Investigation of On-Skin Electromagnetic Actuator for Signaling Direction via Tactile Cues

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ABSTRACT

This work contributes an investigation of on-skin electromagnetic actuator for indicating directions through tactile cues. In the study (N = 16), the actuator was tested on three locations on participants' arms. We compared the perception accuracy on these locations and draw the conclusion that the participants could identify the stimulus clearly with the actuator begin placed on the underside of the wrist best. Taken together, our result demonstrates that our work would be used as an additional stimulus combined with other haptic interaction to deliver rich information to the users in potential.

CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**; • **Hardware**;

KEYWORDS

Haptics, Wearable actuator, On-skin device, Human-Computer-Interaction

1 INTRODUCTION AND BACKGROUND

Haptic feedback is playing an important in people's daily life, and there is a great potential to use the tactile stimulus in various application scenarios. In the past decades, haptic feedback has been significantly deployed for notification [6, 7], directional cues [1, 3, 4] and motion guidance [5] etc.. The communication of direction through tactile cues has the benefit of leaving the users' eye free, but still delivering the useful information precisely. We leveraged the design from [2] to investigate the performance of on-skin electromagnetic skin indicating the direction with the support of tactile cues. We explored the performance of the actuator when placed on different body locations and sought to find the optimal location. A preliminary user study indicated that the participants were able to tell apart the stimulus, and the best position proved to be the one on the underside of the wrist with an average accuracy of stimulus recognition to 95%.

2 SYSTEM DESIGN

We replicated the design of the wearable electromagnetic actuator from [2], which is lightweight and flexible. The technical basis is an Arduino Nano microcontroller with a 5 V operating voltage. The actuator operates based on Lorentz force principle driving a tactor directly contacting with the skin to render three haptic sensations: Dragging, Tapping and Vibration. An electromagnetic field is generated when current is flowing through the coils. Thus, by systematically controlling the current, the direction of the electromagnetic field can be switched correspondingly. We leveraged the *dragging* and *tapping*, and combined them together to actuate the actuator in our test. A complete motion of the actuator consists of two parts: Firstly, the tactor starts dragging from the initial position (left / right) to the end position (right / left) which is only used to drive the tactor to the specific position. Then, the tactor starts tapping 8 times (see Figure 1) to signal the tactile cue in our test. The total duration for one stimulus take around 1 second.

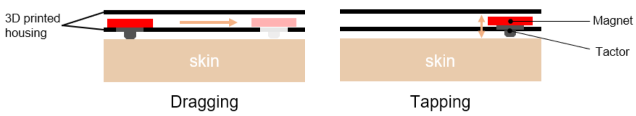

Figure 1: Exemplary stimulus.

3 USER STUDY

The objective of our study was to evaluate if and to what degree a task sensing direction through tactile cues could be supported and to validate the actuator for use in a daily work environment. Consequently, we conducted the experiment to explore the following research questions: **RQ1**: How would the locations the actuator places could influence perception of the stimulus? **RQ2**: Are users able to distinguish the correct direction with the support of haptic cues?

We recruited 16 participants (two of them didn't test with the third location) from our campus. All of them were seated in an office chair, and placed their dominant arms on the desk holding a mouse in their hands. The actuator was attached to the participants' arm with an elastic band. We applied a within-subject design with 3 body locations: (1). underside of the wrist; (2). top side of the wrist ; and (3). underside of the arm closer to the elbow (see in Figure 2), and the order of locations for each participants was randomized.

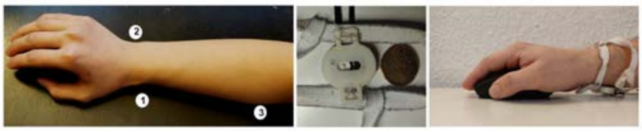

Figure 2: Left: three potential locations; Mid: actuator from [2] in dimension; Right: example for the hand position during the experiment.

Figure 3 demonstrated the procedure for the study. First, each participants was introduced with a familiarization pattern. Then, each participants calibrated the actuator till he / she feels confident to differentiate taps. Later, each participant was tested with random sequence of 20 stimuli. Last, the participants were asked to rate in order of comfort and subjective ability to tell stimuli apart and report their remarks.

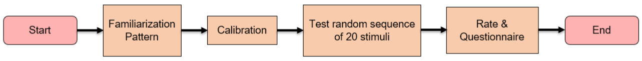

Figure 3: The flow chart of the study.

4 RESULTS AND DISCUSSION

Location Preference: We asked the participants to rank the 3 locations after all the tests without knowing their own results. The position on the underside of the arm was mentioned 11 times as participants reported that they were most confident at this position. The preference when it comes to the top of the wrist and the underside of the arm close to the elbow is not quite as drastic as with the first position.

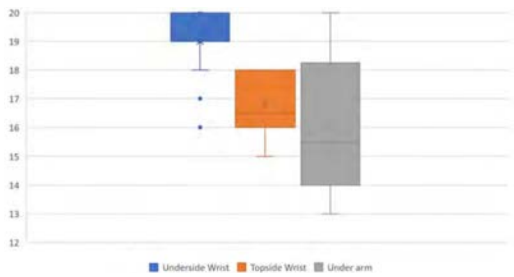

Figure 4: The distribution of correct classification of stimuli for each position tested.

Accuracy: Figure 4 reveals the distribution of the correct guesses per position tested. It is clear that the position where the subjects could identify the stimuli best, is on the underside of the wrist with most being able to correctly identify 18-20 (out of 20) stimuli. Only two outliers were able to only guess 17 or 16 correct. The other two positions were not quite as good for recognizing the stimuli. The results of the underside of the arm were a little more spread than the others with the best identifying 20 stimuli correctly but the worst only getting 13 correct.

Discussion: We collected and reviewed the remarks from the participants. Most of the participants reported that the correct identification of the stimuli was not an easy task as they had to concentrate to be able to feel the stimulus, which was mostly regardless of the position. Additionally, the majority of participants reported that they were able to distinguish the stimuli because they had learnt how the tapping on the left or right felt when indicating the direction rather than feeling the stimuli. The performance of classification of stimulus also relies on the placement which the actuator needs to be precisely positioned. Once finding the correct position during the calibration session, the participants were able to tell the stimuli apart. It is notable that these positions were quite dependent on the individual due to various sizes and thicknesses of the individuals' arm. We infer that the size of the contact area might be an impact factor. The bigger and flatter the contact surface is, the easier a subject could tell apart the stimuli.

5 CONCLUSION AND FUTURE WORK

In this paper, we investigated the potential of directional indication with wearable actuator through tactile cues. The results from this study indicated that participants could identify these left and right stimuli with the actuator being placed on the underside of the wrist best. This result offers a new potential to indicate direction on people's skin when integrated with more electronics to deliver diverse and comprehensive information, for instance, provide additional spatial stimuli (lateral movements information) in passive haptic learning instrument. However, some participants mentioned just learning how right and left felt instead of being able to correctly assign the stimuli by their direction. It could potentially be really interesting to test more stimuli, since after a longer period they might forget the assignment they did in their head in the future. Also, we are looking forward to modify the actuator for higher force and longer moving distance that might make it easier to differentiate the stimulus.

ACKNOWLEDGMENTS

This paper is partially funded by the project "Neuromorphic Systems and Soft Electronics for Resource-Constraint Artificial Intelligence in Soft Robotics and Wearables (softNEURO)" at Karlsruhe Institute of Technology (KIT).

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