Bi-manual Skin Stretch Feedback Embedded within a Game Controller

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ABSTRACT

This paper presents the design and initial characterization of a video game controller prototype with tactile skin stretch displays embedded into its thumb joysticks. This work builds on previous work using lateral skin stretch at a single fingertip to provide direction cues. Our game controller allows a gamer to receive directional tactile feedback through the same interface he/she makes game inputs, and has the potential to enhance the gaming experience. Direction cues correspond to the direction of applied skin stretch. Modern game controllers typically have users angle their thumbs diagonally inwards to reach the joysticks, however, this may affect the cognition of skin stretch cues. Testing with a game controller prototype that allows for both forward and angled alignment of the user's thumbs shows no significant difference in accuracy or response time due to thumb orientation. Our results show no significant reduction in performance due to the required mental rotation of stimuli delivered in the angled thumb configuration. Furthermore, the angled thumb configuration appears to have ergonomic advantages. A more integrated game controller prototype is in development, which will permit further human factors testing to examine effects such as stimulus masking.

KEYWORDS: Haptic device design, tactile display, direction cueing, video gaming, skin stretch feedback, shear feedback.

INDEX TERMS: H.1.2 [Models and Principles]: User/Machine Systems--Human information processing; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Design for wearability; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O

1 INTRODUCTION

The video gaming industry is an ever growing market that is continuously searching for new and innovative ways for users to experience their gaming environments [1].

When haptic interfaces first entered the mainstream gaming market in the mid 1990s they were considered revolutionary. Suddenly gamers could experience the forces rendered on a joystick while playing flight simulator games, they could feel the gravel beneath their virtual cars as they drove in racing games, and they could even feel the clash of two dueling lightsabers in Star Wars themed games [2]. However, little has changed in the haptic rendering systems used in home gaming consoles since Nintendo's 1997 release of the "rumble pack" for the Nintendo64 system. Then, like now, the haptic sensation given by a game controller is created by a simple eccentric motor, causing a vibration. We believe that in order for haptics in game controllers to continue advancing we must begin integrating new forms of tactile communication that go beyond the simple buzzing of an eccentric motor. Specifically, we seek to explore the integration of fingertip skin stretch feedback into game controllers. With this addition, direction cues that correspond to the direction of applied skin stretch can be communicated to a gamer, directly through his/her sense of touch.

Our new game controller has the potential to enhance the gaming experience, as it will provide a new way for games to communicate with users, e.g., using tactile direction cues applied to the left thumb to communicate where a gamer should move to escape an opponent, while presenting cues to the right thumb to indicate where a player was hit by an opponent. Skin stretch feedback can also complement current audio, visual, and vibrotactile cues. For example, in a fishing game the force of a fish pulling on the line as it jumps can be seen in the bend of the rod and heard in the splash of the water. These forces could also be presented to the player as scaled skin stretch tactor motions as a form of sensory substitution. Another use might be to pulse the motion of the skin stretch tactor along with vibrotactile feedback in a cadence to match machine gun fire, to enhance the player's sense of immersion. However, it is important to understand how to best present this new information. This is especially true given the possibility for both perceptual and cognitive masking to occur. In particular, this paper investigates response times and accuracy for identifying direction cues using two different controller configurations, and compares these results to previous studies.

We first present the design of a game controller with bi-manual skin stretch feedback, which was designed for perceptual and cognitive testing. We then present experiments that provide a baseline characterization of user performance with the game controller and discuss these results. Progress towards a more refined and integrated game controller prototype is also presented along with plans for future work.

2 BACKGROUND

We are interested in providing direction cues through an interface embedded within a handheld device – ideally we would like to have the ability to communicate independent direction cues to both the right and left hands. Having such an ability would allow different functionality to be mapped to the cues given to the two hands, such as the type of specialization that is seen for the thumb joystick inputs on game controllers. For example, most modern game controllers map inputs from the left thumb to character motion while the right thumb often controls the camera angle or gaze of the player.

In the past, vibrotactile feedback is one method that has been successful in giving direction cues to a person. However, these cues are typically delivered through a wearable torso belt [3], rather than being embedded within a portable device. While it may be practical to embed vibrotactors within a game controller to provide direction cues, we believe it would be difficult to package

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the vibrotactors in a manner that would permit multiple independent direction cues to be delivered. We feel it is more appropriate to try to communicate two independent direction cues directly through a fingertip(s) (or thumbs) of each hand.

There are many forms of haptic devices designed to deliver tactile cues to user fingertips. Typically devices include vibrotactors (e.g. [4]), or pin arrays (e.g. [5, 6]), which are designed to give a variety of cues. Unfortunately, these devices often require more space than is practical to embed within a portable device. In contrast, the skin stretch display developed previously [7], is reasonably compact (i.e., small enough for two to be integrated into a game controller) and provides a salient direction cue isolated to a fingertip (or thumb).

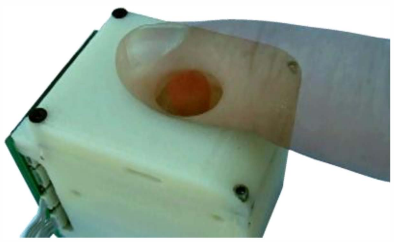

Figure 1: Tactile skin stretch display device [7], shown with a translucent finger. The red tactor makes contact with the fingerpad, stretching the skin of the finger as it moves. The direction cue corresponds to the direction of applied skin stretch.

The tactile skin stretch display is a haptic device that can communicate directional information. Users place their finger or thumb on top of the conical aperture, with the red tactor contacting the pad of their finger (see Figure 1). The tactor is then displaced in the direction of the desired direction cue (e.g., if a “forward” cue is to be rendered, the tactor is displaced towards the tip of the user’s finger). The force between the tactor and the user’s finger stretches the skin laterally in the direction of the displacement. Previous work has shown that with as little as 1 mm of displacement, users can accurately determine the direction of the tactor’s motion [8]. Through several design iterations, this device became more compact and self-contained. Its relatively small size gave rise to the possibility of integrating skin stretch feedback into consumer devices. There have already been several experiments exploring its integration into a car steering wheel [9] and mobile handheld devices [10].

3 System Design

In order to evaluate the feasibility of providing direction cues to multiple fingers in a game controller, multiple pieces of hardware and software were developed and integrated. An overview of each significant subsystem is provided below.

3.1 Mechanical Design

Direction cues were provided through a thumb joystick on a prototype game controller. Like with many modern game controllers (e.g., Microsoft Xbox 360 and Sony PlayStation 3 controllers), our prototype game controller had two thumb joysticks. Each thumb joystick utilized a two-axis gimbaled assembly with spring returns to bias the joysticks to their centered positions (see Figure 2). The gimbals were specifically designed to allow the joystick to rotate in all directions at a maximum rotational angle of 20º from the centered position. This angle was chosen to closely approximate the maximum range of a Sony PlayStation 3 controller. Mechanical stops were used to ensure that this range of motion was not exceeded.

A tactile skin stretch display is placed at the center of each gimbaled thumb joystick assembly. The tactile display assembly consists of an aperture-based finger restraint, two RC servo motors, and a flexure stage for converting the rotary motion of the servos into decoupled translational motions, as described in [7]. Each skin stretch display was individually calibrated to produce 1 mm of tactor movement in each of the 4 directions.

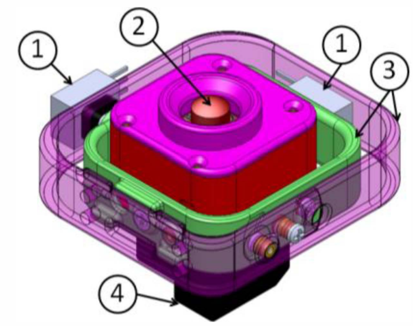

Figure 2: SolidWorks model of the game controller’s skin stretch display gimbal design. 1) potentiometer, 2) skin stretch tactor 3) gimbal ring, and 4) servo motors.

Each gimbaled assembly incorporated two 10 kΩ single-turn potentiometers. These potentiometers measure the current orientation of the thumb joystick, and provide a structural bearing on one side of each axis of rotation to the assembly (with a bushing and shaft opposite each potentiometer to define each rotation axis).

3.2 Software and Electronics

A dsPIC30F4011 microcontroller was used to manage the movement of the shear display tactors, and to read and interpret the values read on the gimbals’ potentiometers.

The microcontroller reads the state of all four of the potentiometers every 2 ms, and watches for a state change in the position of each joystick (e.g., if a joystick was toggled in any direction more than approximately 10 degrees). When a state change occurs, a single character is sent to the serial port which represents the state of all four potentiometers, that is, whether each potentiometer was centered or tilted more than 10 degrees to either side. This character is read and interpreted by reaction timing software developed using Matlab and the Psychophysics Toolbox [11]. A PlayStation Joystick was also used to record responses in our tests. The software to record responses on the PlayStation joystick also consisted of Matlab and the Psychophysics Toolbox. This software assures that responses are recorded with ±1.5 ms accuracy. Figure 3 shows an overall system schematic.

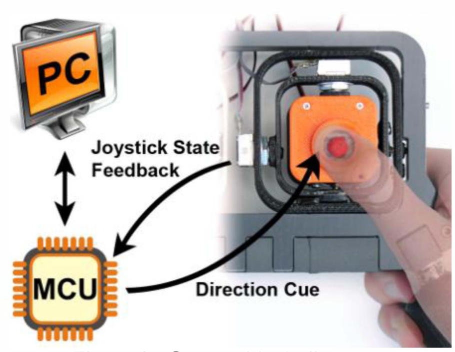

Figure 3: System block diagram.

3.3 Controller Configuration

The prototype game controller was designed with adjustable handles. This permits testing with different controller configurations and allows us to investigate both the ergonomics of the controller (a focus of future studies) and the effect of thumb alignment with respect to the axis on which skin stretch cues are applied. Directional skin stretch cues are applied in a reference frame that is aligned with the frame of the controller, as indicated in Figure 4. The alignment of the thumb could be an important factor if mental rotation of our tactile stimuli, as studied by [12, 13], impairs user's performance in the *angled* configuration.

To quantify any possible effects that thumb orientation, and the associated hand configuration, has on user performance, we tested the prototype controller in two configurations. One configuration, which we refer to as *angled* (see Figure 4(a)), was designed to be similar to a modern game controller such as an Xbox 360 or PlayStation 3 controller. The second configuration we refer to as *straight* (see Figure 4(b)), and was designed to force users to keep their thumbs aligned with the principle axis of the shear display (on which direction cues are applied in the below experiment). This was done to characterize user performance, based on response time and accuracy, for interpreting and responding to direction cues. This data will provide guidance and design constraints for future device prototypes.

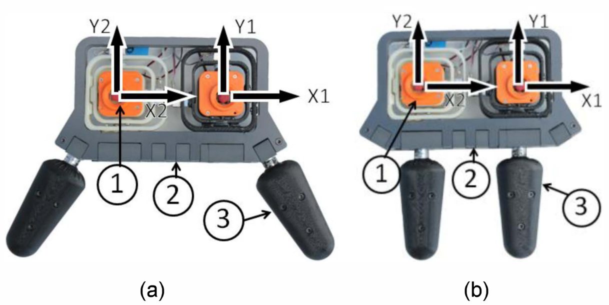

Figure 4: (a) Prototype game controller with handles in *angled* configuration, similar to commercial game controllers. (b) Game controller with handles in the *straight* configuration, to force users to keep thumbs aligned forward on shear displays. Each photo's numbered items are: 1) thumb joysticks with skin stretch feedback, 2) controller frame, and 3) adjustable handles.

4 Experimental Methods

Two three-part experiments were performed to characterize response times and accuracy for two different controller handle configurations (Figure 4). All parts were performed with the users sitting at a desk, listening to white noise via headphones to cancel out environmental distractions and servo noise (see Figure 5).

Figure 5: Test setup, showing a user interacting with the prototype game controller and responding with the PlayStation joystick.

4.1 Experiment Design

Users interacted with the prototype game controller in the *angled* configuration (Figure 4(a)) for half the experiment and in the *straight* configuration (Figure 4(b)) for the other half. In all tests, users were given direction cues through the skin stretch display on the right thumb joystick. After receiving a direction cue, users responded with their perceived direction as quickly and accurately as possible in one of three ways. As indicated in Figure 6, the user would either respond with their left hand using a standalone PlayStation joystick (to facilitate direct comparison to prior work [10]), the prototype controller's left thumb joystick, or its right thumb joystick (i.e., the same joystick on which the direction cue was applied).

The two handle configurations were chosen to better understand if mental rotation of the skin stretch stimuli may be a factor in the *angled* handle configuration, which most closely resembles today's modern game controller. Though little cognitive cost was noted for rotation angles up to 40 degrees when skin stretch cues were applied to a fingertip [12, 13], user's thumbs may exceed this angle. Furthermore, rotations at the thumb joint can further complicate the interpretation of skin stretch cues [14]. Participant responses with the PlayStation joystick in these two handle configurations can be used to isolate the effects of mental rotation.

Multiple response modes were chosen to better understand the final configuration of our game controller. That is, if a user is to receive direction cues from a game it is important that he/she can respond appropriately with either hand. Note that responses with the right thumb are expected to be faster than with the left due to the high stimulus-response compatibility, whereas ergonomic considerations are likely to influence the relative response times between the thumb joysticks and PlayStation joystick. The PlayStation joystick provides a baseline for comparison for the other response modes.

In each experiment, skin stretch cues are rendered to the user's right thumb in one of the four cardinal directions (forward, right, backwards, left, corresponding to +Y1, +X1, -Y1, and –X1 in Figure 4). For a given test condition, the user receives 40 direction stimuli for each test condition, 10 in each direction in a randomized order. A computer-controlled random delay, with values ranging from 0.8 to 1.3 seconds, was included between stimuli to prevent habituation.

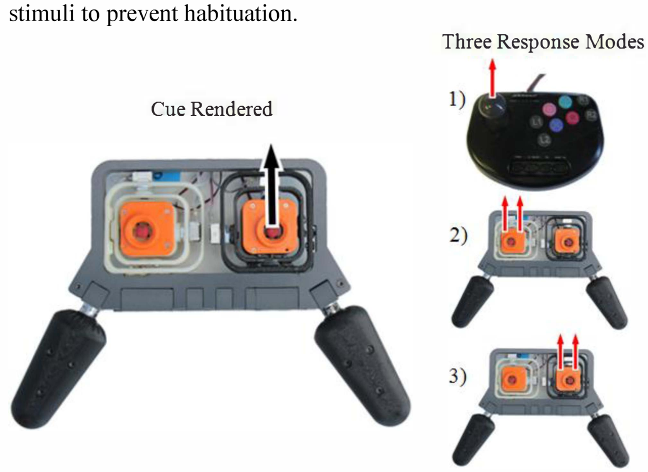

Figure 6: Cues were rendered via the right thumb joystick. Users responded to the cue via a 1) PlayStation arcade joystick, 2) the left thumb joystick, or 3) the right thumb joystick.

Previous work designed direction stimuli to efficiently communicate direction cues, which correspond to the skin stretch tactor's motion. Each stimulus had three aspects: an outbound move, pause, and a return/inbound move (see Figure 7). The outbound move communicated the desired direction, and the tactor moved in one of the four cardinal directions. The outbound tactor motion is approximately 1 mm in the specified direction, at a speed of approximately 10.5 mm/s with the user's thumb in contact with the tactor. The tactor would then pause for 200 ms, and then the inbound move would return the tactor to the center position. This pause is necessary to prevent temporal stimulus masking [8].

A fail-safe was built into the control of the experiment so that if no response was received within 4 s, then that trial's data was thrown out and the next randomized cue was delivered. This corresponds to when a participant missed a direction cue and did not respond (possibly due to distraction). This was done so that a full data set could be recorded for all directions and test conditions. This was analyzed by the MATLAB experiment code in real time. Of the 2,880 total cues given in the results described in Section 5, this occurred 52 times.

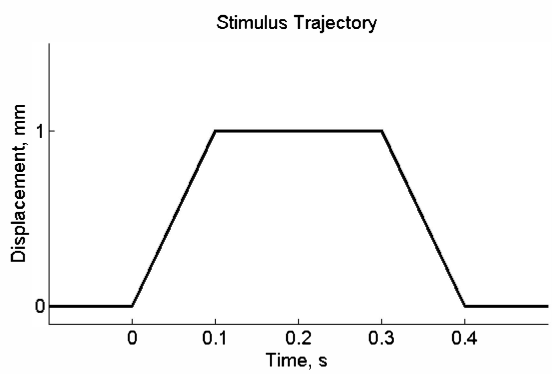

Figure 7: Skin stretch stimulus trajectory, including a 200 ms pause between the outbound and return movements.

4.2 Participants

Twelve participants between the ages of 20 and 31 (1 female) took part in this experiment. Participants were predominantly right-hand dominant (1 left handed) and had little or no experience with our prototype game controller.

5 Results and Discussion

5.1 Response Accuracy

Figure 8 shows the mean accuracy of participants for both handle configurations (Figure 4) and all 3 response conditions (Figure 6).

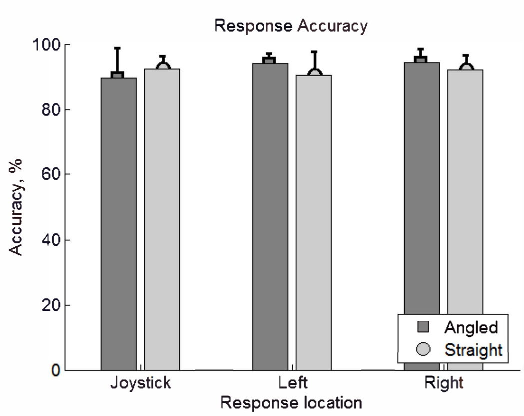

Figure 8: Precent accuracy for each of the six modes. Error bars indicated the 95% confidence intervals.

For each mode of operation there was a very high rate of accuracy (exceeding 89% in all cases). No significant differences between the accuracies under each case was found [F(5,66) = 0.53, p = 0.7537]. These results correlate well with the accuracies found in [12] and [13] and indicate users are capable of accurately interpreting direction cues using our prototype game controller, regardless of the handle configuration. Hence, the mental rotation of the tactile stimuli appears to have no significant affect on the participant's accuracy.

5.2 Response Time

Figure 9 shows the mean response times of participants for both handle configurations and all 3 response conditions. Only correct answers were used in comparing response times. Timing data more than 3σ from the mean were rejected as outliers. In total, 45 responses were rejected as outliers. Response times for the thumb joysticks were adjusted by subtracting 9.2 ms to account for serial communication delays between the microcontroller and PC. This time delay was characterized prior to experiments. The PlayStation joystick was read directly into digital inputs on the PC with a ±1.5 ms timing accuracy, as described in [12] and [13].

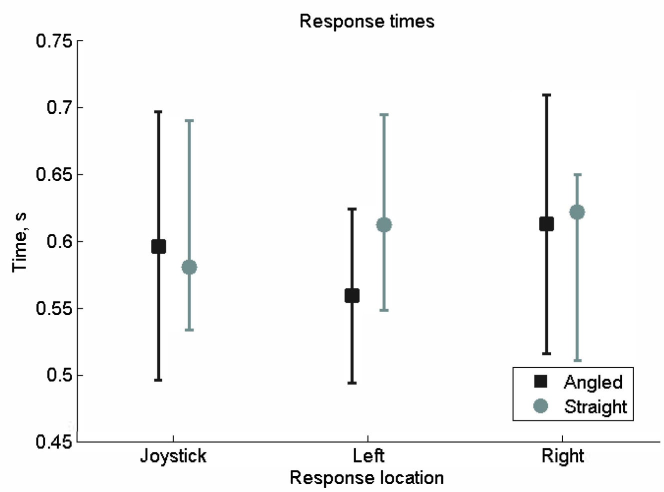

Figure 9: Mean response times for the three different response modes (left hand with joystick, left thumb joystick, and right joystick). The handle configuration is indicated in the legend. Error bars indicate 95% confidence intervals.

Joystick response times were first compared to those in [10] and [12], which respectively report average response times of 0.6049 s and 0.546 s for thumb-aligned, 4-direction skin stretch cues. The mean values of these prior studies and our joystick-measured response times, which averaged 0.5767 s, differ by less than 5.5%, falling well within the confidence interval for our joystick responses.

A one-way analysis of variance (ANOVA) shows no significant difference in participant response times between handle configurations [F(1,70) = 0.27, p > 0.60]. A direct comparison of the participants' PlayStation joystick responses for the *angled* and *straight* handles does show slightly faster responses when the handles are *straight*, but this difference is not significant. This indicates that mental rotation due to thumb orientation does not appear to impact accuracy or response times. This is consistent with findings in [12], which shows that there is no significant reduction in reaction time from mental rotation of angles less than approximately 40 degrees.

A one-way ANOVA with respect to response time shows no statistical difference between the participant response times for the three response modes (see Figure 6) within tests using the *angled* handles [$F(2,33) = 0.46$, $p > 0.63$] or within tests using the *straight* handles [$F(2, 33) = 0.41$, $p > 0.66$]. Faster responses with the left thumb, though not significantly faster than with the right, was counter to our expectation that high stimulus-response compatibility would have shown the opposite trend. Furthermore, faster responses with the thumbs in the *angled* configuration, while not statistically significant, suggests possible ergonomic advantages to the *angled* handle configuration. This is in agreement with participant comments, who often reported that responding in the *straight* configuration was more difficult than for the *angled* handles (especially in the "forward" direction due to reaching a kinematic singularity in extending their thumb).

To further investigate the differences between response modes, we baselined the thumb joystick responses with respect to the PlayStation joystick responses for each handle configuration. This allows us to eliminate subject-to-subject variability that can result from participants having different inherent aptitudes for our experiment and allows us to focus on each participant's relative performance as a function of test configuration (the real focus of this study). The responses in the *straight* configuration were baselined versus the Playstation Joystick responses when cues were delivered in the *straight* configuration (see Figure 10 (a)). The same was done for the *angled* configuration (see Figure 10 (b)).

When the handles are in the *straight* configuration, there is no significant difference between responding on the right and left thumbsticks [$t(11) = -0.58541$, $p > 0.57$]. However, Figure 10(b) shows that there is a significant difference between the two response locations when in the *angled* configuration [$t(11) = -3.1061$, $p < 0.01$]. While this effect was quite small (~0.05 s), it was still counter to our expectations, since the high stimulus-response compatibility for the right hand responses would have been expected to show the opposite trend. This may have implications for how to implement direction cueing in games, but this will need to be investigated further as this effect may be insignificant once skin stretch cues are integrated with multimodal feedback.

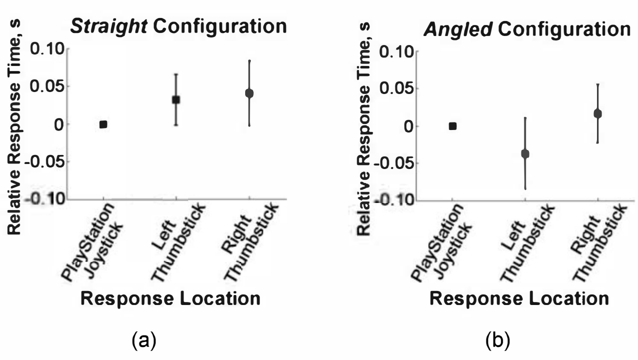

Figure 10: Baselined relative response times for each response location for the *straight* configuration (a) and *angled* configuration (b). Right and left thumbstick responses were baselined against each participant's respective response with the Playstation Joystick for each hand configuration. Error bars indicate 95% confidence intervals.

6 Conclusions and Future Work

We have designed and built a prototype game controller capable of providing tactile directional feedback to the user through its thumb joysticks. The device was evaluated for both accuracy and response time in two different handle orientations, *straight* and *angled*, in order to investigate possible effects of mental rotation on the accuracy and response times of users.

Response times and accuracies were similar to prior work which investigated multimodal direction cueing and mental rotation of skin stretch direction cues [10, 12, 13]. Our results indicate that thumb orientation does not influence participant accuracy or reaction times ($p > 0.60$). Hence, our current study suggests that future experiments should be conducted with a controller designed with angled handles (similar to current commercial game controllers), as there appears to be possible ergonomic advantages, observed in the slightly faster response times with the *angled* handles, and there is no significant effect of mental rotation on accuracy or response time.

A new self-contained gaming controller, much like current gaming controllers (see Figure 11), has been created and will be presented in a separate publication. This controller permits further testing of effects such as stimulus masking. Future experiments are planned to determine if there are masking effects between the two tactile skin stretch displays, or between vibrotactile feedback and skin stretch feedback. Once the device is fully characterized, it will be integrated into gaming environments, where its full potential will be realized.

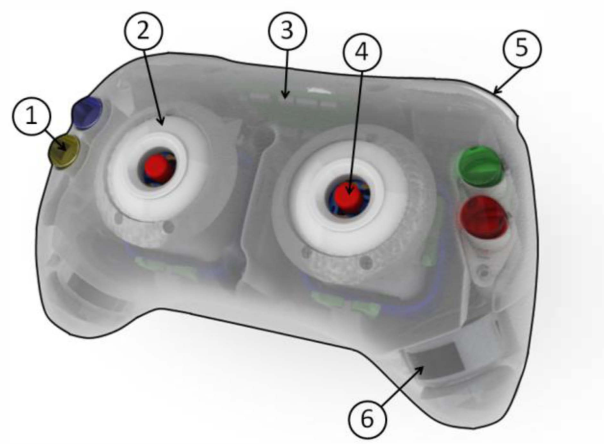

Figure 11: A translucent view of our controller design showing the: 1) push buttons, 2) gimbaled joystick, 3) microcontroller, 4) skin stretch feedback, 5) bumpers and triggers, and 6) vibrotactors.

7 Acknowledgements

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