
Q					1		2							2	2		9	2	1	1						
R		2											1	2		2	2	11								
S		2	1								1						2		11		2			1		
T						2						1				1			1	10		2		3		
U			2									2			2						11	3				
V			1				1					1		2	2						2	10		1		
W				2									1	2	1		1				1	1	11			
X	1			1		1			1		1					2	1	1	2					8	1	
Y			1	3		1		1	1	1			1			2		1		2	1	1			4	
Z				1		1			1		7		1			1		1								7

Table 2. Results on identification of letters displayed by pin array. The percentage of correct answers is 71 percent.

Letter displayed by pin array \ Answer	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	7				1	1		2			2			3										2	1	1
B		20																								
C			13									3			1				3							
D				16												3									1	
E					12	1					1			1			1	1								3
F					1	8		1			1							1	1	1						6
G							15								1		2	1								1
H						1		13			2		1	3												
I									19	1																
J										16		3										1				
K											14	1						3							1	1
L			1							1		18														
M		1						2			1	1	8	3				3					1			
N						1		1						8							5	1	4			
O															19						1					
P																20										
Q															1		13	6								
R											1							19								
S																		1	19							
T																2			1	13				1	2	1
U										1					5						14					
V										1				1							7	11				
W													1	3									16			
X				1							2						1					1		15		
Y		1									2									2				2	12	1
Z					1						2	1						1	3							12

Here the results are shown. Tables 1 and 2 are the confusion matrices on identification of the letters displayed by focused ultrasound and pin-array, respectively. They are filled with the numbers of answers from all the subjects. The blank boxes mean their values are zero. According to the percentages of correct answers, the letters displayed by the pin array is about 1.5 times clearer than those by the ultrasound-based tactile display. One possible reason is that the output force by the ultrasound-based tactile display is weak. Note that, as mentioned in Introduction, this relatively lower percentage is not necessarily negative for our purpose in which we intend to convey non-verbal information in midair while the appearance of letters are seen on the PC screen.

The subjects expressed the tactile feeling as follows. All of them said "the pressure is surely localized and moved on the palm." Some of them described the feeling as a tickling sensation like a small soft-haired blush or electrostimulation.

4 CONCLUSION

In this paper, a system which transmits handwriting motion in a tactual manner was presented. It records the writer's handwriting motion and reproduces it on the reader's palm. It enables them to share the handwriting motion and exchange non-verbal information in addition to the appearance of characters and graphics. An ultrasound-based noncontact tactile display is used for tactile stimulation. It stimulates the reader's palm with a pressure spot whose diameter is 15 mm. The spot moves at a 1-mm resolution. It moves according to the motion data from a graphic tablet. The principles of the tactile display were explained and the developed system was introduced. Finally, experiments and results were shown. It was shown that users can identify the 26 capital alphabets at a 44-percent accuracy rate with the ultrasound-based tactile display. The future works includes (1) increasing the output force of the ultrasound-based tactile display to make the sensation clearer and (2) employing a hand-tracking technology to enable users to feel the sensation in an arbitrary position in midair.

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