SOMATOSENSORY INTERFACE FOR THE IMMERSION OF PLAYERS WITH VISUAL IMPAIRMENTS

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ABSTRACT

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Accessibility in gaming is crucial for fostering inclusivity, empowering individuals with disabilities, promoting social connections, and driving innovation. While there is currently a societal push for changes in software to increase accessibility, there are limits to the accessibility that software on its own can provide. We must combine software with hardware to ensure comprehensive accessible solutions. This project combines software and hardware to create a gamepad that returns vibrational feedback from detected changes on screen in the game Undertale. Using computer vision, the software of the project detects player movements as well as enemy movements. Using an array of vibration motors, the player receives haptic feedback of enemy proximity through the gamepad. This translates what would normally be only visual or audible stimulus to include another sense, giving the player more information to act upon and allowing for quicker response and fuller immersion.

Key Words: Accessibility, Gaming, Vision Impairment, Computer Vision, Haptic Interface

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INTRODUCTION

Human beings perceive the world and interact with it through the senses. Our sense of sight allows for perception, navigation, awareness, and independence. When this sense is compromised, we employ other senses to make up for the loss. One sense that is often harnessed in this situation is the sense of touch. It is one of humans most informative senses, used for interacting with and being present in our surroundings (Kortum, 2008, p. 25). Knowing how those with accessibility needs operate in their daily lives allows us to design optimal solutions for them to interact with products and services that may otherwise be inaccessible.

Accessibility should be about more than providing ways for more people to enter the workforce. It should be about making life more beautiful, and more pleasurable. About creating spaces and methods for those with disabilities to be able to overcome their limitations, and to be able to explore and enjoy life and all it can offer. Ideally, accessibility efforts should set up those without disabilities to have more choice and autonomy. Even if accessibility leads back to helping those with disabilities enter the workforce, it should allow them to achieve more socially valuable jobs, rather than relegating them to mindless work through limited accessibility.

This project leverages the idea of implementing accessibility in entertainment spaces to make them easier and more enjoyable. It involves the creation of a pad like interface with embedded vibration motors. The primary focus of these motors is to provide the player with navigational information while playing games, although they can be leveraged for other purposes. The gamepad combines software and hardware to allow for a comprehensive accessible solution. It is designed to work with the game *Undertale*, an RPG in which the player is a lone human who falls into an underground world filled with monsters (Plagge, 2018). The player must find their way through the underground, encountering friends and enemies along the way (Plagge, 2018). The gamepad and its software detect on screen changes in the game and translate them into vibrotactile signals, which the player interprets to navigate the game.

REVIEW OF CURRENT ACCESSIBILITY PRACTICES

The field of accessibility in technology is quite large and has made quite a few advancements and developments. Many of these inspired my work and I have drawn quite a few ideas from them. I cannot describe every advancement made in recent years, but the following is a summary of some of the most influential or important to this project.

Accessible Games

As accessibility in gaming becomes more prevalent, we can find games that are more creative and willing to stride away from the "typical game" to provide options for their players with disabilities. While the biggest changes are found in indie games, AAA game companies have also been taking notice and integrating accessibility functions in their games.

The Vale: Shadow of the Crown is one of the first games I came upon in my research on accessible games for players with visual impairments. It is a role-playing game that provides the player with only auditory and haptic feedback (*THE VALE,* 2021). There are no active visuals in this game. For the majority of the game all that can be seen on screen are particles floating (Bowling, 2021). The story is akin to a gamified audiobook, with voice acting, music, and sound queues. The player must still navigate the environment, purchase items, interact with NPCs, and fight enemies. They just have to do so through solely audio cues (Belanger, 2021). Another take on the audio-based game is *BlindSide*. *BlindSide* is an iOS horror game that implements the phone's gyroscope to track the player's rotation, and similarly rotate their virtual character (Kent et al., 2023, p. 170). The player must "navigate" the environment using sound cues provided in 3D audio, moving using the touch screen and rotating their body (Kent et al., 2023, p. 170). For obvious reasons, these games relate heavily to my project. Being able to play games without visuals is this project's ultimate goal. *The Vale* and *BlindSide's* uses of directional audio resonate strongly with the use of vibration motors in the gamepad to signal direction.

HyperDot, or *HyperDotA11y*, is a game where the player's one objective is to dodge. This game initially excited me as it both involved a research campaign working with disabled content creators (Thompson, 2020), and the gameplay was the exact same goal as Undertale's fight sequences. *HyperDot's* approach to accessibility makes them a leader in the field and can provide a benchmark for all companies. Their level of consideration for players with disabilities should be considered a standard in the industry. To make this game accessible, the creators worked directly with disabled content creators to receive feedback (Thompson, 2020). They had the players stream the game and report any issues they encountered live (Thompson, 2020). Unfortunately, I could not take much from the game itself as their accessibility features do not line up with the goal of this gamepad. However, I believe it still warrants a mention, as this is how developing for disabilities should be done. This would be the best way to continue the project into user testing of the gamepad.

Released in 2020, *The Last of Us Part II* features more than 60 accessibility settings (PlayStation, 2020). It is probably the game that had the most influence on this project, and that inspired my ideas of using cues for navigation. The Last of Us Part II has a vast array of accessibility options for visually impaired users. Users can turn on high contrast display, a screen magnifier, and colourblind modes (Tran, 2020), but the true magic comes from mixing the various accessibility features. In using a combination of camera and aim assist, ledge guard, automatic pickup, traversal assistance, and skip puzzle, users can play the game without visuals at all. This removes the need for sighted assistance, and allows exploration of the open world environment unaided (Kombat, 2020). As this is the final goal for the use of the gamepad, The Last of Us Part II's accessibility integrations are incredibly interesting peruse and contemplate.

Accessible Devices

Since this project focuses on the inclusion of hardware in accessibility for games, it would not be possible without a review of current hardware for accessibility. The following are three pieces of equipment that are geared towards accessibility, as well as specifically towards visual accessibility.

The Xbox Adaptive Controller (XAC) is a reimagined video game controller, made to have external buttons and joysticks connected to it (Stoner, 2020) to be flexible for different setups and play styles. It allows for any combination of buttons, mounts, switches, and joysticks. This is extremely helpful for those with motor limitations, who cannot use a standard controller comfortably or at all. The XAC is used in this project for prototyping, to allow for flexibility of setup and to simplify the process of adding buttons to the gamepad. The XAC makes button addition incredibly easy, as Undertale is setup for controller use. This is in contrast to connecting and programming the buttons through an Arduino, which can be done but is more work for a simple prototype. Unfortunately, the cost of the Xbox controller can be prohibitive, as users would not only have to buy the $129.99 CAD controller, but also the additional hardware of buttons, joysticks, and other needed connections.

The Body-Braille System is a communication system for deaf-blind users (Ohtsuka et al., 2012, p. 672). It works through an array of two vibrators placed on the body, which vibrate or do not vibrate three times in succession to signify the points of a Braille character (Ohtsuka et al., 2012, p. 674). Body-Braille is used to create the “Hellen Keller Phone”, where users can receive signals from other users over Skype, which are translated by the phone into the correct vibrations to display the Braille characters (Ohtsuka et al., 2012, p. 673). The Body-Braille system is a great example of how simple vibrations can be used to transmit complex information to a user.

Vibrational Navigation has been studied at length for use in directional navigation. Through using actuators, a navigation tool can provide users with stimuli indicating directions to walk or obstacles to avoid (Spiers et al., 2023). One tool uses an illusion called “Phantom Sensation”, where the body feels the average of two vibrators to create the sensation of vibration between (Luces et al., 2019). This allows for more specific directional information, rather than being limited by the number of vibrotactile actuators available. Such a tool vibrates in the direction users are meant to travel, to help them orient themselves in the correct direction (Luces et al., 2019). Other similar tools inform the user of which direction is magnetic north (Kärcher et al., 2012, p. 1). This allows users to orient themselves in familiar environments to allow them the sense of autonomy of choosing where to go with the security of knowing what direction is north (Kärcher et al., 2012, p. 1). This tool aids for walking in a straight line, something that might seem inconsequential to a sighted person, but can be difficult for those who are blind (Kärcher et al., 2012, p. 10). The tools created under this concept gave me a further understanding into the different ways vibrations can be used to give navigational information. They also gave me information on what has been tried, and what works most effectively.

HAPTICS AND THE HUMAN BODY

Understanding the ways vibrations are detected is vital for this project, to allow for precise determination of vibration frequency and amplitude for various tasks. To do so we must understand the receptors in play, how they vary in different locations, and how each part of the whole interacts and responds.

This gamepad employs cutaneous touch as the sensory method. Cutaneous touch speaks of tactile perception conveyed through the skin, and the sensation of surface features using nerves (Kortum, 2008, p. 25). There are four types of mechanoreceptors in the skin that detect various force sensations: Pacinian Corpuscles, Meissner Corpuscles, Merkel disks, and Ruffini Capsules respectively detect vibration, velocity, the edge of objects, and skin stretch (Lin & Otaduy, 2008, p. 55). The skin also has free receptors, or nerve endings, which perform many functions such as detecting pain, temperature, and light touch (*Somatosensation - Somatosensory Receptors*, 2022). Each type of mechanoreceptor detects specific ranges of vibration, from 0.4–500Hz, and have their own optimal sensitivity ranges (Remache-Vinueza et al., 2021). As one moves about the body, the ability to recognize stimuli changes (Remache-Vinueza et al., 2021). Noting the specific location in which the vibrations will be detected is important for fine tuning the range of vibrations to be presented.

It is also important to understand the terminology when dealing with vibrations. Intensity and amplitude are both often used interchangeably and measured in meters (m). They refer to the amount of energy displacement measured from the “at rest” value, or the magnitude to the “peak” (Li et al., 2015). Frequency refers to the rate of vibration (Li et al., 2015), noted in the amount of cycles per second and recorded as hertz (Hz). Duration refers to the length of time for which the motor vibrates. Spatial location refers to where the vibrator is placed.

Using vibration for signaling to a user can have social benefits as well. Contrary to audio signals, vibration can be discreet and offer the user a measure of privacy (Li et al., 2015). It also avoids the distortion or attenuation of an audio signal that could happen in a loud environment, or with other noises happening at the same time. Tactile feedback has also been found to be equally or more effective than other sensory feedback (Li et al., 2015). In a study where auditory, visual, and tactile signals were used for a selection task, tactile feedback was found to allow the subject to select targets more quickly (Akamatsu et al., 1995).

METHODOLOGY

The project leverages computer vision to translate on screen changes into haptic feedback for the player to detect and use to decide their next moves.

Python was chosen as the language for this project for multiple reasons. First, Python is user friendly. It is easy for beginners to learn, while still managing complexity at higher levels. Its code is short and readable and is widely used. This beginner friendliness is why Python was chosen over languages such as C++ or C#. Ideally, this project would be able to be ported to other games. This would require others to code what the computer registers as enemy proximity, and an open source, easy to use language best lends itself to this goal. Due to Python's popularity, there are many libraries and tools created for it and built into its core (Gorelick & Ozsvald, 2020). Furthermore, Python is a language with which I am already familiar. I have learned Python in my schooling, and this allowed me to jump into the project rather than spending valuable time learning a new language. While I also know how to program in Java, Python has more advantages and integrations, allowing for smoother connections.

OpenCV is an open-source computer vision framework with tools and libraries. It integrates well with Python and is easy to use. It works off both video and live screen capture, and so is useful for live game capture and pre-recorded gameplay, for use in demonstrations of function. This allows for quick examples of how the program works, rather than requiring playthrough to fight sequences, which can take a while. While PyAutoGUI was a contender, OpenCV's image recognition is more detailed. OpenCV has the ability to give a confidence argument, allowing detection of similar but not pixel perfect matches. This eliminates false negatives that come from the computer's perfection.

Tesseract OCR is an Optical Character Recognition engine, developed by HP and now open source (Smith, 2007, p. 1). It is used to recognize text in images and convert this text into a string parsable by the computer (Malathi et al., 2021). The decision to use an OCR came from the lack of vocalization in Undertale. While the game has some fantastic music, speech is non-existent. Rather, a beeping noise plays as dialogue appears in text form. Unfortunately, Undertale also employs a very stylistic font which can be hard to read, despite the excellent contrast of bold white font on a black background. As this project is aimed towards those with visual impairments who would have a harder time reading, this wouldn't do. Text-to-speech felt like the obvious choice here, leading to the use of an OCR. Using an OCR to read the text live cuts down on time spent, rather than prerecording or preregistering every line of dialogue in the game. While Tesseract was mostly accurate without training, it had its troubles with the font. Exclamation marks would become the letter "t", "N" s would become "H" s, and so on. This led to the need to train the OCR on the Undertale font. Training consisted of creating box files off images of text and correcting each recognized letter and box location, then converting it into training data that Tesseract could read through unicharsets and shape tables.

Tesseract is only half of the text-to-speech solution. Python does not have a built-in text-to-speech functionality, and so the Google Text-to-Speech library (gTTS) combined with the playsound library come into play. gTTS uses Google Translate's text-to-speech API to save spoke audio data to a file (Durette, 2023). Playsound then runs the audio file asynchronously, allowing the program to continue running while the audio is being played. Other considerations for the project included pytt3sx and Bark. While there are advantages to pytt3sx, such as its ability to work offline and play itself (Bhat, 2020), I chose gTTS because its voice sounded less mechanical. Playsound also natively has the ability to play asynchronously, which was not available for pytt3sx. While Bark has the most natural voice of the options, it simply took too long to generate audio files, and would require pre-generation and assignment.

The hardware of the gamepad is fairly simple overall. The controls of the gamepad consist of a joystick and four buttons that connect to an Xbox adaptive controller. The buttons are vibrant colours with bold lettering on them, to make them easier to see with vision impairments. They are 30mm in size, with a clicky feedback. I investigated larger dome buttons as they would be easier to see and click, but they were out of budget for this prototype. While other games might require more hardware, for Undertale these are all the inputs that are needed. These inputs could be connected to an Arduino for cost reduction, but for prototyping the controller makes things simpler.

Inside the gamepad are four vibration motors at the four corners, which connect to an Arduino through a breadboard. These are stuck to the gamepad's cardboard shell, which has padding on top to spread out vibrations and make the gamepad more comfortable. The buttons and joystick being integrated into the touchpad are important, rather than using a controller on top of the game pad. With the buttons and joystick spread out on the body, the user's hands are also spread out on the gamepad. This allows for more hand contact with the surface to feel vibrations and their direction.

Undertale UI is lain out in a very specific and repetitive way. Dialogue boxes are always in the same location, user menu input is shown with a heart icon, and enemy attacks are almost always in white. These predictable patterns make it simple to code the software for the gamepad.

Starting out with the text to speech, as dialogue boxes are always in one of three locations it becomes a matter of detecting when there is text in these locations. Text is always preceded by an asterisk, and so when one is detected on screen its location can be found and text can be extracted. The only caveat to this is when there is a heart icon on screen. A heart icon represents user choice. This means it is a menu and text should be read out as the user hovers the various options. This is simplified by using OpenCV matching to identify if there is an asterisk on screen, to read text around it, unless there is a heart on screen. If there is a heart on screen with the asterisk, then only text immediately right of the heart should be read.

A main component of Undertale is the fights. As the player traverses the environment, they come upon enemies that they can fight or speak with. Navigating the fight menu is fairly simple. There are four moves the player can make: “Fight”, “Act”, “Item”, and “Mercy”. The computer detects which move the player is hovering by noting the location of the heart and reads that to them. When the player selects an option, the heart is removed. If the player chooses to “Fight” a target appears, and the player must hit the center as the line moves back and forth. The computer determines when the line is approaching the center of the target, and buzzes to inform the player. If the player chooses to “Act”, use an “Item”, or provide “Mercy”, they enter a submenu that uses the same method as the menu in dialogue. Where the heart is detected, the text to its immediate right will be read. Once an action or item is selected, the player will enter an enemy attack sequence. Enemy attacks are almost always in white, and so it is a matter of detecting when white pixels are approaching the heart and sending vibrations to the game pad on that side. One caveat here is that the borders of the fight area are also white. Thus, the computer must differ between when an enemy is approaching, and when the user is approaching the edges of the box. The computer must also translate that information in two different ways, as the player should know when they hit the wall. The current vibration motors are unable to vary the intensity of vibration. This means they are unable to pulse at different strengths to signify different things. To be able to differentiate between enemy approach and approaching the borders, the vibration motors pulse at different lengths. Approaching enemies are long strong pulses, and approaching borders are quick pulses.

As of now, the project is unable to guide the player through the environment. The paths in Undertale are fairly well defined through colour contrast, and there are no time limits on arriving in a location, allowing the user to take their time with navigation. Unfortunately, this means that players with little to no vision still would not be able to play the game. However, a future solution to this is discussed in the section *Continuations for Project: Changes for users with visual impairments*.

CONTINUATIONS FOR PROJECT

This has been a four-month project, and I am one person with limited knowledge and experience. I was therefore unable to accomplish all my ideas for the project. There are many additions and changes that can be made to the project. These would make the gamepad more accessible, functional, and modular. The changes fall under three categories. General changes are changes that could be made to improve the game pad for all cases. Changes for users with visual impairments are further additions to this version of the gamepad, meant to aid gamers with visual disabilities. Finally, changes for users with other disabilities covers large scale changes that could adapt the gamepad to those who fall into categories other than only visual disability.

General Changes

To make the gamepad more functional, the first move would be to add more buttons. The majority of games are created to be played on controllers with two joysticks, a directional pad, and 4 buttons, or with a mouse and keyboard. While Undertale doesn't require those, for the gamepad to be able to be used for more games, it would require the additional hardware. It should be noted that the gamepad is able to use the directional pad on the Xbox adaptive controller. However, as it is a large flat surface, the vibrations would be dampened through the controller, and reduce the gamepad's effectiveness. The Xbox adaptive controller also allows for "companion mode", allowing a standard Xbox controller to be connected and used alongside the adaptive controller. This can be used to compensate for the lack of buttons and joysticks currently. However, having the controls built into the pad would be the best long-term solution.

Changes for users with visual impairments

A simple but important change to the controller that I was unable to achieve would be adding Braille to the controller body. Braille should be long lasting and precise, and unfortunately, I do not have the ability to add it to the controller. Braille could be added to the body in multiple locations to render the gamepad easier to navigate without sight. It could be on the buttons themselves to designate the letters, as well as distributed around the gamepad to detail other items. Such items could include options and share buttons, where the vibration sensors are, and more.

Adding modularity to the controller would be essential to take it further in practice. One way this could be done to enhance the experience would be to add the ability to connect a Braille display. While information can be presented through text-to-speech and voice over, many games style their audio specifically to create their atmosphere. Adding text-to-speech over this audio can distract from the ambiance. This leads to the addition of the Braille display. Instead of audibly overlaying text that is meant to be visually read, this text can be converted and displayed on the Braille display. The gamepad may flash a light or use a vibration pattern that indicates when text is available on the display. This also avoids the use of robotic text-to-speech voices, which rarely mesh well with the style of game. This Braille display could also be used for other purposes. Perhaps there are signs or notes in the game, or descriptive audio that could be returned to the user through the display.

This leads to another potential feature that could be added. With the progression of AI and image recognition, it is possible it could be used for descriptions. While it might not be the most detailed descriptions of the visuals, using computer vision and recognition libraries could allow players with visual impairments to receive a description of their environment, character, and NPCs. Of course, this would require heavily detailed coding, far past the scope of what I could accomplish, but it could be achieved, even if as a community effort. Game community members could collectively contribute descriptions that could be linked to areas of the game and distributed through the gamepad's Braille display.

Similarly, AI and image recognition could be used for navigation of the environment. A program could be trained to map the paths of the game and direct the player during their traversal. This could be done through user training or machine learning. Unfortunately, this process may lead to players missing out on some of the side quests or NPC interactions the game offers. However, this may be a worthy trade off for the player as it allows them to better play, or play at all, a game that may have been previously inaccessible.

Returning to the concept of Braille devices, I feel I must draw attention back to the Body-Braille device previously mentioned in the section, *Review of Current Accessibility Practices*. As a quick review, the Body-Braille system consists of two vibration motors pressed against the body (Ohtsuka et al., 2012). These motors vibrate or do not vibrate three times in series to in total depict the six dots of a Braille character (Ohtsuka et al., 2012). The gamepad has vibration motors on either end of the body, both of which can be distinguished between. This leads to the possibility of the adaptation of the Body-Braille system for use on the gamepad. The two sides of the gamepad could vibrate or not vibrate to signify the dots of Braille. Although use of this system would be an adjustment, it has the advantage of not requiring the player to lift their hands off of the controls. While the user would have to move one had to a Braille display to read, the vibrations from the Body-Braille system can be sensed during play. This could have a variety of uses. Perhaps there is a quick time event where the player has to press the "A" button. The gamepad could vibrate once on the left and the player would know to press the A button. While there are still situations where text-to-speech and a Braille display would be more efficient and effective, using the adapted Body-Braille system could have its benefits.

Changes for users with other disabilities

Accessible modularity means a piece does not stop with providing accessibility in just one way. I imagined methods in which this gamepad and software could adapt to provide accessibility in other ways. One method could include separating the controls and vibrations for those with mobility limitations. While those with motor limitations may or may not have visual impairments as well, the vibration in the gamepad may still help. Perhaps they cannot move their head to view the screen properly or have some other overlapping disability. Separating the controls and vibration element of the gamepad could be beneficial. The user could have the vibration pad placed on a section of their body, using their own controls to enjoy the game. A study done on suitable body parts for wearable vibration feedback in walking navigation found that the ears, fingers, wrist, neck, and feet were the most preferred for stationary vibration feedback (Dim & Ren, 2017). These are locations that would be easily reachable from a computer, and on which a smaller vibration pad could be placed. The vibration pad could also be split into sections to be placed on various sections of the body, depending on how the user feels most comfortable. A limitation to this change would be the requirement of the wires. At this point in the project's life, the vibration motors need to be attached to the Arduino. While it would be possible to have some form of wireless connection of the motors to the computer, we must consider the viability. How much would it cost to make the motors wireless. Would there be a delay in information transfer, and would this affect the gamepad's usability?

Systems such as "TOTEM" (Saitis et al., 2022) and Body-Braille (Ohtsuka et al., 2010) have explored the use of vibration to portray music. The two take different approaches to the problem. TOTEM uses actuators carried in a bag, unobtrusive and able to be carried on the shoulder, for use in crowds for live music (Saitis et al., 2022, p. 8). It consists of five presets of different "textures" of vibration, each aimed at portraying a different audible range (Saitis et al., 2022, p. 9-10). Body-Braille uses a pad that users place their hands upon (Ohtsuka et al., 2010, p. 444), and vibrates on different fingers to correspond notes in an octave (Ohtsuka et al., 2010, p. 445). While neither of these systems could be transplanted one for one to the gamepad, they both show that it is possible to portray music through vibrations. This would be another potential addition to the gamepad software, this time for those with auditory impairments. Audio such as speech and music could be conveyed through the vibrations in the gamepad. Of course, this wouldn't be the same as hearing the music, but it could simulate this and give the player more than they would have. In research by Remache-Vinueza et al., the advantages to a larger base for this are discussed (2021, p. 6). They suggest that "resolution of stimuli perception may increase as the area covered by the actuator increases" (Remache-Vinueza et al., 2021, p. 6). The wide area mentioned in the research is a chair. By using a chair, the user can be presented with vibrotactile feedback from the back, the seat, the seat arms, and perhaps the legs depending on the chair (Remache-Vinueza et al., 2021, p. 7). This could be another pivot for the project, which would also benefit users with mobility limitations. Laying out an array of vibration motors on a chair could allow for more detailed vibration patterns for more intense communication. This could also allow for a detailing of what would typically be audio cues. If a game provided audio only as a cue the player needs to react to, it could vibrate in a specific location to let them know, versus a vibration that informs the player of speech.

FURTHER POTENTIAL ADAPTATIONS

Developing a gamepad that is comprehensive in its accessible features does not stop there. While this specific project was limited in scope, future research could integrate the following further potential adaptations.

One adaptation that could be made is flattening the gamepad and removing the buttons, turning it into a vibrating desk mat or pad. The desk mat would sit on the user's desk, below their mouse and keyboard, where their arms and hands rest. This could be useful for aiding in virtual navigation. Perhaps the pad vibrates a certain way when the user has entered a new text field, or rapidly pulses when hovering a button. If attempting to navigate to a specific preset, the desk mat could vibrate in a direction to inform the user. Perhaps for those with auditory disabilities, the mat could rumble when there is sound, or vibrate once strongly if there was a ping from a non focused window. The desk mat could also be set up to notify the user to alarms and timers they have set, or notifications from their messaging services. Perhaps it could connect to the user's phone to inform them of a text message or call.

Continuing with the idea of a desk mat, this project could also be evolved from gaming to other forms of entertainment. When watching a video, the pad could detect sound and visuals and associate them with vibrations. If the screen is overall darker, perhaps the mat vibrates low and slow to convey the unease portrayed by dark. If there is a sudden change or flash on screen, the pad could vibrate violently to symbolize this.

These adaptations could allow for further immersion in movies and media for those with and without disabilities, providing them with another sense to use to enjoy entertainment.

If we consider the *Continuations for the Project*, we can remember the concept of the chair with vibration motors distributed across it. This idea can be combined with the above to create detailed vibrations based on all the user's tasks. With motors distributed along the seat of the chair, the back, the arms, perhaps even a footrest, users could receive detailed and customized vibrations based on their preferences. They could have their right arm vibrate to let them know they are typing but not in an input field. Their back could pulse once to let them know they are hovering the "minimize window" button, and twice to let them know they're hovering the "close window" button. Perhaps their seat vibrates every 30 minutes to remind them to stretch and drink water. With such a wealth of vibration motors, the user could potentially customize to their exact needs and preferences.

The computer vision aspect of this project could be adapted to work with a camera to provide the user with the ability to better detect their surroundings. If the user were able to pre-emptively record scans of their belongings, the program could potentially guide them to said items. Say the user was looking for their water bottle in their room, but unfortunately are very nearsighted. This prevents them from being able to scan their room efficiently to locate the bottle. If the bottle were scanned, with the correct implementation of computer vision and AI, the user could use their camera to scan their room. If the bottle is found by the camera, they would receive a pulse while hovering it. The camera could temporarily remember what was seen and guide the user to the bottle. If the camera scanned to the right and left of the bottle, and what the user is recording was seen to the left, it could pulse right to let the user know to move to the right.

This could also be adapted to current existing applications such as Be My Eyes. Be My Eyes is a program that matches up users that need to borrow a pair of eyes for every day tasks with volunteers (Salam, 2019). It is currently taking steps to implement AI into its program using the visual input of GPT-4 (“Be My Eyes,” 2023). One use case suggested by Michael Buckley, the CEO of Be My Eyes, is the user scans their fridge, and the program extrapolates what ingredients exist and suggest a recipe (“Be My Eyes,” 2023). The combination of this and the project could be helping the user navigate to the item, as was written in the previous adaptation. The user could hold the phone in front of them and could receive directional vibrations that inform them where to look for their required ingredients.

CONCLUSION

The gamepad and software created for this project work to create fuller immersion in games for players with visual impairments. It does so by detecting on screen changes in the game and translating this into positional information. This positional data is used to compare the player's location on screen to the location of enemies. The information is then signaled to the player through vibrational motors on the gamepad. These vibrations tell the player where the enemy is so they can avoid it. The software also implements text-to-speech to make the game prompts easier to receive.

The combination of hardware and software in this project allows for extensive coverage for accessibility. In its current form, the project can aid players with visual impairments. However, there are methods in which this gamepad can be adapted to help those with other disabilities. The concepts discovered in the creation of this project can also be adapted for purposes other than a gamepad. These adaptations would create tools that users with visual impairments can use in their daily life for assistance in both virtual and physical navigation. Tools for accessibility are incredibly important as they can give their users autonomy and freedom that they might not otherwise be able to achieve.

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