Feedforward Interactions for Mid-Air Haptics: An empirical investigation

As part of the King's Undergraduate Research Fellowship

Introduction and Overview

Mid-air haptics is a novel technology that **creates tactile sensations via ultrasound on a user's skin** in mid-air **without direct contact with their body** [1]. In recent years this has been adopted in VR/AR [9], simulated driving [2], and contamination-free interactions where physical contact with the device is not desirable under the pandemic [3].

However, **the available gestures' visibility** and **the guidance to users for undergoing such interaction** have not yet been adequately emphasised, given that those systems are typically designed for use **without prior training** [7].

Aims, Objectives and Methodologies

As Vermeulen et al. suggested that feedforward can effectively bridge Norman's Gulf of Execution if properly designed [8, 6], **the disambiguation of the term "affordance"**, as defined earlier by Norman, **in the domain of virtual objects** constitutes one of this project aims [5]. On the other hand, the essence of **investigating the match between the system's provided actions** and **those intended by users** cannot be neglected, either [6].

To respond to those under-explored concepts being synthesised from previous works, **a 40-50 minute two parts study** has been run repeatedly **across 27 participants** inside the department's interaction room, with the board and environment setup depicted as follows:

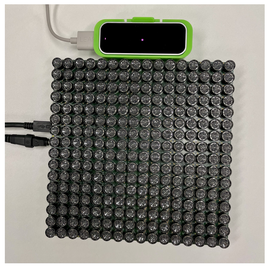

Figure 1. Board setup.

Figure 2. Study setup.

The study revolves around **the feasibility of prompting specific physical actions to users** via **generating mid-air haptics stimuli from the board**. All participants were located such that they had visual access to **only the large television** rather than the coordinator's display, with **approximately 20cm from their right hands vertically down to the board** being placed in front of them. **Two types of data** have been collected throughout the experiment. One corresponds to **the user's response** gathered via **several Excel spreadsheets**, and the other refers to **quantitative data** captured by **a tablet** for the sake of avoiding generating paper copies, which are all accessible here:

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Part 1: Direction Detection

This part of the study focuses on a set of **4 cardinal directions** (i.e. **up**, **down**, **left** and **right**) followed by a set of **4 common gestures** (i.e. **swipe left**, **swipe right**, **tap** and **pinch**). Participants have been instructed to **watch a short video representing those 4 directions/gestures** as hand movements (displayed as two screenshots below) **at the beginning** of each sub-part, plus a familiarisation stage **experiencing all 4 directions/gestures at once in random order** and being informed **the "correct" correspondence between the system's generated stimuli and their announced response**.

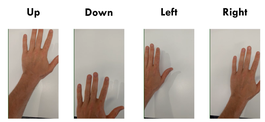

Figure 3. Part 1.1 gestures.

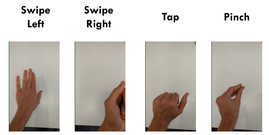

Figure 4. Part 1.2 gestures.

A **subsequent randomly generated 10 trials** have been carried out, in which they have been prompted to **speak out the stimuli each time**. **All users' intended responses** have been recorded into Excel spreadsheets that would be used to **perform the Chi-Square test analysis**, their **subjective experience** has also been captured using metrics such as **NASA TLX** and **5-point Likert scale**.

Part 2: Path Tracing

This part of the study **guides each user's hand** through **5 randomly generated paths from the start to the destination**, with the grid (figure below) inspired by the Android device's unlock screen.

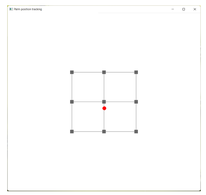

Figure 5. User Interface for hand tracking.

Participants have been told to **localise their hands** where **the red dot lies precisely in the start coordinate**. **Four directional sensations** are then played using **the laptop's arrow keys**, with **the stopwatch recording time throughout each keypress period**. The data includes **5 trajectory plots** and **corresponding completion times** for each user, leading to a follow-up analysis creating **the correlation and regression plot** of **the average completion time** against **the path length**, plus their **subjective experience** being captured in the same format as Part 1.

Results and Discussion

Direction Detection

A **5% Significance Chi-Square Test** applied to both subparts reveals **no association** between **the generated tactile stimuli** and **the users' performance**, as **the test statistic** in both cases, is **strictly less than the defined critical value**. On the other hand, the **increasing challenge of participants determining the "Tap" and "Pinch" sensations** potentially causes **the up-scaling effect** on **Mental Demand**, **Effort** and **Frustration** as determined by NASA TLX.

Path Tracing

Apart from **getting similar scores** on users' subjective experience as in Part 1, **the coefficient value** and the below scatter plot with **a line of best fit that touches 3 out of 5 points** deduces **a very strong correlation** between **the average completion time** and **trajectory length**.

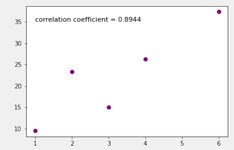

Figure 6. Correlation of average time taken against path length.

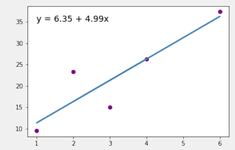

Figure 7. Regression of average time taken against path length.

However, letting participants perform the task straightaway **without familiarisation** with **their relative hand position on the grid** and **the path generated as continuous stimuli** has potentially become **a confounding factor**, leading to **slightly poorer performance on the first trajectory**.

Conclusions and Future Work

The study systematically explores **the possibility of feedforward interactions** via **playing various sensations** to **provide some result indications to users before their response is uttered**, in both **discrete** (Part 1) and **continuous** (Part 2) fashions, with **the outcome as expected** except for **some training effects** appeared **in Part 2**.

To tackle this, **minor study plan modifications** may be applied in future project iterations, plus **the participants' pool** can possibly **be extended to a broader age range** and **discipline** to **minimise the uncontrolled variation** that forms part of **Threats to Reliability** [4].

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