Ultrahapticons: "Haptifying" Drivers' Mental Models to Transform Automotive Mid-Air Haptic Gesture Infotainment Interfaces

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ABSTRACT

In-vehicle gesture interfaces show potential to reduce visual demand and improve task performance when supported with mid-air, ultrasound-haptic feedback. However, comparative studies have tended to select gestures and haptic sensations based either on experimental convenience or to conform with existing interfaces, and thus may have fallen short on realising their full potential. Aiming to design and validate an exemplar set of ultrasonic, mid-air haptic icons ("ultrahapticons"), a participatory design exercise was conducted, whereby seventeen participants were presented with seven in-vehicle infotainment tasks. Participants were asked to describe their mental models for each, and then sketch these visual, tactual and auditory associations. 'Haptifiable' elements were extracted, and these were analysed using semiotics principles, resulting in thirty ultrahapticon concepts. These were subsequently evaluated and further refined in a workshop involving user experience and haptics experts. The final seventeen concepts will be validated in a salience recognition and perspicuity study.

CCS Concepts

•Human-centered computing~Human computer interaction (HCI)~Interaction devices~Haptic devices•Theory of computation~Semantics and reasoning•Human-centered computing~Interaction design~Interaction design process and methods~Participatory design•Human-centered computing~Human computer interaction (HCI)~Interaction techniques~Gestural input

KEYWORDS

Mid-Air Haptic Gesture; In-Vehicle Infotainment System; Icons; Mental Models

1 INTRODUCTION

Mid-air gesture interaction in the automotive domain has been explored to counteract some drawbacks associated with increasingly ubiquitous touchscreen interfaces (e.g. added complexity and increased eyes-off-the-road time [1]) yet remains a relatively fledgling modality. Naturally, gestures have their own limitations, namely potential cultural semantic nuances [2], the learning associated with more intricate gestures [3] and a lack of a sense of agency [4]. Focused ultrasound can be used to create haptic sensations without requiring physical contact [5] which creates the opportunity to bind tangible sensations to mid-air gestures; thus, haptic sensations can provide confirmatory cues thereby increasing one's feeling of control over their gesture. The advent of this technology also provides an alternative to auditory feedback as the latter could plausibly displease vehicle occupants by interrupting conversations and audible media [6]. Furthermore, mid-air haptic icons could allow more expressivity than previous haptic technologies as result of information encoded via novel spatial and temporal interplay [7]. This could provide higher resolution in relaying feature semantics and therefore reduce the onus on having intuitive gestures, learning the meaning of haptic signals or visually attending to a touchscreen for information transfer [8]. From a user experience standpoint, the refinement of mid-air haptics for an automotive gesture interface could also improve user engagement and aesthetic appeal as seen in applications in public digital signage [9].

Preliminary investigations have compared mid-air haptic gesture (MAHG) interfaces with industry trending touchscreen solutions [10,11,12], and have notionally combined existing gesture sets with stock haptic sensations. These studies demonstrated clear benefits associated with MAHG interfaces, such as reduced eyes-off-the-road times and increased task performance. However, beyond their scope, was using semiotic and psychophysical principles to ground original holistic interaction designs by mapping gestures and haptics with specific tasks as well as optimizing haptic intensity, transience, pattern, location on the hand etc. All of these factors are likely to play a key role in augmenting the opportunities that mid-air haptics present, therefore, the aim of this ongoing programme of research is to build and evaluate an exemplar set of robust, function-associated [13] haptic gestures – based on human-centred design– to support an in-vehicle infotainment system (IVIS).

2 METHODOLOGY

2.1 Feature and Participant Selection

It was evident in the related work that the non-driving related task (NDRT) and User Interface (UI) design is principle in the success of MAHGs. Results from Large et al [12] indicated that MAHGs appear superior to a touchscreen interface and mid-air gestures (without haptics), with regard to visual demand and task performance, for tasks that involve incrementally adjusting a setting. However, the results indicate that the touchscreen is more appropriate for the selection of a non-goal orientated 4 x 4 button grid when compared with MAHGs in a car following paradigm simulation. Arguably, the button selection condition might yield different results if the UI reflected the smaller button proportions inherent in some contemporary production vehicles [14]. Hence, an expert UX appraisal was conducted in a Tesla Model X to identify ecologically valid features and interactions in the touchscreen interface that could benefit from actuation using MAHGs. These consisted of discrete selection and continuous adjustment interactions for fan speed, cabin and seat temperature, navigation and audio volume; discrete shortcut interactions for telephone calls and the landing page (home) as well as response to telephone call notifications.

A participatory design study was subsequently conducted with a sample of seventeen participants (Male n11, Female n6, age Range 19 – 65yrs, mean 30yrs) comprising members of the Nottingham Electric Vehicle Owners Club, staff and students at the University of Nottingham and non-technical employees at Ultraleap Ltd. Understanding cultural difference was considered important therefore multiple nationalities were recruited for the sample (UK [n7], Mexico [n3], Malaysia [n3], Hungary [n1], Spain [n2] and India [n1]).

2.2 Participatory Design Study Procedure

The procedure encompasses an amalgamation of learnings from related literature [6,7,15,16,17,18]. Six of the participants were involved in individual face-to-face sessions where they experienced the mid-air haptic technology (the exposed group) ; eleven were organized remotely as a result of Covid-19 lockdown measures (the non-exposed group), the technology was therefore comprehensively demonstrated to them via remote video call (Figure 1: i.).

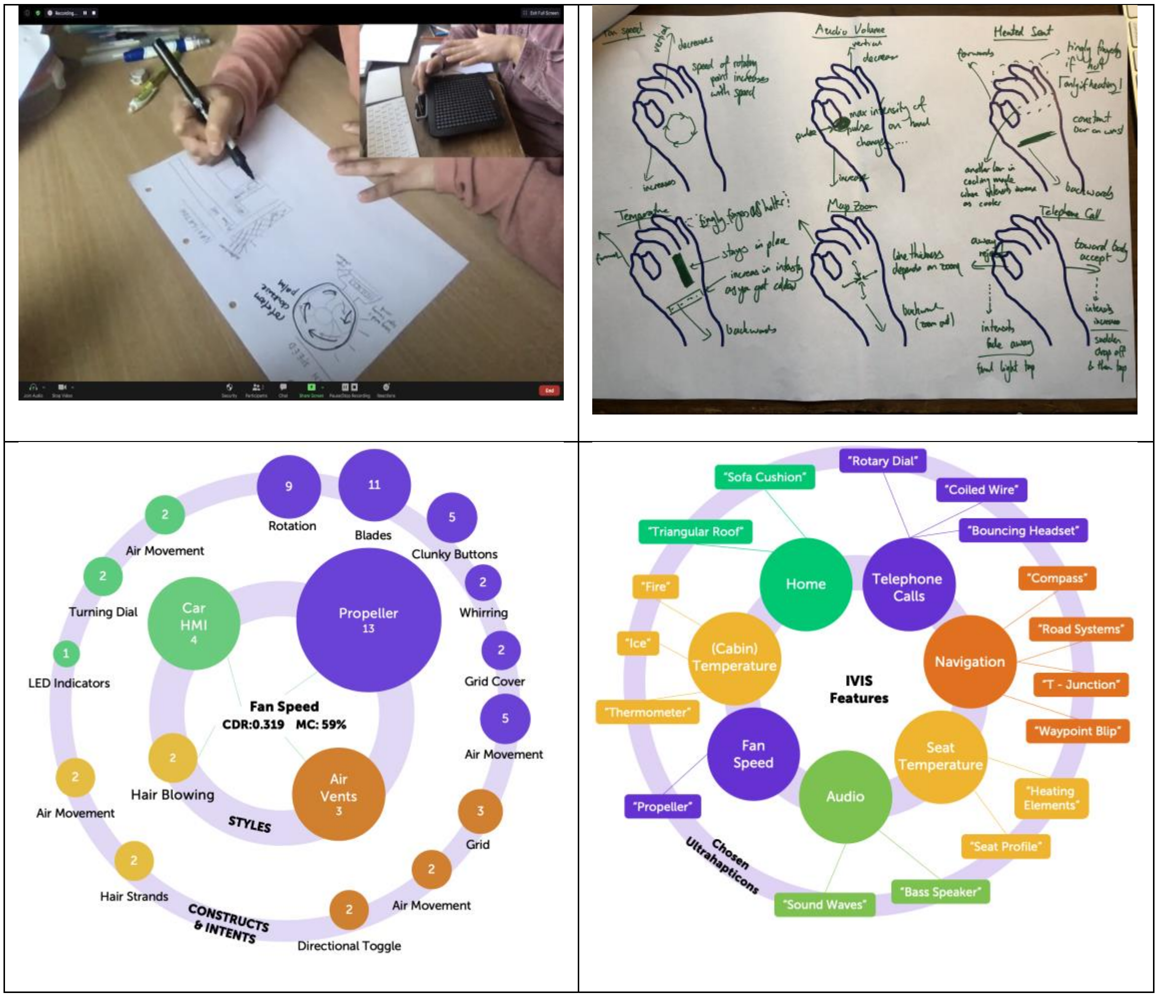

Figure 1: (In clockwise order from top left) i. Extracting features from mental models during a remote demo of the Ultraleap STRATOS Explore array ii. Dynamic ultrahapticon designs iii. Semiotic components observed in the fan speed sketches iv. Final ultrahapticon concepts.

2.2.1 Cognitive Mapping

Following a practice word-association task, participants verbalised the mental models they associated with each infotainment feature. Specifically, participants were asked "For the words [infotainment feature] what would you associate [tactually i.e. physical sensations; visually, as mental images or objects and auditorily i.e. sounds.]?". Participants were encouraged to consider the words themselves and not the features within context as Panëels [17] found that structuring the questioning in this way led to less bias yet still yielded concrete metaphors.

2.2.2 Mental Model Visualisation

The next stage involved asking the participants to sketch the visual, auditory and tactual elements they had previously mentioned. In consideration of differing sketching abilities, the participants were encouraged to follow a "think-aloud" protocol as they sketched; this would enable the investigator to review video footage to understand the participants' thought processes if the sketch wasn't sufficiently communicative. The investigator demonstrated with an arbitrary example of a radio metaphor illustrated as a retro "boombox" radio, and then directed the participants to render a conceptual sketch for each feature (Figure 1: i.). The “exposed” group were then demonstrated examples of sensations via the Ultraleap STRATOS explore array and the non-exposed group had the technology and types of sensations thoroughly described to them with aid from a graphical visualiser. The participants were then informed of twelve tunable, mid-air haptic parameters that could be manipulated to create different sensations. Using this information the participants highlighted elements of each sketch they thought most embodied the metaphor (i.e. the antenna on the radio example); they were then encouraged by the investigator to elicit how they would use the parameters, along with a nominal open palm gesture, to encapsulate these characteristics as their personal mid-air haptic icons (“ultrahapticons”).

2.2.3 Ultrahapticon Refinement

The next step guided the participants to extend their designs to include how specific dimensions of the sensation would adapt to reflect a user-manipulated change in the feature setting (real-time interactional feedback). This time the participants were asked to consider that the feature will be adjusted using a more realistic “index finger and thumb pinch” hand pose and that they should elicit what axis this hand pose should move along to influence the function (Figure 1: ii.). This gesture was selected based on current design guidelines for automotive gesture interfaces generated by the array manufacturer- Ultraleap.

3 ANALYSIS AND RESULTS

3.1 Semiotic Decomposition

The ultrahapticon study elicited 119 total sketched designs which were analysed for their semiotic components to determine the most intuitive designs for each feature (referent). First the participants’ mental model sketches were classified into distinct prevailing styles (proposals) (see example in Figure 1: iii.). Although not specifically instructed to, many of the participants proposed multiple styles for a single referent. To account for this, the proposals were analysed for “Max Consensus” (MC: percent of participants eliciting the most popular proposal) and “Consensus-Distinct Ratio” (CDR: the spread of participants displaying the most popular proposal - the closer the value is to 1, the smaller the spread and the more agreement there is among participants) [19]. Singular incidences of proposals were eliminated resulting in a shortlist of 23 ultrahapticon styles for the 7 features.

The next level of analysis involved breaking down the styles into exemplar level semiotic components; their feature “constructs” and “intents” [20] (Figure 1: iii.). Constructs are physical characteristics of a feature that, collectively, comprise the holistic mental model (e.g. the rails of a rocking chair); an intent is a symbolic construct that is used by the designer to express meaning or behaviour (e.g. blurred lines indicating movement of the rocking chair). Derived from the 23 styles were 88 distinct semiotic features; these were analysed further for consensus which indicated that 65 were commonly occurring (appearing at least twice). 32 of these were adapted by the participants into their ultrahapticon designs.

These ultrahapticons were subsequently decomposed into their value level components to understand the participants’ expectation of the real-time interactional feedback. This included understanding any consensus regarding construct rendering; what spatial, temporal and spatiotemporal parameters were used to signify feature intents; location of the sensations on the hand, axial direction of the pinch gesture and the dynamic adaptation of the sensation to reflect the feature adjustment.

3.2 Workshop

Limited consensus was observed among the participants during the technical “value level” part of the study and sometimes the concepts were not feasible. Therefore, some results were adapted based on literature heuristics and where high disagreement occurred, all variations were considered for that icon style. Additionally, frequently reoccurring constructs and intents from popular styles that weren’t selected for haptification by participants were reimagined as sensations by the investigator on the basis that these may have been discarded purely due to the participants' partial understanding of feasibility. This was exacerbated by the language barrier in some cases which was the only cultural difference observed in the study. To refine the resultant 30 user-centred ultrahapticons, a remote workshop was conducted with four mid-air haptic experts. The ultrahapticon design process was described to the attendees after which they were asked to rate each concept on a five-point Likert scale pertaining to feature appropriateness, expected salience, naturalism, instant recognisability, perspicuity, and technical feasibility. They then provided expert consultation on how to adapt the designs to improve the aforementioned aspects. The data from the workshop was used to hone the concepts and the result was a shortlist of 17 sensations for 7 features (see Figure 1: iv.).

4 CONCLUSIONS AND FUTURE WORK

The next phase in this research will determine the most articulate icons from the shortlist; the icons will be prototyped along with synchronous hand poses based on established psychophysical principles and then evaluated in a salience study. An initial objective will be to understand the "articulatory directness" of the icons [21], that is the strength of the link between feature and metaphor and whether the icon rendering reflects the intended symbolism. This includes identifying the optimal way of manipulating haptic spatio-temporal dimensions to reflect the dynamic interaction with a specific feature.

The next study will also focus on perceptual optimization [16] of the icon set by testing the icons' salience under simulated workload similar to that of a driving task. This will determine whether certain icons are masked through cognitive load and whether some sensations are confused with others within the set. When eventually tested in a driving simulator, this design process will improve the likelihood of validating distraction and task time measures associated with this MAHG concept without perception confounds.

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