

FunBox Classic

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Abstract — The Funbox Classic (FBC) project yields a portable, handheld game console design designated for friendly user interface with a touch of nostalgia. The final prototype will emulate five vintage console platforms and deliver a complete gaming experience, including comforts of LCD screen display, handheld button command controller operations, and all other amenities to enhance the user’s experience. Integrated auxiliary features, such as alternative source battery charging circuits and Bluetooth controller interaction will further offer modern features to a classic device. Complete with a custom case design, the FBC bridges the past with the present for a unique gaming experience.

Index Terms — Audio amplifier, emulator, Lithium Polymer battery, power controller, solar charger

I. INTRODUCTION

Designed as a handheld game emulator, the FBC core component is a Raspberry Pi 2 (RP2), with software to support the GameBoy (GB), GameBoy Color (GBC), GameBoy Advance (GBA), Nintendo (NES), and Super Nintendo (SNES) console platforms. The featured games can be emulated and played on the FBC by either uploading them to the SD card in the RP2 or by means of an external storage device into the USB port on the exterior case. The RP2 also serves as the central operating system for the FBC, feeding data to key components, such as screen display and audio. The screen will display the emulated games when the device is powered on, with built-in backlighting for optimal visual output. A stereo speaker amplifying system will enhance the gaming experience, with a headphone jack feature available to isolate the audio to only the user. A SNES controller design will be incorporated to operate the console, and a Bluetooth feature will allow for additional controller operations via third-party operations, such as a smartphone application. The FBC will be internally powered by a 4.12V Lithium Polymer (LiPo) source battery, allowing for the prototype to be ideal for portable travel. The LiPo battery can be charged by either a wall charger plug-in, or by an exterior solar panel. A

mechanical relay in the charging circuit will alternate between the wall charger and solar panel to avoid two charging sources afflicting the battery at the same time. An LED indicator light will provide an indication for the user as to what the charging status of the battery is, as well as when the battery reaches a low enough voltage to need to be recharged. Finally, an exterior case will consider all of the components to be arranged to allow for a comfortable user gaming experience, along with an aesthetically pleasing design.

II. SYSTEM OVERVIEW

The core concept behind the FunBox Classic will be explained here, along with highlighting other key concepts necessary for the proper functionality of the system, which will be explained in more detail.

A. Standard Operating Flow

The operation of the device begins with the user switching the power switch to the on position. From there, a control signal from the battery reaches the TPS61030 power chip and turns it on. It then allows the power from the battery to be properly amplified and passed onto the Raspberry Pi 2. Once the RP2 has received the battery, it turns on as well.

Following this, the software portion of the system comes into play. Using the EmulationStation GUI, the user is able to select the desired emulator and the game they wish to play with this emulator using the internal controller. Once in a game, the controller switches to controlling the game, allowing the user to either play the game or return to the emulation selection menu. The user can also opt to shut the system down and then turn the power off using the power switch.

B. “Simultaneous” Charging

The battery is able to charge using either the bq24210 solar charging chip or the MCP73831 general purpose charging chip, depending on which charging mode is currently enabled. These chips control the flow of power to and from the battery, alternating between charging and draining fast enough to give the appearance of those actions being simultaneous. This is key to the proper operation of the system.

C. Decoupling Capacitors

Decoupling capacitors are necessary for power system response time. Normally, power supplies are slow, with a roughly 10 us response time. When a powerful system, such as the RP2, is quickly changing its power

requirements to maximize efficiency, it takes 10 us every time for the power system to correct itself.

That's where the decoupling capacitors come in. They add a mini charge "storage" near the chip. These charges are exhausted first when power requirements change, giving the chip time to catch up. The capacitors, made as small as reasonable for maximum speed, are placed as close as possible to the chip. This is to counter the harmful effects of impedance on speed. Additionally, making the traces short and wide will increase the performance of the decoupling capacitor.

III. HARDWARE COMPONENTS

All hardware components and their specifications for the FBC will be listed discussed in this section in details.

A. Raspberry Pi 2

One of the biggest decisions that had to be made was what would be the core of the FBC. Smaller ICs such as the ATmega line of chips, as well as FPGAs, ruled out, as neither were suitable for our purposes. Between the Raspberry Pi 2 and the BeagleBone Black, the RP2 was chosen due to its preexisting support for the applications required, as well as its lower cost. Additionally, it contains 40 GPIO pins, which suits our purposes.

The RP2 features a Broadcom BCM2836 900 MHz quad core processor running on ARMv7 architecture. Additionally, it contains 1GB of RAM, a VideoCore IV 3D graphics core, 4 USB ports, a 3.5mm jack for combined A/V and HDMI. These specifications make it around as powerful as an original Xbox, perfect for running the applications required of it.

B. Audio System

The audio design of the FBC consists of a stereo speaker system and an audio jack for headphone use. Audio signals are accessed from the game ROM by the emulators, and are driven to both the speakers and audio jack IC's. For the stereo system, two 8Ω speakers are utilized to output sound from the left and right sides of the FBC. An amplifier is needed to modulate the audio signals from the RP2 to the speakers, so two LM4861 Audio Power Amplifiers will be used for each speaker to output a frequency of as much as 20kHz. Additionally, a LM4880 amplifier IC is used for the audio jack, as the two-input two-output function accommodates the tip and ring pins for the jack. All three amplifiers used in the audio circuit operate at a range approximately 2 - 5.5V, making them ideal for a low-power device, such as the FBC.

The 3.5mm 4-pin audio jack, as seen in Fig. 1, and amplifier IC's were chosen specifically for this system to

alternate audio output between speakers and headphones. An internal tip switch, pin 4, in the audio jack indicates if a headphone plug has been inserted into the port, and all three of the amplifiers have a Shutdown pin to correspond to if the port is open or closed. If the port is clear, with no headphone plug inserted, the tip switch signals a high to the LM4880 shutdown pin and a low to the LM4861 shutdown pins, effectively powering down any signal to the audio jack. Likewise, when a headphone plug is introduced, and the tip switch is pushed away from the tip connection, the speaker amplifier shutdown pins are turned to high and the jack shutdown pin is set to low. This results in audio ceasing to output from the speakers, and only via the audio jack. [1]

The entire audio system volume output can be controlled by the user with a thumbwheel potentiometer. A 5-pin 10kΩ potentiometer is needed for this application, as there is a left side and right side signal input from the RP2, and volume control needs to happen simultaneously from both signals. The user can slide the thumbwheel to increase the internal resistance of the potentiometer, with the maximum setting of 10kΩ effectively muting the system.

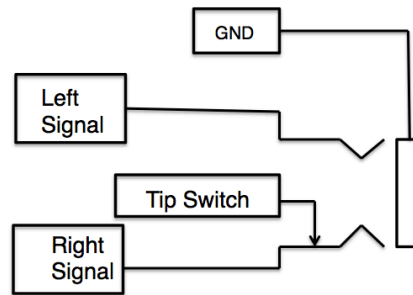


Fig.1. 4-pin audio jack model to audio circuit

C. Battery

There are many different types of batteries and five types were considered for this project: Alkaline, Nickel-Cadmium, Nickel Metal Hydride, Lithium-Ion, and Lithium Polymer (LiPo). A LiPo battery was decided upon due to its rectangular shape, its weight, its capacity limits, and its cost efficiency. It was further decided that the battery would be 2500 mAh, as this would give the FBC a battery life of approximately five hours, which fit the stated requirements of the project. The battery was rated at 3.7V.

D. Wall Charging Circuit

Having chosen a LiPo battery, an appropriate charging mechanism must be selected. Direct charging would be a possibility, however it was decided that the risks of

overcharging outweighed the time gained through simplicity. Realizing that, it was further decided that the circuit needed to handle 5V input from USB and charge the battery through the constant current and constant voltage methods. The current must remain at 500 mA and the voltage must remain at 4.2V for each of those methods, respectively.

After much deliberation, it was decided that the MCP73831 would serve as the charging chip. First, the chip had the best balance of complexity of integration vs. features. Second, the chip contained options to hook up to a charging indicator LED. Finally, the max charging current was 500 mA. Based on these circumstances, the MCP73831 was the ideal choice for our applications.

E. Solar Charging Circuit

An auxiliary means to charge the source LiPo battery is through a solar charging circuit. An external solar panel, comprised of four monocrystalline silicon solar cells, generates a voltage to charge the battery. The solar cells have a dimension of 86mm x 14mm, which, when stacked above one another, closely match the RP2's dimensions. This is ideal, as the panels will be on the back of the FBC and must fit the size constraints. Each solar cell has a maximum power point voltage of 4V and current of 44.6mA. Monocrystalline cells perform better with indirect lighting than cheaper-grade materials, which is desired for the location of the solar panel. In order to effectively charge the LiPo battery as much as by 4.2V, the four cells will be divided into two groups. Each group will have two cells connected in parallel to double the output current. Then, the two groups will be connected in series to double the output voltage. The ideal end result will be a panel that outputs approximately 8V and 89.2mA at maximum power point. Realistically, based on the indirect lighting, it is likely that the panel will only output around 4V, which will still effectively charge the battery.

A charging circuit is required of the solar panel to supply the battery with a constant voltage and current. The bq24210 IC is specifically designed for low-powered devices while supplying a constant voltage and current to the LiPo source battery. Given the low power draw from the chip and minimum requirement of resistors to limit the panel's current, the bq24210 also ideally works with the power circuit and the PCB size constraints.

F. Alternating Battery Chargers

Preventing the risk of charging the LiPo battery from two different sources simultaneously, the FBC must be able to alternate the wall charging and solar circuits. The wall charger is the primary charging source for the battery, and the solar panels alternatively charge the battery when

the wall charger is not present. To ensure the solar panel charger does not impact the battery at the same time as the wall charger, a mechanical single pole, double throw (SPDT) relay will be implemented. The rated coil voltage for flipping the internal relay switch is 5V, which corresponds to the rated voltage of the wall charger. By default, the relay switch will be positioned to directly connect the battery to the solar charging circuit. When the wall charger is introduced, a feed from the wall charger voltage will go to the coil, flipping the relay switch to now directly connecting battery to the wall charging circuit. When the wall charger is removed, the relay switch will flip back to the solar charging circuit. This mechanism can be seen in Fig. 2.

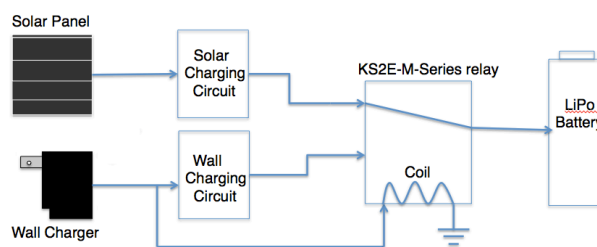


Fig.2. Implementation of relay to alternate solar and wall charging circuits.

G. DC-to-DC Converter and Regulator

With a proper charging circuit in place, it was next necessary to design a DC-to-DC converter to step the battery up to the 5V required by the RP2. As a result, the project required a booster converter chip. Several requirements were set out, chief among them being output current. The system would most likely have run at 700 mA or lower, but it was decided that the chip should have a maximum output of at least 1A, in case more power was needed. Further, the system required an output of a little more than 5V, to account for unexpected voltage drops and noise, an enable/shutdown pin, and it needed to be synchronous instead of nonsynchronous, due to the smaller size and higher efficiency. Fitting these conditions was the TPS61030. This chip takes an input voltage of 1.8-5.5V and can turn that into another output within that range, depending on resistors in the circuit. Further, it is 95% efficient for the purposes of the FBC, as shown in Fig. 3.

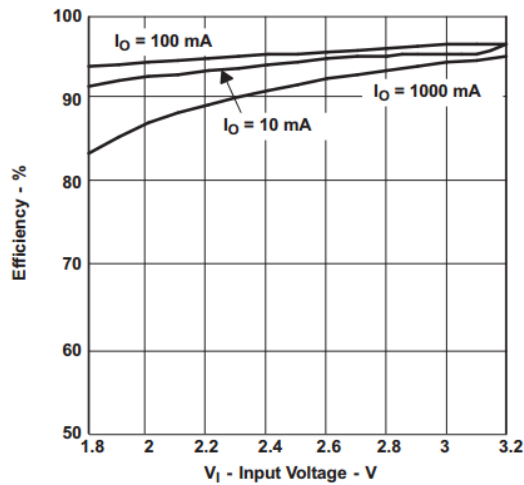


Fig.3. Implementation of relay to alternate solar and wall charging circuits. Courtesy of Texas Instruments.

H. Screen

For the screen, it was necessary to choose one that would best fit the FBC's most advance system, namely the SNES. At a maximum resolution of 512x448, the SNES was the most resolution heavy console that the FBC emulated. However, this graphics mode was rarely used and, in testing, was able to be scaled down below that. Furthermore, when not used, the SNES only output at 256x224, and that became the golden number to match.

A variety of options were explored, from SPI to HDMI, but ultimately it was decided that the screen would connect to the RP2 through composite. An inexpensive 4.3" car rearview monitor screen was chosen, with a 480x272 resolution. The screen can be seen in Fig. 4.

The screen was taken out of its casing and any excess wiring and adhesive removed. The screen was originally 12V input, but after cleaning the board, it was soldered to one of the 5V GPIO pins on the RP2 for power.

IV. CASE DESIGN

A. Case Architecture

The exterior casing of the FBC is going to be modeled in likeliness to preexisting handheld gaming devices, but is also going to be heavily dependent on the availability of positioning components around the RP2 and PCB. The general architecture of the FBC will be the stacking of the PCBs and RP2 on top of each other, and finally the display screen, which will be showcased on the exterior surface. The controller board will be placed at the base of the screen, which will correlate with the exterior command buttons used to operate the device. With this basic layout,

a design modeling after the rectangular GBA will be more relatable to serve the function of ease and comfort.

Additional indentations in the case must be considered for practical operations. Namely, the positioning of necessary openings for buttons, switches and ports, which will be dictated by their placement on the PCB and RP2. The power slide bar, volume wheel, and USB and audio ports must be exposed, with only a few millimeters allocated for positioning over the regions of the board. The backing of the case will be of equal surface area to accommodate the solar panel, and will have an opening for the JST cables to connect the panel to the PCB. The left and right speakers are 23mm in diameter, and are not surface mounted to the PCB, lending more flexibility to position them just on either side of the boards. However, based on acoustics testing, it is found that the speakers perform better when encased in a hollow cylinder construct. An interior design to the case will service that enhancement, with a mesh opening on the exterior to output the volume.

B. Case Manufacturing

The case will be manufactured by means of 3-D printing. By services of the University of Central Florida, student-operated 3-D printers are available for use, and in compliance with financial constraints, are free of service for projects within an allotted surface area. The case will be printed out of plastic, and be comprised of a top surface cover and bottom surface cover, connected by metal screws. The dimensions for the case are 158.5mm x 160.5mm, as seen in Fig. 4.

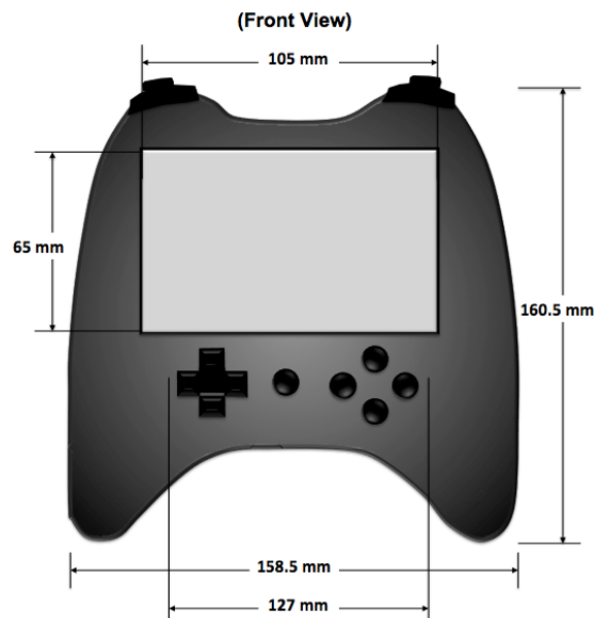


Fig 4. Case Design

V. HARDWARE DETAILS

A. Hardware Overview

The hardware is made up of four main components: the Raspberry Pi 2, the Mainboard, the Power PCB, and the Controller PCB. The relationship between these parts can be seen in Fig. 5.

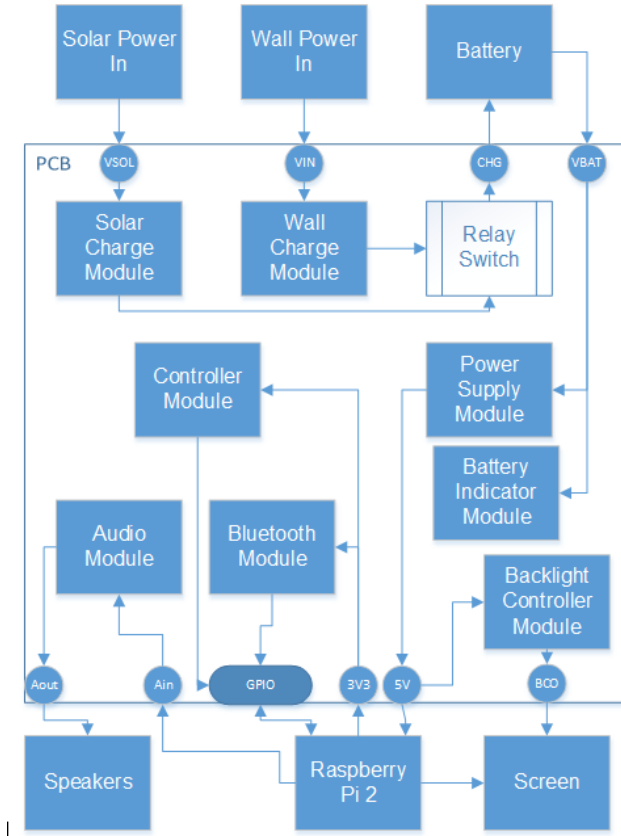


Fig. 5. Hardware Block Design

The Raspberry Pi 2 is the main core of the processing for the system, and was not created for this project. The Mainboard consists of the audio module connected to speakers and a headphone jack, which handles all audio input and output; the Wall Charge and Solar Charge modules connected through a relay switch, which allow the battery to charge through either mean; the deprecated battery indicator module, which was removed due to design issues; the deprecated Bluetooth module, which was removed due to a fundamental incompatibility between the chip and its intended purpose; a GPIO header that connects to the RP2; and the deprecated power supply module, which was removed due to technical issues and repurposed in the Power PCB.

The Power PCB consists of the updated Power Supply Module, and connects to the battery and the Mainboard for the purpose of powering the system at large. The Controller PCB is a SNES controller board wired directly to the USB ports of the RP2.

B. PCB Design

Designing the PCBs to accommodate the above hardware configuration is not a simple task by any means. This stage in the design process involves a close and careful consideration of each of the individual modules and how they interact with each other. The designs of the two PCBs created for the FBC are shown in Fig. 6 and Fig. 7, representing the Mainboard and Power PCB respectively. One key thing that is important to notice is the isolation between the left and right halves of the Mainboard, with the right being for power only. This saved the project a total board failure when the power section failed. Also please note that the ground planes have been removed to make the design easier to see.

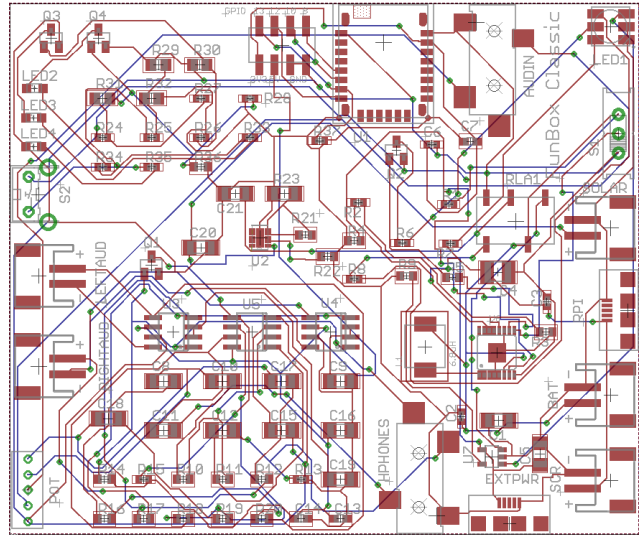


Fig. 6. Mainboard

The largest piece of the mainboard is the Bluetooth chip, seen at the top. The bottom left of the board contains the three audio amplifier ICs, the potentiometer used for volume control, and connections to the speakers. The upper left portion contains the deprecated battery indicator circuit, which was removed when it was discovered it drew 1.25A of current even if the switch was not pressed. Next to the Bluetooth chip is the 8-pin connector to the RP2's GPIO pins.

The right side of the board features the power portion of the Mainboard. The largest flaw with this section of the

board was that the traces were far too thin. Due to an incorrect calculation for current, the traces were set to a 6mil size, and promptly blew upon plugging in the board. The high current traces were identified and replaced with wires soldered to the components and vias. This fixed the majority of the issues, but the boost converter portion remained broken. Therefore, this board continues to be able to charge the battery with solar panels and the wall charger, as well as display a charging indicator in the upper right LED. The boost converting capabilities were deemed critical to the system's success, and thus those operations were moved to the Power PCB, which will now plug into the second JST connector on the right in lieu of the battery.

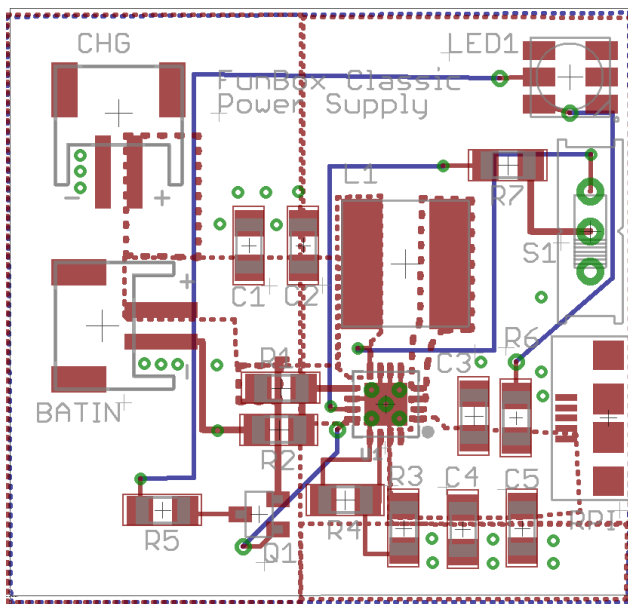


Fig. 7. Power PCB

In the revised boost converter design, the subpar 6mil traces were replaced with short, wide pads, exactly as the design specification calls for. Note the largest component on the board, the inductor, and where it lies on the Mainboard in Fig. 6. This should give an idea of the scale of the two boards. The capacitors and resistors were made a standard, and larger, size to allow easy manual soldering. The CHG port connects to the existing Mainboard in the BAT slot. The BATIN port connects to the battery and the RPI port connects to the RP2.

One of the key design modifications made was the addition of multiple vias for ventilation and heat dissipation. The fatal flaw in the previous board design was the TPS61030 overheating in a few seconds, thus preventing further boost conversion. As a result, vias have

been placed in the ground pad under the chip, linking the two ground planes for maximum heat dispersion. In addition, vias have been added around high current areas in the ground plane, to also allow for heat dissipation.

C. Connections

To ensure ease of use and testing with the system, many components were chosen so that cords can be plugged in with no soldering.

The audio signal is received directly from the RP2 through a 3.5mm jack on both the Mainboard and the RP2 connected together. The audio is then sent through the audio amplifiers and, depending on whether or not a set of headphones is plugged into the HPHONES jack, is sent either to the two JST connectors for the external speakers or the headphones plugged into the HPHONES jack.

The power system has two key JST connectors on the Mainboard, two key JST connectors on the Power PCB, and one key MicroUSB port on both the Mainboard and the Power PCB. The MicroUSB ports serve to both accept the wall power and to output the stepped-up battery power to the RP2. The two JST connectors on the Mainboard are for the solar panels and for connecting to the Power PCB. The two JST connectors on the Power PCB are used to connect to the Mainboard and to plug in the battery.

The 8-pin connector plugs into the RP2's GPIO ports. Two pins, 3v3 and 5V, are used to power the Bluetooth chip and the audio amplifiers respectively. Two pins are used for ground. The remaining four pins are used to interface with the Bluetooth chip.

VI. SOFTWARE DETAILS

The FBC has three main sections of software: RetroPie, EmulationStation, and the Emulators. Using all three in tandem, the best possible user experience can be achieved. A general view of how these three sections fit together can be seen in Fig. 8.

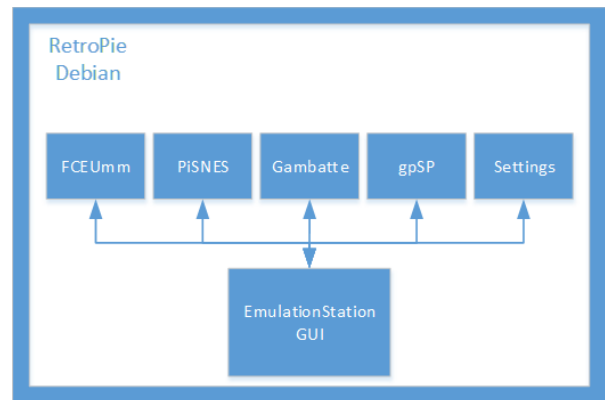


Fig. 8. Software Flowchart

A. RetroPie

RetroPie is a modification of the baseline Debian install for Raspberry Pis called Raspbian. RetroPie has one overall goal: to turn the Raspberry Pi into a dedicated retro-gaming console. It is a collection of works including emulators, drivers, and other software features such as networking and file copying through different file systems.

Central to RetroPie is the RetroPie Setup Script. It allows automatic installation and configuration of all emulators, front-ends, drivers, and any other components one might need for a retro-gaming system, including built-in support for SNES controllers.

ROMs for each emulator can be copied in one of two ways. First, a SAMBA share can be used to copy ROMs onto the SD card using a network connection. This option was disabled for power consumption reasons. Secondly, the USB daemon exists which can transfer ROMs from a USB stick in either FAT, FAT32, or EXT4 format to the EXT4 format found in the RetroPie system.

RetroPie supports a wide range of emulators, but most importantly it supports emulators for the five systems the project requires: NES, SNES, GB, GBC, and GBA.

B. EmulationStation

EmulationStation is a clear, concise, easy to understand GUI which, while originally a separate application, is included with RetroPie. It has native controller support and, if a controller is not supported, native controller mapping support, allowing a user to set custom button configurations.

It is a minimalist system, only showing a given emulator on the main page if ROMs exist on the SD card for that emulator. In this way, it cuts down on user fatigue with the GUI, allowing the most optimized experience for each and every user.

Settings for RetroPie can also be accessed through the EmulationStation menus. However, these settings cannot be controlled by a controller: a keyboard is required. In addition, these settings can seriously mess up the user experience for the average user that doesn't know what they're doing. As a result, the ability to access settings through EmulationStation has been removed, to cut down on user accidents or anything that brings the user out of this easy to use system.

The software is lightweight, instantly understandable, and very customizable, although most settings will be locked upon final completion to prevent the user from messing up the curated experience. The GUI can be seen in Fig. 9.



Fig. 9. Emulation Station

C. Emulators

To cover the wide range of systems that the project requires, many emulators were needed. These emulators were carefully hand-picked, to ensure user satisfaction. Each emulator was carefully and rigorously tested and the final results reflect the best balance between performance and cost, mainly power and accuracy cost.

The NES games are handled by FCEUmm. This is a port of the famous FCEUX emulator, which also adds additional mapper support. This additional mapper support is key for emulating the NES properly, as it used these mapper chips contained in game cartridges to get around the low memory provided by the original console.

The SNES games are handled by PiSNES. PiSNES, as the name might imply, is a port of a SNES emulator, SNES9x, specifically for the Raspberry Pi. As a result, it is already custom tuned for maximum performance on this platform, guaranteeing the best user experience possible.

The GB and GBC games are handled by Gambatte. Gambatte is a well-known, accurate GameBoy and GameBoy Color emulator. What's most important about this emulator is that it has built-in support for the RetroArch backend, which made it easy to adapt as a plugin for the system.

Finally, the GBA is handled by gpSP. This was a trickier one to choose, as the GBA emulators did not always want to cooperate with the system as it stood. gpSP was originally a GameBoy Advance emulator for the PSP. As a result of the PSP having a low-power MIPS chip, it was much easier for someone to port to another low-power chip, albeit with a different architecture. As a result of originally running on much slower hardware at full speed, it runs beautifully on the RP2, exceeding the expectations set out in the project documentation.

The wide variety of emulators working seamlessly together is what makes this project work at a conceptual level. If it was necessary to leave the EmulationStation GUI to access and run all these emulators, through a bash

prompt for example, it would not be nearly as accessible to users and, therefore, would falter as a project.

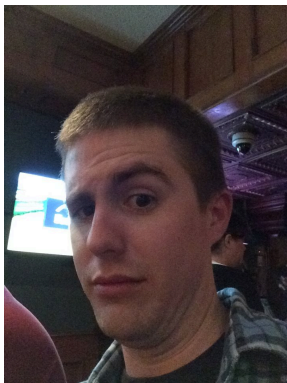
VII. CONCLUSION

The FBC project provides many takeaways from a learning perspective on the conceptual design and execution of an engineering endeavor. From abstract brainstorming to detailed specifications, the lessons and experiences bestowed upon the group members from every angle attributed to the engineering perspective.

On the design and implementation aspect, the FBC was the result of a long series of steps in planning, prototyping, testing, and troubleshooting. Generalized ideas, such as emulating games, have ballooned into full-scale designs, complete with customized circuits and necessary requirements to be fulfilled. Considerations of the bigger picture of the end goal were observed for every component in place. How the system was powered trickled down to all features that directly fed from the power source, which further trickled down to the actual features boasted in the specifications, such as the screen display and audio output. Multiple circuit integrations provided understanding of the importance of oversight in the project design, with mindfulness demanded on allocation of power via voltage necessities and current draw. And the lesson of prioritized solutions was applied for any mishaps, assumptions, or errors that occurred in the original design, and what needed to change to optimize the end result.

The value of teamwork was evident throughout the production as well. We, the members of the FBC project, received the experience of collaboration and camaraderie. Each member brought to the project a drive to accomplish a designated feature to enhance the FBC design. Communication was crucial, especially for the deadlines imposed and goals set for each milestone. The environment of working in a set group toward a common goal within a selected timeframe was an experience best gained going forward into the industry.

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