Skin Stretch Feedback for Gaming Environments

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***Abstract* — This paper presents the design and development of handheld gaming devices that provide a new form of touch feedback: skin stretch feedback. Our prior work showed 1-1.5 mm of skin stretch applied to the fingertips (or thumb tips) could provide direction cues with high accuracy. The direction of each cue corresponded to the direction of applied skin stretch. Haptic feedback via tactile skin stretch can be used to provide tactile gaming effects and directional information through the same interface used for game inputs. Tests conducted with devices that resemble modern game controllers indicated which grip style is preferred by users and how to present direction cues to achieve the highest recognition rates. The main contribution of this paper is to show an initial demonstration of the benefits of skin stretch feedback in a multimodal gaming scenario.**

Keywords-Consumer electronics, haptic interfaces, skin stretch feedback.

I. Introduction

As video games have become more immersive, the way users interact with them has changed to provide an experience beyond onscreen graphics and sounds. Devices such as the Nintendo Wii Remote and Wii Balance Board, Microsoft Xbox Kinect, and Sony PlayStation Move have been recently introduced to the market. These devices provide an active and innovative way for gamers to provide inputs to their games. However, thumb joystick (thumbstick) input remains the most common input method.

In the mid-1990s, haptic interfaces revolutionized the gaming industry. Force feedback joysticks allowed gamers to experience forces in scenarios such as flight simulators and the recoil of a gun fire. Vibrotactile rumble feedback added to the gaming experience by providing haptic feedback in addition to the standard audio and visual experience of video games. Both of these forms of haptic feedback can greatly enhance the gaming experience and sense of immersion. Yet since the mid-1990s, haptic feedback in gaming systems has leveled off. The amount of haptic feedback in game controllers remains limited to a vibration sensation created by an eccentric mass motor (EMM).

We believe that new forms of tactile communication should be integrated into the gaming experience in order to continue to enhance it further and improve immersion. In this paper, we present the integration of skin stretch feedback into gaming scenarios. Using skin stretch feedback, we can communicate information to gamers through their fingertips. Direction cues can be provided haptically to a user, improving their sense of immersion and game performance. Skin stretch cues can also be used to enhance the gaming experience through the development of tactile gaming effects.

We have developed a smartphone peripheral and a game controller with skin stretch feedback for use with smartphone games and console games, respectively. Both of these devices provide a new way for games to interact with gamers, and they have the potential to revolutionize the gaming experience. Using tactile direction cues, this feedback could potentially suggest where a gamer should move to escape danger on one thumb, while simultaneously communicating damage cue effects to the other thumb. These haptic cues, combined with vibrotactile haptic cues and audio/visual cues, will provide an even more interactive gaming experience.

Because skin stretch feedback will be used in conjunction with current audio, visual, and vibrotactile cues, it is important to understand how to best present the new tactile cues. It is also important to verify that skin stretch direction cues are still perceived at high recognition rates when integrated into these multimodal gaming environments. Previous studies have shown that users are able to discriminate direction cues at high rates, however, with tactile cues presented to both thumbs and in combination with other modes of feedback it is possible for both perceptual and cognitive masking to occur. This makes it even more important to understand how to best present skin stretch cues for gaming environments.

We have developed a variety of short video game demo programs that showcase the enriched game play that our new feedback creates. To-date, we have used these demos to elicit subjective feedback of our game controllers and the implemented haptic feedback. We will now also use these to investigate and improve upon the effectiveness of skin stretch feedback used for gaming through objective user tests to measure user performance. In the remainder of this paper, we first present a background on skin stretch feedback, and related devices and research. We then present the design of two devices which utilize skin stretch feedback for gaming purposes: console type game controller and a smartphone peripheral. We present the initial testing of these devices and their results, as well as a description of gaming scenarios created for these devices. Conclusions and plans for future work are also included.

II. Background and Related Work

Skin stretch feedback was initially conceived as a means to provide direction cues in a package compact enough to be embedded within a handheld device [1]. Other haptic devices have been developed to provide directional cues to a person, such as through a torso belt with vibrotactile feedback [2]. However, these designs require wearable hardware, rather than hardware that can be embedded within a handheld portable device. While vibrotactors are currently embedded within game

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controllers, they are not well suited to communicate directional information without being placed in an array. Furthermore, we believe it would be difficult to package an array of vibrotactors in the small space of a game controller while also being able to produce multiple independent direction cues. Many other haptic devices that use vibrotactors [3] or pin arrays [4, 5] to communicate direction also require more space than portable devices allow. For this reason, we feel that skin stretch feedback will be the best option to communicate direction information through handheld devices. This also allows us to provide two independent direction cues through the fingertips of a user.

The skin stretch display (display = haptic feedback device) previously developed is compact enough for two to be integrated into the thumbsticks of a game controller device. Users place their thumb or finger on top of an aperture (conical hole) such that their finger pad is in contact with a skin stretch tactor (Fig.1). The tactor then moves to communicate a cue to the user. The tactor is displaced in the tangent plane of the fingerpad in the direction of the desired cue, where the "forward" direction is towards the tip of the user's finger. When the tactor moves, the force between the tactor and the finger causes the skin to stretch laterally in the direction of displacement. The skin stretch tactor in our devices is a cap from a ThinkPad TrackPoint™ interface. Users can accurately determine the direction of this displacement with as little as 0.5 mm of tactor displacement [6]. The compact nature of this device makes it practical to use skin stretch feedback in many handheld and portable consumer devices. Previous implementations include integration into a car steering wheel [7] and mobile handheld devices [8] to provide navigational cues.

Our lab's previous work characterized the most efficient way to communicate direction cues and used a three step tactor motion: an outbound move, a 0.2-0.3 sec pause, and an inbound move. The total tactor travel used is approximately 1 mm at constant velocity of approximately 10.5 mm/sec. The pause is necessary in order to prevent temporal masking of the tactor in-out motion [6].

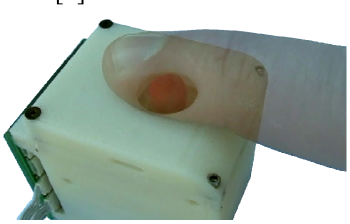

Fig. 1: A tactile skin stretch device with a finger placed on the aperture (conical hole). The tactor (shown in red) stretches the skin of the finger as it moves. The aperture on the top of the skin stretch display restrains finger motion in the plane of tactor motion.

III. Gaming Device Design

Two devices were designed that incorporate skin stretch feedback for use with gaming. One is a game controller, similar to console game controllers, for which we have developed custom PC game demos. The other is a smartphone peripheral, which can be used with smartphones or tablet computers. Both devices use two RC hobby servo motors to actuate each skin stretch tactor. Further design details of these devices are presented below.

Console/PC Game Controller Design

We developed a game controller to incorporate skin stretch feedback into console gaming. This controller is similar to modern controllers used with the Microsoft Xbox 360 and Sony PlayStation 3 game consoles. In addition to standard game controller inputs, such as buttons and thumbsticks, this controller also integrates skin stretch feedback into the tops of the thumbsticks. Direction cues and tactile effects can be given to the user through these thumbstick skin stretch tactors. The design of the skin stretch feedback mechanisms used within the thumbsticks was previously presented in [1]. This design utilized a flexure stage to convert the rotary motion of the RC servos into decoupled translational movements.

Our controller's thumb joysticks use a two-axis gimbal that includes mechanical spring returns. The skin stretch feedback device [1] is placed at the center of the gimbal. Spring returns are used to bias the thumbsticks to their centered positions, just as in modern game controllers. These thumbsticks were designed to rotate at a maximum angle of 10º from the center position, resulting in thumb motion of about 6.9 mm (again similar to modern game controller thumbsticks). The gimbals utilize two 10 kΩ single-turn potentiometers, which measure the orientation of the joystick. An aperture is used to hold the thumb in place over each tactor to encourage contact between the finger and tactor (see Fig. 2).

Fig. 2: Game controller prototype with skin stretch feedback integrated into the tops of thumb joysticks.

Smartphone Peripheral Design

To enable this skin stretch feedback at the thumbs in a portable handheld gaming environment, a prototype was fabricated for two-handed use with a smartphone or tablet computer device running the Android operating system. The internal actuation mechanism used for skin stretch in this peripheral was modified to be thinner than the design shown in Fig. 1. This was done to have a similar aspect ratio and thickness to current smartphones (see Fig. 3) [10]. This required a change in the device's mechanism design, which resulted in nonlinear device kinematics. However, these nonlinearities were compensated for in software to produce accurate, consistent lateral skin stretch feedback [10].

To enable intuitive user input for game play, each tactor includes a force sensor such as those found in the ThinkPad laptop TrackPoint™ pointing device. This effectively results in an *active* version of a TrackPoint™ pointing device.

Combining skin stretch feedback with a TrackPoint™ force sensor allows us to program and create a variety of haptic interactions with our device, including tactor motions that mimic a spring loaded game controller thumbstick. The peripheral also features button input and vibration haptic feedback.

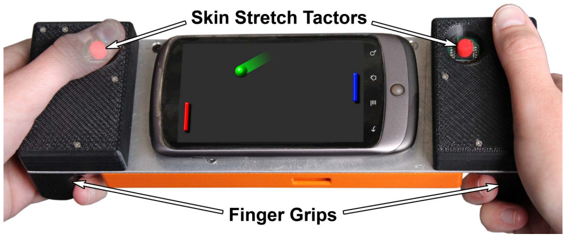

Fig. 3: Skin stretch peripheral prototype for use with smartphone or tablet computer gaming.

The two skin stretch displays are designed such that they can be swapped to opposite ends of the peripheral. This allows testing of the peripheral with a user holding their thumbs against the tactors in either a straight or angled orientation.

IV. Software Interfaces

Each of the devices utilizes software interfaces to communicate with external devices.

Console/PC Game Controller Software Interface

The game controller uses a Microchip dsPIC30F4011 microcontroller. This microcontroller sets the positions of the two skin stretch tactors and sets the vibrotactor magnitudes, as well as communicating the game controller's button and thumbstick states to the game program. The microcontroller exchanges information with the PC through RS-232 serial communication, with the PC receiving information about the button and joystick states and sending tactor and vibrotactor values to the microcontroller at a rate of 60 Hz, to be compatible with a Microsoft XNA development environment. Figure 4 shows an overall view of the system architecture.

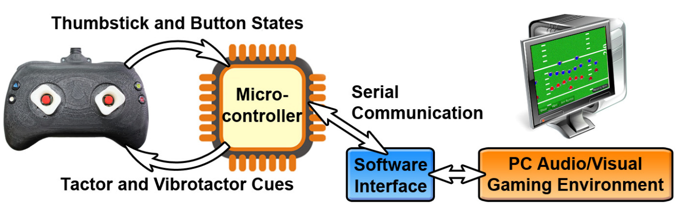

Fig. 4: High level system architecture of the game controller. A microcontroller inside the game controller commands the tactors and vibrotactors while communicating joystick and button states to the PC.

The gaming environments on the PC use Visual Studio 2010 with Microsoft XNA Game Studio 4.0. A software interface is used to enable programmers to create games with our skin stretch game controller much like they would with an Xbox controller. In this way, games can also be tested using an Xbox controller, with the only difference being the lack of skin stretch feedback. An additional Visual Studio class has been created specifically to create custom tactor movements. Through this class, programmers can specify the desired movement signature for the tactors to create their own custom tactile effects for use in gaming.

Smartphone Peripheral Software Interface

The smartphone peripheral also uses a Microchip dsPIC30F4011 microcontroller. This controller is responsible for commanding the lateral motions of the two skin stretch tactors, setting vibration states, communicating with the smartphone, and capturing the user's input through the force sensors and tactile buttons. The tactor positions are updated at a rate of 100 Hz. The microcontroller communicates wirelessly with the smartphone through a serial interface using a Roving Networks RN-42 Bluetooth modem.

The Android operating system on the smartphone runs a background service developed with the Android SDK in the Eclipse development platform. This manages the communication of skin stretch commands, vibrotactor states, and accepts force sensor and button inputs from the peripheral. As this method of wireless Bluetooth communication can be prone to corruption due to wireless inconsistencies, larger sequences of data sent from the phone to the microcontroller are ran through a cyclic redundancy check to ensure consistent tactile cues are given to users. Figure 5 shows an overall view of the system architecture.

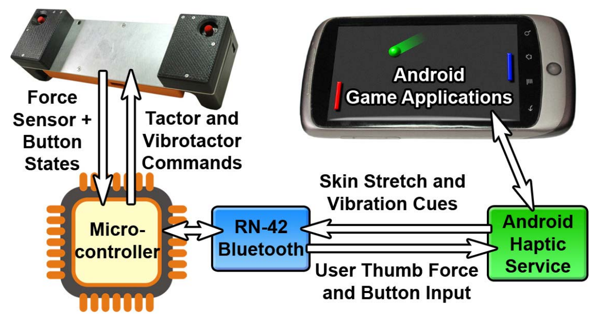

Fig. 5: High level system architecture of the smartphone peripheral.

V. Gaming Device Testing and Results

Initial tests with the console-style game controller and smartphone peripheral devices were done to evaluate the best way to present cues to users of these devices. Through these experiments, we were able to verify that a high percentage of cues were understood with these devices [9, 10].

Both studies [9, 10] investigated the effect of grip orientation on the perceived accuracy of direction cues. More specifically, these studies looked at performance differences related to the way users aligned their thumbs when experiencing skin stretch feedback. Participants in these studies either held their thumbs aligned with the "forward" motion of the tactor (straight configuration), or with their thumbs angled with respect to the "forward" direction, similar to modern game controllers (angled configuration).

Results of these studies suggest that response times and accuracies were not significantly different between the two configurations in a matching experiment [9]. However, a users' ability to identify a direction is better when their thumbs/hands are held in an angled configuration [10]. In addition, participants in both studies reported that the angled configuration was more comfortable. These results suggest that an angled configuration should be used for handheld devices with bimanual skin stretch feedback.

Other results indicate that subjects perform similarly when cues are delivered to a single thumb [10]. Some rotational confusion is observed when providing directional skin stretch cues to a single thumb (especially in the straight/aligned-thumb configuration), and this confusion is mirrored when interpreting cues given to the opposite thumb. However, there is no significant difference in accuracy between cues received on just the right thumb and cues received on just the left thumb.

There is a significant improvement in perceived direction accuracy when both thumbs receive the same direction cue, and the rotational confusion that was observed when cues were provided to a single thumb appears to not be present when cues are received by both thumbs [10]. The highest accuracy rates were obtained when subjects received the same feedback on both thumbs, rather than through just one tactor. Further testing is ongoing to investigate user performance when different cues are provided to different thumbs.

These results provide an outline for how to display information to users via skin stretch feedback. They suggest that the ability to communicate direction cues varies as a function of grip style and whether a cue is provided to one or both thumbs simultaneously. This knowledge influences what we will provide via skin stretch feedback to users in gaming environments. The lessons learned through these experiments will be applied and evaluated in a gaming scenario. This will enable us to evaluate and trade off how skin stretch cues should be displayed.

VI. Gaming Prototypes

Several gaming prototypes have been designed and planned to evaluate the effectiveness of skin stretch feedback in gaming. While a simple "pong" game has been developed for the Android smartphone peripheral, a majority of the game development has occurred for our console/PC style controller, which is described further below.

A wide range of tactile effects have been developed and demonstrated using skin stretch feedback for several PC-based game scenarios. Our demos and informal testing have found that users generally have a positive response to these tactile effects, and we continue to improve and refine the way we present skin stretch feedback in concert with multimodal game scenarios.

Examples of several game scenarios developed to showcase the use of skin stretch feedback during game play include: tank assault, tilt table/maze navigation, Spiderman (web shooting), and fishing scenarios. Skin stretch feedback in these scenarios has also been combined with visual, auditory, and vibrotactile feedback to create congruent gaming interactions.

Performance Evaluation on Console/PC Game Scenarios

Our user testing involved the following game scenarios to evaluate the participants' completion time and accuracy as a function of provided feedback conditions. Their performance when assisted by skin stretch feedback has been compared to conventional visual feedback conditions. In each of these scenarios, directional skin stretch cues were fed back to the users in the same manner as done in prior tests [6, 9, 10], as briefly described at the end of Section II. Participants completed a brief training period before each round of tests.

Sports Scenario

In this scenario a user controlled a quarterback in an American-style football game trying to complete a pass to an open receiver (see Fig. 6). Before each play, the user was shown the routes to be run by each receiver. During the play one receiver became open (chosen randomly by the game's algorithm). The user was instructed to find this receiver as quickly as possible and try to complete a pass to the open receiver (this was done by pointing/aiming the right thumbstick at the receiver and then throwing the ball by pulling the controller's right trigger). Each user was tested under three test conditions with 30 plays (trials) in each test. The three test conditions were ordered in a balanced latin squares order across all 24 participants to account for learning effects.

During one test condition, participants were <u>not</u> given any tactile feedback and visually determined which receiver was open based on visual separation between the receiver and defender. Once the user aimed the thumbstick at the correct receiver, they were given positive feedback indicating their correct aim, as the receiver would blink visually.

During another test condition, participants determined which receiver was open based on skin stretch direction cues pointing in the direction of the open receiver. Once the thumbstick was aimed at the correct receiver, vibrotactile feedback was provided to indicate the correct aim. Skin stretch cues were composed of the skin stretch tactor starting from a centered position, moving radially outward in the cued direction, pausing for 0.3 s, and then returning to the center.

During the final test condition, visual, skin stretch, and vibration feedback were given to the user. Skin stretch feedback and visual separation of the receiver and defender indicated the direction of the open receiver and vibrotactile and visual feedback were provided as above, to indicate when a participant was aiming correctly at the open receiver.

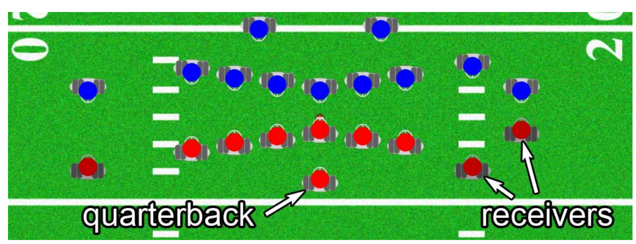

Fig. 6: An example sports game scenario, playing quarterback in an American Football game.

Navigation Scenario

In this scenario, a user navigated an area, collecting up to 12 fuel cells (target objects) within a 45 second time limit (see Figure 7). The navigation area included barriers, and users were only able to see objects within a certain radius from their position. Five different feedback modes were tested with this game scenario, with each participant completing three training maps and three timed/scored maps for each type of feedback. The ordering of feedback modes was balanced across all 20 participants in this study. Four of the feedback modes combined tactile feedback with visual feedback, as the skin stretch feedback led users on the most efficient path for collecting all 12 targets. Skin stretch feedback was provided through both thumbsticks, and users controlled their movement around the area using the left thumbstick. The five feedback modes used were:

1. Visual-only: users navigate using only visual cues.
2. Visual plus steady pulsing skin stretch: users navigate using visual cues and cues from the tactors pulsing at a steady rate in the direction of the next fuel cell.
3. Visual plus varied rate pulsing skin stretch: users navigate using visual cues and cues from the pulsing tactors at a varied rate in the direction of the next fuel cell. The tactors pulsed faster as users approach a target.
4. Visual plus sustained skin stretch: users navigate using visual cues and cues from the tactors, which remained pointed, relative to the tactor's center position, in the direction of the next fuel cell.
5. Visual plus sustained skin stretch with reset: users navigate using visual cues and cues from the tactors pointed in the direction of the next fuel cell. When a cell was retrieved, the tactors reset to their center of their workspace, and then moved outward to again point to the next fuel cell.

A pulsing skin stretch cue is composed of the skin stretch tactor starting from a centered position, moving radially outward in the cued direction, pausing for 0.3 s, and then returning to the center. In a sustained skin stretch cue, the tactor also starts in the center position and moves radially in the cued direction, but then rather than returning to center the tactor moves circumferentially as the cued direction changes (creating a cue vector from the center position and its current radial position). Directional cue updates can be updated at 60 Hz (the game's update rate) for sustained cues, whereas pulsed cues are only applied approximately once per second.

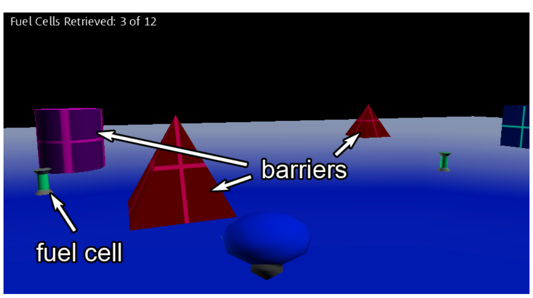

Fig. 7: A navigation game scene with barriers and 12 targets.

VII. Results

Basic results from the two scenarios are shown below.

Sports Scenario

The mean completion percentage was 86.6% for the visual-only mode, 90% for the skin stretch only mode, and 91.6% for the combined visual and skin stretch mode. However, one-way analysis of variance (ANOVA) shows no significant difference in participant completion percentage between feedback modes [$F(2, 69) = 1.78$, $p = 0.1758$].

A one-way ANOVA shows a significant effect of feedback mode on time of each play [$F(2, 2157) = 486$, $p < 0.0001$]. Post hoc comparisons indicate the visual-only mode was significantly longer than the mode that provided skin stretch feedback [$t(719) = 27.49$, $p < 0.0001$] and from the combined mode [$t(719) = 28.58$, $p < 0.0001$], but no significant difference shown between the skin stretch only and the combined mode [$t(719) = 0.33$, $p > 0.7$]. However, we recognize that it takes time for the visual contrast to occur during each play. Using a conservative number, we can say that visual contrast occurs 1.5 seconds from the start of the play. The play time of visual-only modes can be adjusted by subtracting this number. An adjusted play time for the skin stretch and combined modes subtracts a value of 0.4 seconds – the amount of time from the start of the play until the tactor begins to move. While tactor motion begins at 0.4 s, additional time needed for these directional cues to be recognized (0.4 s is used to provide as conservative comparison to the visual-only case). Adjusted play times are shown in Fig. 8. Using these adjusted values, a significant effect remains [$F(2, 2157) = 5.14$, $p < 0.01$]. There was a significant difference between the adjusted visual ($M = 1.547$, $SD = 0.92$) and adjusted skin stretch modes ($M = 1.42$, $SD = 0.84$) [$t(719) = 2.69$, $p < 0.01$]. A significant difference also remains between the adjusted visual mode and combined mode ($M = 1.41$, $SD = 0.82$) [$t(719) = 3.06$, $p < 0.01$]. Even with this conservative adjustment, the results remain significant despite some subjects in the visual-only case aiming and looking for the blinking of a receiver before a receiver is visually open at the 1.5 second time mark on some trials.

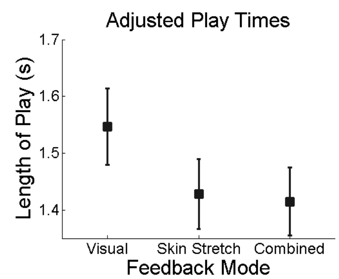

Fig. 8: Mean length of play and 95% confidence intervals for each of the three feedback modes.

Navigation Scenario

A one-way ANOVA shows no significant difference in the number of collected fuel cells between feedback modes [$F(4, 295) = 2$, $p = 0.095$]. Participants were able to collect all 12 fuel cells in the majority of 45 second trials for each mode, with the lowest mean of any mode at 11.8 collected cells.

Because each map had a different minimum distance that could be travelled to collect all 12 cells, a measure of efficiency has been used to compare the five feedback modes rather than just a measure of time alone. This measure uses the minimum distance that could be travelled to collect all 12 cells divided by the time a user is moving forward for that map to calculate an effective velocity for the trial based on the navigation area used. A high number is desired, since this means a user is collecting the cells at a fast pace with respect to the minimum possible path distance. A one-way ANOVA of this speed and efficiency measure shows significance between some of the five feedback modes [$F(4, 295) = 4.39$, $p < 0.0018$]. Post hoc comparisons indicate that people performed worse in the visual condition (M = 28.1, SD = 5.99) than in the varied rate pulsing (M = 32.04, SD = 7.78), sustained (M = 33.29, SD = 7.89), and the sustained with reset skin stretch conditions (M = 31.77, SD = 7.33). There was no significant difference shown between the visual and steady rate pulsing skin stretch feedback conditions (M = 31.23, SD = 6.62), and no significant difference between any of the skin stretch conditions with respect to each other. These results indicate that participants spent more time wandering in the visual mode, and did not choose the most efficient path, whereas in the skin stretch feedback modes, users recognized the path the cues were leading them on, and their efficiency was improved. Figure 9 shows the mean values and 95% confidence intervals of this measure for all five feedback modes.

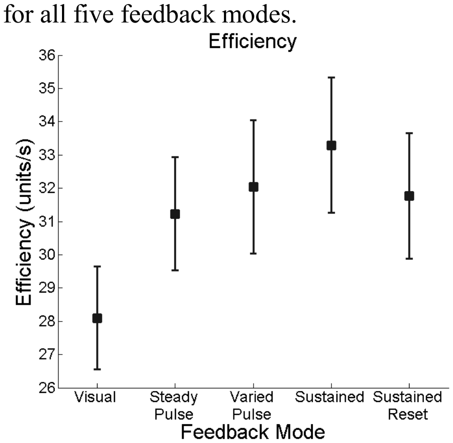

Fig. 9: Mean efficiency and 95% confidence intervals for each of the five feedback modes.

Participant Surveys

Participants completed surveys after each game scenario, indicating their preference for overall experience in each mode, and how they felt their performance was for each mode, among other information. For the football game, 18 of 20 users preferred the combined feedback mode, and 15 users felt they performed best with the combined feedback mode (which matches the recorded results). For the navigation game, users rated the sustained skin stretch feedback mode as the one they liked best. This may have to do with the higher update rates that this feedback mode is capable of portraying, such that it begins to allow participants to close the afferent-efferent feedback loop during game play. Participants, however, felt that both the sustained and varied pulsing skin stretch feedback modes provided the greatest performance improvement of the five modes tested.

VIII. Conclusion

Two devices have been designed to incorporate a new type of haptic feedback into games. In addition, software interfaces are used for these devices to communicate with existing gaming platforms. Through the use of skin stretch feedback, gamers receive new directional haptic information. Previous results indicate that human users perceive direction cues more accurately when the cue is delivered to both thumbs, and that users more accurately identify a direction when their thumbs are in an angled configuration. We use this knowledge to tailor the way we provide skin stretch feedback in gaming situations. Results from two game scenarios have shown performance benefits of adding skin stretch feedback to a gaming scenario. In addition to performance benefits, users also reported an overall positive experience when this feedback was added to gaming scenarios. Further analysis of our game play and survey results will be presented in a future publication.

Skin stretch feedback is a promising technology which can be used to increase user immersion into games, and improve user performance in certain game scenarios. In an ever expanding video game market, skin stretch feedback has great potential to create a more compelling gaming experience.

Acknowledgements

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