HandLog: A Deformable Tangible Device for Continuous Input through Finger Flexion

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Figure 1 HandLog components and usage (from left): 3D printed core; foam sleeve (white) with embedded conductive foam (black) sensors; HandLog device with core and sleeve; Whole hand finger flexion gesture

ABSTRACT

We introduce HandLog, a novel handheld interaction device that supports single handed deformation through finger flexion as a continuous digital input. It consists of a 3D printed core inserted within a foam sleeve embedded with conductive foam columns. By measuring resistance changes across the columns during deformation, whole hand or individual finger flexion motions can be mapped to digital data in real-time. We conducted a user study that demonstrated the successful use of the device for game input. The results indicated that users could quickly become competent with the device and that when compared with discrete controls its supported interactions created a more engaging experience. HandLog has great potential for other application domains, including hand exercise for rehabilitation and handheld controllers for smart homes in ubiquitous computing.

Author Keywords

Deformable input device, Tangible Interaction

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INTRODUCTION

Our hands form a gateway to our interactions with the real world. With them we feel, lift, touch and manipulate objects, from squeezing toothpaste from the tube in the morning, to flipping the pages of a book at night. Within our hands lies an expansive repertoire of skills that allow us to interact with the world, at times without the slightest thought (Wilson 2010).

Ever since Hiroshi Ishii first introduced (Ishii et al. 1997) his vision of tangible interaction, a world where the affordances and latent skills of our interactions with the physical could be translated to our interactions with the digital, researchers have been investigating ways to augment computers with graspable objects to leverage these skills and use it to interact with the digital world with the aim of creating a richer and more intuitive multi-sensory experience (Fitzmaurice et al. 1995, Patten et al. 2001). Early research focused on graspable objects that could be lifted, rotated and relocated (Ullmer et al. 1998). More recently, research has begun exploring *deformable* objects; those that can be deformed as a form of input themselves (Ishii et al. 2012) to provide a greater depth of interaction and tactile sensation (Kildal 2012). An example of recent work in deformable interface is the Skweezee system (Vanderloock et al. 2013, Agrawal et al. 2015) that uses soft objects such as plush toys or cushions to capture gestural inputs. However, there is a lack of research in deformable interfaces that utilize the intricate and continuous range of movements of individual fingers of the hand.

We set out to extend this agenda by creating an input device that leverages people's natural, innate skills in interaction with their hands by allowing the deformation of the device through individual finger flexion, or whole hand squeeze as a continuous input. Finger flexion is defined as the curling of the fingers to grasp and deform an object. In this paper we present the design and evaluation of HandLog (see Figure 1), a handheld deformable input device that maps deformations through individual finger flexion to digital inputs. HandLog is a cylindrical device with a core housing covered by an interchangeable multi-point deformation sensitive foam sleeve. In order to detect deformations through finger flexion, HandLog contains conductive foam columns strategically placed throughout the foam sleeve. By measuring resistance changes across these columns whole hand and individual finger flexion gestures can be mapped to continuous digital input.

We conducted an evaluation of the HandLog that demonstrated its use as a game controller and generated insights into deformation through finger flexion as a continuous input. The study indicated that deformation through finger flexion as a continuous input could create a more engaging experience. The design of HandLog supports swapping of the foam outer sleeve for multiple levels of passive force feedback through the use of different foam densities.

The contribution of the paper includes (1) the design and evaluation of a novel handheld deformation interaction device, HandLog; which (2) extends prior work (Smith et al. 2008) by affording the use of deformation through individual finger flexion as continuous inputs in real-time, and (3) supports multiple levels of passive haptic feedback through the use of an interchangeable foam sleeve.

RELATED WORK

Within Human Computer Interaction over the last two decades Tangible User Interface (TUI) research has become an established field that seeks to interlink the way we interact with the physical and digital worlds through the creation of technologies that physically represent digital information and serve as inputs for control, allowing users to physically touch and manipulate data with their hands (Ishii 2007). TUI is a major research topic in ubiquitous computing (Ballagas et al. 2003), reality based interaction (Jacob et al. 2008), augmented reality (Ullmer et al. 2000), pervasive computing (Blackwell et al. 2005), embedded computing (Jordà et al. 2007, Shaer et al. 2010) and wearable computing (Mistry et al. 2009).

Tangible user interfaces

Initial concepts of TUI, such as Fitzmaurice's (1995) Graspable User Interfaces, saw the creation of objects that could be moved spatially and directly as inputs. The interactive objects were rigid and not deformable, limiting the ways in which they could be used to interact with data. Recent approaches have moved to organic TUIs, i.e. interfaces that can deform, transform and actuate, creating more natural way of manipulating data (Vertegaal et al. 2008, Ishii et al. 2012). One such type of organic TUI is passive deformable interface. To further the agenda of tangible interaction and better allow us to harness the innate skills within our hands through deformation, many researchers have explored different types of sensing techniques for handheld soft deformable input devices.

Deformable interfaces

There are several approaches to sense the deformity of soft material, through measuring conductivity and density. Conductive soft material, such as foam or fabric, is the common underlying technology used in deformable input devices (Jansen et al. 2012). The use of conductive foam was originally built on the original work of Murakami and Nakajima's (1994) who created deformable shapes from conductive foam bars to create a more intuitive and direct control for 3D-modelling. Changes in the foam bars resistance are measured to detect shape deformation. A prototype device in a shape of a cube was created to explore the types of interaction supported by soft deformable devices. Current examples include fabric deformation sensors such as PinStripe (Karrer et al. 2011) and handheld pressure sensing surfaces for topography design, SOFTii (Nguyen et al. 2015).

Digital Foam (Smith et al. 2008) embeds cylinders of conductive foam within a non-conductive soft medium. Resistance value of conductive foam cylinders changes upon deformation. A spherical digital foam (Smith et al. 2008) was designed to support 3D modeling through spatial mapping of the foam deformations to a 3D model. A glove based input device was built with a Digital Foam sensor (Hoang et al. 2013) placed under the palm to support direct manipulation modelling techniques using passive haptic feedback.

The Skweezee System (Vanderloock et al. 2013) also utilizes conductive material within soft objects embedded with electrodes. This technique measures the resistance between pairs of embedded electrodes. The authors developed an algorithm to recognize gestures performed on the object through patterns of resistance values. This technology can be applied to any deformable object that can be filled with conductive fabric. The gestures supported by this sensor include a full two hand squeeze allowing the use of discrete inputs. It does not yet allow the motion of a gesture to be used as a continuous range of inputs.

Another approach to measure deformity of soft material is through density sensing. The FuwaFuwa sensor utilizes photoreflectivity measurement from embedded photoreflectors to determine the density of padding within a soft object and thus its shape deformation. (Sugiura et al. 2011). This form of sensor is limited by the requirement for light penetrable soft padding material and accuracy in sensing small precise localities of deformation.

HANDLOG

HandLog is built using conductive foam, a similar approach as Digital Foam (Smith et al. 2008). The Digital Foam prototype was designed for two handed thumb palpations for the benefits of 3D modelling. Previous handheld deformable interfaces do not support individual finger flexion deformations as a continuous input. They either lack the deformation measurement accuracy to support individual finger flexion as an input or only have the capacity to support gestures as opposed to motions as an input. They also often have a fixed design without the ability to change the material used.

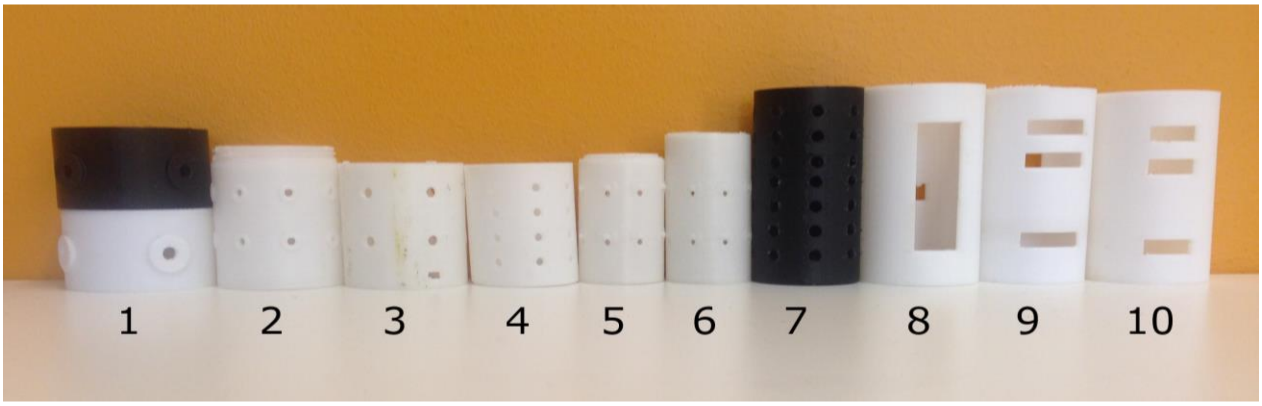

Figure 2 Iterations of the 3D printed core with different lengths and wiring openings (left is oldest)

HandLog is a deformable input device with the following advantages as compared to previous works:

1. Supports real time continuous input, using whole hand squeeze or individual finger flexion.
2. Has an interchangeable sleeve which allows for variance in deformation force feedback.

Materials and Design

HandLog consists of two components: a 3D-printed core housing the electrical hardware and an interchangeable foam sleeve containing an array of conductive foam cylinders. This design allows interchangeability of the outer foam sleeve with different foam density as required by the application and/or user. The inner core is 3D-printed, and houses the wiring and Arduino Pro Mini microcontroller. The Arduino can be connected to the computer via a cable or through a Bluetooth controller embedded in the core, for mobile interaction.

As the user squeezes and compresses the HandLog, the resistance changes across the conductive foam cylinders are measured and mapped to deformation of the sleeve. The conductive foams are laid out on the foam sleeve to match with the location of the finger joints, creating a multi-point pressure sensitive surface. The layout of the conductive foam cylinders enables localization to detect the pressure from separate joints on different fingers. This supports mapping of individual finger flexion to continuous digital input.

The foam sleeve (see design rendering in Figure 3) is made up of a non-conductive supporting foam base containing an array of conductive foam sensors connected with an external layer of conductive fabric, similar to Digital Foam design. The density of the non-conductive foam provides the passive haptic feedback to the user. Depending on the requirement of the application, foam sleeves with different density can be supported. The design of the HandLog into 2 components enables interchangeability of the foam material. HandLog also has a modular design where multiple devices can be joined back to back to create a longer version that can accommodate two-handed interaction.

Fabrication

Our initial prototype uses a medium density non-conductive supporting foam with a deformable magnitude from surface to base of 12mm. The 7 conductive foam sensors were strategically placed as seen in Figure 4 to allow input with the index, middle and ring fingers as well as the thumb when holding the HandLog with a full grasp.

Core Housing

The purpose of the cylindrical 3D printed core is to house the Arduino microcontroller and to provide connections to the foam sensors in the outer sleeve. We conducted several iterations of pilot testing, in which we asked participants to comment on how comfortable it was to hold and squeeze the prototype, to determine the optimal size for the core. Throughout the progression of core iterations and their informal testing and design, we found that a thinner device fit more comfortably within the users' hands. As a result of this, the diameter of the core was reduced to 45mm. The final diameter was constrained to a minimum of 45mm by the Arduino Pro Mini microprocessor in use and its attached circuitry. The final version is a cylinder measured at 80mm long with a diameter of 45mm and a 2mm thick wall, printed using PLA plastic.

There are openings on the core housing for wiring connections from the Arduino to the foam sensors on the outer sleeve. The bottom of the foam column is also covered in conductive fabric, and connected to a wire with a pin at the end, which goes through the opening on the core to plug into a socket clamp on the Arduino. This mechanism enables swapping of the foam sleeve by unplugging the pins and sockets. We explored different shapes and sizes of the opening, from circles to rectangles. A tight opening restricts the movement of the wire, impacting the feasibility of sleeve swapping. A large opening affects the structural strength of the core housing and does not provide the required platform for the foam sensors. Figure 2 shows the iteration of multiple core housing designs with different lengths and wire openings. Our evaluated prototype uses design number 10.

Foam Sleeve

Throughout the development of the HandLog three different foam sleeves with different densities were tested. The density of the supporting foam affects the pressure needed to alter resistance measurements across the foam cylinders with finger flexion. Fatigue and exertion was a major concern, raised by the participants in pilot testing. Detachment of the foam sleeve and the core enables swapping multiple types of foam densities to suit many application domains, such as game input or hand rehabilitation exercises.

In the original design of HandLog, the foam sensors are embedded in a matrix configuration, as shown in Figure 3. The layout of the sensors in a matrix allows 3D positioning of the grip forces distributed on the device. The hand grip can be reconstructed by knowing which sensor and to what extent it is depressed. This design enables the identification of individual finger flexion, which was not available in previous works.

In our initial prototype, we explored 7 sensors with 2 for each index, middle and ring finger and 1 for the thumb, as shown in Figure 4. Six of the 7 foam sensors are laid out in a 2x3 matrix configuration (see Figure 1), matching with the digital and the middle knuckles of the three fingers when holding in a cylindrical grip (see Figure 4). There are markings on the outer conductive fabric to provide visual indication on where to place the hand. This design allows the identification of the finger force by mapping the resistance to the corresponding foam sensor on the matrix, as described in the Finger Flexion section below.

Microcontroller

The resistance of each foam sensor is measured through a series of voltage dividing circuits and an analogue-to-digital converter connected to the Arduino Pro Mini microcontroller placed inside the HandLog core. The converter maps voltage values between 0 and 1023. The type of digital foam sensor is a low density soft polyurethane conductive foam, which provides an analogue voltage reading range of 600 discreet values. The analogue voltage value is mapped to the thickness of the foam of 12mm, providing a sub-millimeter precision in the deformation.

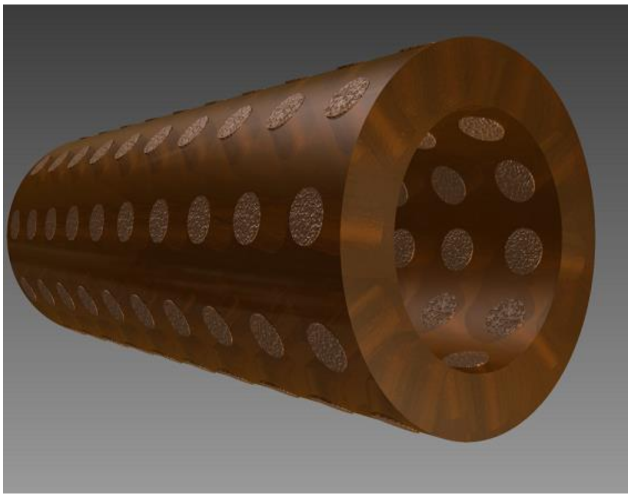

Figure 3 **Design rendering of foam sleeve with matrix of conductive foam sensors**

Figure 4 **Positions of conductive foam sensors relative to the hand while grasping the HandLog**

Finger flexion

Each foam sensor is connected to each of the analogue pins on the Arduino board and therefore can be individually identified. The measured resistance with ID of the sensors is sent to a computer through either a cable or Bluetooth serial connection to be mapped to digital data. Finger flexion force for each finger is calculated based on the ID and the resistance value of each foam sensor. Figure 4 shows the contact points on the finger joints (blue dots) corresponding to the locations of the foam sensors shown in Figure 1 (black foam columns). Figure 5 shows the measured resistance changes that occur over time when HandLog is deformed through a compression with the index finger followed by compression with the ring finger.

EVALUATION

In order to evaluate HandLog and in particular the interactions it supports we conducted a formal study using HandLog as a controller to play two adapted simple games. The performance metrics of these games were compared with that of participant performances with traditional keyboard arrow controls. To gain further insights the quantitative data was supported by qualitative data gathered through a short questionnaire and a semi-structured interview.

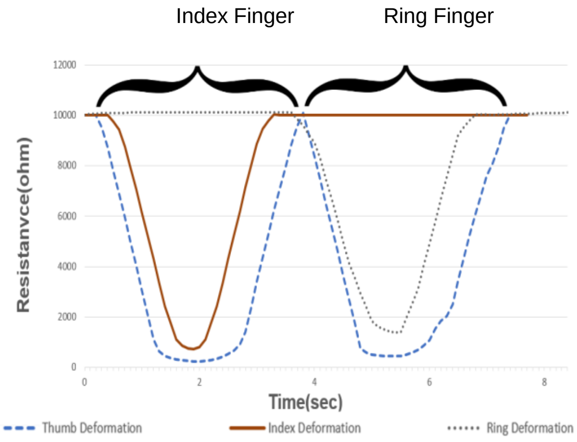

Figure 5 **Measured resistance across deformable sensors during deformation through flexion with the index then ring finger.**

Participants

We recruited 14 right-handed participants (8M/6F) from the university campus, aged between 20 and 53 years, with an average age of 26.7 (SD 3.7). None of the participants had experience with using the HandLog before.

Study Setup and Design

We implemented 2 desktop games, called HeliGrasp and FingerRacer. HeliGrasp is a side-scroller game where the player controls the height of a flying helicopter with the objective of collecting stars. FingerRacer is a racing game where the player navigates a car travelling on the highway with the objective of avoiding collisions with other cars. Both the helicopter and the car in the games travelled at a constant speed.

Our study had a 2x2 within subject design. Each participant played all 2 games using 2 different devices, HandLog and a standard keyboard. The order of the games was randomized between participants. We collected quantitative and qualitative data to compare game performance between the 2 devices, and investigate the usability of the device through player's experience. Game performance indicator was the number of stars collected for HeliGrasp, and race time for FingerRacer. Even though the car travelled at a constant speed, crashing into other cars on the highway affected race time.

To evaluate player's experience with the device and interaction style, a questionnaire and an informal interview was conducted after game play. The questionnaire collected data using a 10-point Likert scale. The assessment criteria were adapted from a list of usability characteristics provided by Hornbæk (2006) with the inclusion of immersion and physical exertion. The informal interview focused on the participants' preferences and experience, as well as their ideas and opinions on the application of the technology.

The HandLog is calibrated for each participant by capturing the maximal resistance value, corresponding to the maximum force the participant can apply to the device. Minimal resistance value is observed when the grip force is only enough to hold the device without any deformation.

For HeliGrasp, the participant controlled the height of the helicopter by performing a whole hand grasp on HandLog using flexion force of all fingers with a vertical grip (see Figure 6). The deformation of HandLog was mapped linearly to the helicopter's height by using the averaged resistance of all foam sensors. Maximal deformation, as per calibrated, brings the helicopter to the top of the screen, and minimal grip force drops the helicopter to the bottom of the screen. An average of the resistance value across all foam sensors is used for HeliGrasp, to represent the full hand grip. For keyboard condition, the up arrow key was used to raise the height of the helicopter. Each key press would increase the height by a fixed value. The helicopter would gravitate towards the ground if no key was pressed. The gravitation enables fair comparison for the HandLog where constant pressure needs to be applied to maintain the helicopter's height.

For FingerRacer, the participant held HandLog in a cylindrical grasp but only applied flexion force on the index and the ring fingers to steer the car. We asked participants to hold HandLog horizontally facing down with their right hand (see Figure 7), so that the index finger steered the car left and the ring finger steered right. The average value of 2 foam sensors for each finger (shown as blue dots in Figure 3) is used to mapped to the angle of steering for the car. The harder the participant press with the corresponding finger, the sharper the car turns. For the keyboard condition, arrow keys were used to steer. The participant pressed and held the key to continuously increase the steering angle.

Procedure

The study was conducted in a lounge room setting with participants sitting comfortably at a desk facing a TV screen, see Figure 8. Upon arrival participants signed a consent form and were then given an introduction to the games they would be playing and the inputs to be used for each. The participants were given a short practice run of each game using HandLog and the keyboard. Calibration of the games to the participants' ranges of flexion was performed during the practice run. The order of games and inputs for each participant was decided through random allocation. Following each game play session, participants were asked to complete a short questionnaire regarding their experience with the interaction style and Handlog. At the completion of the study a semi-structures interview was conducted. Each session was 30 minutes in duration.

Figure 6 The vertical grip: whole hand squeeze of the HandLog for the HeliGrasp game

Figure 7 The horizontal grip with flexion of index finger to steer the car for FingerRacer

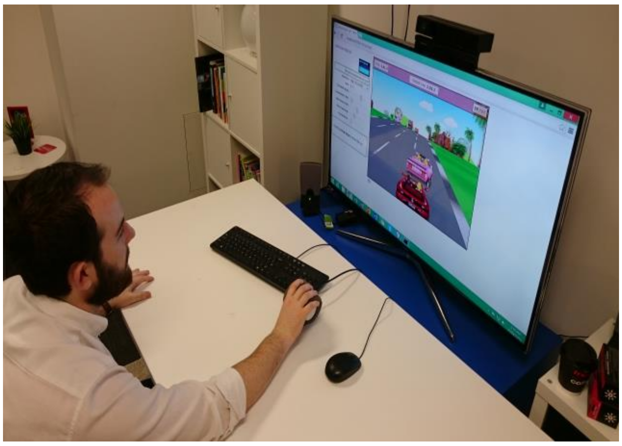

Figure 8 Study setup: participant is playing the FingerRacer game

RESULTS

Of the 14 participants, 12 were able to complete both games using the HandLog and its respective interaction style. One was unable to calibrate due to their hand being too small to reach the embedded deformation sensors. There was an error with capturing data for another participant. The quantitative results indicated that HandLog was comparable to keyboard for whole hand and individual finger interaction, while the qualitative results highlighted advantages with fluidity and engagement. There were limitations and challenges due to force exertion, especially for the ring finger.

Performance

Considering that HandLog is a novel input device and participants did not have any prior experience, we charted the performance data for each game play over multiple segments within the gameplay session, to identify how performance changes over the course of the game.

HeliGrasp

We did not find any significant difference between the 2 conditions for HeliGrasp. For HeliGrasp, the participants were asked to collect 50 stars. We divided the session into 5 segments of 10 stars each. We performed a paired t-test on the score of HeliGrasp for each segement, i.e. number of stars collected, for the keyboard and HandLog conditions, with a Bonferroni correction ($\alpha=0.05/5=0.01$). No significant result on any of the segment was found ($p1=0.025$, $p2=0.046$, $p3=0.05$, $p4=0.35$, and $p5=0.016 > \alpha$).

FingerRacer

We did not find any significant difference between the 2 conditions in the first 3 laps of FingerRacer. A significant difference was found for the last lap that affected the performance of HandLog.

For FingerRacer, each race was segmented into 4 laps. We performed paired t-tests on the lap time in FingerRacer for the keyboard and HandLog conditions, with a Bonferroni correction ($\alpha=0.05/4=0.0125$). No significant difference was found for the first 3 laps ($p1=0.04$; $p2=0.22$; $p3=0.49$), except for the last lap where it took the participant longer time to complete the lap using HandLog (mean 35.92s, SD 1.21) than using keyboard (mean 31.97s, SD 0.81) ($p4=0.0108<0.0125$).

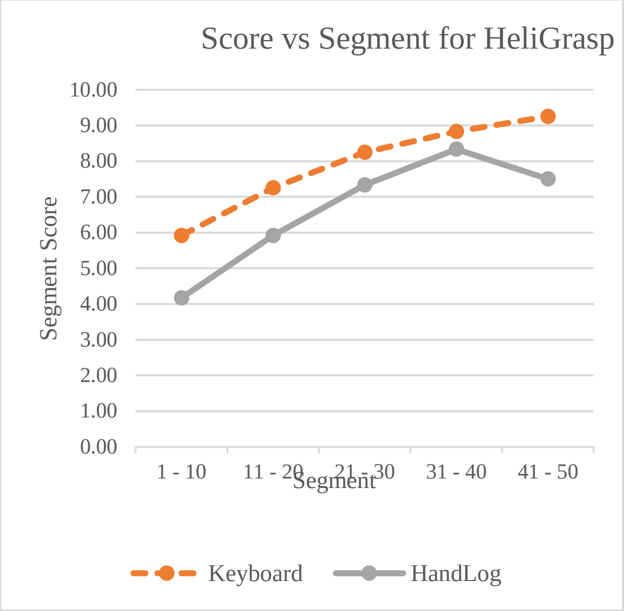

Figure 9 Score comparison for HeliGrasp by segment

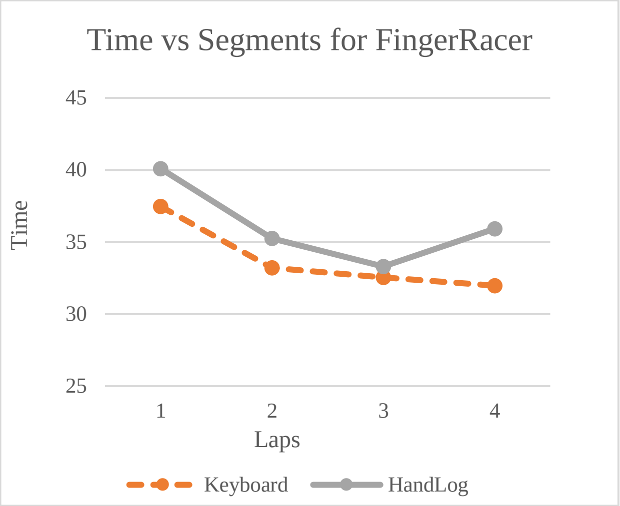

Figure 10 Time comparison for FingerRacer by lap

Figure 9 shows the mean score for each segment (the number of stars collected in a block of 10 stars) between the keyboard and the HandLog for the HeliGrasp game. Figure 10 displays the mean time for each lap of the race between the keyboard and HandLog in the FingerRacer game.

Questionnaire

We collected data on the following usability characteristics: enjoyment, focus (how well is their focus on gameplay without being conscious about the interaction with the device), immersion, preference, self-rated skill development, competence, frustration, difficulty, mental and physical exertion.

Means for participant characteristics were calculated and separated based on negative and positive connotation of usability. The results indicated participants felt competent using HandLog and that their skills with the interactions types improved throughout their gameplay. All participants were able to play the games without looking at the device. Figure 11 and Figure 12 summarise the mean score for the positive and negative characteristics of the questionnaire data.

Interview

Interview responses were transcribed and coded into themes, with 5 key experiences emerging.

Fluidity

Six of the 13 participants who played FingerRacer commented that playing with individual finger flexion through HandLog felt more fluid when compared to keyboard inputs. Fluidity was defined as the smoothness with which they were able to change direction when weaving through cars. Participant 7 commented that "*Especially in the driving (game), it felt a lot more fluid*" and "*turning was much smoother*". Participants also linked this greater level of fluidity to a higher level of engagement, enjoyment and an experience more similar to real life driving.

Size

The size of the device emerged as a common theme that participants would change to improve their experience with HandLog. Participant 6 commented that "*Something that really (fits) in my hand would be easier to use*".

Five of the 14 participants made similar comments about the size of the HandLog. The current prototype is measured a total of 90mm across with a 45mm core.

Ring finger

During the final interview and also throughout gameplay the use of the ring finger for flexion was described as difficult or unnatural. Five of the 14 participants made statements indicating that this interaction had caused them fatigue, or that they felt unnatural using their ring finger in that manner. Three participants indicated they would have preferred to use their middle finger to turn right.

Physical exertion

Physical exertion was mentioned by 8 participants as a factor that impacted their performance and/or enjoyment throughout gameplay. This is illustrated in the quantitative data of the FingerRacer where the performance dropped significantly for the last lap of the race.

Skill Development

Participant indicated a feeling of quick familiarity with HandLog and its interactions and a feeling of having significant skill development throughout gameplay. Six of the 14 participants felt very confident in the development of their skills with 3 participants mentioning that with practice or another play through they could beat their scores with the keyboard controls.

DISCUSSION

In our research, we set out to extend prior work within handheld input devices based on the principle of deformation (Kildal 2012) utilizing conductive foam (Smith et al. 2008). We have designed and created HandLog, a device which extends prior work by leveraging users' natural, innate skills in providing distinct continuous input from individual fingers, and presented the results of a user study which validates the interaction techniques afforded by the novel device.

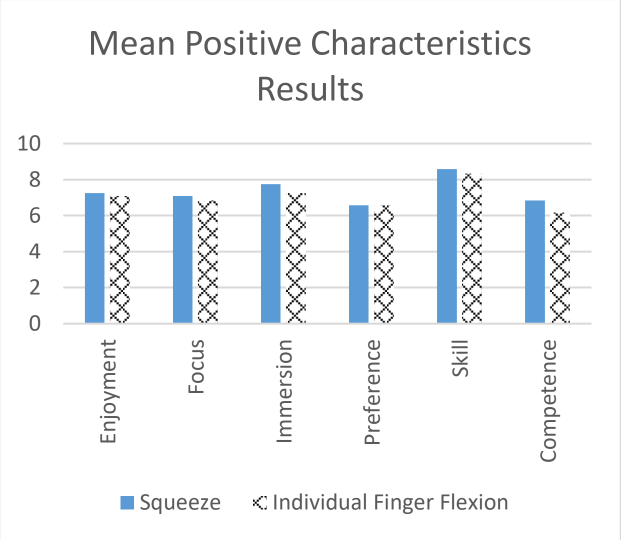

Figure 11 **Mean questionnaire results for positive characteristics**

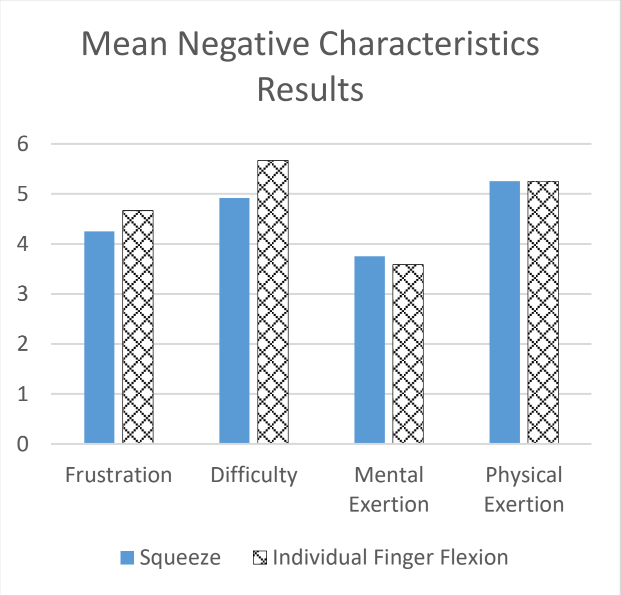

Figure 12 **Mean questionnaire results for negative characteristics**

The user evaluation utilised HandLog within a gaming context as a controller producing quantitative and qualitative data through the measurement of performance metrics, heuristics questionnaires and semi-structured interview. Quantitative results showed participants developed throughout gameplay a comparable level of performance to keyboard inputs, they also highlighted a performance drop-off in participants towards the end of gameplay which was linked to physical exertion. The quantitative questionnaire results showed that participants enjoyed the interactions with HandLog and that they felt competent with their device and their skills development. Semi-structured interview themes outlined the usage of the ring finger, size, physical exertion, skill development and fluidity as key themes.

Finger dexterity and exertion

Performance metrics for HeliGrasp indicated that there is no significant differences in the use of full hand squeeze and individual finger flexion as continuous input through HandLog, as compared to traditional keyboard input. The difference in performance metrics for FingerRacer in the last lap is a potential indication of fatigue when playing with individual finger flexion through HandLog than when using arrow keys. However participant improvement was noticed throughout the race, as discussed through survey and interview responses.

Participant statements made during the gameplay and the final interview noted the physical exertion on the ring finger in the racing game. Based on this insight it is suggested that future interactions utilizing individual finger flexion as an input should consider finger dexterity and focus more on the middle and index fingers. This is supported by a study by Li et al. (1998) demonstrating that the maximal force exerted by the index and middle finger is significantly larger than that of the ring and little finger. The result suggests that deformation through individual finger flexion with the ring finger input should be considered with care when designing applications. A gap in current understanding of what combination and pairing of fingers for input should also be considered for future research.

Size matters

We also gained significant insight into the user's preference and experience with the device. We found that the continuous interaction that is afforded by Handlog allowed for a more fluid and experience facilitating a more engaging and enjoyable experience.

During informal testing throughout the iterative design process of HandLog it was found that a smaller device felt more comfortable to hold and natural to use. This finding is supported by previous research conducted by Smith et al. (2008) on a spherical digital foam device. The users in their study commented that a smaller size would be more comfortable and easier to use, for two handed thumb palpation gestures.

Furthermore, we also learnt that one size does not fit all, when it comes to handheld input devices. One participant withdrew from the study because her hands could not perform a full grasp on the device. The design of HandLog caters for this variability by supporting swapping out the foam sleeve for different sizes as well as different foam density.

Our current implementation of HandLog only contains 7 sensors, which requires it to be grasped over a specific location. Future iterations of the device could utilize a more expansive sensor array to support grasp recognition, overcoming this limitation.

Continuous Input

The participants commented that using the continuous inputs of deformation was more enjoyable and immersive than discrete keyboard inputs and that the use of tangible input device did not distract from their focus on game play. This result is supported by the coded theme of fluidity from interview transcripts. Participants commented that during the racing game, the use of finger flexion felt smoother and more natural when driving between other cars, as they had more control over the turning speed. The experiment demonstrated the benefits of facilitating finger flexion as a continuous input, with more fluid interaction and enjoyment of game play.

Application

Research has identified that deformable objects have potential applications as input devices for serious games as a part of patient rehabilitation (Follmer et al. 2011). Current deformable devices within this area use discrete inputs through gesture recognition (Moraiti et al. 2015). Serious games with continuous inputs have the capacity through motion measurement to provide beneficial information to both therapists and patients in a rehabilitation context (Alankus et al. 2011). There are areas of physical rehabilitation therapy that can benefits from the exertion capability of HandLog, especially for hand exercise with individual finger exertion. Based on the success of individual finger flexion as a continuous input for simple games, future applications of this interaction style could explore this domain to develop an understanding of how the measurement hand based motions used in deformations can provide meaningful feedback to patients and therapists.

Applications for handheld deformable interfaces as controllers within the home have been explored based on their fit within the agenda of embedded and ubiquitous computing and the capacity to leverage the skills from our real world interactions to reduce cognitive load and allow user to focus on the task (Agrawal et al. 2015). The continuous input interaction style will be particularly suitable when the value selected from the range does not require is ambient or does not require precision where the advantages of reduced cognitive load are applicable and the precision of discrete inputs is not required. Based on these criteria two potential applications for deformation through finger flexion as a continuous input for selecting values within the home have been identified. To adjust ambient values such as lighting levels or volume and to choose the rate of fast forward and rewind where users can use their skills in finger flexion to rapidly shift from fast forwarding quickly to playing at a normal rate.

CONCLUSION

We have presented HandLog, a handheld deformable interaction device that supports deformation through finger flexion as a continuous input. It consists of a 3D printed cores inserted within a foam sleeve embedded with conductive foam columns. By measuring resistance changes across the columns during deformation, finger flexion motions can be mapped to digital data in real-time. Our experimental results demonstrated that participants could understand and use the device to play simple games through deformation with full hand finger flexion and individual finger flexion. The use of deformation through individual finger flexion as an interaction style was found to create a more engaging experience. A limitation was found to exist around the use of the ring finger to facilitate this form of input. There is great potential for HandLog to be applicable in other application domains, including hand exercise for rehabilitation and handheld controllers for smart homes in ubiquitous computing.

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