Senior Design I Divide and Conquer

Smart Laser Cat Toy

Group 3

Adriana Guevara	Photonics Engineer
Carlos Ricard	Photonics Engineer
Xaria Davis	Computer Engineer
Benjamin Love	Electrical Engineer
Leife Francisco	Electrical Engineer

Reviewers

Dr. Peter Delfyett	CREOL
Dr. Qun Zhou Sun	ECE
Dr. Mike Borowczak	ECE

University of Central Florida
Department of Electrical and Computer Engineering
Dr. Lei Wei

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1 Executive Summary

Our senior design initiative tackles a common challenge confronting today's cat owners: the struggle to provide substantial and interactive moments with their pets. Most of us can relate to the balancing act between a bustling professional life and the desire to offer quality time and stimulation to our domestic animals. Specifically focusing on cats, which require a holistic approach to well-being that includes both physical and cognitive stimulation, we have designed an interactive toy to effectively address these challenges.

What sets our toy apart from other cat toys? We've come up with three different features. First, our toy is different from a normal laser pointer because it can change the shape of the laser. Since cats are curious animals with high intelligence and visual acuity, changing the shape will increase their interest.

Second, the system integrates with a mobile app that offers expanded controls and adaptability. The app will have multiple features. The app will have a pseudorandom sequence that adds an element of unpredictability into the laser's path, closely mimicking the erratic movements of natural prey. The next direct manipulation of the laser's characteristics and has the capacity for pre-programmed remote interactions, ensuring your cat remains engaged even when you are not around.

The best feature of our endeavor lies in its inclusive design. The app will connect using a user-friendly, Bluetooth-supported interface. We've consciously simplified the user experience to require minimal tactile interaction, making it ideal for individuals with hand movement constraints, seniors facing joint issues, or busy professionals.

Our toy changes the standard laser pointer to a more comprehensive toy that includes several features; it's a comprehensive engagement solution for a pets well being. By addressing the specialized requirements of a broad spectrum of cat owners, our interactive toy pioneers a new standard in enriching the physical and cognitive lives of our feline companions.

2 Project Description

2.1 Project Background

The project is an interactive cat toy that builds off of the idea of a laser pointer. The parts of the system are a laser diode system, a passive infrared motion sensor system, a camera system, a bluetooth based communication system, a phone application, and a power system that uses a battery management system.

The passive infrared system will be present on all four sides of the enclosure to account for the cat coming from any area of the room. The detection of motion will then enable the camera system to activate and read the color of the cat collar tag that is illuminated by an LED and brightened by a Fresnel lens. This detection will then activate the laser system. The laser system will consist of optical apertures that enable the laser to change design as the cat plays with the laser.

The device itself will also be controlled by a phone application that will allow the pet owner to change time settings of the laser system, manually turn the device on or off, and be able to manually operate the laser system as well. This will allow the user to interact with their pet if desired. The phone application will deliver signals through a bluetooth communication system. The project will be powered by a battery source.

2.2 Motivation

In a typical household with cats, a cat is stimulated by manual motion of a laser pointer. This enables the cat to play with the laser, increase mental stimulation, and increase exercise. However, as modern society progresses, a homeowner may not always have time to play with the cat for long periods of time, especially when the cat needs to have more exercise throughout the day. Our motivation for this project is to create a cost effective toy that adds more flexibility and user control to a traditionally fun toy for cats.

Furthermore, we would like to make this toy more inclusive for those with hand restrictive mobility problems. As stated, a normal laser pointer is moved manually by the pet owner, this is not possible with people with health conditions like arthritis, where the moving of the hand or wrist can be excruciatingly painful, or for paralyzed owners, who are unable to move their hands. By making the laser system automated, it reduces user effort and allows them to still play with their cat even though they are physically unable to move the laser.

While health conditions can be a large inhibitor for interacting with a cat as a pet owner, sometimes one may be extremely busy to dedicate an hour or more a day interacting with the cat. By creating an automated laser system that can also be enabled through a user-controlled app, this allows the pet owner to not only accomplish daily life tasks, but ensure proper stimulation and exercise of the cat on a daily basis. Moreover, this project is designed to increase the health of the cat by making an environment where exercise is increased while creating a more convenient for the owner and stimulating for the cat.

2.3 Goals

2.3.1 Core Goals

1. The toy will be portable, lightweight, and battery powered.
2. A mobile application will be created to allow the owner to communicate with the toy.
3. A bluetooth transceiver will enable the mobile application to communicate with the toy.
4. The use of optics and photonics will be utilized to differentiate between multiple pets.

5. A passive infrared motion sensor will be used to automatically turn on the toy when a cat is ready to play.
6. A camera system will be enabled through the detection of an LED collar tag.
7. The laser system will consist of a polarizer/lens system that will allow the use of one laser diode to show simple shapes on the wall.

2.3.2 Advanced Goals

1. To ensure the cats safety, automatically shutdown the toy if they get too close to the laser.
2. Provide owner analytics and insights into their cat's playtime behavior.
3. Have a different profile for multiple cats on the mobile application.
4. The passive infrared motion sensor will enable the device when a cat approaches from any direction.
5. Implement optical beam shaping elements to optimize the shape of the laser.

2.3.3 Stretch Goals

1. Allow the owner to create and save custom sequences.
2. Make the mobile application cross-platform.
3. The shapes and patterns will consist of different colors on the wall.
4. The collar tag will be waterproof so that the cat can wear it during all activities throughout the day.
5. The laser system will be able to change the shape of the beam rapidly.

2.4 Objectives

2.4.1 Core Objectives

1. Utilize a battery power system.
2. Design an enclosure that is lightweight and holds all required components.
3. The mobile application and device will communicate via bluetooth signal.
4. The device will only operate for a cat using a camera system that recognizes red colors from an LED collar tag, brightened and focused by a Fresnel lens.
5. Use a phototransistor and IR LED to activate the system to begin the turn-on process in the passive infrared sensor.
6. Laser will produce a triangle, vertical line, and horizontal line on the wall through a lens system.

2.4.2 Advanced Objectives

1. Passive infrared sensors will have a "too close" range setting that enables an automatic shut-down process.
2. The mobile application has the following features: play time, number of times pattern changed, battery level, cat profiles.
3. Use four passive infrared sensors around the rectangular-shaped device to ensure 360 degree pet detection.

4. Use IPX-4 LEDs to make the collar water-resistant.

2.4.3 Stretch Objectives

1. The mobile application will include custom sequences that the user can create.
2. A white light source will be used into a diffraction grating to show patterns and shapes with various colors.
3. Use IPX-7 LEDs to make the collar waterproof.

2.5 Related Work

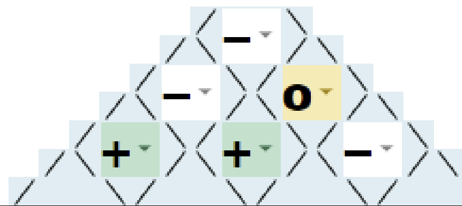
There have been multiple senior design projects in the past that share the similar goal of automating a cat toy. One such project is the Autonomous Pet Entertainment System (APES) that utilizes a roaming device with an embedded laser diode to interact with pets. This device was motorized to allow for movement. We have decided to take a different approach in order to make the system stationary. This allows us to avoid issues that may arise from differing floor types, such as wood, tile, carpet, etc. (It should be noted that the APES was built by an engineering team during quarantine amidst the COVID-19 pandemic and, from the demonstration, appears to have only been tested on hard flooring such as wood and tile.)

2.6 Engineering Specifications

	Requirement	Specification
1	Laser System	1. 1mW laser output 2. Wavelength between 630-690 nm (red).
2	Passive Infrared System	1. Detection Range: 0.5 ft to 3 ft 2. Response time < 15 seconds 3. Detection Wavelength: 950 nm
3	Printed Circuit Board	1. Size < 900 cm^2 (30 cm * 30 cm) 2. House all non-optics systems
4	Bluetooth Based Communication System	1. Maximum Range:10 ft 2. Link Budget ≥ 50 dB
5	Power System	1. Rechargeable battery provides 30-60 minutes runtime 2. Provide power to all systems with less than 10 dBm of noise. 3. Have a minimum of 3 voltage rails that provide dedicated power to each peripheral.
6	Collar Activation System	1. Detect 1 color: red LED 2. IPX-4 LED for water resistance between 5-10 minutes 3. Fresnel Lens Focal Length: 25 mm 4. Tag Diameter: ≤ 25.4 mm 5. Detection Range: 0.5 ft to 3 ft 6. Response time < 15 seconds
7	Mobile Application	1. Latency ≤ 200ms
8	Polarizer Activation System	1. Diffraction grating (1000 lines/mm) 2. Polarizing film (can transmit all visible light).

2.6.0.0.1 Table 1: Engineering Specifications

2.7 House of Quality

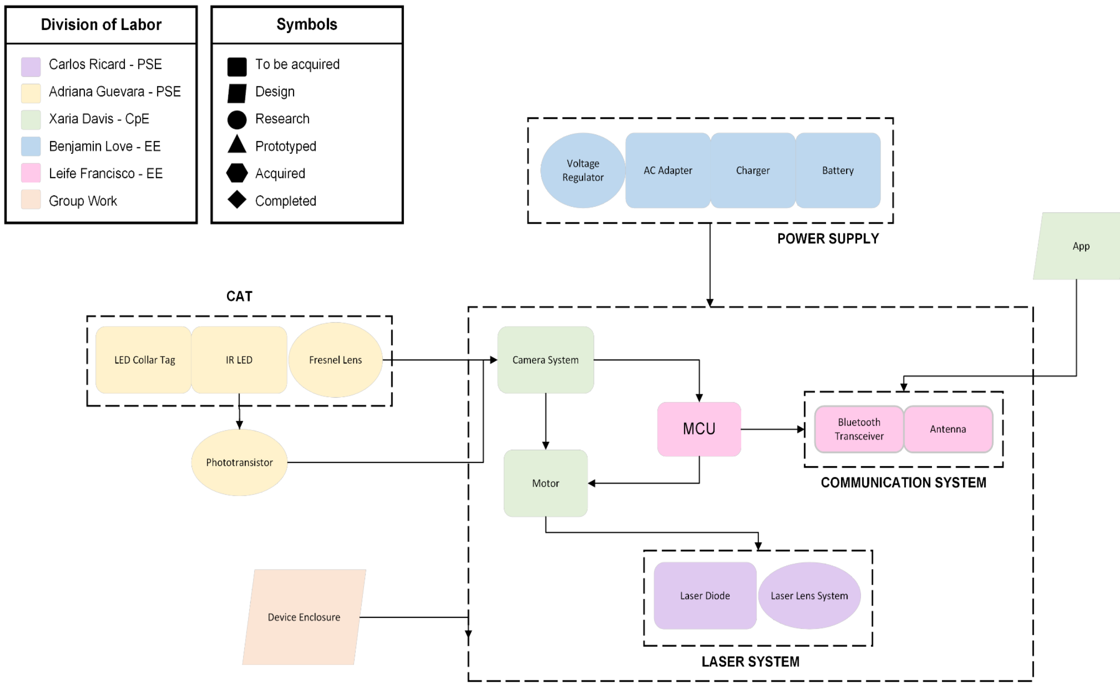


Column #	1	2	3	4
Direction of Improvement	▲	▲	◇	▼
Functional Requirements / Customer Requirements (Explicit and Implicit)	Laser that changes shape	All functions can be controlled by the app	Has a strong bluetooth connection	the toys battery shall last two hours on a charge
mental stimulation for cats	●	○	○	○
ease of use for owners	○	○	○	○
battery life	▽	○	●	○
Bluetooth Connectivity	○	○	●	○
Targets for Engineering Requirments	laser that has 2 shapes	the app shall control the laser and have a response time of 1 second	The materials shall be lead free unless it is absolutely vital that they not be.	The battery shall last two hours on a charge

2.7.0.0.1 Figure 1: House of Quality Diagram

2.8 Project Diagrams

2.8.1 Hardware Block Diagram



2.8.1.0.1 Figure 2: Hardware Block Diagram

2.8.1.1 Printed Circuit Board

The second major requirement for our project is that we need to design, build, and test a printed circuit board (PCB). In our interactive cat toy project, we decided that the PCB will house the power system, a communication system, an ATmega 2560, and other peripherals that are necessary to the success of the project. The purpose of this is not to purchase an Arduino, it is to use the Arduino Mega Rev3 as a reference design for the scope of the project. The Arduino Mega Rev3 will be used as a reference design because it is an open source hardware platform. Furthermore, Arduino's are renowned for their ecosystem, these microcontrollers offer the project flexibility, integrability with other peripherals, and are low cost. As an added benefit, the Arduino IDE is easy to use and provides a variety of open source code to use as examples and has a wonderful community of developers.

As stated previously, the reason the ATMega family was chosen for the design as the chipset for the microcontroller on the board is that it is widely available and accessible. These microcontrollers are widely used by enthusiasts, hobbyists, and developers. This means that there is a large body of knowledge widely online available for support. This wide accessibility means during the troubleshooting phase of the project the team will have an easy time finding hardware and software support when things go wrong.

Furthermore, the ATMega family offers more than enough processing power to handle the requirements without an unnecessary amount of excess. This means that the chip will be capable of giving the user an excellent experience while providing reliability and speed.

The Arduino family is most notably known for its incredible flexibility. Unlike purchasing a pre-built module, the printed circuit board will be tailored to the specific needs of the project. The reduction in peripherals which will preserve power and processing capabilities since the project will not require to add extra peripherals that other modules include.

To accurately choose a microcontroller is it a good idea to do market comparisons. The group compared the ATMega family microcontrollers to the STM family of microcontrollers. While the STM family of microcontrollers provides more processing power and memory, they lack open source hardware specifications, widely available peripherals, and have a difficult and expensive hardware abstraction layer. The main reason that the STM family of microcontrollers does not meet customer specifications is that the STMicroelectronics corporation does not offer a hardware abstraction layer like the ATMega family of microcontrollers does. The HAL has been secured by a paywall. Furthermore, this family of microcontrollers does not have an open source hardware reference design documentation.

2.8.1.2 Communication System

The communication system within the cat toy PCB serves three main tasks; to ensure seamless interaction between the mobile application and the device by transmitting data in a timely manner, to transmit data accurately, and to control the shape and mode the laser will operate in. In this section, the rationale for choosing bluetooth as the communication protocol for the cat toy project will be discussed. Furthermore how this communication standard meets hardware requirements, power efficiency, data rate, and overall system integration will also be discussed.

Initially it was important to consider three short to medium range communication standards; Zigbee, Bluetooth, and Wifi. While these options were considered, Bluetooth was chosen as the best middle ground approach. First, Zigbee is traditionally used in IOT devices and consumes exceptionally low power. On the other hand, Wifi uses a large amount of power. Bluetooth is more energy efficient than wifi but slightly less than Zigbee and offers a middle ground.

Second, the cat toy requires continuous high bandwidth transmission to ensure timely and accurate control of the laser's shape and patterns. Zigbee uses low power but also has a low data rate. Since it has a low data rate, it does not meet our requirements for data rate. Bluetooth’s ability to transmit up to three Mbps meets our demands and allows the cat toy to deliver an exciting experience for the user and cat.

The third reason to choose Bluetooth is that the antenna Bluetooth uses can be directly integrated into a PCB. For example, inverted F plane antennas are compact and known for their efficient performance. This makes them ideal for compact internet of devices like our cat toy. The use of this type of antenna allows us to integrate the entire communication system onto a compact portion of the PCB which will make sure the cat toy hardware and interface do not subtract from the overall gameplay experience while maintaining optimal connectivity.

In conclusion, Bluetooth was chosen based on various factors. Bluetooth offers the efficiency, high data rate, simple network, a compact antenna, and direct connection to the hardware. All these features make Bluetooth the optimal communication protocol choice for constraints of the cat toy design project.

The paragraphs above describe the reason bluetooth was chosen over other short range communication protocols. To summarize, bluetooth was chosen over Zigbee and Wifi due to data rate, power, and the availability of hardware.

2.8.1.3 Laser System

The laser system in this device will utilize a single laser diode and other optical components to display images on a wall. The system will be able to display the image in several locations on the wall at separate times in order to keep a cat constantly entertained. There are two main approaches that are in consideration at utilizing different techniques to accomplish this. One technique will utilize a diffraction grating and polarizer film to move the image, while the second would utilize wedge prisms to do the same.

The laser itself will be a red laser diode that outputs a beam at 630 nm to 690 nm of the electromagnetic spectrum. Red laser diodes are typically cheaper to make and easier to operate making it an ideal choice for light source. The power output of the laser will be limited to 1-5 mW to match the output of commercial laser cat toys. It is important that the laser never exceeds 5 mW as it would be too dangerous to use.

The laser system will utilize several other optical components to achieve beam separation and movement on the wall. Two of these optical components will be a diffraction grating. The diffraction grating will be used to separate the laser light into several different laser beams called diffraction orders. Diffraction gratings have these characteristics due to how many equally-spaced slits that are measured in lines/mm. As the lines/mm increase the distance between the diffraction orders increase due to the wavelike properties of light and destructive interference. The points where constructive interference occurs would be the separate diffraction orders that are now coherent enough to look like separate laser beams enabling it to be used as a beam splitter in this device.

A polarization filter will be placed a distance away from the diffraction grating to filter out all of the individual laser beams except for one, limiting the output image to one. This is due to the polarizing film filtering out light that is different polarization based on the orientation of the film. The polarization filter will be mounted on a rotating motor that can change the orientation of the polarizer film to filter out a majoof all of the laser beams and choose a desired output location.

The laser system will also utilize stencils to create images with the laser light. To ensure that the laser light can sufficiently fill the stencil and produce a complete image, a simple beam expanding setup will be used. This setup will consist of two identical lenses placed a distance away from the laser diode. By adjusting the distances between the laser and the lenses, the waist of the laser beam can be adjusted to the desired size.

2.8.1.4 Motion Sensor System

The optical motion sensor of the smart cat toy will serve to activate the camera system and in turn, activate the laser system to begin playing with the cat. The passive infrared (IR) sensor will serve as a motion sensor to enable the camera system to turn on. This passive sensor will consist of an IR light-emitting diode (LED) and a phototransistor, the phototransistor will enable the optical signal received from the IR light emission to be converted to an electrical signal. The IR LED will emit light and reflect the light back onto the phototransistor and the passive system will not activate the camera system. As the cat gets closer to the device, the IR LED will no longer reflect light onto the phototransistor and it will cause the passive system to send a signal to the camera system that it must turn on.

The camera system will be programmed to activate the laser system that enables the cat to play with the toy. Since some pet owners may have both cats and dogs, an LED of visible wavelength will be placed on the cat collar behind a Fresnel lens to allow the camera system to know that a cat is present and ready to play. By designing the Fresnel lens to be in front of the LED tag, it will diffuse the light to the camera system since the LED light is not dispersed widely throughout the room. This will also increase the brightness of the light to allow for color capture of the camera system. A large advantage of the Fresnel lens is that it has a short focal length so it can be placed near the LED tag and enable a smaller design to not be in the cat's way of daily activities. Once the camera system reads the specified LED color of the collar tag, the laser system will be activated for a specified amount of time.

2.8.1.5 Power System

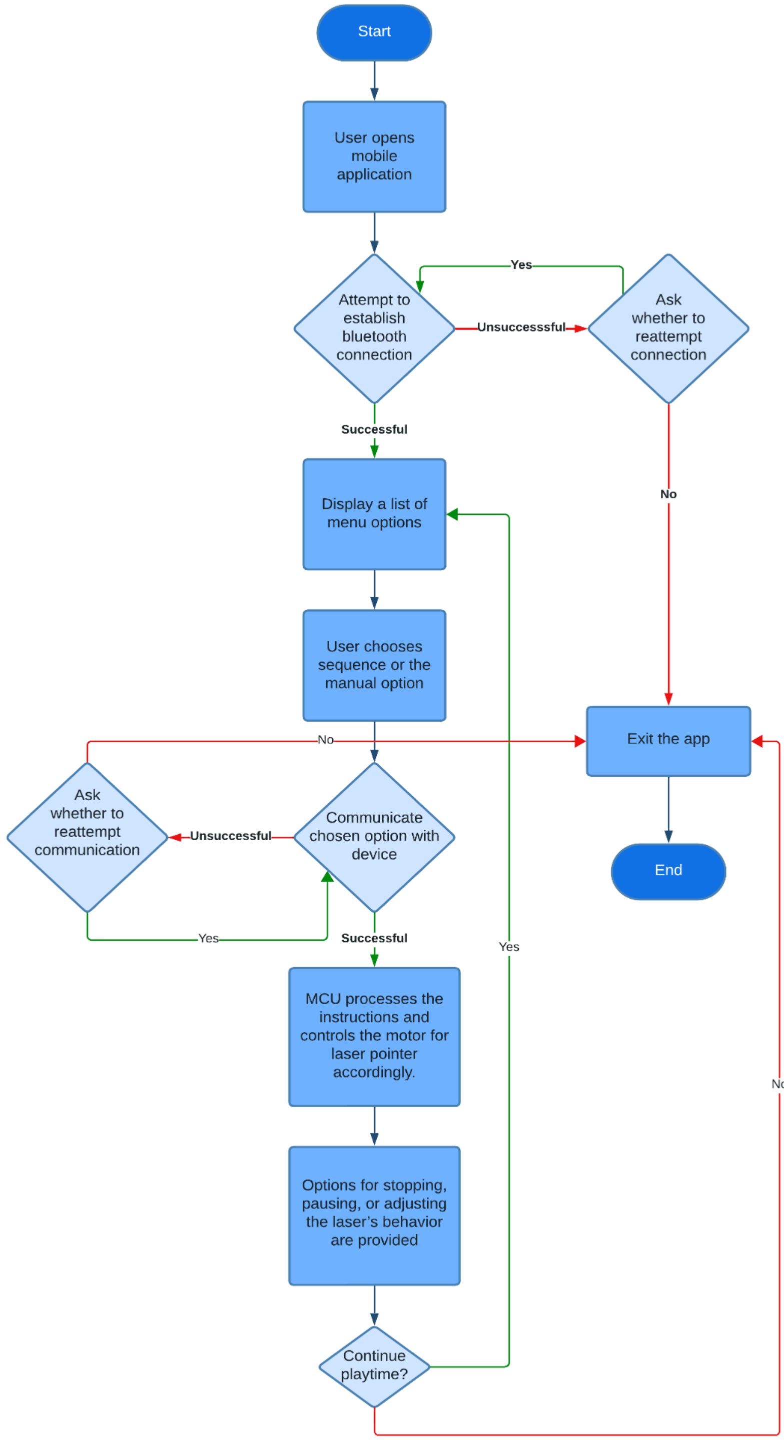
The power system will consist of, at a minimum, a single lithium-ion cell, multiple voltage regulators of a to-be-determined type, and a constant current-constant voltage charging circuit. Further stretch goals may include an input power/battery bypass circuit to enable "charge and play" operation, or USB-PD (power delivery) integration to allow charging from a USB type C charger.

An integrated lithium-ion battery will be the primary power supply. A single cylindrical cell is desired here as introducing multiple cells requires a more complicated charger and battery management system (BMS). Conversely, one cell makes these jobs trivial, potentially allowing both to be accomplished with a single commercially available IC.

A BMS of some description is mandatory with lithium-ion batteries owing to their volatility and intolerance of overcharge and overdischarge. The primary job of the BMS is to cut off the supply and demand of current at the cell to prevent this, typically by measuring the voltage across the cell terminals.

Different voltages for subsystems of the toy will each require their own voltage regulator. Discussions of the regulator type of choice are ongoing, mainly if linear or switching regulators are desired. Linear regulators, which reduce a linear DC voltage input and maintain a linear output, provide smooth output voltage relatively free of noise. However, they are also inefficient owing to their high resistance and thus of debatable choice for battery-powered applications. Switching regulators, which employ cycling the input voltage at a high frequency through transient components, have more noise to be dealt with, but higher efficiency and less waste heat.

2.8.2 Software Flowchart



2.8.2.0.1 Figure 3: Software Flowchart Diagram

3 Administrative Content

3.1 Budget Estimate

	Description	Unit Cost	Quantity	Total
1	ATMega 2650	$15.00	1	$15.00
2	Bluetooth Transceiver	$5.00	1	$5.00
3	IR LED	$0.41	8	$3.28
4	Phototransistor	$0.84	8	$6.72
5	LED	$0.58	3	$1.74
6	Fresnel Lens	$20.27	3	$60.81
7	Camera	$8.99	1	$8.99
8	2.5AH Li-ion Cell	$6.95	1	$6.95
9	Laser Lens Motor	$24.99	1	$24.00
10	Laser Diode	$6.75	1	$6.75
11	Diffraction Grating	$10.00	1	$10.00
12	PCB Boards	$1.40	5	$7.00
	Total			$156.24

3.1.0.0.1 Table 2: Budget Estimates

** Note: These are estimates and may change due to compatibility, supply chain, or pricing issues.*

3.2 Milestones

Milestone	Due Date	Status	Responsible Team Member
Senior Design 1			
Initial Meeting & Idea Generation	Aug. 29th	Completed	Whole Team
10 Page Divide & Conquer	Sept. 15th	Completed	Whole Team
Midterm Demo for Photonics Students	Oct 12th	Pending	Adriana, Carlos
75-Page Draft Due(15 Pages per student)	November 2nd	Pending	Whole Team
Publish 75-Page Draft on Website	Nov 16	Pending	Whole Team
Final PSE Demo	Nov 30th	Pending	Adriana, Carlos
150-Page Final Report	Dec 4	Pending	Whole Team
Senior Design 2			
PCB Assembly	TBD	TBD	Leife, Benjamin
Optical Systems Assembly	TBD	TBD	Adriana, Carlos
Testing and Redesign	TBD	TBD	Whole Team
Final Testing	TBD	TBD	Whole Team
PSE Final Presentation	TBD	TBD	Whole Team
Final Presentation	TBD	TBD	Whole Team

3.2.0.0.1 Table 3: Milestones

3.3 Work Distributions

	Requirement	Responsible Team Member
1	Laser Diode System	Carlos Ricard
2	Passive Infrared Sensor	Adriana Guevara
3	Collar Activation System	Adriana Guevara
4	Printed Circuit Board	Leife Francisco
5	Bluetooth Based Communication System	Leife Francisco
6	Power System	Benjamin Love
7	Polarizer Activation System	Benjamin Love
8	Phone Application	Xaria Davis
9	Embedded Programming	Xaria Davis

3.3.0.0.1 Table 4: Work Distributions

4 Research and Part Selection

5 Design Constraints and Standards

5.1 Design Constraints

5.1.1 Battery System

Given that the toy will be battery-powered as a design goal, a suitable battery system is key to the function of the other systems. The battery and associated components need to do more than simply hold a charge. They must also provide adequate current, give a consistent voltage or predictable voltage range, keep the battery cell or cells at a safe state of charge at all times, and offer circuit cutoff in case of an electrical fault or extreme temperatures. In short, safety is important, and it starts with appropriate cell selection.

One of the most fundamental design criteria with battery-powered devices is whether or not multiple cells are required. Using multiple cells in a *pack*, or group, can allow for greater current capacity, higher voltage output, increased device runtime, or all of the above. However, all of the multiple-cell options increase the complexity of not only the pack, but also the charging circuit and BMS. Therefore, it is crucial that the use case of the pack dictates the use of multiple cells, or lack thereof. There are two ways to combine cells: series and parallel. Cells at this level are not much more than DC voltage sources, and are typically modeled as such. As basic circuit design goes, connecting cells in series adds the voltages of each cell together, and connecting them in parallel adds their currents. Notice that there was no mention of whether the cell voltages are the same in that last sentence. This is a core part of the problem; Connecting multiple cells in any way requires additional and/or more complicated components to regulate voltage and current in each cell. This is referred to as “balancing,” and is the act of matching the state of charge of cells as close as possible. Cells have a usable voltage range, with the voltage across the cell terminals dropping as they are discharged. If one cell has a voltage differing from the others in a pack, this causes problems. If they are connected in series, the lowest-voltage cell in the pack risks being over-discharged, which can destroy the cell. If they are connected in parallel, drastic differences in voltage can cause dangerously high surges in current through wiring and busbars as the cells “self-balance.”

With all that said, this risk and additional work can be necessary if a project demands the power of a large pack. With the majority of pertinent cell chemistries having a nominal voltage of 4 to 4.2 volts and limited current output per cell, it is not hard to understand why a smartphone can make use of only one cell, but a large electric lawn care tool cannot. For this project, the plan as of now (late September/early October) is to use one cell if possible. The largest constraint for power requirements will be the size and type of servo motors used in the polarizer system. Although there are high-quality single cells available that can output enough current, there are still reservations about the runtime. To improve runtime, two cells could be connected in parallel *with adequate safety measures in place*, or the project can be designed for two cells in series. The rest of the systems (Raspberry pi, microcontroller, laser diodes, etc.) have relatively low power consumption and thus are not as alarming.

5.2 Standards

5.2.1 IEEE Bluetooth Standard 802.15.1

Since a significant part of our senior design project depends on bluetooth connectivity the standard that acts as the glue to our entire ecosystem is the bluetooth communication system. The standards that apply to our group are IEEE 802.15 and the bluetooth core standard. From these documents, the technical requirements were discerned, along with guidance on potential design constraints that impact functionality and compatibility

At a glance, 802.15.1, is simpler and more straightforward, it is for these reasons the group chose to use 802.15.1 as a reference to understand how the bluetooth physical layer, baseband, MAC function. While Bluetooth Core Standard is more recent to off the shelf market technologies diving deeper, it's evident that the Bluetooth Classic’s core functions and requirements have not changed significantly over the years. Because the core principles of the transmitter and receiver designs remain relatively unchanged,it is more useful to use the IEEE 802.15.1 standard to understand bluetooth and use it as a guide to right design requirements to pick out off the shelf bluetooth transceivers for our design.

The IEEE standard details the requirements for transmitters. The first relevant are the class power requirements for the antenna. It is important to note that there are three primary power classes: 20 dBm, 4 dBm, and 0 dBm. For the project design, which prioritizes a reliable connection up to 10 feet, the second class, operating at 4 dBm, emerged as the optimal choice. Given that Bluetooth technology is inherently designed to facilitate connections over a range of approximately 10 meters (roughly 30 feet), our selection provides a significant margin. This ensures a stable connection even if there are potential interferences or real-world constraints that might compromise range. The second reason that class 2 requirement for an antenna was chosen is that according to the IEEE standard class 1 receivers require received signal strength indicators. This adds another layer of complexity to the design of the receiver which would add cost. These are two examples of how the institute of electrical and electronics engineers 802.15.1 document helped us verify design requirements.

The second system that the IEEE 802.15.1 standards document helped us understand was the characteristics that the receiver should have. The main characteristics of a receiver are its sensitivity and noise suppression. Most of the noise suppression is done using the inherent signal processing characteristics. However, one interesting characteristic of bluetooth wireless receivers I did not know is that the required sensitivity of the antenna is negative 70 decibels per milliwatt.

Like most digital receivers every Bluetooth device is equipped with an internal system clock, which is fundamental in governing its data transfer timing and hopping sequences. This clock is derived from a consistent, unadjusted native clock that always remains on. The uniqueness of the Bluetooth clock system lies in its synchronization method: rather than direct synchronization, devices synchronize by adding offsets to their native clocks. However, this synchronization is temporary. Given the free-running nature of native clocks, offsets need regular updating to maintain synchronization. Synchronization is an important characteristic that maintains proper communication between the controller device and the listener device. It is an important characteristic to look for in a bluetooth module or transceiver which allows us to understand if the part we will buy is going to perform in the necessary way to maintain a good connection.

It's worth noting that the Bluetooth clock doesn't correspond to real-world time. In terms of specifications, it uses a resolution of at least 312.5 µs and operates at 3.2 KHz.

When multiple Bluetooth devices come into close proximity, they form a mini network, known as a piconet. Within this network, one device takes on the role of the master, setting the tone for timing and frequency hopping. For seamless communication, slave devices adjust their clocks based on the master's clock which is shared with them. It's essential to recognize the significance of specific Bluetooth timings—312.5 µs, 625 µs, 1.25 ms, and 1.28 s—as they are the backbone of data transfer processes. For instance, the master-to-slave data transmission initiates during specific slots, defined by these timings.

For a project like a Bluetooth-connected cat toy, understanding these nuances is paramount. Whether the toy or the app assumes the role of the master, synchronization is key. Being well-acquainted with these timings and synchronization processes will not only facilitate smooth communication but also assist in troubleshooting and refining any potential delays or issues.

5.2.2 IEEE/ANSI C63.4-2014

The standard C63.4-2014 is a standard about EMC. EMC is electromagnetic capability. Electromagnetic capability is another term for how much energy is radiated by wires when they conduct electricity. EMC standards pertain to our cat toy. Our cat toy heavily relies on radiation mechanisms to provide entertainment and communications. These radiation mechanisms are bluetooth and a laser that changes shape. Furthermore high frequency transients occur during the switching phase of switched mode power supplies.

The standard C63.4-2014 is a standard about EMC. EMC is an acronym for electromagnetic capability. There are three parts of our system that have the potential to radiate energy. The three parts are the bluetooth communication system, the laser system, activation system, and the power system.

The bluetooth communication system has the largest potential to provide EMC problems. The reason why the bluetooth communication system presents this problem is that the bluetooth communication system is a radio system that has a specific frequency. Since all transceivers which are essentially radio systems rely on radiative transfer of energy using antennas it is actually radiating and therefore we need a criteria to select parts that provide appropriate EMC levels. The problems that come from EMC non-compliance are after this.

The second system that has the potential to cause EMC problems is the laser system. This system is also a system that uses the radiative transfer of energy to send high energy photons that emit light. This light emission may cause noise, electromagnetic interference, and electromagnetic compatibility problems with nearby sources that also rely on radiation as a mechanism of energy transfer or information transfer to function. An example of this is turning on a microwave next to a cell phone. The microwave if it is not properly shielded will radiate and disrupt the bluetooth signal since they are at the same frequency. While it is unlikely something like this will happen. The guide provides us with a benchmark for understanding how the laser system may affect other systems around it.

The third system that could have EMC problems is the power supply system. The power supply system will use a combination of switched mode power supply's either boost or buck converters. Both of these converters rely on switching and during that time high frequency transients occur on the power lines. These high frequency transients are small in amplitude but we need to make sure that none of the noise that inadvertently will be introduced to the system will cause EMC problems.

The first reason that EMC is such a large problem that must be accounted for in our design is noise. The size of our system has to be small. Since our system needs to be small to be convenient any high frequency transients that occur have a huge potential to cause noise. This noise can disrupt the function of the receiver in the bluetooth system, the laser, the laser diode activation, the printed circuit board, and the memory within the printed circuit boards microcontroller.

The second reason that EMC/EMI needs to be considered in our design is parts selection. In the last paragraph we discussed noise and how the potential it has to affect various parts throughout our board. The standards provided by C63.4-2014 will give us a benchmark that helps us pick parts that can handle any noise or electromagnetic interference that will be produced.

The third reason the EMC/EMI needs to be considered in our design is that it gives recommendations on how to minimize EMI/EMC through proper circuit design and layout design. The institute of electronic and electrical engineers and American standards institute guide C63.4-2014 provides shielding techniques and grounding techniques to prevent electromagnetic interference and electromagnetic capability.

6 Software Design Details

6.1 Software Development Process

6.1.1 Overview

Software development refers to the process of planning, designing, programming, testing, debugging, and maintenance of software applications. At the fundamental level, software refers to a collection of instructions, data, and programs that enable a computer or a computing device to perform specific tasks or functions. The software development process refers to a systematic and structured approach to software development. There are many different methodologies developers choose from, but the key aspects remain the same:

- Understand the project requirements
- Design a blueprint or architecture for the software
- Build a model for prototying and simulation
- Code in the appropriate language
- Conduct various types of testing
- Deploy to production environments
- Conduct maintenance
- Create comprehensive documentation
- Ensure the project stays on schedule and within budget

The software development process is critical for creating high-quality, reliable software that meets the needs of users while maintaining efficiency and effectiveness in development efforts.

6.1.2 Different Methodologies

6.1.2.1 Overview

The existence of multiple software development methodologies is beneficial because of the diverse nature of software projects. Each software project encompasses unique sets of requirements, timelines, and complexi- ties. One methodology may excel in a certain context but is unsuitable in another. It is also important to note that team dynamics may be a big influence when it comes to choosing the methodolgy, or methodolo- gies, for a project. Having a variety of different methodologies allows developers and project managers to choose the best approach based on the project requirements. Some of the most popular software development methodologies include: Agile, Waterfall, Lean, and DevOps.

6.1.2.2 The Agile Methodology

The Agile Methodology emphasizes customer feedback and the ability to respond to requirement changes and any stage of the development process. It is a flexible and iterative approach to software development that prioritizes collaboration, adaptability, and delivering incremental value to customers. It breaks down the project into smaller, more manageable chunks, called sprints, that generally last 1 - 4 weeks. After each sprint, teams reflect to see if there is anything that can be improved and adjust their strategy for the next sprint. Regular feedback loops, daily stand-up meetings, and continuous improvement through retrospectives are integral to Agile. It also promotes transaprancy, self-organization, and a customer-centric mindset. This approach allows for faster and more frequent deliveries, enhancing the project's flexibility and alignment with evolving customer needs.

6.1.2.3 The Waterfall Methodology

The Waterfall Methodolgy follows a linear software development approach. As the name suggests, it is characterized by its sequential progression through predefined phases, mimicing the flow of a waterfall. Un- like Agile and other iterative methodologies, Waterfall follows a strict, one-directional flow from requirements analysis, design, implementation, testing, deployment, to maintenance. This makes the Waterfall method- ology perfect for projects that have clear and stable requirements. Each phase is meant to flow seamlessly into the next, so there is no way to continue to the next phase without the deliverables of the previous and current phases. This results in an emphasis on thorough documentation and upfront planning. This approach allows for a comprehensive understanding of the project scope and requirements before moving forward, making it easier to manage projects where changes late in the process can be costly and disruptive. However, because of its rigidity, it is challenging to accomodate any changes in requirements or adapt to any unforseen issues once a phase is complete.

6.1.2.4 The Lean Methodology

The Lean Methodology in software development is a unique approach focused on optimizing efficiency and minimizing waste throughout the development process. It draws inspiration from lean manufacturing principles, aiming to create value for the customer while eliminating unnecessary steps and resources. What sets Lean apart is its emphasis on continuous improvement, empowering teams to regularly assess their processes and make adjustments for enhanced productivity and quality. This methodology prioritizes delivering a Minimum Viable Product (MVP) quickly to gather feedback and iteratively refine the product. Additionally, Lean promotes a culture of collaboration and cross-functionality, encouraging teams to work together seamlessly, share knowledge, and remain adaptable to changing requirements. By placing a strong focus on delivering value and reducing waste, Lean stands out as a methodology that fosters a leaner, more efficient, and customer-centric software development process.

6.1.2.5 The DevOps Methodology

The DevOps methodology is a transformative approach in software development that combines software development (Dev) with information technology operations (Ops). This methodology emphasizes a feedback-driven iterative process, encouraging teams to learn and improve continuously. It aims to shorten development cycles and accelerate the delivery of software through continuous integration, delivery, and monitoring, as well as automation. By promoting a holistic view of the software lifecycle, DevOps ensures that both development and operations are aligned with business objectives, leading to faster deployment, quicker feedback loops, and the ability to respond swiftly to changing requirements. DevOps encourages learning from failures and using them as opportunities for growth and enhancement. This makes it stand out as a dynamic and responsive approach in the realm of software development methodologies.