Literature Review of Video Game Input Devices

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ABSTRACT
In this paper, I present an overview of the history of the video game controller as an input device for console and handheld video games. This paper will cover all notable video game controllers, from the paddle controller introduced in 1972 with the Magnavox Odyssey, to the controllers for the more modern video game consoles, such as the Wii and Xbox 360. As well, this paper will discuss the recent developments in touchscreen technology in the context of mobile games as well as the most recent developments in biofeedback controllers. Finally, this paper will address some of the potential avenues of future research.

Author Keywords
Input devices; Video game controllers; Literature review;

ACM Classification Keywords
H.5.2. User Interfaces: Input devices and strategies

INTRODUCTION

The video game industry is one of the most profitable industries in the world. Video games were a popular form of entertainment since the early 1970s, well before Human-Computer Interaction was a field of research. As a result, the input devices used for the first several decades had no bearing on any HCI principles. They were often awkward and unwieldy, and many of them were commercial failures because they were so unusable.

Recently however, video game controllers have begun to evolve rather quickly, and have tried to leverage emerging technologies. From 1972 until the mid-2000s, all controllers were very similar. They all featured some number of buttons, and a 2-to-4-directional input device. Since 2006, when the Wii was released, there has been a shift away from that style of controller. The dominance of smartphones has cause an increase in the number of touchscreen games. The Wii U now features a touchscreen tablet as a controller. The PlayStation 4 has replaced a number of buttons with a touchscreen, and the Xbox One now features a camera for providing facial recognition and voice input. Other companies, such as Valve, have even tried to replace the canonical D-Pad, which has appeared on every console's controller for the past 30 years.

BACKGROUND

The first computer game was Tennis for Two, developed by Willy Higinbotham in 1958. Unfortunately, this game was developed several decades before Human-Computer Interaction was a field of research, and several more years before anyone thought to conduct studies on HCI within the world of video games. As a result, there is virtually no literature available before the 1980s and very little literature available until after 2000. Despite this, in order to properly understand and appreciate the work that is currently being done in this field, it's essential to understand the history behind it.

Until 1983

This section describes a number of the input devices that were developed until 1983, which marked the collapse of the video game industry in North America, and the industry's shift to Japan.

Paddles

In 1972, the Magnavox Odyssey, the first game console meant for home use, was released. Atari Pong, the arcade game, was released later that year. These systems both played the same type of game: a simulated table-tennis game, a genre now known colloquially as Pong. These games were very simple; users could only move in two directions: up and down. As a result, the controller that was designed for these games was equally simple. Called a paddle controller because it controlled a table-tennis paddle, it consisted of a dial that could be rotated up to 330 degrees, and a button. Rotating the dial would cause the paddle on the screen to move.

This controller did not change until 1977, when Atari released a slightly newer version, called the Driving Controller, for the Atari 2600. This controller was almost the same as the original version, except the dial could be turned in a full 360 degree circle, and was only used in a single game to control a race car. Some see this as the first attempt to model a video game controller after a real device (a steering wheel).

Joysticks

In 1977, Atari released the Atari 2600, and introduced a new type of input device: the joystick. While the joystick was first used to control a prototype game in 1967, and used in Sega's Missile arcade game in 1969, Atari was the company that made it popular and accessible.

The joystick released by Atari was quite simple. It featured a 4-directional digital stick and 1 button. Because the joystick was digital, rather than analog, it could detect the direction of the input, but not the amount of force applied. The design turned out to be incredibly successful. Games on the Atari 2600 were simple 2D games, so the 4-directional joystick was sufficient, and the games were often simple enough that 1 button was enough. The joystick turned out to be surprisingly adaptable, and nearly all games could be adapted to use the joystick. Because games could be easily designed with the joystick in mind, it became the prevalent video game controller until 1983, when the gamepad was created.

Trackballs

The trackball is a device that has never received much attention as an input device. In 1979, Taito Corporation released the first game to use a trackball as an input device. It was a simple soccer game where you could use the trackball to control the players.

As an input device, the trackball is quite simple. Conceptually, it's similar to the Atari Driving Controller, but extended to 3D. It features a ball mounted on a tracking system, where input can be given by scrolling the ball in any direction. Historically, it has received very little attention outside of arcade games. Initially, the Atari 2600 and 5200, as well as the ColecoVision supported peripherals that used a trackball. More recently, the Apple Pippin, released in 1995, used a controller with a trackball.

Because this device was created before HCI was a mature field, it's only recently that work has been done to determine the role of trackball controllers on video games. Natapov conducted research comparing the role of the trackball in console-based video games to the role of the mouse in PC games. One of the main benefits of the trackball over a joystick controller is that with a trackball, the player can control the speed at which a cursor moves. He replaced the joystick from an X-Box 360 controller with a trackball and asked users to complete a pointing task. He found that users were able to improve their throughput by over 58% by using a trackball compared to a D-Pad or joystick controller [18]. In another study, Natapov asked users to use a standard controller, the modified trackball controller, and a mouse and keyboard to complete an obstacle course in a First Person Shooter game. He found that the PC had the best completion time, while the gamepad had the worst, and the trackball controller was roughly halfway between them. He asked users to complete a shooting task as well, and found similar results. Additionally, he found that most users actually preferred the trackball controller over the standard gamepad, with 68% preferring it for the obstacle course and 93% preferring it for the shooting task [17]. This indicates that there may be some benefits to using a trackball controller

Light Guns

The first light guns were invented in 1936 by Seeburg, and consisted of a gun shaped device that, when the trigger was pulled, would shoot a beam of light at a target (in this case, a duck). If the light hit the target, a photodiode (a diode that converts light into current) would register a "hit" and increase the score.

The first use of this as a video game input device was in 1972 when Magnavox released Shooting Gallery for the Odyssey. Unlike the original gun, which shot a beam of light, the new light gun contained a photodiode in the barrel. When the trigger was pulled, the TV screen would turn black, and the targets would flash white. If the gun was pointed at a target, the photodiode would activate and score a hit. It would use the time between pulling the trigger and scoring a hit to determine which target was shot. This is quite similar to the principle behind the light pen. Due to rumours about needing a Magnavox TV to use this light gun, it was a commercial failure, and light guns only became popular in 1984 with the release of the NES Zapper. Unfortunately, this technology requires a CRT monitor, and it not compatible with LCD and plasma screens.

Figure 1. Video game controllers until 1983. Clockwise from top left: A pair of Atari paddle controllers, an Atari digital joystick, an Atari Trak-ball controller, and a NES light gun.

1983 - 2009

In the early 1980s, HCI was still in its early infancy. It wouldn't be until several decades later that it would be used to analyze video game input devices. This is unfortunately, because it was during this time that the most influential changes were made to video game controllers.

Gamepad

In 1983, Nintendo released the Famicon, the first home console to use a gamepad controller. Unlike previous controllers, the gamepad featured an input device called the Directional Pad (D-Pad), in addition to several buttons. While a device similar to the D-Pad was used in arcade games prior to this, it was the NES that made them successful. One of the suggested reasons for the widespread success of the gamepad over the previous joystick controllers was that it allowed the users to enter commands using the D-Pad using smaller gestures than a joystick would require [21]. Unlike older controllers, like the Atari 2600 joystick, which allowed users to enter 4 different directions, the D-Pad allowed them to press any combination of directions at a time, resulting in 8 directions. The combination of allowing users to use smaller gestures to use the D-Pad and allowing users to move in 8 directions gave users much more control over the game, which was essential for several of the games that followed.

Analog Joysticks

While the gamepad was a huge success, and still continues to influence controller design, it wasn't a suitable controller for movement in 3 dimensions. This was due to a few issues with the D-Pad. While it was suited perfectly for 2D games, where the player only moves in 2 or 4 directions, it caused problems when used in a 3D environment. For instance, when playing a 3D game like Super Mario 64, there was no way to move at an angle that was not an increment of 45 degrees. This made it very difficult to move around realistically within the game.

In 1996, the Nintendo 64 was released, and was the first home console to feature an analog joystick. Unlike the older digital joysticks, analog joysticks were capable of detecting both the input direction and the amount of force applied. While the Nintendo 64 did not use an analog joystick, but rather used a digital joystick that emulated analog functionality [19].

In order to control the camera, Nintendo included 4 "C" buttons. Unfortunately, these presented the same issues for camera control that the D-Pad did for controlling movement. Soon afterwards, Sony released the first dual-joystick controller, the Dual Analog, featuring a joystick for controlling the character and a joystick for controlling the camera.

With the introduction of dual analog joysticks, the number of buttons on a gamepad has increased drastically, from 3 on the NES gamepad (1 D-Pad and 2 buttons) to 15 on the standard PlayStation 2 controller(1 D-Pad, 8 buttons, 2 joysticks, and 4 "bumper" buttons). It's been shown that the increased complexity caused by an increase in the number of buttons does not have a negative impact on user experience. Specifically, it's been found that even with 15 buttons, controllers require very little mental effort, and only cause minimal amounts of wrist and finger fatigue [16]. It has, however, been shown that there is a correlation between the number of input buttons on a controller and the size of the user's hand, and the usability of the controller [5], suggesting that players with smaller hands will encounter more difficulties when using a controller. Interestingly, the decreased usability that occurs due to smaller hands does not have an impact on the users' preferred controllers.

Wii Remote

In 2006, the Wii was released, and with it came the first mainstream motion controller. Although it was preceded by the Nintendo Power Glove in the late 1980s, the Wii Remote was the first successful motion controller. The Wii Remote features a D-Pad, several buttons, and an accelerometer that can detect motion along 3 axes. The Nunchuk addon adds an analog joystick and 2 buttons, and the Wii Motion Plus adds a gyroscope for more precise movements. The Wii Remote also features an infrared camera that is used to determine where the Wii Remote is pointing, relative to an IR light source (eg. the Wii sensor bar).

The Wii Remote is also unique because it was the first standard controller that actually required a substantial amount of interaction (there were previous controllers that did this, but

Figure 2. Some of the more iconic gamepads. Clockwise from top left: a Nintendo Entertainment System gamepad, a Nintendo 64 controller, a PlayStation 2 Dual Shock controller.

they were commercial failures). Instead of players only using their fingers and thumbs, many games required gestures and full-body movement. This has been shown to have a series of benefits. First, it's been found that using a Wii Remote causes players to have higher perceived energy levels [10]. While this may not actually cause the players to feel as though they're having more fun, other research indicates that an increase in perceived energy levels may increase memory performance. This may mean that motion controls can be used to improve the performance of learning games. The same experiment found that the more interactive controls also have no impact on user frustration.

The interactive nature of the Wii Remote allows it to easily be used in more social genres of video games, such as casual sports games. It's been found that the social nature of these sports games, where people can casually play sports with friends and family, has tremendous mental and physical health benefits for the elderly. Jung et al. [11] conducted an experiment that studied the effects of Wii games on the mental and physical health of 45 residents of an old age home. They found that the residents who played Wii games had higher self-esteem and felt less lonely than the residents who only played board games. While there are a number of factors that may have caused this, the evidence seems to suggest that the main benefits were the results of the more interactive controllers. Gerling et al. [9] conducted a similar experiment, finding that the social benefits of motion controllers such as the Wii Remote are also applicable to elderly adults who are more frail. They also found that despite being in poorer physical health, the frail elderly enjoyed the more interactive input devices [8].

Additionally, Bott et al. [4] have shown that the Wii Remote can be used to replicate the behaviour of musical instruments, in addition to sporting equipment. In this study, participants were asked to play a game that required them to pretend to play a virtual violin and guitar. Unlike other games, such as Wii Music, which plays a note as long as a button is held, Bott et al. present an interface that solely uses the users' gestures as input. The study found that participants found the MIMI interface to be much more realistic, expressive, enjoyable to use than the normal button-based interface, and also found it to be less difficult to learn and less frustrating to use.

Aside from the Nintendo Power Glove, which was not responsive enough to use as a controller, the Wii Remote was the first game controller that players would use to interact with the game in 3D. Specifically, players could move the controller in 3D space as a means of interacting with the game. Until this point, controllers were always 2D, and could only accept input from a 2D joystick or D-Pad. Sreedharan et al. [23] conducted a study to determine the impact that a 3D controller could have on immersion in a 3D environment. They asked participants to perform various exercises using a player avatar in the game Second Life, including navigation and gestural tasks. Their observations showed that users tended to prefer the 2D input (the joystick and D-Pad) for the navigational actions, while they preferred to mimic the gestures for the gestural tasks. 80% of participants also used gestures, rather than buttons, for the basic "yes" and "no" gestures. They did however, find that users unfamiliar with 3D controllers tend to either use 2D input methods or devise ergonomically awkward gestures. Overall however, they study found that 3D controllers do provide a more enjoyable and intuitive interface for immersive 3D games.

In addition to Sreedharan et al. [23], there have been other studies that have shown that the Wii Remote can be used as a 3D input device for navigation tasks. Shiratori [22] found that the Wii Remote can be used to physically simulate the motion needed for a navigation task. Two Wii Remotes were attached to a user's wrists or legs or by held in their hands, and the study participants were asked to physically simulate the movements needed to run around a track. Additionally, users were asked to use a standard joystick interface for this task. The study found that the wrist and leg interfaces were scored much higher on "immersion" and "like" than the hand-held and joystick interfaces, and there was no significant difference in the "fun" or "ease of use" between devices. This suggests that a Wii Remote may be the optimal controller for immersive games.

CURRENT RESEARCH - 2009 ONWARDS

Motion Sensors

In November 2010, Microsoft released the Kinect, a motion sensing input device that uses stereoscopic cameras to detect gestures, as well as a microphone for voice input. While Sony had released the EyeToy in 2003, it used a standard webcam, and was unable to detect the 3D positions of objects, and required a brightly lit room to function correctly. Unlike devices like the EyeToy, which took a 2D image and applied computer vision algorithms to it, the Kinect projected a grid of infrared lines, and used this to create a depth map of the images that the cameras recorded, and then created a 3D image out of this. Freeman et al. [6] found that the impact that an input device without a physical controller, such as the Kinect, has on performance within games is unclear, and depends primarily on factors such as the responsiveness of the game and the user's level of experience.

Because the Kinect creates a virtual skeleton of its users and tracks their body movements, many studies have been conducted to determine whether it can be used in exercise games. Similar to the findings with the Wii Remote, Gerling et al. concluded that the physical benefits of full body controllers do not just apply to people in good physical health, and even more frail adults enjoy using more interactive controllers [9, 8]. Landry et al. [14, 15] conducted studies in which they used a Microsoft Kinect to instruct a group of children in a series of exercises. These exercises had a number of goals, such as encouraging cardiovascular exercises or developing motor skills. Anderson et al. [1] conducted a study in which they used a Kinect to teach users a sequence of physical movements. In this study, participants were asked to learn a series of movements, using a number of different teaching techniques. The study found that a mirror technique, which teaches the user by showing how their movements compare to the "correct" movements, was significantly more effective than video-based techniques.

There are also many studies that have shown that the Kinect provides many benefits to users who may have physical disabilities.

As well, the Microsoft Kinect has possible uses as a therapeutic tool. Bartoli et al. [3] have shown that using a camera-based input device, such as a Microsoft Kinect can have a positive impact on autistic children when used in an education context. The children who participated in this study were between ages 10 and 12 and all had low-moderate cognitive deficit and low-medium sensory-motor dysfunction. Over 5 weeks, the children attended sessions where they would play various games using a Kinect as an input device. The study found that over time, the sustained attention demonstrated by the children increased. The study also found that the number of times where the children's behaviour required therapist intervention decreased over time. While Bartoli et al. present the findings as very tentative, the study demonstrates the positive effects that a video-based input device could have .

Biometrics

Recently, some researches have attempted to determine the viability of biofeedback as a user input mechanism. Biofeedback is the ability of a person to control their basic bodily functions, such as breathing, heart rate, and brain waves. While biofeedback controllers such as the Atari Mindlink have been designed before, the cost of this technology has been so prohibitive that these controllers were consistently cancelled early in development. It's only now that advances in technology have lowered the cost enough to make this sort of controller accessible to the general public.

Dekker and Champion conducted an early experiment in which they used biofeedback to control a game's difficulty level [2]. They asked users to play a game while connected to a biometric sensor that monitored players' heart rates and breathing. Then, based on these measurements, the game's

Figure 3. Microsoft Kinect (top) and a Wii Remote and Nunchuk attachment (bottom).

“horror” components, such as the number of zombies present, as well as the lighting and volume would change. When users became more excited, the game’s colour and volume would change, and would face and become quieter if the user was calm. The game difficulty would also increase whenever the user became too calm. 70% of participants noticed the changes that occurred, and 70% of them liked the way the game adapted itself, suggesting that biofeedback can be used to improve the gameplay experience by modifying the game based on the users’ biometrics.

Stach et al. conducted a similar study, and attempted to use biometrics as a way of normalizing the difficulty of exercise games between users [24]. The rationale behind this study was that because different players have different experience levels, expecting them to perform at the same level can have a detrimental effect on their experience. Instead, they believe that biometrics could be used to determine the effort that a user exerts by comparing their biometrics to some baseline level, rather than their overall fitness level. In this study, they asked users to play a multiplayer racing game while wearing a biometric sensor, and used both a normalized and non-normalized speed algorithm. They found that users did not notice a difference in engagement, but noted that there was a significant decrease in the performance difference between players. This indicates that biometric controllers could be used both to normalize the experience for exercise games, and to dynamically balance multiplayer games based on the users’ biometrics.

Other researchers, such as Kuikkaniemi et al. have found that while using biometrics to modify the game may improve the gameplay experience, this is not always the case [13]. Implicit biofeedback consists of biometrics that the player may not be aware of, such as brain wave patterns, and can often complicate the development process, and has no real impact on the gameplay experience. On the other hand, explicit biofeedback consists of factors that the player may be able to control, such as breathing and heart rate, and can lead to an improvement in the gameplay experience.

Touchscreens

The first commercially available video game system that uses touchscreens was the Nintendo DS, released in 2004. Previously, Sega attempted to develop a game system that used touchscreens, but was ultimately forced to cancel the project due to the prohibitive cost of touchscreens in the 1990s. Since 2004, touchscreen devices have dominated the handheld and mobile gaming markets, and are used for handheld game systems, as well as games on smartphones and tablets.

Figure 4. An iPod Touch (top) and a Wii U controller (bottom).

For some games, such as games where the controls are very simple, a touchscreen is the ideal input device. Oshita et al. [20] found that when there are very few buttons on the screen, or when the actions that the users are expected to perform are very simple, the time required to perform an action as well as the number of errors committed are significantly lower using a touchscreen, as opposed to a gamepad. Zaman et al. [25] found that the opposite is true when users are asked to perform a more complex task. An experiment was performed in which users were asked to play Assassin’s Creed on both the Nintendo DS and the iPhone. Users experienced fewer character deaths and were able to complete tasks more quickly using the Nintendo DS. While the iPhone has several fewer buttons than the Nintendo DS, and as a result required significantly less mental effort in order to use it, the lack of haptic feedback on the iPhone may have been the cause of the difference in performance.

Some researchers have found ways that touchscreen technology can be used to improve the gameplay experience. Gao et al found that touchscreens can also be used to recognize the emotional response of players [7]. In their study, they measured the speed and force which with users interacted with a game. They then used a machine learning algorithm to determine which emotion the user was feeling at the time, with a success rate of over 70%. Similar to biofeedback controllers, game developers could use this to modify the playing experience to make it more enjoyable for the player. Kolly et al. have also found that by measuring the mean touch time and pressure of different users, a touchscreen can correctly identify the user out of a group of 5 people with 80% accuracy [12]. They found the users all demonstrate idiosyncrasies that could be used to identify them. Specifically, users all have distinct timings (both time spent holding a button and time between button presses), the perceived input point (the point that they touch the screen, according to their mental model), and the pressure with which they touched the screen. This could be used to dynamically detect changes in users, as well as correctly identify users in a multiplayer game. Finally, the Wii U controller consists of a touchscreen tablet embedded into the middle of a traditional gamepad. At this time, there are no studies that have determined the efficacy of this controller.

FUTURE RESEARCH

Because the video games are such a quickly evolving field, there are many possible avenues of future research.

Perhaps the most likely field of research in the near future is the development of input devices for virtual reality games. Currently, there are a number of hardware developers working to develop a fully immersive virtual reality device, such as Facebook's Oculus Rift and Sony's Project Morpheus. Because there have never been any commercially available virtual reality devices like it, there is minimal research into how different input devices impact the user experience.

As well, the fields of speech and facial recognition have seen a lack of development in recent years. Because there is now a large shift towards having cameras as an input device (eg. Kinect, Wii U), there will likely be an increase in research in facial and voice recognition as an input mechanism, and studies to determine the viability of such a mechanism.

Finally, there will likely be continued research into biometric input devices. Specifically, devices that do not require explicit user feedback (eg. controller breathing and heart rate), but rather the implicit biometrics mentioned above, such as brain wave patterns. While papers have said that including this sort of control scheme does not have any impact on gameplay, I suspect that due to advances in technology that allow home users access to technology that can monitor their brain wave patterns, there will be an increase of interest in this possibility.

CONCLUSION

The video game controller has a long and interesting history as an input device. From the earliest devices, like paddle controllers, to the more recent controllers which feature gyroscopes, accelerometers, and touchscreens, the field of video game controllers has undergone tremendous change. Unfortunately, this was a field that existed long before HCI was a mature field of research, and it was not until recently that people have begun to investigate the role of the video game controller in the user experience. Since then, studies have been done not only to determine the role of the controller in the games, but also the role that these controllers have had on the lives of the players. This research has shown that controllers can be used to engage children in physical activities, be used as an education tool for physical skills such as dance and martial arts, be used in therapy for developmental disorders, such as autism, and be used to greatly improve the quality of life of the frail and elderly. Fortunately, the research does not stop there. As outlined above, there are several areas where more research into video game controllers can be conducted. As the past development of controllers has shown, there are always emerging technologies that be leveraged to develop better controllers which not only improve the gameplay experience, but can also improve the lives of many people.

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