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INTERACTIVE GAME FOR CHILD

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ABSTRACT

The goal of this project is to create a custom handheld game for Luke, a nine-year-old child with severe visual limitations. To accommodate this limitation, the handheld was designed to engage multiple senses with a lower emphasis on visual interpretation. It is expected that this handheld will provide educational and physical benefits. The lower emphasis on visual cues will help Luke to develop other senses such as touch and hearing. Although not a primary focus, this will provide a common activity in which all children can enjoy, this will facilitate Luke to interact with his peers while providing entertaining and educational benefits.

To facilitate the development of this handheld, the team was divided into three sub-teams: Electrical, Software, and Mechanical/Industrial, where each can function semi-autonomously while maintaining a working relationship with each other.

INTRODUCTION

Luke is a nine-year-old child who fine and gross motor skill delay, some hearing loss, and visual impairments. He enjoys swimming, all types of music, hiking, biking, cars and has a pet fish named “Phelps”.

His visual impairments include difficulties in the fields of contrast and myopia. With the help of his Assistive Technical Specialist, Luke is currently learning how to operate a computer using a 20-inch monitor and a keyboard with textual markings. The software, ZoomText, is set at seven times magnification which enables Luke to utilize programs such as Microsoft Word and various educational games. For example, one of the games has animated characters teach him how to use the keyboard.

Luke relies on defining characteristics (i.e. the ears of a rabbit) and the scale of the objects to differentiate objects from one another. For example, he was able to distinguish between a teddy bear and a little boy in a picture.

Several prototyping sessions were held to learn more about how Luke would interact with several key components of the handheld and its associated games. The first prototype session utilized an Xbox controller with its vibration modules. The second prototype session involved interaction with one of the games and the chosen LCD screen. The third prototype session involved interaction with the second and third game, in which his reaction was gauged. All prototype sessions proved to be informative in the development of the project.

HARDWARE DESIGN METHODOLOGY

Processor

Central to the design of the hand-held hardware platform was the selection of the microcontroller. It needed to be capable of controlling elements of the hardware subsystems while also running the game software. One of the customer requirements was for the handheld to have a graphic display, therefore it was also necessary for the microcontroller to be able to interface to an external display. This involved generating game graphics and appropriately sending them to the display device. In a discussion with Dr.

Phillips, the Parallax Propeller was suggested as a microcontroller that was used in homebrew game development kits with simple graphics capability. After evaluating the Parallax Propeller against a few other microcontrollers, it was selected due to the balance between technical specifications and simplicity. Several beneficial features of the Parallax Propeller found were: availability of open-source code for applications such as graphics and audio, its packaging simplicity (44 pin LQFP), an active forum community, the ability to generate NTSC and VGA video signals and an available development board.

Audio Subsystem

The audio subsystem was designed to deliver stereo audio either to onboard speakers or headphones plugged into the handheld by the user. Considerations into the design of this system were speaker drive power, volume adjustment, headphone switching, and power consumption. In order to reduce design complexity the National Semiconductor LM436, an all-in one audio amplifier solution was chosen. Important part features and its application to the design are seen in Table 1.

Feature	Design Use
Dual Amplifier Package	Stereo Capability
Bridge Tied Load Capability	4 x Output Power of Standard Single Ended Output
Headphone Sense Input	Automatic Speaker/Headphone Switching
DC Volume Control	Use of Linear Potentiometer for Log Signal Attenuation
Shutdown Pin	20 uA Low Power Current

Table 1: LM4836 Important Design Features

One of the shortcomings of the Parallax Propeller was the lack of an onboard hardware DAC. In order to generate analog audio signals using a digital output pins, a duty cycle modulation scheme along with a low pass filter was utilized. An onboard counter of the Propeller was used to generate a signal of much higher frequency than the audio sampling frequency. Additionally, the amount of time this high frequency signal was high for a single sampling period was directly related to the DC level of that audio sample. Therefore, the duty cycle modulated counter along with the low pass filter acted as a DAC. A simple first order low pass filter seen in Figure 1 was utilized. The resistor and capacitor in this filter were selected to appropriately set the audio cutoff frequency.

In order to verify the design of the audio hardware, a prototyping board was utilized. The IC came in a TSSOP package, therefore a TSSOP prototyping board was ordered. One difficulty encountered with this was the presence of a heat sink slug on the bottom of the LM4836. The prototyping board was modified by cutting away solder pads with a rotary cutter to accommodate the heat sink pad. After this the audio subsystem design was verified and modified as needed using the prototyping board and external hardware.

The speaker was selected using the following criteria: form factor, power handling, frequency response, and listening tests. Two initial speakers were ordered as seen in Table 2. Both choices offered an impedance and power handling combination that suited the output drive capabilities of the audio amplifier. After listening tests, the Kobitone speaker was selected for use in the audio subsystem.

Speaker	Form Factor	Impedance	Power Handling
Projects Unlimited AS02708CO-WR-R	27 x 21 mm [1.06 x 0.82 inch]	8 ohm	1.1 W
Kobitone: 235-CE221-RO	22 mm [0.87 inch] diameter	8 ohm	1.1 W

Table 2: Initial Speaker Selections

In a discussion with Professor Slack, it was recommended that the tactile switches be examined for possible bounce issues. Using the setup in Figure 2 the electrical/mechanical behavior of the switches was observed. Signal transitions after button presses were observed to deem whether switch debounce hardware was necessary. After experimentation, bounce was not observed from the switches, thus no hardware was needed. Additionally, a polling routine was used to observe buttons. If an interrupt based routine was used, switch bounce would be a larger concern.

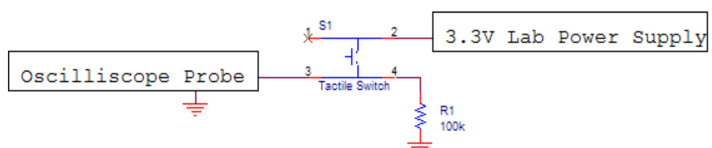

Figure 2 - Switch Bounce Measurement

LCD Selection

As mentioned above, the customer desired some form of graphic display. After discussion about the different types of displays that could be used, which included an array of different color LED's to a color LCD, we tested Luke to see what would work. The tests were performed on a laptop with shapes of varying sizes and colors moving across the screen. The intensity of the laptop screen was also changed to determine Luke's perception thresholds. After performing these tests it and taking in to consideration handheld weight and the available power from a battery it was determined that a self contained LCD module that accepts an NTSC input signal would be best suited for the task. This decision was also made because it was deemed the integration of a custom

LCD and LCD controller into the design would not be possible in the projects time constraints. The selected display is a 4" LCD with a brightness of 220 nit, it requires a supply of 12VDC and 125mA. The LCD was purchased from lcdtft.com, with part number LCD4CHL. Later electrical testing of the LCD shows that it actually requires around 175mA and that it requires a significantly greater amount of current at startup.

Power Subsystems

During concept development, a battery life ranging from two to four hours was given in the product specifications. In order to design a gaming system with this length of battery life while still maintaining low weight and ease of use, a 6V 1600mAh Ni-MH battery pack was selected. Lithium battery chemistries were avoided due to safety concerns. The Ni-MH battery pack is charged by removing it and connecting it to an external battery charger. This battery pack proved to be too big physically and required a change to a smaller battery with a capacity of 7.2V 700mAh. With this reduction, a nominal battery life of 1.5 hours is expected. In addition to the selection of a Ni-MH battery pack, DC/DC converters were necessary to provide both 12V to the LCD and 3.3V to all other subsystems. Low drop out linear regulators were avoided due to their inefficiencies and because a battery capacity of less than 12V was desired for weight reasons. The entire system is protected from faults by a 1.1A PTC placed on the PCB near the battery interface.

To step-up the battery voltage to 12V the MAX618 DC/DC converter was selected for minimum external components and small size. The converter is available in a 16 pin QSOP package and is capable of delivering over 500mA of current. Design verification was performed using the MAX618 development board available from Maxim IC. The final project PCB layout followed the development board layout for the 12V power supply exactly to avoid issues with switching noise and EMI.

To step down the battery voltage to 3.3V the MAX1685 DC/DC converter was selected for its small size, high switching frequency and high current capacity of 1A or greater. In addition this converter has multiple low power and shut down states that allow it to run in the microampere region while still providing 3.3V to its host. This converter is available in a 16 pin QSOP package. Design verification was performed using the MAX1685 development board available from Maxim IC. The final project PCB layout followed the development board layout for the 3.3V power supply exactly to avoid issues with switching noise and EMI.

Tactile Feedback

The handheld includes two tactile feedback motors taken from an XBOX 360 controller. The two tactile feedback motors are driven with separate fixed frequency, variable duty cycle PWM signals that are fed to the gate of power MOSFETs. Each motor will have independently controllable variable speed. A freewheeling diode has also been installed in the circuit to avoid damage to the MOSFET from motor EMF. The circuit for driving the motors is shown in figure 3.

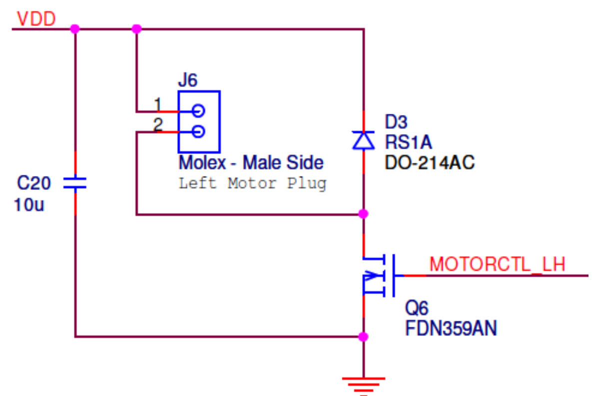

Figure 3 - Motor Driver Circuit

PCB design

In order to integrate the electrical subsystems into a compact package the use of a custom PCB was recommended during project reviews. Custom PCB layout was done using the free PCB Artist software available from Advanced Circuits where the boards were ordered from.

The PCB has a custom shape allowing for maximum layout area inside the enclosure while providing a cutout for the battery. In addition the shape was chosen to allow one contiguous PCB holding all subsystems including the user interface buttons. To avoid noise and EMI issues, power circuitry, the propeller and audio circuitry were all confined to different areas of the board. Large ground planes were placed around and between these subsystems to provide additional shielding. The printed circuit board artwork can be seen in figure 4 with an image of the PCB in figure 5.

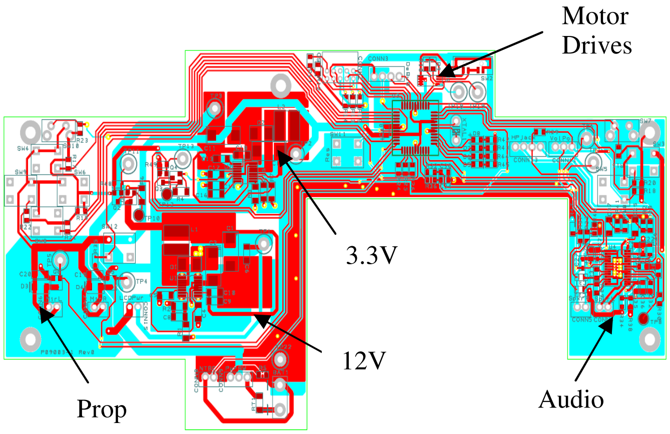

Figure 4: PCB Artwork

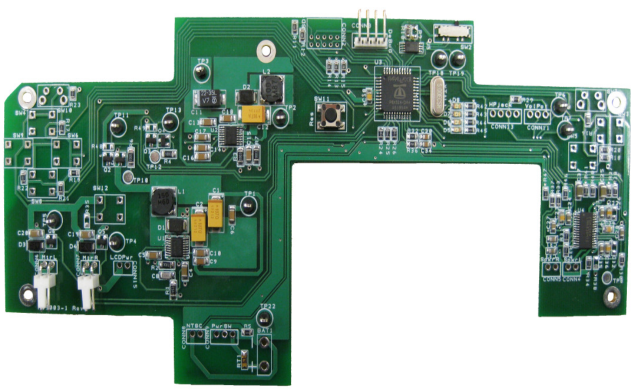

Figure 5: Completed PCB with Subsystems Populated

SOFTWARE DESIGN METHODOLOGY

API: Audio

The audio driver was designed to play a WAV located on the SD card. The base code of this player was taken from **rayslogic.com**. In order to initialize the playing of a file, a routine is called in which the name of the .WAV file on the SD card is passed as a parameter. This driver utilized the SD SPI routines (see SD section) to load .WAV data into a buffer onto the Parallax Propeller RAM. Then an assembly loop utilized the data in the buffers to control the onboard counters utilized to generate the audio signal via external low pass filtering (see audio subsystem design). When initially prototyped, clicking/popping noises were heard at the beginning and ending of the audio playback. The initial pop was empirically found to be due to the generation of offset bias on the input signal lines, while the ending pop was due to the shutting off of the hardware counter on the Propeller. To circumvent this issue the mute feature of the audio amplifier was utilized. The following scheme was developed to play audio files:

1. Mute Audio Amp
2. Ramp Input Voltage to DC Offset Voltage
3. Unmute Audio Amp
4. Play Audio Files
5. Mute Audio Amp
6. Shutdown Propeller Hardware Counter

This solution did not remove the clicking and popping activity, but instead masked it by disabling the audio amplifier when it occurred.

API: Video

The video driver consisted of two main components: graphics and NTSC video generation. In this scheme, the graphics driver would draw to a display bitmap in the Propeller RAM. The NTSC driver took care of all the timing and signaling needed to convert the display bitmap to an NTSC video signal for the LCD output. The driver used for this was supplied with Parallax Propeller, TV.spin. This graphics driver was based off the standard Parallax Propeller graphics driver, graphics.spin. This allowed for the setup of the display bitmap and display bitmap buffer. In this double buffering scheme new graphics were drawn to the display buffer and then the updated content of the display buffer was written to the actual display bitmap. Additionally the graphics driver provided routines to draw different graphics onto the display bitmap such as squares, rectangles, arcs, and lines. Custom modifications were made to these routines to accommodate for the games developed.

In order to interface the Parallax Propeller an SPI driver, fsrwFemto.spin, was utilized. It allowed new code to be loaded from the SD card into Parallax Propeller RAM and for general data to be read from the SD card to Parallax Propeller RAM. The loading routine was called at system boot-up to load the current game cartridge. The general read routine was utilized when playing audio files from the SD card.

API: Vibration

The vibration API was based on code that generated a scaling PWM signal. The code used a counter built into the Propeller and an accumulation register to output the desired signal. Parameters were hardcoded into the assembly portion of the code to setup and generate the signal. The SPIN code portion controlled the scaling aspect of the signal. The code was modified to deliver a standard PWM signal with the ability to dynamically set the frequency, duty cycle and the motor to be controlled. This was accomplished by modifying the assembly routine to take values passed in from the SPIN code. The SPIN code was also changed to pass the desired values to the cog where the assembly code was running. The assembly code would then read each of these values from memory and setup the counter accordingly. A SPIN function was created that allowed the programmer to pass in values relating to duration and intensity of the motor vibration.

Games

Three games were designed to provide entertainment for Luke: Simon, Avoidance, and Maze. Each game consisted of varying difficulties and focused on audio and tactile cues. Many of the features of these games originated from the prototype sessions. The first prototype session introduced Luke to the vibration modules and ensured that he was comfortable with the vibration feedback. The second and third sessions involved Luke playing simplified versions of the games where his interactions were gauged and adjusted to fit his level of play.

Simon

The driving force behind the development of the Simon game was the desire to introduce him to video games and the intended interface of the handheld. This game was a very simple and common game for children. This involved Luke to follow a sequence of colors which were generated by the game. It was determined after the first prototyping session that the game's difficulty would need to be scaled down to suit Luke's early game skills.

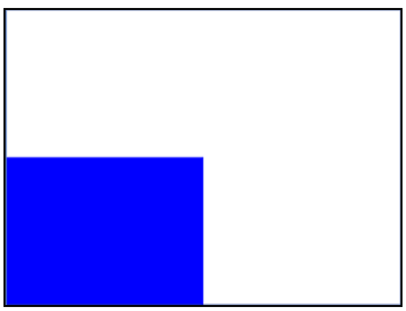

Figure 6: Simon Game

Avoidance

The Avoidance game focused on having the player, represented by a triangle, avoid hitting a square that was falling down the screen. To alert the player to move the triangle, the hand held vibrated. Another feature of the game is to retrieve bonus items. The bonus items are represented by circles that move down the screen along with the square. When they are hit by the triangle, the score is increased and a sound is played. When the player hits the square a life is lost and when all the lives are gone, the game is over. A different sound effect will be played to signify an obstacle being hit in order to show the user an unintended action.

The game also features different difficulty settings. The different settings in this game affect how fast the square and the circle move down the screen. The concept of the game is simple, but the more fast paced nature of the game will help Luke develop his motor skills.

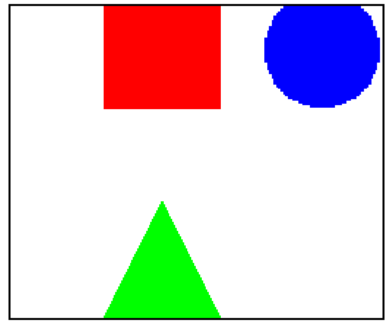

Figure 7: Avoidance Game

Maze

The Maze game focused on navigating throughout a series of pathways to reach an end target. This game utilized the system of navigation known as "Hot vs. Cold". The system has the player following audio cues, rather than having to look at the screen, in order to navigate the map. The player listens for "Hot" sounds to indicate getting closer to the target and "Cold" sounds to indicate moving away from the target. This system allows the player to almost completely eliminate the visual aspect of the game pending appropriate level design.

Although the game play mechanics are solid, the lack of customer experience in video games detracts from the overall enjoyment. The learning curve to be overcome in playing a new game was compounded with the learning curve of the new activity of playing video games. It was therefore decided to start the game at an easier level to help the user become accustomed to the new environment. Harder levels would be offered if he wished to move on in the game.

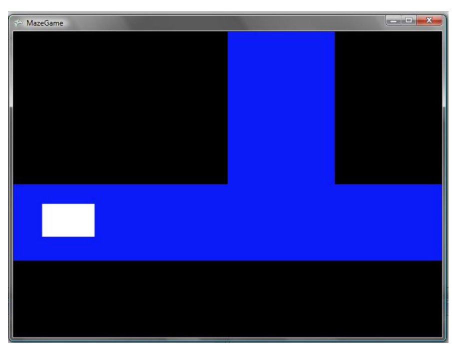

Figure 8: Maze Game

MECHANICAL AND INDUSTRIAL DESIGN METHODOLOGY

Figure 8: 3D Model Rendering of Handheld

Casing

The overall casing is made to be as simple as possible to maximize internal volume and reduce cost of manufacture. During earlier prototype sessions, Luke showed a preference for the Sony Playstation 2 controller, which has smaller, rounded handles compared to the Nintendo Entertainment System and Microsoft Xbox 360 controllers. The main body of the casing was expanded from the thinner designs seen on early concepts in order to accommodate internal electronic components. A white color scheme was selected because it was easier for the customer to identify buttons against a white background as opposed to a black one, contrary to our original expectations.

The handles are placed slightly closer to the top of the console. This is intended to shift the point of balance further away, causing the console to tilt slightly towards the user. This will add to long-term user comfort. The curvatures of the handles are intended to allow some variations in grip while maintaining easy button accessibility.

The mechanical design of the casing was mainly driven by the external dimensions and ergonomics. Once the main internal components were selected by the electrical team, a meeting was held to organize the components in the most compact package possible, since a small overall size was desirable in order to meet customer needs and increase usability. These packaging dimensions were then used to develop the overall external design.

It was decided early on that using rapid prototyping technologies would be the fastest, easiest, and cheapest way to build the majority of the mechanical components. This construction method allowed great freedom in the design of all of the mechanical components, since machining considerations were not needed. An SLA process using DMX-SL-100 material was found to be most suitable, since it was designed specifically for small runs of usable plastic parts. Its mechanical properties are similar to ABS plastic, which would be the material of choice if this was to be a production part. Molding ABS plastic parts was considered, but the lead time needed for the molds was deemed unsuitable, even with the recent advances in rapid mold prototyping. Additionally, a metal case was ruled out due to both machining time and cost, and because of the limitations on geometry that would have been imposed.

The external design of the casing had few mechanical features of note, but it was designed with a wall thickness of 3 mm (0.12 in.) based on twice the thickness of the Xbox controller that was benchmarked. The Xbox controller was excellent in both torsion and bending, but had the advantage of a long development time and of a designed molding process. The factor of safety designed into the Xbox controller was assumed quite high, so as to withstand daily use and abuse. Using this controller as a benchmark, a theoretical factor of safety of twice that of the benchmark seemed prudent on what would be an untested device.

With a complete model of the exterior of the casing, attention was turned to the internal mounting and attachments. All of the internal components were modeled in SolidWorks so that an assembly drawing could be made and fitment checked. The basic layout of the internal components had been established earlier when the external case dimensions were established, so it was largely a matter of designing mounts to keep each part in its place. Components that might need to be removed for repair, such as the LCD and PCB were designed to be screwed in, while more durable components were designed to be glued in.

One facet of the mechanical design that had to be closely coordinated with the electrical team was the dimensions of the PCB. Initially a PCB footprint that took up most of the bottom portion of the case was laid out. This ended up being scaled down so that only the upper portion of the original footprint was used. Additionally, coordination was needed on the placement of the buttons on the PCB. This was important not only for the PCB layout itself, but also for the design and constraint of the mechanical buttons. The PCB itself was attached to the case using threads cut in the plastic itself.

The LCD, the two halves of the case, and the screw for the battery cover, were mounted with M3-0.5 hexagonal electrical standoffs as screw bosses. In a production part, these would be molded in to the case, but with that option unavailable, these bosses were glued in. While there is a possibility of the glue failing, the fix is simple enough that it could be done by the end user if needed. It was a concern that if the plastic was tapped instead of using the metal bosses that the plastic threads would have a limited number of uses before becoming too worn to properly functions. A repair to these threads would have been much more involved, even if they proved to be slightly more durable initially than the metal bosses. However, the plastic was tapped for the PCB mounts, since that was mounted in a position that did not leave enough depth to insert a standoff. Additionally, the PCB would probably not need to be removed unless a replacement was needed.

The components which did not have fixed mounting points were constrained by a variety of methods. Molded pegs were used for the power switch and volume control knob. The parts would then be permanently glued onto the pegs. The headphone jack was glued on 3 sides, and further limited by the protrusion of the jack itself. The vibration modules were given their own groove to sit in, which prevented axial motion, and in conjunction with the speaker mount piece, limited the radial motion as well. The speakers, lacking attachment points, were similarly constrained, but also glued in place to limit axial motion.

The casing was initially to be two pieces. Delays in the initial design forced this plan to be modified. The case is still composed of 2 major pieces (referred to here as the top and bottom), but there are now 2 smaller pieces as well (referred to as the front and back). The top and bottom bolt together using 4 screws, and hold the major components such as the battery, PCB, and LCD. The front piece guides the cartridge and has the power button mounted to it. As this was originally intended to be part of the top of the case, it is located by 2 pegs on the top and glued permanently in place. The back piece holds the speakers, volume control, and headphone jack, and additionally constrains the vibration modules. This piece bolts in using 2 of the main casing mounting bolts. The majority of the design work was done on the top and bottom casing, while time constraints forced the front and back pieces to be done at a rapid pace. While they both fit mechanically and accepted their components, the overall fit and finish is rough, especially on the exposed surfaces.

User Interface & Ergonomics

The design of the mechanical buttons was done in collaboration with the industrial designers, who modeled the exposed portions of the buttons. Once these were completed, the basic shape was extended downward and flared out to prevent the button from falling out of the case. The extended section matched the extended guides that followed the holes in the top of the case. This prevented the buttons from wobbling in their holes. Finally, the buttons rested on their respective electrical buttons. The electrical buttons provided a surprisingly good "feel" to the button action, and the SLA buttons are light enough that they do not accidentally actuate the electrical switch.

Direction pad (D-pad) – This was scaled downed slightly from standard D-pad to accommodate smaller hand size. The buttons are slightly raised while the pad has a slight concave curve in the center. With the use of mock-up models, this was decided to be the most comfortable shape, which allows the thumb to rest in the indent and provide more leverage when actuating the buttons.

Action buttons – There are two different buttons featuring different shapes and colors to allow for easy distinction. The buttons are also arranged in a position that follows the arch of the thumb as it pivots to provide comfortable play.

Triggers – Two Large buttons that are easy to activate in a variety of grips.

Pause – Set into the side main body of the casing between the screen and D-pad. This provided a convenient yet unobtrusive location for a button that will be used occasionally. The crescent shape follows the natural pivot of the thumb to allow easy, comfortable access.

Power – A sliding on/off switch that is located on top of the console. This reduced the possibility of accidentally turning the console on/off compared to a single push button.

Analog joysticks were considered during initial design concepts, but were deemed unnecessary and omitted.

Speaker Placement – The speakers were placed on the bottom of the console, separated as far as possible to allow for a stereo sound field.

Vibration module Placement – Placed on the bottom, towards the user and separated as far as possible to allow easier distinction from one another. The weight will also cause a natural tilt towards the user, placing the screen in a more natural viewing angle and reducing user fatigue over time.

Volume Adjust – Placed next to the Audio Jack making it intuitive to locate. There is also a ridge surrounding this and the audio jack to allow user to easily locate by feel.

Audio Jack – Placed on the bottom of the console to ensure that the wire will be unobtrusive.

CONCLUSIONS

The integration of the various parts of this design proved to be successful. The software operates with the hardware which accepts user input. As a result, the device outputs vibration, sound and visual cues. Luke is now provided a handheld in which he will be entertained.

Although this design was successful, one of the problem areas with the design had to do with the battery. Not only was the designed compartment slightly too small, proper consideration of the wiring was not taken. Both of these problems were rectified by switching to a smaller battery and redesigning the battery cover so that it integrated the wiring connections. This solution was found after an attempted widening of the original housing. This new design is much more serviceable and was an effective, although unplanned, upgrade.

The Electrical Engineering team successfully designed and developed a first generation playable platform. This version of the device meets all of the system specifications. Game play is achieved via data transfer from a SD card cartridge. The vibration modules, speakers, and headphone jack provide non-visual cues and feedback to the user during game play. A playing time of 1.5 hours exceeds the requested expectation. While only a prototype, this device has laid the groundwork for future work in Senior Design teams to continue developing this assistive device.

RECOMMENDATIONS

Overall, it is suggested the weight and size be reduced to improve portability and a redesign of the game cartridges to improve durability.

Due to the time constraints of this project, a proper FEA analysis was not able to be conducted. If it was analyzed, the wall thickness could most likely be reduced since it was based on twice the thickness of the Xbox controller and not on any engineering experiments. Another area of improvement is action of the D-pad. It is possible to actuate multiple buttons with a single press, which is undesirable. A suggested improvement would be to switch to 4 individual buttons arranged in a cross shape.

Currently, the device only utilizes one stereo channel so multiple audio sources cannot be mixed i.e. the device does not play more than one sound at once. Multiple audio sources would provide a more rich gaming experience for the user. The Hydra Game System has the capability to play multiple source audio such as synthesized sounds; however Hydra cannot play .wav files without modification.

Future devices should address the size of the system memory as more memory would be helpful. The prominent memory consumer was the video code. The video resolution was substantially reduced and there was still little memory left for other key functions such as audio and vibration modules.

Currently the device is designed to only enter a low power stage, it does not wake up from this stage without a hard reset. External hardware can be introduced to address this issue. A soft power button could also be introduced.

Future teams should research a non-removable rechargeable battery supply as it would be more convenient for the user. Additional circuitry would be required.

It would be beneficial to create a standard API library for future game development. Currently the APIs are extremely customized for their respective games. This would create a better programming and development environment.

It is recommended to heavily research the Propeller Chip's proprietary language, Spin. It is a basic language that, while exhibiting aspects of object oriented languages, should not be treated as such. The code architecture of anything built in Spin should be mostly procedural because trying to force Spin to act in a modular fashion has the tendency to cause problems. Utilize pointers and keep track of memory usage as there is a limited amount.

Lastly, Physical prototyping of any of the games in development is strongly recommended. By physically prototyping each game, it will lead to a cheap, fast, and easily changed version of the game to test. The physical prototype should just be a rough mock-up of the game that can be played on paper, cardboard, grid, etc, and should adequately represent both the feel and mechanics of the game. Utilizing this would help enormously with developing primarily audio based games. It is also recommended to first program in a familiar language, so that the game can quickly be put together in order to be tested. Though this version you would be able to convert over to spin code fairly easily.

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