Transmitting Full Set of Alphabet Letters to Human Hand via Writing Motion with 5-minute Training

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Abstract— In this paper we report a method to transmit symbolic information to untrained users with only their hands where no visual or auditory cues are available. Our simple concept is presenting three-dimensional letter trajectories to the readers’ hand via a stylus which is electronically manipulated. Despite its simplicity, experimental participants were able to read 14mm-height lower-case alphabets displayed at a pace of one letter per second with the accuracy rate of 71% with their first trials, which was improved to 91% after 5-minute training. These results showed small individual differences among participants (SD = 12.7% at the first trials and 6.7% after trainings). Our findings include the fact that this accuracy is retained even when the letters are downsized to 7 mm. Thus we revealed that the sighted adults potentially possess the ability to manually read small letters accurately at our normal writing speed. Our method can be applied to such handy devices that would allow us reading texts in our pockets.

I. INTRODUCTION

It is almost a common sense that the hand is unsuitable for reading through our own experiences. Although researches on conveying symbolic [1] or graphical information [2] via our hands to us have a long history, these are categorized into ‘visual-tactile substitution’ systems, which have been used mainly for blind people. Only a few researches reported on the reading ability of the sighted: by touching embossed letters [3, 4], tracing trajectories of engraved letters with a stylus [5], writing letters on their palms [6, 7, 8], and guiding their fingers along letter trajectories [9]. All these researches indicated that the letters had to be presented to readers for at least several seconds for accurate letter identifications (some of them left the duration of displaying letters out of account). Sometimes the letters were displayed repeatedly as many times as they wanted. In addition, the size of the letters used in the experiments was much larger than our natural handwriting. Thus, human hands are supposed unsuitable to convey information to the sighted people practically.

In this paper we experimentally demonstrate that the sighted people can read lower-case alphabets as small as a single key of standard computer keyboards at a normal writing speed with a simple method. The simple method we try here is presenting 3D trajectories of pen writing including up-and-down motion. The device consists of two simple components: two-dimensional linear actuators and an on-off two way solenoid, whose details are described in the next section. In the following of the paper, we describe the experimental evaluation of the device from the perspective of practical symbolic information conveyance. Discussions on the perspective of the proposed method in terms of its possible applications and scientific contributions are given in the final part of the paper.

II. CHARACTER DISPLAY SYSTEM

A. System Construction

Figure 1 shows the schematic diagram of our setting. An on–off two-way solenoid actuator, which moves vertically, was attached to the two-dimensional horizontally moving stage. Horizontal motions represented trajectory of letters, while the vertical motions imitated the contact of a pen tip to paper (in the actual experiment a resin plate was placed under the solenoid instead of paper). We used a pair of linear actuators driven with stepping motors (model EZS3D005-A, EZS6D005-A, product of Oriental Motor Co., Ltd.) jointed perpendicularly to each other. They were mounted on a resin plate. An on–off two-way solenoid (model 8M14-02-62-12 VCC-100%, product of Mecalectro) was attached on the stage of the linear actuators with its lower tip pointing the resin plate. Both the linear actuators and the solenoid were electronically controlled by the computer via a micro-controller board (Arduino Mega 2560, product of Arduino), resulting in three-dimensional movement of the tip of the solenoid. On the lower side of the solenoid, metal spacers were attached in order to adjust the vertical movement range of the gripper. Participants held the gripper, the upper side of the solenoid stylus, during the experiments with their arms on the arm rest, while vertical on–off movement of the stylus as well as lateral movement along the letter trajectory was reproduced. The maximum range of the device movement was 50 mm x 50 mm horizontally and 1mm vertically. We placed an elastomer sheet under the stylus in order to attenuate the sound caused when the stylus hit the surface.

B. Trajectory Patterns

Trajectories of lower-case alphabets were recorded by actual drawings by the authors on a graphics tablet (model PTH-850KO, product of WACOM). The extracted trajectories are shown in the figure 2. The letters were drawn with no serif. The movement of the stylus tip, including the on-off contact state between the pen and paper, was recorded. The recorded trajectories were temporally smoothened by FIR filtering for removing jumpy horizontal movements of the stylus. The character shapes were appropriately deformed from the standard typefaces for enhancing the differences among confusing letters. In the experiments, spatially resized trajectories were presented to the participants according to the experimental conditions. They were also temporally stretched...
so that all letters were displayed within a constant duration. During these processes, temporal changes of trajectory velocities were also scaled keeping the similarity.

III. EXPERIMENTS

A. Methods and Procedures

We conducted two experiments where the participants were asked to identify the presented letters. Participants were told in advance that the presented letters were randomly chosen out of 26 lower-case alphabets. For each trial a letter was displayed only once with no repetitions. Participants answered verbally what letter was displayed. No equivocal answer was permitted. Throughout the experiments participants wore headsets playing white noise to nullify auditory cues caused by the mechanical movement of the experiment system. During the tasks the whole device was covered with curtains to nullify any visual cues. Participants were instructed to concentrate on tactile and kinesthetic
sensation and to keep their eyes away from their arms. There was no time limit for the participants’ responses. The letters were displayed one by one intermitted by the participants’ utterance. All participants were naïve: they had never experienced the experiment system before.

We tested 20 naïve participants, including 8 female and 12 male. Their ages ranged from 23 to 53. One participant of them was Chinese and the others were all Japanese. All participants were right-handed. Each of them was rewarded with a 500 JPY pre-paid card for purchasing books. Prior to the first experiment, participants adjusted their arm postures while the tip of the stylus went up and down, so that they learned to apply appropriate load on the stylus. This procedure was necessary to make sure that the solenoid hit the ground when it was in the ‘off’ state. In all experiment sets, every alphabet was displayed twice in random sequences, 52 trials in all. Participants did not know the number of trials in every experiment set. The following two experiments were performed to all of the participants in the same order (the first followed by the second).

B. First Trial for Naïve Participants

At the beginning part of the first experiment, we demonstrated how the system worked. The participants could see the movement of the stylus for every alphabet once for each. During this demonstration participants were allowed to see the complete set of the alphabet displayed on a board as seen in Figure 2, but not permitted to touch the device. After the demonstration, the sample alphabet board was removed and the participants worked on the identification task. They identified letters with their average height set to 14mm at a pace of one second per letter. It took 5 minutes at the longest for the participants to finish this first trial.

C. Second Trial after 5-minute Training

In the second experiment, a short-time training of the system was executed before the identification tasks. We thought that accustomed writing strokes of alphabets would be different among participants (some of them would start writing ‘t’ with the horizontal bar first while others would do with the vertical bar). The training aimed for getting participants accustomed to the presented letter strokes. In the training the participants guessed displayed letters with the average height of 14mm at a pace of one second per letter. Each letter was chosen by the experimenters and the participants were informed of the correct for every single guess. This procedure lasted for 5 minutes for each participant. After this 5-minute training, participants were engaged in identification tasks under the experimental condition identical to the first trial (14mm/1000ms) at first. Subsequently, they were engaged in the other three task sets (7mm/1000ms, 14mm/500ms and 7mm/500ms) with randomized order.

D. Results

The first experiment showed that average naïve participants were able to identify displayed letters by their average accuracy rate of 71% (SD = 11.2%) under the condition where the average letter height was 14 mm and the duration was 1000ms. The second experiment showed the effect of the 5-minute training. It raised the accuracy rate up to 91% (SD=6.7%) (Figure 3). The paired t-test proved that the
5-minute training brought significant (p < 10^{-4}) difference. The effect of downsizing letters was less evident than that of increasing the writing speed (Figure 4). By applying two-way analysis of variance, we verified that both of letter height (p < 10^{-4}) and writing speed (p < 10^{-15}) had significant effect over the accuracy rate while their interaction did not (p > 0.05). Under all of the five experimental conditions (first trial and four experiments after 5-minute trial), it was concluded that there was no significant difference between male and female participants by the t-test (p > 0.05).

IV. DISCUSSIONS

It is notable that performance in reading 7mm-height letters was 85% (SD = 8.2%), deteriorated by only 6 percentage points compared to that with 14mm-height letters. The result that we can read 7mm-height letters with the movement of hand joints is consistent with the cognitive detection threshold of joint movement verified in previous studies [10] (The possible slowest stroke in our experiment was 7mm/s, which corresponds to 1.15 deg/s in horizontal elbow movement with an arm whose length is 35 cm). The small workspace of the 7mm square implies that the device can be as small as a single key of a standard keyboard, theoretically.

Many participants pointed out that some specific letters were indiscernible at their first trials as the displayed strokes were different from their habitual ones. Five-minute trainings could improve the recognition but the difficulties seemed to still remain. We expect that designing stroke patterns and longer time training can improve the recognition rate.

The achievable reading speeds corresponding to our experiments are 60 letter per minute (with a pace of 1000ms/letter) and 120 letter per minute (with a pace of 500ms/letter) excluding the time for answer. The former one, which guaranteed accurate symbolic communications, is almost the half of the typical adult handwriting speed: 130 letters per minutes [11]. Our experiments suggest that our method enables people to read letters in natural handwriting paces after some improvement of the interface. The pooled confusion matrices (Table 1) indicate that there are some specific pairs of letters hard to distinguish (as seen between ‘x’ and ‘y’ under every condition). If we allow using trajectory patterns designed specifically for the hand-reading which are visually unreadable, like shorthand, the reading pace might be improved.

V. FUTURE PERSPECTIVE

Our result is consistent with the previous study that guided fingers can distinguish the graphical forms on flat surface [12], which suggests that we are able to perceive other graphical symbols as well as alphabets with passive kinesthetic movements alone. This paper proved kinesthetic perception could cover all the alphabets that can express any words without tiring trainings, which provides a new clue and tool to elucidate the expressions of symbolic information in our brains. Precedent studies show that visual cortical areas were activated in blind subjects by reading Braille, while the same parts were not activated for sighted subjects [13] who cannot read Braille. It would be a great interest whether the visual cortical areas are activated by our kinesthetic reading or not, for example. The result can provide some evidence on the relevance between the visual cortical areas and recognition of characters, or we might specify some common activated area by the visual and kinesthetic reading. We also have other types of preceding studies on tactile/kinesthetic-auditory-visual interaction such as activation of pre-motor area by visual reading of hand-written words [14] or auditory-tactile coupling in comprehension of uttered syllables accompanied by tactile stimulation [15]. Our method can be an effective tool to understand how sighted people recognize and handle symbolic information in their brains.

The significant contribution of the research would be that it opens a new field of human computer interface beyond the conventional limitation of visual and auditory modalities. We expect that the communication rate of our method will be much improved by users' practices and technical modification of the interface design. The method can be embedded in various devices in principle. Our next interest includes whether a handheld devices is able to convey symbolic information in a similar way, which will allow us to read texts even in our pockets.

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Table 1. Pooled confusion matrices: table (A), (B), (C), (D) and (E) correspond to each experimental condition denoted under the tables. Numbers in each cell indicate the counts of subjects' answer according to combinations of displayed alphabets and subjects' responses. The diagonal components correspond to correct answers. There should be 40 correct answers at most (2 answers from each of 20 participants).