Flatland: An Immersive Theatre Experience Centered on Shape Changing Haptic Navigation Technology

Adam J. Spiers *Member, IEEE*, Janet van Der Linden,
Maria Oshodi, Sarah Wiseman, Aaron M. Dollar, *Senior Member, IEEE*

***Abstract*— Flatland was a large scale immersive theatre production completed in March 2015 that made use of a novel shape-changing haptic navigation device, the 'Animotus'. Copies of this device were given to each audience member in order to guide them through a 112m^2 dark space to large tactile structures accompanied by audio narration from the production's plot. The Animotus was designed to provide unobtrusive navigation feedback over extended periods of time, via modification of its natural cube shape to simultaneously indicate proximity and heading information to navigational targets. Prepared by an interdisciplinary team of blind and sighted specialists, Flatland is part performance, part in-the-wild user study. Such an environment presents a unique opportunity for testing new forms of technology and theatre concepts with large numbers of participants (94 in this case). The artistic aims of the project were to use sensory substitution facilitated exploration to investigate comparable cultural experiences for blind and sighted attendees. Technical goals were to experiment with novel haptic navigational concepts, which may be applied to various other scenarios, including typical outdoor pedestrian navigation. This short paper outlines the project aims, haptic technology design motivation and initial evaluation of resulting audience navigational ability and qualitative reactions to the Animotus.**

I. Introduction

Comparable experiences for visually impaired (VI) and sighted individuals are rarely achieved in daily life. Often 'VI accessible' versions of cultural experiences (e.g. in entertainment or the arts) provide large amounts of visual stimulus to people who can see, but limited audio descriptions to those who are VI. Examples include movies with additional audio descriptions. This creates a discrepancy, where the medium on display has been designed for sighted persons and later retrofitted for a VI minority.

In our work we seek to explore the possibility of designing immersive *promenade theatre* experiences for both sighted and VI groups. To achieve this aim we make use of a pitch black environment and haptic sensory augmentation technology. This aims to level the sensory abilities of both groups (VI and sighted) as they are placed together into an unfamiliar space, the exploration of which is encouraged via the theatrical setting. Promenade / immersive theatre is defined as theatre where the audience can move about to explore the piece rather than remaining stationary.

*Research supported by NESTA Digital Fund, London, UK.

A. J. Spiers and A. M. Dollar are with the Department of Mechanical Engineering, Yale University, New Haven, CT 06511, USA. (phone: 203-432-4380, e-mail: adam.spiers@yale.edu, aaron.dollar@yale.edu).

J. van der Linden and S. Wiseman are with the Pervasive Interaction Lab, Open University, Milton Keynes, UK (j.vanderLinden@open.ac.uk)

M. Oshodi is with the Extant theatre company, London, UK (maria@extant.org.uk)

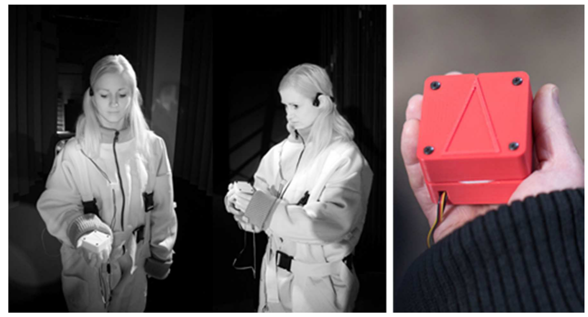

Figure 1: (Left) Audience members equipped with localization equipment, bone conducting headphones and *Animotus* (right)

As in most theatre, Flatland features a plot and characters. These were adapted from the 19th century novella *Flatland*, by E. Abbot [1]. An initial portion of this plot is explained by an actor during an introductory session. Subsequent elements of the plot may then be uncovered by locating *zones* in the performance space, each of which is defined by a large tactile set piece and audio narrative (delivered through wireless bone conducting headphones). In order to locate these set pieces and uncover the story, a haptic sensory substitution device, the *Animotus* (Figure 1), is provided to each audience member. This device was designed with the intention of presenting highly intuitive navigation assistance without distracting from the overall theater experience. This led to the choice of haptic shape changing feedback as the interface for simultaneously communicating both heading and proximity to the next *zone*, with continuous 100Hz updates. Intuitive and unobtrusive mutli-DOF haptic feedback is believed to be useful outside of this specific application, to enable a discrete alternatives to screen and audio based pedestrian navigation in real world scenarios, for both sighted and VI persons.

II. Haptic Device Design Motivation

Though this project is limited to a specific indoor environment, the navigation technology was designed with consideration of real world application to unstructured spaces, such as typical outdoor (and indoor) pedestrian navigation scenarios, complete with the constraints of sidewalks, corridors and obstacles. The technology was also designed to be 'inclusive', to benefit both VI and sighted individuals when the environment is not necessarily dark.

Though the advent of GPS and smartphones have made navigation guidance while walking outdoors commonplace, the main interface for this technology is screen based. In [2] this was considered (for sighted persons) as potentially distracting from various hazards and a possible cause of increasing mobile phone related accidents [3]. While screens are inaccessible for severely VI persons, the use of audio instructions during GPS navigation is used by many.

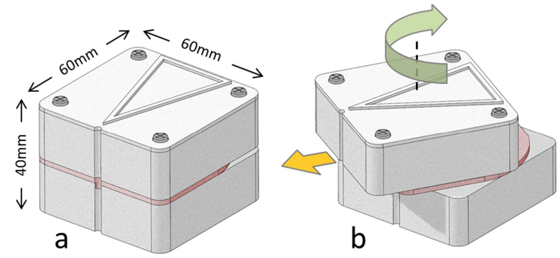

Figure 2: The Animotus a) in home pose, b) illustrating rotation and linear extension. These DOF may be individually actuated.

However, the requirement of headphones in noisy urban environments can mask the ambient sounds used to avoid hazards, appreciate one's surroundings or communicate with others [4]. Haptic interfaces may provide a more appropriate stimulus to both VI and sighted groups, due to the less critical role of touch during walking. Indeed, the most successful and long-standing VI mobility aids are the guide cane and guide dog, which both provide feedback by haptic cues delivered through the cane's handle or dog's harness. The appeal and benefit of haptic navigation to sighted individuals is also apparent in widespread consumer interest in the 'Taptic' interface of the recent Apple watch, which is capable to provide haptic navigation instructions [5].

Various haptic navigation and motion guidance systems have been proposed, often for reasons similar to those described above. The potential of haptics to provide sensory augmentation without drawing on critical attentional resources (i.e. sound and, if applicable, sight) has great appeal [6]. Though many haptic sensations exist, the authors of [7] highlighted that a frequent choice for motion guidance applications has been vibrotactile feedback (e.g. [4][6][8]). This technology has many benefits (the actuators are small, lightweight, inexpensive, low power and easy to control). Vibrotactile feedback is now standard feature in mobile phones where it is primarily used to signify discrete and (generally) infrequent events, such as a new message or incoming call. In [9] the success of such feedback is attributed to the 'firm fit with the usability constraints of signifying alerts'. Other authors [10] have suggested that alerts are not always an appropriate form of information delivery and that designers of technology should consider a haptic stimuli's place in a user's *attention spectrum,* so that it does not distract from more critical tasks. In our work, the goal was to present users with frequent navigation guidance over potentially long periods of time (up to 50 minutes), without interfering with the user's appreciation of the Flatland theatre experience. As such, 'alerting' stimuli were deliberately avoided, as it was felt that frequent high-attention feedback over such a time scale may become distracting or tiresome, as also observed in [8]–[10].

In [7] and [10] a number of wearable or chair-mounted tactile feedback devices are proposed that aimed to avoid 'alerting' sensations of other feedback modes. In [2], Hemmert et al. proposed the use of shape changing handheld objects to indicate direction in a simulated navigational task (users matched the indicated direction by turning an office chair). Considering such modalities as inspiration, the *Animotus* (Figure 1) was designed as a handheld haptic device that could provide constant navigational guidance over extended periods of time by changing shape in the user's hand.

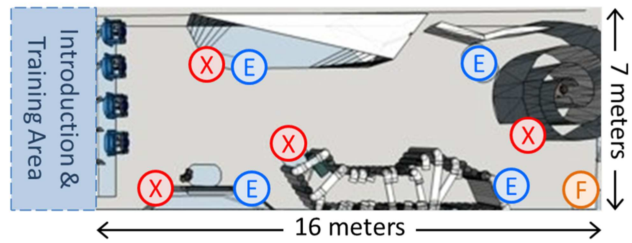

Figure 3: The performance environment, showing (E) zone entrances, (X) exits, (F) final exit and physical zone structures.

The *Animotus* was developed through multiple diverse prototypes, focus sessions with sighted and visually impaired members of the Flatland production team and laboratory based user testing (the outcomes of which will be reported on in separate papers). The final version of the device and its associated articulation is illustrated in Figure 2. When in its *home* pose (Figure 2a), the device shape approximates a cube with rounded edges and dimensions (60×60×40mm). The top half of this cube is able to independently rotate (±30deg) and translate (11.75mm) relative to the bottom half. This allows the device to indicate direction (heading) and distance (proximity) to a navigational target. An embossed triangle on the top of the Animotus is a simple tactile feature to allow a user to identify the top and front of the device, when it cannot be seen. A tactile groove that traverses the front face aids heading perception by aligning when heading error is 0deg.

By holding the device in their upturned (supinated) hand (Figure 1) a user naturally wraps their fingers around the front and sides of the device in a power grasp. The height of the device was selected to permit this grasp to be achieved for a variety of hand sizes. In this grasp the bottom half of the device is grounded on the user's palm, while the relative pose of the top half may be felt by the user's fingers. The force and torque exertion capability of the linear and rotational DOF are 25N and 1Nm respectively, allowing the device to exert sufficient forces to achieve motion, even when gripped tightly. The device weighs 105g and is 3D printed in ABS. Eight of these devices were built, at a cost of $75 each. Each Animotus is controlled by an X-OSC wireless microcontroller and powered by a LiPo battery (120g combined weight). These are worn by the user in a pouch and connected to the Animotus via cables, though future iterations may integrate the components into the device.

Within the Flatland environment (16 x 7 meters), each Animotus served to direct its audience member from one zone to the next, allowing them to gradually uncover the production's plot. An illustration of the environment is presented in Figure 3. Note that most zones have separate exits and entrances, though not all audience members adhered to these. Each Animotus responds to the position and orientation of its user (audience member) by continuously updating its extension and rotation axes (at 100Hz), with respect to the current navigational target. Audience position was measured via a Ubisense localization system, via small active radio tags (weight 40g) worn by each audience member. Orientation was measured via a wrist worn, tilt compensated magnetometer. Together these systems allowed wireless localization of individuals with 0.4m / 2deg accuracy at 100Hz. A centralized navigation computer compared user position and orientation with the co-ordinates of the virtual navigational targets (the entrances to the zones). This generated appropriate actuator commands, sent wirelessly to each Animotus. Heading feedback was provided at 1:1 mapping of user heading error to Animotus rotation angle (saturated at ±30deg). Proximity feedback was scaled to proximity error at approximately 1.65mm of actuator feedback (up to 11.75mm) per meter of proximity error. Once a user had found their current target zone, their Animotus assumed the dormant 'home' pose, allowing the user to explore the zone and listen to the audio narrative. A large pocket on suits worn by the audience (also part of the narrative) allowed the Animotus to be temporarily stowed, if the user wanted to use both hands to explore a zone. The Animotus would begin guiding the audience to their next target zone once they left their current zone. Each audience member was assigned a different zone order to avoid crowds forming. All audience members were simultaneously guided to an exit at the end of the performance, for a plot conclusion.

III. Observations and Evaluation

Flatland was experienced by 94 individuals, 15 of whom were VI. Evaluation was achieved quantitatively (through logged localization data) and qualitatively (via interviews). All audience members signed a consent form approved by a University ethics board. Numerical analysis gave insight into a large data set from a varied pool of individuals. Though the Animotus was initially developed under controlled laboratory conditions, Flatland provided an opportunity for in-the-wild testing of this technology with users who were not necessarily focused on completing an experimental study. Of the 94 audience members, 82% were able to locate all zones in the space, 12% (2 VI, 9 sighted) missed one zone and 6% (2 VI, 4 sighted) missed more than one zone.

Analysis of localization data was completed on user trajectories between zones, referred to as paths. For each path it was possible to calculate metrics such as average walking speed (*user distance / time elapsed between zones*) and motion efficiency (*Euclidean distance / User distance between zones*). 50% efficiency indicates the user has walked twice as far as the Euclidean distance. For each participant, the mean of each path metric was calculated. Histograms of this are shown in Figure 4. Both metrics show a symmetric distribution centered on 47.5% walking path efficiency and average walking speed of 1.125m/s. This illustrates a wide range of participant performance. In a yet unpublished lab study, we found a 1DOF shape changing navigation device from a previous 2010 immersive theatre performance [11] to lead to an average path efficiency of 27%, thus indicating navigation interface improvement. Typical human walking speed is 1.4m/s [12], illustrating a surprisingly small average reduction in pace. Analysis of individual paths is underway.

Audience reaction to the Animotus varied greatly. Some relied fully on the device, noting surprise at how intuitively they were able to use it and commenting that without it they would have been lost. One individual found the device too controlling, preferring to ignore its instructions. Though no attempt was made to make the Animotus seem like a person or animal, audience members instilled emotional and characterful traits, for instance referring to it as being "cute", "hesitant", "a companion" and "like a pet".

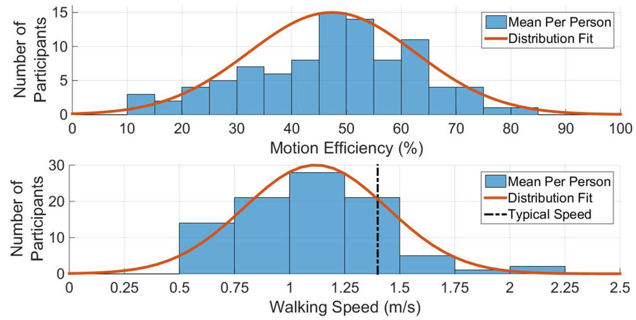

Figure 4: Histograms of mean motion efficiency and walking speed per participant (n = 94). Typical speed is based on [12].

IV. Discussions and Future Work

This work-in-progress paper has focused on the haptic navigation interface used to guide audience members between *zones* in the Flatland immersive theatre experience. This project has highlighted the role haptics can play in unifying cultural experiences across individuals of different sensory abilities while also demonstrating the results of in-the-wild testing of a unique shape changing device. Future work includes in-depth analysis of the extensive data generated from Flatland in addition to application of the Animotus to other navigational scenarios. For example, the device may provide haptic guidance to a distant destination via successive waypoints or route (path) following. Attention loading comparisons of this system with other navigation interfaces would also be interesting.

References

[1] E. A. Abbott, *Flatland: A Romance of Many Dimensions*. Oxford University Press, 1884.

[2] F. Hemmert, S. Hamann, and M. Löwe, "Take me by the hand: haptic compasses in mobile devices through shape change and weight shift," *Proceedings of the 6th Nordic Conference on Human-Computer Interaction*, 2010.

[3] J. L. Nasar and D. Troyer, "Pedestrian injuries due to mobile phone use in public places.," *Accident; analysis and prevention*, vol. 57, pp. 91–5, Aug. 2013.

[4] R. Velázquez, "Wearable Assistive Devices for the Blind," *Wearable and Autonomous Biomedical Devices and Systems for Smart Environment*, pp. 331–349, 2010.

[5] "Apple Watch Technology," 2015. [Online]. Available: https://www.apple.com/watch/technology/.

[6] S. M. Kärcher, S. Fenzlaff, D. Hartmann, S. K. Nagel, and P. König, "Sensory augmentation for the blind.," *Frontiers in human neuroscience*, vol. 6, no. March, p. 37, Jan. 2012.

[7] A. A. Stanley and K. J. Kuchenbecker, "Evaluation of tactile feedback methods for wrist rotation guidance," *IEEE Transactions on Haptics*, vol. 5, no. 3, pp. 240–251, 2012.

[8] S. K. Nagel, C. Carl, T. Kringe, R. Märtin, and P. König, "Beyond sensory substitution--learning the sixth sense.," *Journal of neural engineering*, vol. 2, no. 4, pp. R13–26, Dec. 2005.

[9] I. Oakley and J. Park, "Did you feel something? Distracter tasks and the recognition of vibrotactile cues," *Interacting with Computers*, vol. 20, no. 3, pp. 354–363, May 2008.

[10] Y. Zheng and J. B. Morrell, "Haptic actuator design parameters that influence affect and attention," *2012 IEEE Haptics Symposium (HAPTICS)*, pp. 463–470, Mar. 2012.

[11] J. van der Linden, Y. Rogers, M. Oshodi, A. Spiers, D. McGoran, R. Cronin, and P. O'Dowd, "Haptic reassurance in the pitch black for an immersive theatre experience," in *ACM Ubicomp Conference*, 2011,

[12] R. C. Browning, E. a Baker, J. a Herron, and R. Kram, "Effects of obesity and sex on the energetic cost and preferred speed of walking.," *Journal of applied physiology (Bethesda, Md : 1985)*, vol. 100, pp. 390–398, 2006.