IDENTIFYING A PERCEPTUAL MAPPING FROM BIDIRECTIONAL SKIN STRETCH PATTERNS TO MOTOR SPACE PERCEPTIONS: A PRELIMINARY STUDY

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INTRODUCTION

Sensory substitution via cutaneous skin stretch has been widely used in a broad field of applications for the past decade. Its efficiency has also been shown in devices such as a wearable haptic display [1], a stylus-like device [2], a fingertip haptic device [3], an upper limb skin stretch device [4], etc. Although there have been ample applications, to the authors' best knowledge, a perceptual mapping from cutaneous skin stretch to motor space perception has not yet taken into account.

It has been presented that subjects can distinguish directional differences when unidirectional skin stretch is applied [4] [5]. In this study, we identify mappings between bidirectional skin stretch patterns via two mechanical contactors and subjects' motor space perceptions. This study was performed as a preliminary study of a larger problem in which we develop an armband type sensory augmentation device to improve the balance of aged-workers, the handicapped. Specifically, the identified mappings will be presented as probability density functions (PDFs) by utilizing the maximum likelihood estimation (MLE). Our two main research questions throughout this study are i) "Which skin stretch pattern will be perceived with the smallest covariance across the subjects?" and ii) "Will simultaneous actuation of two motors be perceived to the subject as skin stretch toward the diagonal direction?"

METHODS

Twelve healthy young adults (9 male and 3 female, age 20-30 years) with neither neurological nor musculoskeletal impairments participated in this preliminary study. Figure 1 depicts the experimental setup. Subjects were seated on a chair without hand rails, 60cm and 50cm from a monitor and a floor respectively, and wore an armband type skin stretch device at non-dominant hand side arm. The subjects were instructed not to touch the chair or their body part to prevent unnecessary sensory cues except the skin stretch by two motors. Their auditory cue was also blocked by listening to music with head phones. Prior to the experiment, written consent was obtained from each subject. This research was approved by the University Institutional Review Board.

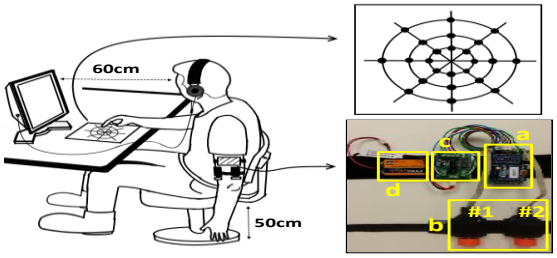

Figure 1: Experimental setup. Subject was seated in front of a table and given instructions via a monitor (left). The subject was instructed to point out intensities and directions on the provided chart (right top). Armband type sensory augmentation device: a) 9V battery, b) motor driver, c) XBee module, and d) two motors and contactors (right bottom).

The skin stretch device (superscripts after each subpart represent labels in Fig.1, right bottom) was controlled wirelessly via XBee[a] radio communication module (XBP24-API-001, Digi International, Minnetonka, MN). Note that the wireless control capability using XBee was employed to meet the requirements of wearability and portability of the skin stretch device that monitors human postural sway wirelessly and stimulates sensation with various intensities and directions by feedback control. Various bidirectional skin stretch patterns were generated via two DC motors[b] (1524T009SR, Faulhaber, Croglio, Switzerland) and contactors, controlled by a motor driver[c] (Sabertooth 2x5, Dimension Engineering, Akron, OH). Two contactors stretched subjects' skin left/right (by motor #1) and front/back (by motor #2) with respect to facing forward direction. A 9V battery[d] was used as power source.

The experiment consisted of two sessions according to two positions where the skin stretch is applied: upper and lower arms. For both sessions, bidirectional skin stretch patterns were generated from combining the intensities of stretch by the speeds of two motors, i.e., H: halt, W: weak, M: medium, S: strong, and R: reverse direction. Hence, there were twenty-four skin stretch pattern combinations with motor #1/motor #2 : $\mathbb{S}$ ={H/W, H/M, H/S, W/W, M/M, S/S, W/H, M/H, S/H, W/RW, M/RM, S/RS, H/RW, H/RM, H/RS, RW/RW,

RM/RM, RS/RS, RW/H, RM/H, RS/H, RW/W, RM/M, RS/S}, which will be referred to as *stretch pattern set*. Each stretch pattern $s_i \in \mathbb{S}$ was repeated five times and was presented to the subjects in randomized order. All stretch patterns lasted for two seconds, then the subject was instructed to point out a discrete point $m_i \in \mathbb{M}$, *motor spaces perception set*, within five seconds on the provided chart. The chart consisted of three different levels of intensity and eight directions (see the chart in Fig. 1, right top). Given all subjects' m_i according to s_i, we wanted to finds a mapping $s_i \rightarrow p(m|\mu_i, \Sigma_i)$

$$p(m|\mu_i, \Sigma_i) = \frac{1}{\sqrt{2\pi}\Sigma_i} e^{\frac{-(m-\mu_i)^2}{2\Sigma^2}} \quad (1)$$

by using MLE. In Eq (1), μ_i and Σ_i are mean and covariance related to stretch pattern s_i, respectively. This perceptual mapping is illustrated in Figure 2.

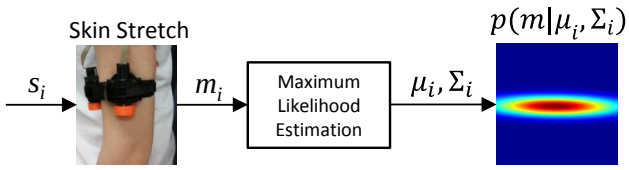

Figure 2: Perceptual mapping from s_i to $p(m|\mu_i, \Sigma_i)$.

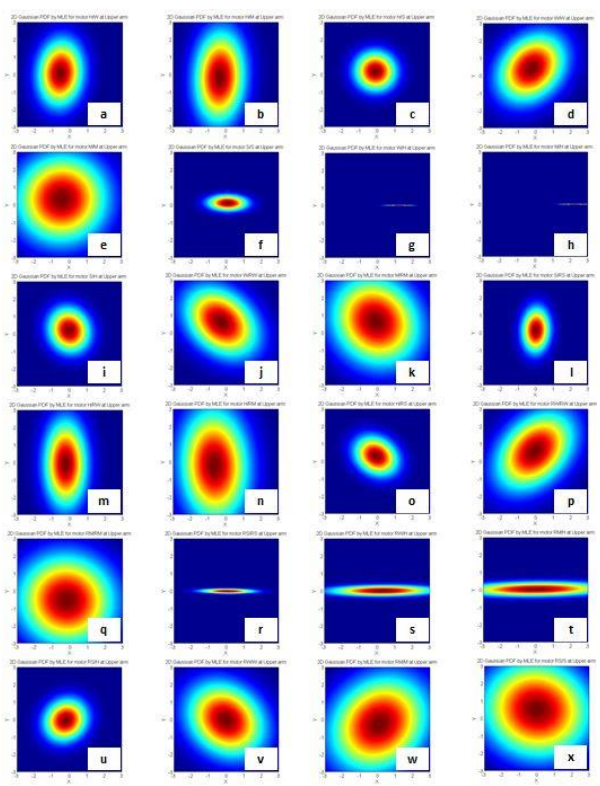

Figure 3: $|p(m|\mu_i, \Sigma_i)$ according to twenty four $s_i \in \mathbb{S}$: (a) H/W, (b) H/M, (c) H/S, (d) W/W, (e) M/M, (f) S/S, (g) W/H, (h) M/H, (i) S/H, (j) W/RW, (k) M/RM, (l) S/RS, (m) H/RW, (n) H/RM, (o) H/RS, (p) RW/RW, (q) RM/RM, (r) RS/RS, (s) RW/H, (t) RM/H, (u) RS/H, (v) RW/W, (w) RM/M, (x) RS/S.

RESULTS AND DISCUSSION

Figure 3 shows $p(m_i|\mu_i, \Sigma_i)$ according to twenty four stretch patterns s_i being overlaid on the provided chart. Recalling our research questions, we found that g) and h) were perceived with the distinctively smaller covariance for all subjects. Comparing (g) W/H and (h) M/H to (s) RW/H and (t) RM/H, however, revealed interesting phenomenon. Although only difference between "(s) RW/H and (t) RM/H" and "(g) W/H and (h) M/H" was the rotating direction of motor #1, it was perceived as two different directional stretches by the subjects. This phenomenon was also observed when motor #2 solely stretched toward the front/back direction (see (a) M/W, (b) H/M, (m) H/RW, (n) H/RM in Fig. 2). Therefore, further investigation should be followed by mounting additional motors (say motor #3 and #4) at the opposite side of motor #1 and #2 respectively, then checking $s_i \rightarrow p(m|\mu_i, \Sigma_i)$ for "(s) RW/H and (t) RM/H."

For our second research question, the plots with larger covariance indicated that the subjects experienced difficulties perceiving the intensity and direction of stretch when both motors were rotating at the same time. This tells us that two perpendicular directional stretches should be applied with separate time intervals when we want to guide the subject by skin stretch. Specially, covariance tended to increase when medium intensity was applied by both motors. Note that almost identical results were observed for lower arm data; however, plots and analyses are not presented due to space limitation.

CONCLUSION

This preliminary study found that a perceptual mapping, from skin stretch patterns to motor space perception, depends on stretched spots on the upper and the lower arms and the intensity of stretch. Also, the identified mapping revealed that skin stretch in the diagonal direction could not be decomposed as the summation of two vectors. For future work, sensory warping/remapping after finding an initial perceptual map is expected to be promising direction.

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