

Real-time Sensory Substitution to Enable Players who are Blind to Play Video games using Whole Body Gestures.

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ABSTRACT

Gesture-based interaction adds a new level of immersion to video games, but players who are blind are unable to play them as games use visual cues to indicate what gesture to provide and when. Though visual cues can be substituted with audio or haptic cues, this often requires access to the source code, which is not attainable for commercial games. We present a solution that uses real-time video analysis to detect the presence of a particular visual cue, which is then substituted with a vibrotactile cue that is provided with an external controller. A user study with 28 sighted participants with a popular commercial gesture based game showed no significant difference between visual and vibrotactile cues, which demonstrates the feasibility of real-time sensory substitution as a cost-effective approach for making gesture-based video games accessible to players who are blind.

Keywords

Accessibility, Natural Interfaces, Gestures, Exergames, Visual Impairments, Blind, Haptics, 3D Interaction.

Categories and Subject Descriptors

H.5.2 [User Interface]: Haptic I/O

General Terms

Human Factors, Performance.

1. INTRODUCTION

The way we interact with software is increasingly modeled after how we interact with the real world; as such interaction is most natural to us. The emergence of more immersive and healthier forms of interaction –through the use of whole-body gestures– has propelled video gaming to the cutting edge of human computer interaction design. All console manufacturers offer gesture-based interaction that use computer vision (Sony EyeToy, Microsoft Kinect) or computer vision combined with inertial sensing using a handheld controller (Nintendo Wii, Playstation Move).

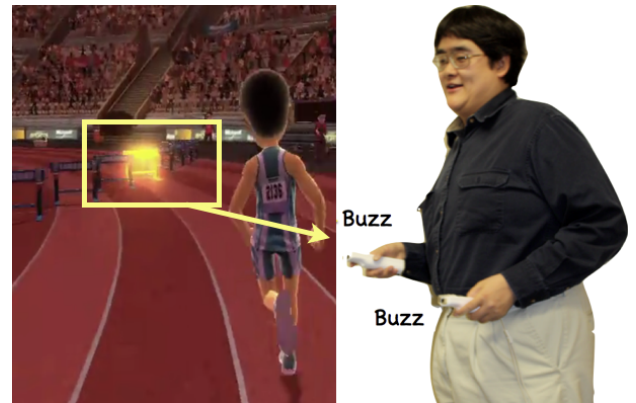


Figure 1: A legally blind player (right) playing Kinect Hurdles game (left) where visual cues that indicate when to jump are detected using real time video analysis and substituted with vibrotactile cues that are provided with a handheld controller.

Because gesture based games are intuitive to play, they have successfully attracted elderly [8] and they also facilitate more social forms of gaming [18]. Despite their appeal to non-traditional gamers, gesture-based video games are inaccessible to players who are blind as they require the player to perceive visual cues that indicate what gesture to provide and when. Access to gesture based games, exergames in particular, could create new exercise [13, 14] and socialization opportunities for users who are blind, which is important as: (1) they suffer from higher levels of obesity due to fewer opportunities to be physically active [11]; and (2) users who are blind are often isolated and lonely [19].

Video games can be made accessible to players who are blind using sensory substitution [3], e.g., replacing visual cues with non-visual, i.e. audio or tactile cues [22]. Previous research found that gesture based exergames can be made accessible using vibrotactile cues [13, 14], however, computer vision based gesture recognition systems are controller-less and to implement sensory substitution access to the source code is required, which is not attainable for commercial games. This paper presents real-time sensory substitution, a technique for sensory substitution without modifying the source code of a game. This paper is organized as follows. Section 2 provides background and related work, Section 3 discusses real-time sensory substitution. Section 4 presents the results of a user study. Section 5 discusses these results, Section 6 outlines future work and the paper is concluded in Section

2. BACKGROUND AND RELATED WORK

Gesture-based video games typically simulate real physical activities, because they use whole body gestures. A physical activity, such as tennis, typically involves spatial (where to hit the ball) and temporal challenges (when to hit the ball). Performing spatial and temporal challenges relies upon a combination of sensorimotor (senses and motor coordination) and cerebellar (muscle) control [5, 17]. Sensorimotor-based physical activities are difficult to perform for players with visual impairments, as they are mostly visio-spatial [10]. For example, in tennis to successfully hit the ball, which is a combination of spatial and temporal challenges, the location of the ball is predominantly acquired visually, which -when you are visually impaired- may be difficult or impossible to achieve.

Gesture-based games typically involve similar temporal and spatial challenges as the physical activity that they simulate. Some gesture-based games only involve a temporal challenge, for example Wii Sports Tennis [1], only involves swinging the Wii remote at the right time but the direction in which the Wii remote is swung is not taken into account, to keep the game simple to play. Other exergames such as Eye Toy Kinetic [2] involve spatio-temporal challenges as this game superimposes virtual objects at random locations to be punched and kicked over a video image of the player using an external camera. Targets are defined in space in front of the player and player has to provide directed gestures aimed at these targets. Because video games and gesture based video games primarily use visual cues to indicate what input and what gesture to provide they are inaccessible to players with visual impairments. This limitation affects players who are legally blind and totally blind more than players who are partially sighted or those with low vision, as these individuals have been identified to be able to play existing exergames through small modifications, such as increasing the contrast or volume of the game [4].

Gesture-based interaction using non-visual modalities has been explored in the following approaches. Finger gestures have been defined that allow users with visual impairments to interact with mobile touch screens [9, 20], where primarily audio feedback is provided, but these approaches don't use whole body gestures or involve games where fast responses are required. AudiOdyssey [6] is a music game in which players receive audio instructions that indicate what gestures to provide using a motion-sensing controller (Wii Remote), as to create and record musical beats. The player can then layer these recordings to create complex musical tracks. Providing the right gesture as indicated using an audio cue is primarily a temporal challenge.

In previous work we explored how to make gesture based games, specifically exergames, playable using non-visual feedback. VI Tennis [13] (see Figure2:left) implements the gameplay of a popular upper-body tennis exergame (Wii Sports Tennis) that is played with a Wii remote. Wii Sports Tennis only involves performing a temporal challenge, e.g., when the ball approaches, the player has a few seconds to provide the upper-body gesture, e.g., swing their Wii remote from back to forward like a tennis racket to return the ball. VI



Figure 2: Individuals who are blind playing VI Tennis (left); and VI Bowling (right).

Tennis implements the same audio feedback as Wii Sports Tennis, though vibrotactile cues provided with a Wii remote are used to convey the location of the ball. Because this game requires fast responses, simple vibrotactile patterns were used to increase their correct identification. A 250ms vibrotactile cue, provided with a fixed frequency of 250Hz indicates the bouncing of the ball to indicate to the player to prepare for returning the ball, and a 2000ms cue indicates the time frame in which the player must provide their gesture.

In user studies with this game vibrotactile feedback showed significantly better performance than when only audio cues are used. A reason for this improved performance is that cues presented simultaneously in multiple modalities can be detected at lower thresholds, faster and more accurately than when presented separately in each modality [12]. Vibrotactile feedback has the benefit over audio feedback in that it doesn't interfere with being able to talk with other players while playing the game or listening to music. Gesture-based games such as exergames are often played in social contexts [15] or they feature music [16] and the input the player needs to provide is matched with the rhythm and beats of a song.

VI Bowling [14] implements the gameplay of Wii Sports bowling (see figure 2:right). The sport of bowling is self-paced, as it consists predominantly of a spatial challenge, e.g., throwing the ball at the pins. In Wii Sports bowling players aim their ball by adjusting a visual marker on screen using the arrow keys on their Wii remote and by twisting the Wii remote while throwing (the direction in which the Wii remote is moved is not taken into account).

In VI bowling longitudinal shape and the direction in which the Wii remote is pointing are used to convey the location of the pins that is indicated using directional vibrotactile feedback. Players scan their remote along the horizontal plane, like a dowsing rod and the pins' location is rendered using a directional vibrotactile cue of 250Hz. When the remote points within 20° of the target, the vibrotactor is pulsed for 100 ms with 2,500 ms delays and this delay is decreased linearly with 125 ms for every 1° of error. When the player points the remote precisely in the target direction, the vibrotactile cue feels continuous and the player's arm conveys the direction of the pins. A user study with six blind adults found that the users were able to find the target

direction on average in 8.78 seconds and were able to throw their ball with an average error of 9.76° .

3. REAL-TIME SENSORY SUBSTITUTION

One of the biggest barriers towards making games accessible for players who are blind is that access to the source code of the game is required to implement sensory substitution, which for most commercial games is not possible. Though several games have been identified in the related work section that use gesture-based interaction and are accessible to players who are blind, these games are often clones of existing games or they are novel games that have been developed from scratch. The goal of Real-Time Sensory Substitution (RTSS) is to allow for sensory substitution of visual cues into audio or haptic cues but without requiring any modifications to the game, which may allow for more cost effectively creating accessible games.

3.1 How it Works

In a previous study with children with visual impairments playing unmodified exergames, such as Dance Dance Revolution and Wii Sports, it was found that children were able to play these games when a human observer provided verbal cues to them that indicated what input to provide and when [4], for example “step left”. This observer watches the visual cues provided by the game on the screen and analyzes these as to determine what verbal cues to provide to the visually impaired player. Based on these experiences, we developed a solution that uses real time video analysis to identify particular visual cues on screen and substitute these in audio or vibrotactile cues, similar to how a human observer would do this.

Certain games lend themselves to RTSS more than others. Additional audio cues can make the game more accessible, but at the same time such cues could potentially interfere with existing audio or music in the game [21]. For gesture-based games, vibrotactile feedback was determined to be a more feasible modality of feedback than audio for sensory substitution [13, 14] as it doesn’t interfere with existing audio, such as music, and it allows players to socialize with each other while playing the game. Vibrotactile cues can be provided with most controllers as most of them contain a rumble feature. However a controller can only be connected to one host, e.g., the console that runs the game and additional vibrotactile cues can therefore only be provided by modifying the game, which is impossible. Alternatively, a player who is blind could hold or wear an additional controller but this setup was deemed not to be very practical. Recent gesture based input systems have become controller-less such as Microsoft Kinect, which opens up the opportunity for the player who is blind to hold a controller that could provide vibrotactile feedback.

Consequently, to investigate RTSS, we use a setup as displayed in Figure 3. A USB video capture unit (Dazzle Video Creator Plus HD) was used to provide a video stream to an external laptop. Although the XBOX 360 supports high definition video, the non-high definition NTSC composite video signal was used to limit the video processing time. The video feed was split, with the same feed being displayed on a flatscreen TV and one being sent to the video capture unit simultaneously.

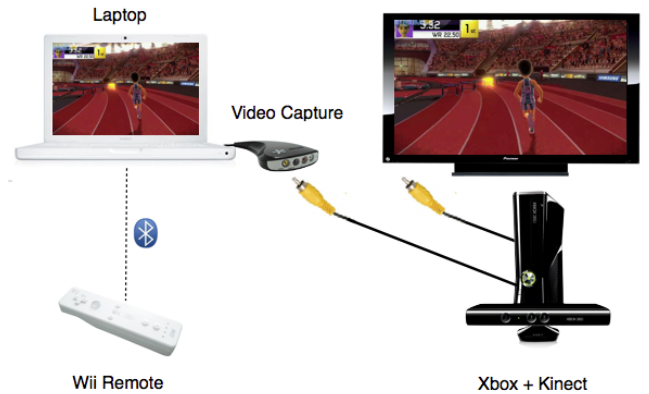


Figure 3: RTSS System Setup

To provide vibrotactile feedback we used a Nintendo Wii remote, which contains a vibrotactor that provides feedback with a fixed frequency of 250 Hz , which can be varied only by pulsing the motor activation. Though the tactile spatial resolution of a Wii remote is limited, an abundance of tactile receptors makes fingertips the most sensitive to vibrotactile feedback [3]. Another benefit of using a Wii remote is their low cost and they can be easily connected to any computer that supports Bluetooth.

3.2 Runtime Video Analysis

Kinect Sports was used for our initial study. This game was chosen as it was one of the first games to utilize the controller-less gesture based input system called Kinect. Players can play six motion-controlled sports such as bowling, boxing, track and field etc. We specifically focused on the track and field games, which include hurdles, sprint, javelin, discuss throw and long jump, because these games utilize visual cues that can be easily identified through video analysis. For example in the hurdle game, the player makes their character run by jogging in place. When the player needs to jump over a hurdle, a visual cue of a yellow cloud would appear at the location of the upcoming hurdle to notify the player to prepare. When it is time to jump, the yellow cloud would briefly change to green (see Figure 4).

Similar cues were used in the other track and field games, which made it an easy target to find within a captured video frame. The software for the video analysis was written in C# and ran on Windows XP. Rather than tailor the video analysis to one game, we opted for developing a generic approach that could be used for different games. An XML based configuration file describes what the video analysis software should do in certain situations for a specific game. The video feed from the video capture card was processed at the rate of 24 frames per second (fps) and had a resolution of 640×480 pixels.

The software runs in constant loop analyzing the video stream for key video sections defined within the XML configuration file. If one of the key video sections is found within the current frame, the software then perform the specified action as defined in the configuration file (either play a certain audio or haptic cue or both). There was little amount of lag

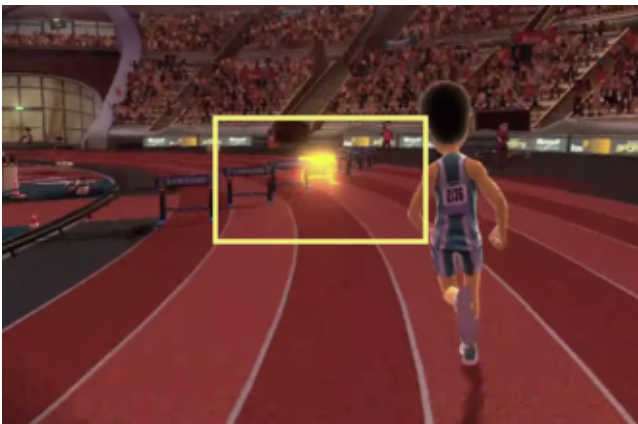


Figure 4: Runtime video analysis of the Kinect Hurdles game. The yellow box indicates the area in which we look for the visual cue that indicates to the player to jump.

in analyzing the frame, and then starting the appropriate cue, however this lag did not affect the game play. Figure 5 shows a sample configuration file used by the RTSS software for one search area. A rectangular space within each frame is defined in the `<section>` tag where also a color range is defined in RGB values. Since the video capture was analog, the colors were not always going to be an exact value and to address this, maximum and minimum values for each RGB component have to be entered.

For each frame, we test if any pixel in the section is within the defined color range. If this is the case, we stop analyzing the current frame and one or more actions will be executed as described in the configuration file. Subsequent frames will be tested to check if the cue is still visible. The system can play an audio cue or provide a vibrotactile cue using the Wii remote, or both. The `WiiMote` tag defines which Wii remote will activate its rumble motor (0-3), and for how long which allows for the use of multiple Wii remotes or vibrotactile patterns with different length to indicate different types of inputs. A value of -1 for duration indicates to keep the rumble running as long as a pixel with the specified color is detected. Alternatively a value can be provided that indicates the number of milliseconds that a vibrotactile cue needs to be provided. The software can also play an audio cue through the laptop speakers when the test is true. The audio cue can be looped when the `<loop>` value is set to 1. If this value is 0 then the audio cue will be played to completion once and if this value is -1 it will loop until the test fails.

During the development of RTSS a legally blind individual play tested three different Kinect Sports track and field games, e.g., hurdles, javelin and long jump using RTSS and provided us with feedback. These games are somewhat accessible as they use a form of sonification, e.g., the frequency of an audio cue increases the closer the player gets to when the input needs to be provided. However, in previous studies with exergames we found players to perform better when audio and vibrotactile cues are provided simultaneously [13]. We instructed our participant to face the camera and start

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<SECTION>
<XMIN>100</XMIN>  <!-- area to watch
<XMAX>300</XMAX>
<YMIN>150</YMIN>
<YMAX>300</YMAX>
<MINR>230</MINR>  <!-- color range to check
<MAXR>999</MAXR>
<MING>230</MING>
<MAXG>999</MAXG>
<MINB>0</MINB>
<MAXB>100</MAXB>
<ACTION> <!-- perform actions when area detected
  <WIIMOTE>      <!-- haptic cue definition
  <ID>0</ID>
  <DURATION>-1</DURATION>
  </WIIMOTE>
  <AUDIO>        <!-- audio cue definition
  <ID>alert.wav</ID>
  <LOOP>0</LOOP>
  </AUDIO>
</ACTION>
</SECTION>

```

Figure 5: Sample XML Configuration File

jogging in place and jump or throw (depending on the game) when a vibrotactile cue was felt. Different configuration files were created for each of these games. For example, for the hurdles game, once the yellow cloud was detected over the approaching hurdle, we would provide a vibrotactile cue with the Wii remote to indicate that the player should jump. Because the player only has a few seconds to jump, a simple vibrotactile pattern was used to indicate to the player when to provide the input. Once the cloud turned green, the rumble was stopped, as it was too late for the player to react and jump within the allotted time. For both the javelin throw and the long jump the part at the end of the track the player is running on turns yellow, when the player needs to throw their javelin or jump (see Figure 6). After tuning some parameters our blind test subject was able to play each one of the games with good performance.

To facilitate creating XML files for different games and to help define areas and color ranges, players can capture a frame by pressing the trigger button on their Wii remote. A sighted person could do this and once the frames have been saved, they can be opened in a graphics editor where the color of the visual cue can be determined as well as the area where it is visible.

4. USER STUDY

To assess the effectiveness of RTSS, we conducted a user study with 28 sighted participants. The XBOX 360, Kinect, a flatscreen TV and a laptop running the RTSS application were placed in a public area and made available to anyone who wanted to play the Kinect games during a video game party. This video game party was organized to allow computer science students to demo the games they developed for various game development courses.

The XBOX was set up to run Kinect Sports and was always configured to play the one player hurdles mini game. The RTSS software was configured for the hurdles mini game as

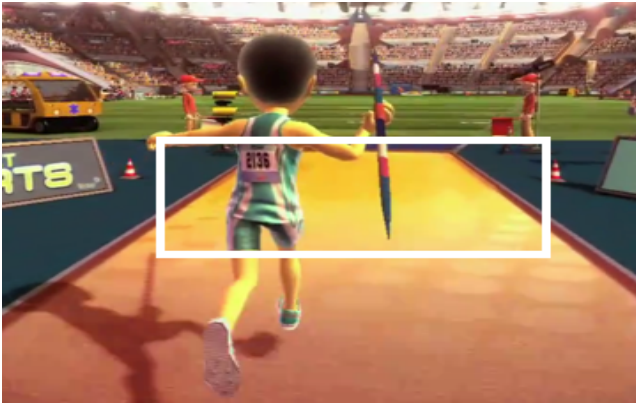


Figure 6: Kinect Sports Javelin throw. The area within the defined box turns yellow indicating the player must throw their javelin.

well. The demo was set up for 5 hours. A game administrator was present at all times to ensure the XBOX game was configured to play the hurdles game as well as to ensure that the RTSS software was running correctly. The game administrator also recorded the results of each game.

Participants were hence tested and recruited anonymously, an approach for doing user studies that has been recently explored [7] and which allows for better understanding of users as it tests them in a more natural, non-test environment. No personal information was collected about the participants other than that they consisted of students and faculty members. This study took place less than 2 weeks after the release of the Kinect, and it can therefore be safely assumed that this was the first time playing Kinect Sports Hurdles for 95% of the participants.

Two versions of the game were tested. The first version of the game was to play the standard Kinect hurdles game using visual and audio feedback. This version was played by 12 participants. The second version of the game, played by 16 participants, was using RTSS and was played using haptic and audio feedback. During the five hours of the party after testing 3 participants, we switched between versions by turning off or on the flatscreen TV. We ensured participants only played one version of the game.

As a player approached our demo, instructions were given based on the version of the game. For the regular version of the game, players were told to run in place and jump over the hurdles when their on screen character approached the hurdles. For the RTSS version, players were given a Wii remote and told to run in place and jump when they felt a vibrotactile cue. A single race consisted of players running around a virtual track and encountering four hurdles. Not correctly jumping over a hurdle would cause the virtual player to stumble and slow down which would result in a slower overall time. Players only ran one race and their time, and number of hurdles successfully jumped were recorded. The laptop screen was not visible to players.

4.1 Player Performance Results

A single factor ANOVA showed no significant difference ($F(1,24) = 0.03, p > 0.05$) in player performance between the success

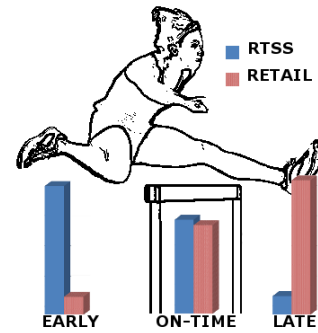


Figure 7: Jump Accuracy

rates of the regular version versus the RTSS version. The RTSS version had a higher success rate with an average of 1.56 ($\sigma=1.03$) out of 4 hurdles being completed successfully compared to the regular version, which had an average of 1.46 ($\sigma=1.27$) successes. There was also no significant difference ($F(1,24) = 0.33, p > 0.05$) between the total time of the race between the two versions. The RTSS version had an average time of 28.67 ($\sigma=8.41$) seconds compared to the regular version which was slightly faster on average at 26.76 ($\sigma=4.76$) seconds.

There was a significant difference in types of unsuccessful hurdle attempts (see Figure 7). An unsuccessful attempt was either due to jumping too early, or too late. Although the error rates were similar between the two games, the errors in the RTSS version of the game were mostly due to the player jumping too early, while the regular version was due to the player jumping too late. The RTSS version contained an average of 2.13 ($\sigma=1.02$) unsuccessful attempts due to jumping too early compared to the regular version which showed an average of 0.3 ($\sigma=0.75$) unsuccessful attempts due to jumping too early. The results of a Single Factor ANOVA show this is significant ($F(1,24) = 27.6, p < 0.05$). Jumping too late also showed a difference where the RTSS version contained 0.31 ($\sigma=0.45$) unsuccessful attempts due to jumping late compared to the regular version that had an average of 2.23 ($\sigma=1.36$) unsuccessful attempts per race due to jumping late. This is a significant difference ($F(1,24) = 20.95, p < 0.05$) according to a Single Factor ANOVA.

Another significant difference between the two versions was in the critical errors. Critical errors were errors that suspended the play of the game, and in this case were either false starts (starting too early) or by moving outside of the Kinect camera's acceptable range. Players were to wait until a gunshot signaled the start of the race. Two of the players playing the regular version of the game created a false start by running too early. Compared to the RTSS version where none of the players created a false start. This could be attributed to the players playing the RTSS version being completely focused on sounds while the players playing the regular version of the game could be distracted by visuals contained within the display. Three of the players playing without the display ran outside of the acceptable range of the camera, while none of the players playing the regular version ran outside the acceptable range. The Kinect sensor was always located in the same place, but players playing without the display had no reason to pay attention to where

they were physically located. Players playing the regular version were focused on the display and that may have created an environment where a player could really run in place without moving. Players playing the RTSS version had no display to look at and had no reason to judge where they were in relation to the Kinect sensor.

5. DISCUSSION

The biggest difference between the games was how the hurdles were unsuccessfully encountered. The RTSS version tended to have players jumping too early while the regular version had players jumping too late. The haptic cue given to the player in the RTSS version was constant and the player had no idea where the virtual player was in relation to the hurdle. The player would simply just jump when the controller started to vibrate. If the player was running fast, as soon as the vibration started, it was the correct time to jump. If the player was running at a slower pace, the player should have waited to jump. The player had no knowledge as to how long the haptic cue would last.

Playing the RTSS version of the game, players were able to determine a success or failure of jumping over a hurdle by listening to the sounds. However, these sounds did not give a description as to if the player jumped too early or too late. Whereas the regular video enabled version of the game gave a visual to the player which would indicate if the player jumped too early or too late and that information could be used by the player to adjust the timing for future jumps.

The haptic cue would start when the visual cue turned from nothing to a yellow cloud. If a player was running at a slow pace, he would jump too soon. Varying the haptic pulse in order to give the player a sense of the distance between the hurdles and his position in the screen may help a player determine more accurately when to jump regardless of the speed in which the virtual player was running.

5.1 Limitations

Although the results showed visual and haptic cues are equally significant, there were several limitations with the current RTSS software.

Video Event Detection

Currently, a rectangular area and a color range within that area is supported. This works well for games such as Kinect Sports where action areas are easily identifiable, are different from the regular background, and are always in the same place. If any of those characteristics are not present, RTSS will not work. There are several games where RTSS is possible in its present form such as Eyetoy Kinetic and the other mini games contained within Kinect Sports, however there are others that will not function properly because the action area is not easily identifiable, or not different from the background or not always in the same place.

Ability to learn from mistakes

The focus of this system was to substitute important visual cues with other modalities in order to play the game without visuals. The important cues substituted in this study were the visual cues that told the player it was time to perform an action. Nothing was enhanced to notify the player the action was done incorrectly. For example, when a player

would move out of the acceptable range for the Kinect sensor, the game would play an error tone and put up a message box explaining -through visuals- what the error was and how to fix that error. Without this visual being substituted, a player without sight would have to rely on a person with sight to explain what the error was. Also, the RTSS system gave no immediate feedback as to how the player was performing the jogging motion. Players using the display could see their character moving in sync with their feet, and they could adjust their running style if needed. This piece was lost when playing without the display.

Text Prompts

Text prompts are present throughout video games, and in order to navigate through the menus, they will need to be substituted for other modalities, for example through audio prompts. Without these present, players without sight need to rely on players with sight to set the game up and navigate to the game. Although the game play visuals are substituted to make the game playable, substituting the in game prompts as well could lead to more independence for people without sight.

Video Processing Time

Kinect Sports provides plenty of advanced notice about an important event that is about to take place. This gives the video processing portion of the RTSS system ample amount of time to analyze the video and substitute in a different modality. In the event that a game was moving at a faster pace or the original visual cues were present for a shorter amount of time, the time required to process the video may become significant.

6. FUTURE WORK

Measure Energy Expenditure

This study was performed to show the feasibility of an RTSS system. The results show that this is a good approach. We seek to measure the energy expenditure of a person with visual impairments while playing an exergame equipped with an RTSS module to see if vigorous levels of physical activity can be achieved. If the combination of RTSS and Kinect games can create vigorous levels of physical activity, this could be a viable form of daily exercise for people with visual impairments.

Menu System

Although the RTSS approach worked when in the game, it did nothing to assist a player with visual impairments in navigating the menus. An additional piece to use a screen reader for games that do not have an additional audio track, or where the in game instructions are not audible, would be a great addition to the RTSS system and make the experience more usable for a person with visual impairments. It would also create an environment where a person with visual impairments could exercise his independence by playing regular games without the need for assistance from a sighted peer.

Object Recognition

The RTSS system outlined here relied on simple cues available in Kinect Sports. Many of the games contained blobs that were always in the same place and always the same color. This simplified the object recognition as only a spe-

cific color in a specific location was monitored. An image signature where a blob of image data in the captured frame can be compared to a known image and determined to likely be the same data should be incorporated into the RTSS system. This will allow for more complex sensory substitution such as identifying moving objects. If this piece is implemented and functions correctly, it will open the doors to making many different kinds of existing regular games accessible to people with visual impairments. There are potential social benefits from this as well as a person who is blind will be able to play the same popular games as his friends.

7. CONCLUSION

This paper presents a technique called real time sensory substitution (RTSS) that allows players who are blind to play gesture-based video games, without having to make any modifications to the game. A user study with 28 sighted players playing Kinect Hurdles found no significant difference in performance based on the accuracy or time to play the game in a version with visual and audio cues when compared to a version of the game with audio and haptic cues. Players using the RTSS system tended to perform the action too early when compared to the regular version where players performed the action too late. Players playing without visual cues tended to wander outside of the playing area defined by the Kinect system, where as players playing with visual cues tended to miss important audio cues. Future work will measure the energy expenditure with hopes to create enough energy expenditure to be considered vigorous physical activity. We will also support the menuing system to encourage independence for people who are blind, and contain better object recognition which will make more games accessible to people with visual impairments.

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