ViPong: Probabilistic Haptic Feedback for Eyes-Free Interaction

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Abstract

We describe a mechanism for the delivery of haptic feedback to users of a simple game via the use of probabilistic inference. This not only enables the creation of dynamically changing game conditions but also a more adaptable, accessible and enjoyable haptic gaming environment for potential use by visually impaired users. The ViPong proof of concept application uses a mouse instrumented with a custom built lateral vibrator to enable a person to compete eyes-free in a game of pong using only haptic feedback linked to the position of the ball. A preliminary user study shows that it is possible to build eyes-free games using such a mechanism for haptic feedback generation. It also shows that there is some effect on the game play from varying levels of uncertainty injected into the algorithm, with participants performing less well under condition where the uncertainty added to the position of the game ball is high.

Index Terms: H.5.2 [Information Interfaces and Presentation (e.g., HCI) (I.7)]: User Interfaces (D.2.2, H.1.2, I.3.6)—Haptic I/O, Evaluation/methodology

1 Introduction

Haptic feedback greatly enhances the interaction with computational devices. The use of discrete vibrational pulses has been shown to reinforce a user's sense of interaction with touch-screens, for example [8], where the reassuring mechanical click of a button is no longer present. Similarly, more continuous forms of haptic feedback have been used in an attempt to increase a user's sense of interaction and overall performance with a system. Yao and Hayward [16], for example, present the simulation of a ball rolling inside a tube with haptic feedback generated from the combination of a physical model and a custom made actuator. They found via the use of continuous feedback that the size of an inner cavity, inside which the virtual ball was moving, was guessed accurately by most participants.

The term eyes-free interaction is often referred to when talking about technologies for the visually impaired but it is increasingly referred to the design of interactive systems for the wider population, who may instead require their visual sense to be freed up for other more important tasks. For example, [2] describes the design of a system that enables eyes-free interaction via 3D audio feedback with a radial pie menu on a mobile device. The study finds that users were less distracted and could walk closer to their normal pace while interacting with the mobile device without the need to look at the screen. Similarly, Smyth and Kirkpatrick [10] report the design of a haptic eyes-free version of a GUI tool pallet operated using a phantom device. They found that although no improvement in performance over the traditional visual interaction was observed, equally no significant drop in performance was observed. Users were able to learn the technique quickly and free the use of their visual sense for other tasks.

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The design of easy-to-use, attractive and accessible haptic games for people with visual impairments presents a number of issues. Even the most basic characteristics of today's mainstream games include elements that it is still very difficult to represent in touch, such as 2D or 3D graphics, see for example [1, 4, 9]. In addition, given that even some relatively simple games involve the tracking of multiple objects and events, it can prove extremely difficult to represent these accurately via use of the haptic and/or audio modalities. The selection of what game features to represent as haptic, how to do it and when to do it is not straightforward [12]. But attempts at this have resulted in two main approaches to the design of computer games for people with visual impairments [7]. One approach is to design games that are inherently non-visual. The interaction with such games is exclusively based on audio and/or haptic cues. An example of such a game is Haptic Sudoku [5]. In this game, players can feel the Sudoku board and scan the numbers using a haptic display. Audio cues inform gamers about the outcome of their actions.

Sensory substitution is another approach that replaces cues which would normally come from the visual channel by haptic or audio stimuli. This not only allows designers to create completely new games but it also enables the adaptation of existing games designed for users without visual impairments. Blind Hero [17] is one such example where sensory substitution has been applied to Guitar Hero from Red Octane, a rhythm-based action game that is played by using a guitar shaped input device with colored buttons. The buttons must be pressed after the appearance of visual cues on the screen. In Blind Hero, the visual cues are replaced by haptic cues coming from a motor-based glove device. A user study showed that players with visual impairments were able to play the game successfully and enjoy it. VI-Tennis and VI-Bowling are other examples of games based on sensory substitution [6]. In this case the haptic interface is based on a motion sensing controller enhanced with vibrotactile and audio cues enabling players to detect key events (e.g. a ball bouncing) in the game play.

More generally, the generation of haptic feedback for interactive systems has largely been limited to discrete pulses or vibration patterns triggered by specific system events [3]. One problem with this approach is that it needs to be manually adapted to the specific scenario of use and specific game events. There has though been some movement towards the generation of more continuous feedback using physical metaphors such as in [16], described above. And Strachan et al [11], who describe the use of a rotational dynamical systems metaphor to produce continuous haptic feedback related to interaction with a touchscreen device. We describe here a probabilistic approach to the generation of haptic feedback that aims to provide visually impaired players with access to existing games. This haptic feedback module may then be used to augment existing games with adaptable probabilistic feedback that it is possible to render in multiple modalities making the feedback both more flexible and less subjective than previous 'hand coded' methods.

Williamson and Murray-Smith [14] describe a method to improve user audio feedback through the display of time varying probabilistic information via the use of granular synthesis. They show that by combining an asynchronous granular synthesis technique with Monte Carlo sampling, used to predict future states of nonlinear dynamic systems, that it is possible to sonify a user's potential goals, and their progress toward achieving them in situations where visual display may be impractical. Using a similar approach to the provision of non-visual feedback we use Monte Carlo sampling to predict the future position of game objects, in this example the pong game ball. This approach enables an eyes-free player to sense the approach of the ball by interacting with the generated particle cloud, an example of which is observed in figure 3, via audio or tactile feedback. The relative amount of uncertainty injected into the simulation, a simple parameter change in the algorithm, holds the potential to dynamically change the difficulty of the game. It is hypothesized that a higher level uncertainty will make the determination of the position of the ball more difficult for the user, thus increasing the overall sense of difficulty of the gameplay.

In the remainder of this paper we describe the hardware created for this research, our example application and finally a user study designed to first, test the utility of this approach to enable eyes-free gaming and second to test the hypothesis that increasing or decreasing the injected level of uncertainty has an effect on the perceived difficulty of the game play.

2 HARDWARE

Haptic stimulation is provided to the user by means of a modified mouse equipped with a custom built vibrotactile stimulator as illustrated in figure 1. The actuator is able to deform the fingertip laterally in the proximal-distal and medial-ulnar directions. The use of lateral stimulation reproduces the change in friction similar to that a finger experiences while exploring a textured surface. Such devices have been previously used to reproduce tactual texture with a high degree of realism [13].

Figure 1: The *viTouch* mouse with integrated vibrotactile display.

The deformation of the skin is generated using electromagnetic forces. The surface in contact with the fingertip embeds a permanent magnet attracted by three electromagnets equally distributed on a surrounding circle as illustrated in figure 2. The force applied to the permanent magnet is regulated by independently modulating the current in each electromagnet. To guide the motion in the horizontal plane an elastic suspension connects the magnet to the frame of the actuator. The suspension also acts as a spring that holds the magnet at the center position when no current is present. The actuator has a mass and stiffness similar to that of the fingertip in order to guarantee that the fingertip is stimulated with a deterministic displacement up to 0.1 mm over a frequency bandwidth of 10 – 400 Hz. Even intense vibrotactile stimuli can be accurately rendered.

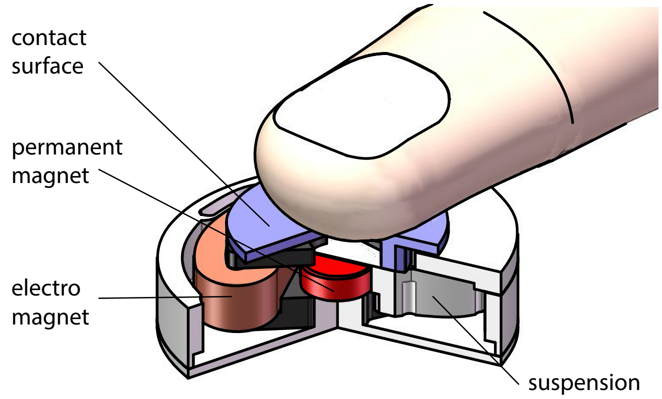

Figure 2: Cross section of the vibrotactile actuator. Electromagnetic forces applied on the permanent magnet, laterally deform the pulp of the fingertip.

An electronic board converts an audio signal originating from the soundcard of the computer to vibrations at the fingertip. It is also possible to encode the direction of the vibration in the left and right channels of the audio output. The electronic schematic was designed with special attention paid to lowering the output noise well below the perceptual vibrotactile detection threshold. The theoretical noise floor of the complete electromechanical system is 50 nm of amplitude. The stimulator is embedded in a modified Logitech LS1 Laser mouse with the original undercarriage of the mouse used along with a 3D printed mould on top.

3 VI-PONG

The viPong application is based on the classic console game. As described above, a particle filter simulation is used to predict future positions of the game ball, which are dictated by a fusion of both the physics of the ball and all the external influences that may have some effect on the position of the ball, such as walls or obstacles, for example. The physics of the ball in this case are very simple in that the ball only has an initial direction of movement and velocity that is used to integrate the position along the screen. When the ball reaches the end of the screen it collides with the user's bat or 'paddle' and is rebounded. In the original Pong game the velocity of the ball would be increased at this point and the angle of reflection would depend on the point of collision with the paddle (i.e. centre of paddle - 0°, edge of paddle - 45°). But, as we wanted to make the comparison of performance between each user more comparable during the experiment during the experiment, we chose to keep the velocity of the ball and angle of reflection constant.

The particle filter predictions of the possible future positions of the ball are thus only influenced by the randomness injected to the initial direction of travel (between +/- 45°) before the simulation begins. This level of uncertainty has an effect on the particle prediction cloud as illustrated in figures 3 and 4, which shows future ball position predictions with both high and low uncertainty added to the initial direction of the ball. As we will see in the user study section the variation of this single parameter holds potential to alter the overall game play experience. Uncertainty may also be injected to the initial velocity of the ball but was not modified in this case.

The reason for choosing such a simple simulation for this first demonstration is two-fold. First, we are able to clearly demonstrate the purpose of the feedback mechanism using such simple dynamics. And second, we are able to conduct a preliminary user study and draw conclusions based only on the effect of the variation of the injected uncertainty that are unaffected by any complex underlying dynamics or external influences on the feedback that may be

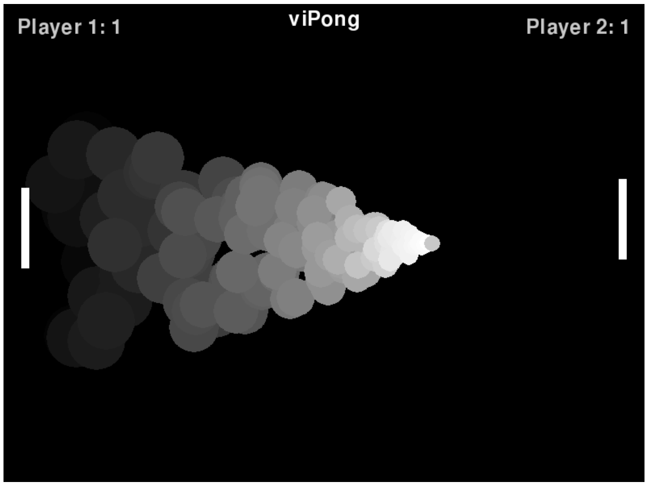

Figure 3: Pong ball future position simulation for the high uncertainty condition. The ball is moving from right to left. Circles representing predictions further in to the future are given a larger radius.

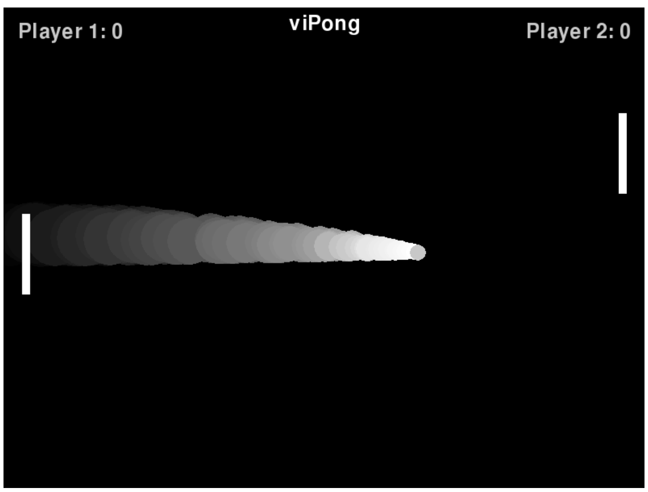

Figure 4: Pong ball future position simulation for the low uncertainty condition. The ball is moving from right to left. Circles representing predictions further in to the future are given a larger radius.

integrated in to later, more complex applications. It is also for this reason that directional vibration functionality described above was not exploited by our application but this does hold the potential in future iterations to provide useful directional information coupled with the presence information from the vibration alone.

4 Haptic Feedback Generation

Haptic feedback is generated directly from the particle simulation in a way similar to that described in [15]. The authors describe an eyes-free GPS navigation system that enables a user to explore an area using a Monte-Carlo simulation of the user's future positions. This combined with pointing and scanning motions from a mobile device, enabled the particle prediction cloud to be moved around in the space and used as a probe for any virtual information that may be present in this physical space. Haptic feed back is generated directily from the Monte-Carlo prediction particles as they interact with this virtual information. The resulting 'impact' of a particle with an object was displayed to the user in both audio and vibration via their mobile device. As more particles impacted with the virtual object the corresponding energy was increased and mapped directly to vibration.

In a similar way, we generate a pulse of haptic feedback for each particle prediction that 'impacts' or interacts with the user's game paddle, illustrated in figures 3 and 4. As more particles impact with the paddle they increase the overall energy imparted to the paddle, which is correlated to the amplitude of a pink noise signal, which drives our lateral vibrator. Higher amplitudes indicate stronger vibration. Particles further along the simulation or further ahead in time, i.e. the larger particles in figures 3 and 4 are considered to contain less energy so that when the ball is further away from the paddle the particles with higher energy (the younger particles) do not impact with the game paddle and the user experiences less vibration. As the ball moves closer the level of vibration increases until the point where the actual game ball impacts with the paddle and a slightly different signal is sent to the vibrator to indicate that the ball was hit successfully.

Using this approach a user feels a simple gradient of vibration corellated to the distance of the ball from the paddle. This kind of feedback can be likened to the audio feedback received from a geiger counter as more radiation is sensed. In more complex games with more complex dynamics where there are potentially several particle streams, depending on the relative outcome, it becomes possible for the user to feel the most likely outcome and adjust their gameplay appropriately.

5 User Study

In order to demonstrate the utility of this kind of dynamic probabilistic mechanism for delivering informative feedback, an initial user study was conducted first to demonstrate the basic hypothesis that eyes-free interaction with a simple game is possible and second to demonstrate that one parameter change in our feedback generation algorithm can alter the user's interaction with the game and potentially their overall gaming experience.

5.1 Method

Eight participants (2F, 6M, aged 21 to 38, M=31) were recruited to take part in the study. As this was a preliminary study, done to test the feasibility of the principle in a future more complex game, none of participants had visual impairments but all were blindfolded when playing. Each participant was briefed about the game and the feedback mechanism was demonstrated. Extra feedback was added to the game to indicate to the user when they had reached the extremities of the game field of play, i.e. the top and bottom of the screen in figure 4. This took the form of an audio signal that lasted for the time that the user's game paddle was in this zone. After 2-4 minutes of training in the visual case, both with and without feedback (a typical example of which is shown in figure 5), the users were then blindfolded and asked to play three 120 second games while receiving feedback with high, medium and low levels of uncertainty injected to the system. The three levels of difficulty were delivered in a random order to each participant. In order to make the comparison between participants easier the speed of the pong ball was kept constant and the angle of reflection from the user's paddle was kept constant. This allowed each participant 7 attempts to return the ball for each condition.

5.2 Results

Results show that it was in fact possible for user's to play the game using only our haptic feedback mechanism after a small period of training. Figure 5 shows an example trace from a sighted user for comparison purposes and figures 6 and 7 show the paddle trace for two different participants; one in the low uncertainty case and one in the high uncertainty case. From both figures it is clear that the participants had some control over and were able to return the ball unsighted.

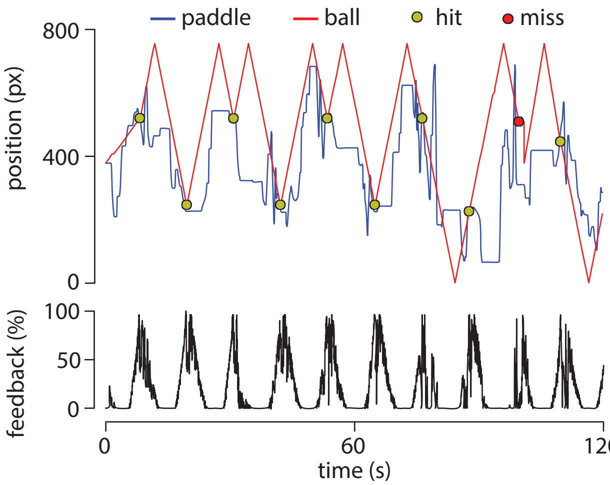

Figure 5: Example data for a user playing the game with visual feedback only. The user only has control of the y-position of the game paddle (blue line). The game ball (red line) is either reflected by the paddles (yellow circle) or missed (red paddle).

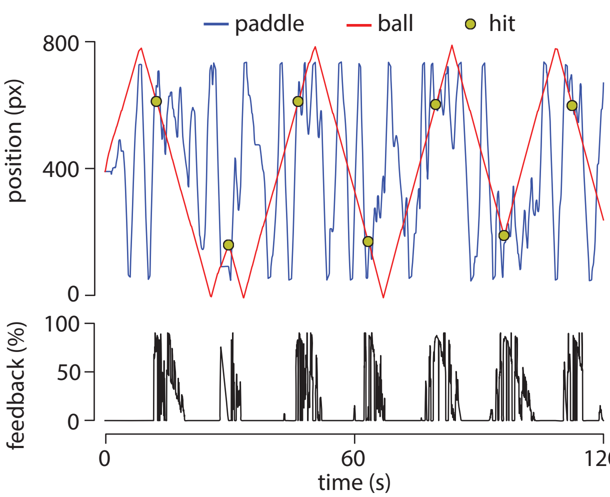

Figure 6: In the low uncertainty condition a blindfolded participant continuously scans the whole space and refines the search when feedback is detected.

Overall, 75% of balls were returned successfully. Figure 8 shows the average number of hits and misses for each uncertainty condition along with the actual values for each individual participant. This shows that on average the participants were less successful in the high uncertainty case.

In order to further answer the question of whether the level of uncertainty injected had some effect on the user's performance we calculated a measure of the energy of in the paddle trace for each participant computed using the following:

$$\frac{1}{T}\sqrt{\sum_{t=0}^{T}\left(\frac{dx}{dt}\right)^{2}} \tag{1}$$

Where x is the paddle y-position. This was designed to give us a measure of the amount of effort expended in the movement of the paddle and hence an objective measure of the difficulty of the task for each participant. Figure 9 shows that on average less effort was

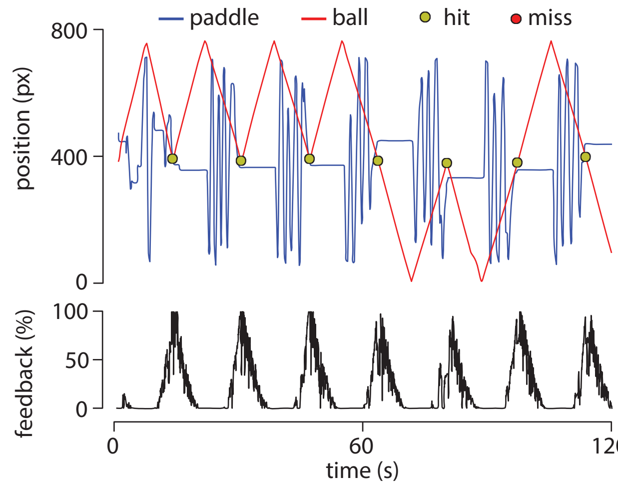

Figure 7: A blindfolded participant with a well-defined strategy continuously searches the space until feedback is located and the ball is returned. They then wait for the ball to hit the other side of the screen (indicated by a short pulse) before recommencing the search.

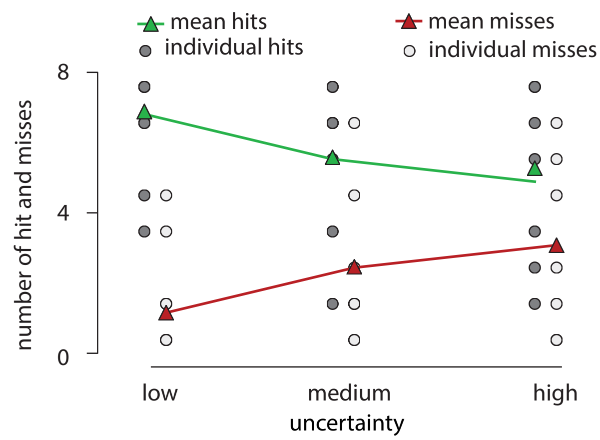

Figure 8: Successful hits and misses for all participant. The mean number of successful returns (green triangles) show that participants were on average less successful in the high uncertainty case than the low uncertainty case. The black dots show the individual hit (left) and miss (right) values for each participant.

expended in the high uncertainty condition than the low uncertainty condition.

In a post-experimental interview, the participants said they found the haptic feedback very useful for creating a mental image of the game environment and the movements of the ball. The majority (7/8) suggested that it should be longer to help them better anticipate the adaptation of their strategy and gradual (i.e. becoming clearly stronger when the ball is approaching and weakening when the ball is going away). Five participants preferred the high uncertainty condition and thought they were the most successful in this one, even though this was not necessarily true. Their preference was explained by the fact that they found this condition the most stimulating one.

6 Discussion

From this initial study it is clear that there is some effect of varying the level of uncertainty in the haptic feedback delivered to the

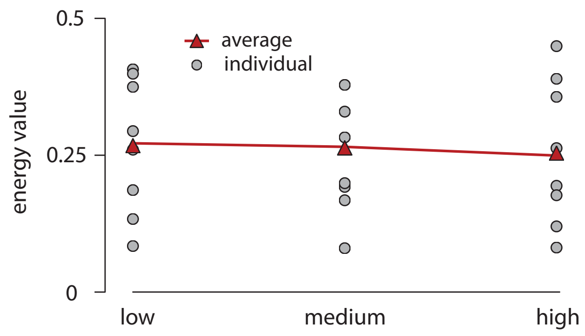

Figure 9: Mean energy for each level of uncertainty. The mean energy value for the paddle movement decreases slightly from the low uncertainty condition to the high uncertainty condition. Black dots indicate the individual values for each participant.

players. The fact that participants were less successful in the high uncertainty case can be explained by a combination of our objective measure and the subjective feedback from participants. In this case there was more feedback in general, so while it was easier to find the feedback, it was more difficult to precisely locate the position of the ball in the cloud, making this condition less successful. However, the spread of the haptic feedback made the participants feel more confident in their performance, although this was not necessarily and objectively true. At the same time, the lower predictability of the position of the ball made them really enjoy the game as it enhanced its playability. Conversely in the low uncertainty condition, when the feedback cloud was located the position of the ball was also located, which made the game relatively easier but less enjoyable. These findings back up our initial hypothesis that low uncertainty would lead to better performance and this is rather intuitive if we consider the participants lack of experience vibrotactile systems in general. While locating a vibrating region in a space was relatively simple for most participants, the searching of that space for regions of higher or lower vibration is not. Further work is required to examine exactly to what extent participants can search and locate specific regions within a vibrotactile space. While the results from this initial study are encouraging in that they show there is some effect of varying the level of uncertainty, a more rigorous study with more participants is likely to yield clearer results with a more precise characterisation of the observed effects.

7 Conclusions and future developments

We have introduced a mechanism for delivering flexible and dynamically adjustable haptic feedback to users of eyes-free games. With this basic example using a simple game we have shown the potential for this probabilistic feedback mechanism to aid the design of eyes-free games and eyes-free feedback in general, when combined with our custom built lateral vibration device. In this case the incorporation of our device into a mouse proved to be successful but given the versatile nature of the vibrotactile actuator used there also exists the opportunity to enhance and evolve the kind of vibrotactile feedback delivered to the user. This includes the investigation of the use of variable texture roughness, for example. Since this device was designed to reproduce such variable textures, the incorporation of this facility to our gaming environments will enhance further the gaming experience.

Use of this device is not limited to a mouse, there is also potential for use in other contexts, such as gesture based interaction, for example. In this context such a device, when placed on the user's finger, could increase the utility of such systems and provide a user with vibrotactile feedback in a context where it is currently lacking. Another potential application includes navigation applications where an eyes-free form of interaction is sometimes beneficial. The ability to control the lateral vibration direction of our device, while not exploited in this study, could prove to be extremely useful in this case.

While this research is still in an early stage there are encouraging signs that this versatile mechanism for providing haptic feedback can be refined and applied to more complex gaming experiences. Any game with a moving agents can have this kind of feedback added to provide eyes-free information about the location and direction of travel. Future work will focus on gradually increasng the complexity of such eyes-free games using the versatility of our actuator combined with our feedback mechanism to not only provide haptic information about the position of a single object but also to differentiate varying objects.

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