Interactive Cat Toy (ICT)

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***Abstract* − With an estimated population of over 400 million domestic cats around the world, there is a substantial market for toys that provide entertainment for pet cats. Our team performed an in-depth investigation to find toy features that cats are best enticed by, and lured into play with. The Interactive Cat Toy incorporates all of the top features that we found during our investigation. These features include: lighting effects, sound effects, toy motion, catnip scenting and animal shaping.**

***Index Terms* − Motion Detection, Light Emitting Diodes (LEDs), Servomotors, Auditory Displays, Mobile Applications.**

I. Introduction

The Interactive Cat Toy (ICT) is a whimsical plush toy that is made to stimulate any cat's playful instincts. With that in mind, our group spent an entire semester understanding and designing multiple components that will grasp the interest and entice your typical domesticated feline. Our findings were that the movement of a tail, sounds, and lighting were all features that were at the top of our list. So, our group decided that the best thing to do was to mash them together! Creating what is now the ICT we have today.

We take things further by expanding on those features by allowing customizability of the ICT for pet cat owners. We began with making interchangeable skins and having the ICT appear to be a squirrel or a lizard (with the possibility of other skin designs to expand upon), we then added the ability to place catnip in the tail, and planned for a mobile application to change the main three feature expressions.

The application has the capability to change each of the main three features. The audio speaker options include three different sounds to choose from, the lighting effect has three different illumination patterns to choose from, and finally, the movement of the tail has three different modes or speeds to choose from.

With the application and the interchangeable skins, there are currently eighteen different combinations of feature expressions for the ICT.

II. Overview of ICT System

Integrated hardware and software components make up the operational system of the Interactive Cat Toy. The toy is designed with hardware that will endure potentially rough cat play with built-in protections for its electronic circuitry. The software is designed to activate toy features and to allow for the control of changing feature expressions through a mobile application.

Beginning with the outside, the toy has interchangeable exterior skins made from robust outdoor fabric that are strategically tailored for feature expression and electronics protection. The exterior skins envelop a chassis which has also been custom designed to the fit of the toy's electronic components. The electronic components include a printed circuit board that connects an MCU with all of the toy's feature components; as well as the power supply and circuitry that switches between powering the ICT and charging the battery.

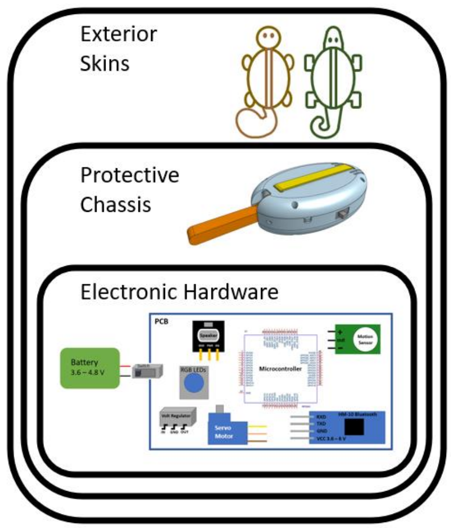

Fig. 1. Venn Diagram of the Overview of ICT System.

III. Hardware Detail

The ICT's selected hardware components are detailed in the following subsections, labeled A-H.

A. MCU

The MCU is the centerpiece of the toy's system and is responsible for controlling all electronic hardware components. We choose the RP2040 microcontroller from Raspberry Pi. The RP2040 is a high-performance, low-cost chip that is easy to use. The RP2040 contains many features that were very useful in development of our project and controlling the functionality of the hardware components. The chip contains 30 multifunction I/O pins, some of which are for specific peripherals such as UARTs, SPI, and I2C and programmable channels for PWM and analog signals. The RP2040 also has sufficient memory storage for code and pre-saved audio files. The microcontroller itself has 264 kB SRAM and is also connected to a 16 MB external flash memory.

We use CircuitPython as our primary programming language for RP2040. Through the testing process, we used a Raspberry Pi Pico, which contains an RP2040, as the development board of the project.

Most significantly, the RP2040 is compatible with many hardware components. For example, the Bluetooth module utilizes the UART functions of the controller to communicate, and the servo motor uses the PWM channel to change position. This made the RP2040 our choice for an MCU.

B. LED Lighting

The lighting for the ICT is provided by a strip of WS2812 LEDs. These are addressable RGB LEDs which allow us to code each LED on the strip into a custom lighting display. It was important for us to be able to create a custom lighting display because limitations existed for the LEDs in regard to both the power supply and safety standards.

From the power supply perspective, the need of a series resistor become important because LEDs are subject to burn out if they are subjected to too much current. This issue can be mitigated with a resistor placed in series between the MCU and the LED strip's data wire. While LEDs do not consistently hold to Ohm's law, we still used Ohm's law in the form of equation (1) as a guideline to determine the resistor value that we would need.

$$Rseries = (Vs - Vrgb)/I \quad (1)$$

Maximum brightness for the WS2812 LED's is attained with 20 mA per red, green or blue LED illumination; and 60 mA per white LED illumination. We limit the current to these amounts in order to avoid burn out of the LEDs, though the data sheet for the WS2812 LEDs states that they can handle current up to 30 mA. Experts suggest this 30 mA only be allowed in short "bumps". [1]

Using equation (1) we equate Vs to 5V since our voltage source will be a 5V voltage bus. Then we find Rseries using Vrgb values for the minimum voltage, 1.8 V, when an LED is illuminated Red and the maximum voltage, 3.4 V, when an LED is illuminated Blue. (We obtained these minimum and maximum voltage values from the datasheet of the WS2812 LEDs)

$$Rseries := 160\ \Omega \qquad Vr := 1.8\ V \qquad Vb := 3.4\ V$$

$$Ir := \frac{(Vs - Vr)}{Rseries} = 20\ mA \qquad Ib := \frac{(Vs - Vb)}{Rseries} = 10\ mA$$

Fig. 2. Calculation for necessary resistor mitigation to avoid LED burn out - PTC Mathcad Express

Based on our calculations a 160 Ohm resistor placed in series with the LED strip will help to accomplish mitigating current to between 20 mA - 10 mA exactly, for LEDs illuminating colors Red - Blue respectively. To keep matters simple, we limit our lighting displays to 60 mA, using at most a combination of 3 illuminated LEDs..

Pertaining to health matters, it has been found that lighting stimulus above 10 Lux can cause adverse health effects, with regard to circadian rhythm. Studies show that production of melatonin is suppressed beginning at 10 Lux in certain lighting environments, for certain populations. [2] Due to our power limitations for the ICT we also limit the brightness of our lighting effects to 3-4 Lumens, which translates to 3-4 Lux (since at 1 meter 1 Lumen is approximately equal to 1 Lux). This keeps the light stimulus of the ICT at less than half of the value of Lux where adverse health effects begin.

Also pertaining to health effects is the wavelength of emitted light. There is much research that shows that wavelengths below 450 nm can cause damage to eyes. [3-5] Some doctors even suggest that wavelengths up to 500 nm can be bad for eyes and health. [5] While research suggests caution for blue - UV wavelengths we cautiously place the limitation on the lighting effects for the ICT to only illuminating colors between red and green (515 - 630 nm). These are also colors that are recommended as safe for toys by the Health Protection Agency, UK. [3]

C. Speaker

The toy requires an audio speaker to produce sounds to entertain cats and their owners. We choose the STEMMA speaker from Adafruit. The 1 Watt, 8 Ohm speaker comes prepackaged with a Class-D amplifier and volume control all within one component that can be easily connected to the circuitry. Since the speaker has its own amplifier, we do not need to AC couple the component, which was a troublesome problem when we deal with audio speakers. Furthermore, the STEMMA speaker is a robust component with low impendence and high wattage to produce audible sound, which is suitable for this project.

The operating conditions are:

- Supply voltage: 2.0 to 5.5 V
- Operation temperature range: -40 to 85 °C.

D. Motor

One of the main features of the toy is the movement of the tail. In order to make the tail move, we use a Servo Motor SG90 inside the chassis, with a little help of mechanical design. The servo motor's rotary position ranges from 0 to 180°. Using PWM, the position can be changed based on the duty cycle of pulse. The microcontroller unit can use its PWM channel to control the rotary position of the servo motor. With a 50 Hz PWM period, the following are the rough estimates of duty cycle needed to rotate to certain positions:

- 0°: ~1ms pulse
- 90°: ~1.5ms pulse
- 180°: ~2ms pulse

The following are other important parameters of the servo motor:

- Speed: 0.1 sec
- Torque: 2.5 kg/cm
- Supply voltage: 4.8 to 6 V

E. Bluetooth Module

The Bluetooth module we are using for the ICT is the HC-05. It was simple to to connect it to the application. The HC-05 Bluetooth module usually comes with 6 pins, KEY/En, VCC, GND, TXD, RXD, STATE. With this module we can check if the device is on thanks to pin STATE and for the KEY/En pin we can choose how we would like to transmit the data, either command mode or data mode. The baud rate in command mode is 38400 bps and for data mode is 9600 bps. The HC-05 module has the capability of being used as a master or slave device, making it able to expand our toy network. The HC-06 Bluetooth module is a little bit different from the HC-05 because it only comes with 4 pins which are VCC,GND, TXD, RXD, it doesn't include the KEY/En and STATE. The big difference between this module with the previous one, though, is that this one can only be used as a slave, while the HC-05 can be used as a master and slave Bluetooth device.

F. Motion Sensor

We want the ICT to be able to detect motion in its surroundings and be able to communicate this with the microcontroller. We chose to use the a PIR sensor. The PIR sensor uses pyroelectric technology to detect levels of infrared radiation. When the sensor detects radiation, the sensor outputs a digital signal to the microcontroller. The PIR sensor comes with adjustable settings for delay time of the output signal and sensitivity of sensor. The following are specifications of the PIR sensor:

- Supply voltage: 3.3 to 5V DC
- Delay time adjustment range: 0.3 s to 5 min
- Sensitivity adjustment range: up to 7 m

G. PCB Design and Connectivity

The printed circuit board must meet all of the toy's connectivity requirements, and the design of the PCB needs to be efficient; while following the standards and constraints that exist.

We decided that, based on the toy's development, we will have one single PCB for the entire toy. That PCB will be able to input supply voltage from the battery source, control the voltage levels, connect to the microcontroller, and provide connections to all of other electrical hardware components.

The design of the PCB mainly follows IPC-2221A – General Standard on Printed Circuit Board as a guideline. The standard covers generic design requirements that tackle different aspects and properties (mechanical, electrical, material, components, and interconnections) of PCB design. The standard also provides general procedures of designing PCBs, such as layout, spacing, and quality assurance.

We also must acknowledge and understand that the project has several constraints that the PCB must follow. First, we need to design a PCB that is small enough to fit the chassis of the toy. Second, the intended consumers of this toy are cats and/or children. Therefore, the team must foresee possible safety hazards, and the PCB design needs to avoid them. Finally, the PCB prototypes must fall within the budget of the project.

At the center of the board is the microcontroller unit, an RP2040. However, to follow the requirements of the project, more external components are needed for RP2040 to function properly. The power pins of RP2040 requires 3.3V DC, and each needs to be accompanied by a 0.1 uF ceramic capacitor connected between power and ground to decouple and reduce the noise level of the supply voltage. Additionally, RP2040 has an internal voltage regulator that converts 3.3V to 1.1V, and we use a 1 uF ceramic capacitor on the input and output pin of the internal voltage regulator.

The RP2040 requires an external flash memory to store its code and data. We use W25Q128JVSIQ, a 16 MB non-volatile flash memory IC storage. It is connected to QSPI pins of RP2040. The flash memory storage's chip select pin is connected to a tactical switch to reset the memory if we need to. For clock purposes, an external 12 MHz crystal oscillator is integrated onto the PCB and connected to the RP2040.

We intend for the PCB to be able to take two different power supply inputs. First is through a micro-USB type-B port, and its voltage is labeled VBUS. A receptacle connector, 10118193-0001LF, is integrated at the edge of the PCB. This is used mainly to putting codes from the computer to the microcontroller and testing the functionality of the PCB and the components. However, when the toy is completed, the USB is no longer needed. The other power supply input is from the battery, labeled VSYS. The battery is the main voltage source for the PCB and all of its components after the toy is completed. VBUS and VSYS are separated by a Schottky diode to prevent feedback to the USB connector. Then, both sources will be passed through a voltage regulator, AP7365-33WG-7, for the microcontroller and other components that require 3.3V voltage level.

For the USB connection, "Data +" and "Data –" is connected from the USB connector to USB_DP and USB_DM pins respectively on the RP2040. Two 27.4 Ω resistors, one for each pin, is placed close to RP2040 to meet the USB impedance specification.

During initial testing, we experienced distorted audio output from the STEMMA speaker. After receiving advises from different sources, we decided to have a separate 3.3V voltage regulator exclusively for the audio speaker. Because of lesser current requirement, we use LDK120M33R to power the speaker.

The dimension of the PCB is 2.5 in x 3.25 in x 2 mm. The USB connector is at the top edge of the PCB. Other component connectors are located near the edge.

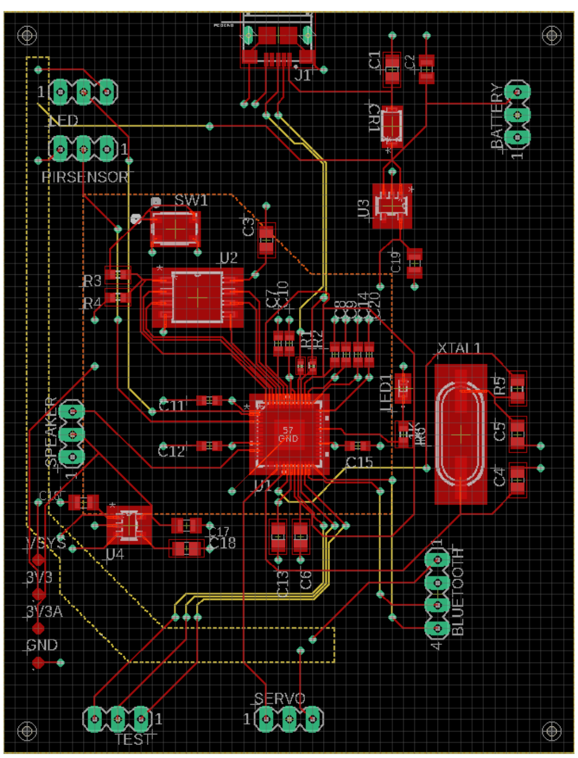

Fig. 3. PCB Layout and Design

H. Power Supply

The Interactive Cat Toy is designed to be a standalone device that will need to contain a power supply that is capable of producing 5 V and about 300 mA per hour for full operation. We based these values on power calculations which include the duty cycles of all the components running through our base program coding. We considered that the ICT should be capable of running the base programming for eight hours, to entertain cats during a typical workday. This would mean that our battery would need to hold a current capacity of about 2400 mAH.

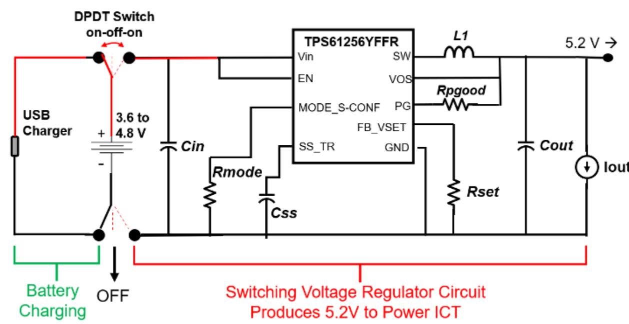

Fig. 3. Power Supply Circuit for the ICT. Voltage regulation portion of the circuit was designed with the aid of Texas Instrument's WEBENCH® POWER DESIGNER.

We designed circuitry for the ICT to run on a 3.6 V, 2400 mAH NiMH battery as well as a 4.8 V, 2200 mAH NiMH battery. Because of a supply chain shortage, due to the Coronavirus pandemic, the 3.6 V battery that was favorable for the ICT was not in supply. We favored the 3.6 V battery over the 4.8 V battery because of its smaller size and weight, which would allow for the ICT to be smaller and lighter. We kept the design for 3.6 V battery as a prototype for future ICT models.

Using a 3.6 V battery required us to include a voltage regulator capable of boosting the voltage to meet the 5 V needed for the ICT. With the aid of Texas Instrument's WEBENCH® POWER DESIGNER, we designed a switching voltage regulator that would boost the power to 5.2 V from either a 3.6 or 4.8 V battery. The additional 0.2 volts were designed in to cover voltage drops across circuit elements. We designed a switching voltage regulator in lieu of a linear regulator because a switching regulator minimized the need for heat sinking; this is because switching regulator transistors operate in saturation and cut-off modes, while linear regulator transistors operate in active mode.

Unfortunately, the supply chain shortage also impacted stocks of voltage regulators. We redesigned the regulator circuit several times over, with substitute parts but there came a point when none of the regulators were available. Since we were also left without our preferred battery, we decided to bypass the voltage regulator and run the device off of just the 4.8 V battery that was in stock. Our breadboard testing proved that the ICT could be run with this power supply without the need for a voltage regulator.

The power supply for the ICT is housed in the chassis of the ICT and is connected to the toy's components via the toy's switch. The slide switch traverses between connecting the power supply to powering the toy, disconnecting the power supply to an "off" position, and connecting the power supply to its charger to be recharged.

IV. SOFTWARE DETAIL

To make the Interactive Cat Toy (ICT) come to life, the microcontroller must be properly programmed to tell each component (STEMMA speaker, WS2812 lights, Servo Motor , HC-06 Bluetooth, and the HC-SR501 PIR sensor) what to do. Our group decided to use Circuitpython as the software language for this job. Circuitpython is a derivative of Micropython, these programming languages are largely similar to each other; while Circuitpython has an extended volume of libraries which can be utilized to simplify coding of component expressions.

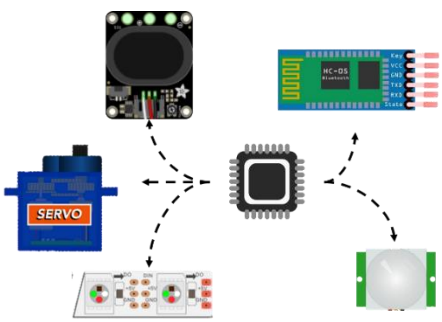

Fig. 4. Communication from the Microcontroller

When making each feature run simultaneously, the async library is utilized. Each component has its own function that tells it exactly how to operate, bringing it to life. Async also allows for each component's function to essentially synchronize with each other, allowing them to come to life all at once. Not only did we have to allow each of the component's functions to run simultaneously, but we also had to program each component's function to allow the cat owner the ability to customize the function via the mobile application.

In our prototype each of the main components (speaker, tail movement, and lighting effects) all get three different options or pattens to choose from. This means each of the main components will have a base option that will automatically run when the ICT is turned on, and another two additional options that can be selected through the application.

To output sound, the STEMMA speaker's function opens and decodes an mp3 file. If the ICT is in base mode, the function will decode the base mp3 file. While if the application is activated and sends a signal for another sound to be played, then the function will open up the selected mp3 file, decode the file, and output the newly selected sound.

When creating the tail motion function using the servo motor, we have to program it to move back and forth between two different degrees. Next the function will allow the motor to go between these two degrees repeatedly by a certain number of degrees to reach to the next targeted degree, this allows for a slower and more realistic 'wag'. Similar to the sound output, the component function of the tail motion will have a base mode and two additional speeds and wagging effects achieved through the application.

The last component that can be modified through the application will be the WS2812 LEDs. The LEDs are programed to illuminate certain colors and to tell which LED should be illuminated. With the RGB color codes, there is an infinite number of colors that can be presented and an infinite number of pattens that can dance on the strip of LEDs.

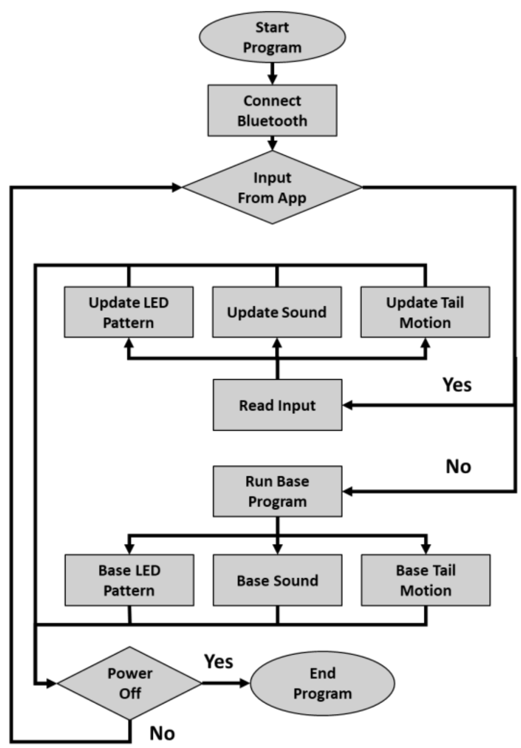

Fig. 5. Software flow chart.

While the HC-05 Bluetooth and HC-SR501 PIR Motion Sensor hold a huge part in our ICT device, these two components don't have to be modified through the application. The Bluetooth, however, does need to continuously check to see if there is an input provided by the application. If there is an input, the Bluetooth's function checks to see which of the three main components (Speaker, Tail, or LEDs) are being requested to be updated, then the Bluetooth's function updates the specified component's function correctly.

The HC-SR501 Motion Sensor's function will only work when the ICT has no motion or any interaction around it. After there is zero motion around the ICT for a certain amount of time, the device will go to "sleep" and only the sensor's function will run. This function simply checks to see if there is any motion in the area. If there is motion, it turns each function back on and waits for it to be called again when there isn't any motion.

With each component programmed in the ICT, the device takes one more step into becoming a stimulating, interactive, fun filled cat toy.

V. Functionality Control

Functionality of the Interactive Cat Toy is controlled by both a switch and a mobile application. When the toy is turned on by the switch, the toy's microcontroller unit, MCU, runs code that expresses feature expressions which have been designed for a "Basic Display". When the toy is signaled wirelessly by the mobile application, the feature expressions are changed to various options which are selectable to the user through the mobile applications' guided user interface, GUI.

A. Switch Control

The switch for the Interactive Cat Toy is a double pole, double throw switch with three positions. The switch has 6 terminals which are rated for 0.5 A and 50 V DC. Based on our power calculations and the battery selection for the ICT the switch will be subjected to at most 500 mA and 5.2 V at any instantaneous time. This is well within the rated value for the switch.

The center switch position allows for the toy to be powered "off". The right switch position allows for battery charging. The left switch position sets the circuit to power and activate the toy.

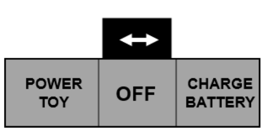

Fig. 4. Double pole, double throw, DPDT, 3 Position Switch

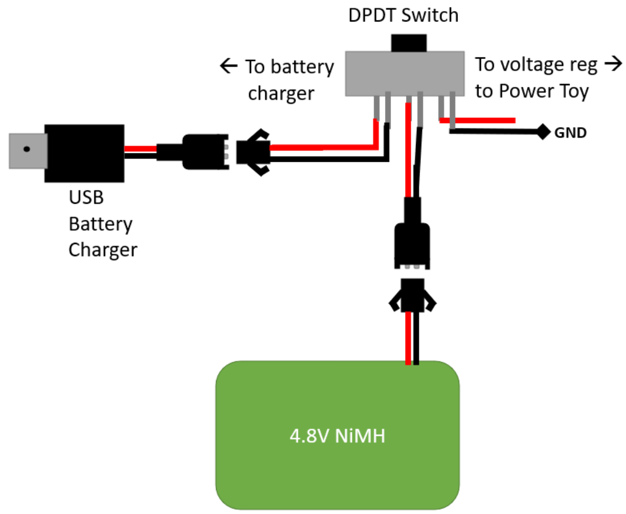

Fig. 5. ICT switch wiring schematic.

In the center "Off" position, the power supply for the toy is completely disengaged. The toy remains dormant when the switch is placed in this position, with no feature expressions.

When the switch is moved to the left position, the toy is turned "On". As stated before, when the toy is turned on by the switch, the toy's MCU runs code that expresses feature expressions which have been designed for a "Basic Display". This "Basic Display" will run in a continuous loop until the switch is moved away from powering the toy, or until the toy is signaled by the mobile application.

A USB charger that is provided with the ICT can be connected and plugged directly into a USB port to commence battery charging. Once the charger is connected, the switch can be moved to the right position to activate battery charging. An LED on the charger indicates when charging is complete.

It is recommended that the toy owner move the switch away from battery charging when the charging is completed and detach the charging cord. Even though the charging cord does contain overcharge protection, this could prevent overheating or burn out of the cord over time.

B. Application Control

We created our application with the MIT App Inventor, which is a web application integrated development environment. The main screen of our application lets the user choose the feature they want to change. They will be able to select from lighting effects, sound effects and motion effects.

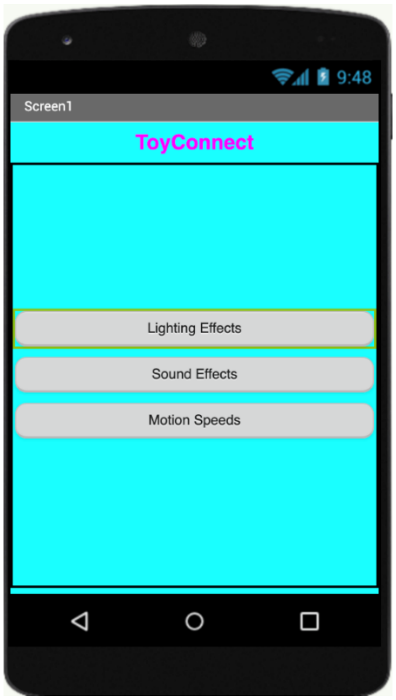

Fig. 5. ICT Application Home Screen

The MIT App Inventor web application is really user friendly because it is based on blocks. Once a selected button is pressed, it will activate the Bluetooth to be able to check for the available devices, once that connects it will allow user to send data through Bluetooth to the MCU.

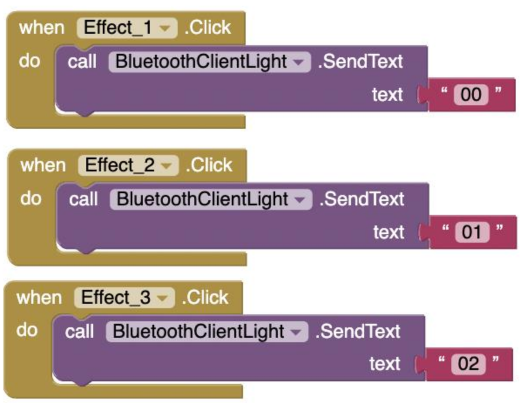

Fig. 6. Block programming for ICT effects.

The next part is what each button will do once it is clicked, so when effect 1 is clicked it will tell the app to send text through Bluetooth in this case the text is 00, and when it gets to the microcontroller it will be translated to bits and that is how different effects are chosen. So for the first effect which is light we choose 00 and then will increment 01,02, and then for the second feature will be 10, 11, 12 and so on.

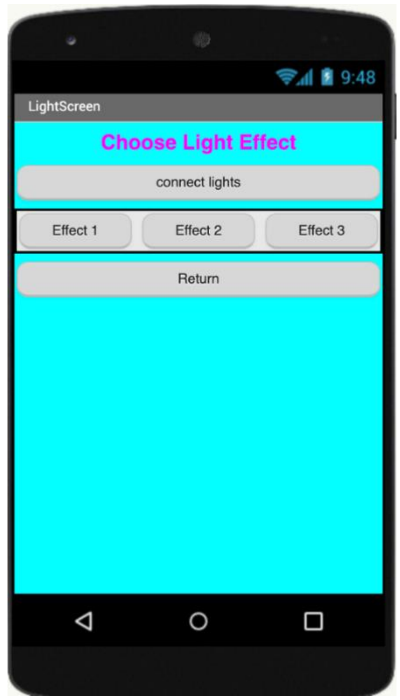

Fig. 7. ICT Application - Feature Selection Screen

All feature screens in the application GUI will have three different selection options. There will also be a “return” button, that will take the user back to the main screen to be given the ability to choose a different feature to alter.

VI. Project Results

The Interactive Cat Toy has been a successful and fun project, but not without challenges. The PCB, the exterior skins and the chassis required redesign several times over to match standards, to meet requirements and to fix problems, such as replacing integrated circuit components that did not work or were out of stock.

Some of the toy’s feature components also faced issues that we had to solve using our knowledge and advice from our professors and others.

The ICT’s software design went through a language change and cycles of debugging and testing to improve its efficiency and functionality. The coding even had to be rewritten to match safety standards that came to our attention during our design process.

Despite all the challenges, we have been able to build a successfully functioning prototype of the Interactive Cat Toy. We find our experience with this Senior Design class project, within the College of Engineering and Computer

Science at the University of Central Florida, to be of great value in gaining hands-on engineering experience.

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We also would like to acknowledge our adviser Bob Meizlik, and our professors Dr. Lei Wei and Dr. Samuel Richie for their encouragement and guidance through the completion of our senior design project.

AUTHOR BIOGRAPHIES

Aliza Grabowski is a Computer Engineering undergraduate student at University of Central Florida of Spring 2022. Aliza contributed to the Interactive Cat Toy by researching the software mechanics of the WS2812 LEDs, Servo Motor, STEMMA Speaker, and HC-SR501 Motion Sensor. Aliza will be the first generation to graduate with a bachelor's degree in her family. The next steps in her life will be helping build her family business to the next level.

Joseph Lopez was motivated for one member of his family to become a Computer Engineer. He is graduating this Spring of 2022, and this will make him the first in his family to graduate from a University outside of his native country of Columbia. He would love to have the opportunity to be able to travel the world while working. For this project, Joseph helped in designing the mobile application and Bluetooth connectivity.

Vu Nguyen is obtaining his Bachelor of Science in Electrical Engineering in Spring of 2022. He is planning to enter the industry after graduation and will decide to get his master's degree in the near future. For this project, he is responsible for designing the PCB and testing the hardware components.

Elizabeth Vargas is working towards attaining her Bachelor of Science in Electrical Engineering this Spring of 2022. She is considering attending graduate school and has been invited to participate in the Ph.D. program with the University of Florida's Department of Materials Science and Engineering. For this project, Elizabeth's electrical engineering work was focused on the design of the power supply circuitry and meeting the lighting requirements specifications.

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