Portable Finish Line Data Capture System for Sprinters

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***Abstract* — The goal of this project is to bring the timing accuracy of digital capture systems to practice for sprinters of all skill levels to improve timing accuracy over analog methods during training, while keeping costs low to be marketed towards sprinters of all skill levels. The design is portable, lightweight, and consumes minimal power, and can be communicated to via a mobile android application through Wi-Fi. The design uses a laser sensor connected to a microcontroller for timing, which controls LEDs and speakers as well as times sprints. An android application communicates with the microcontroller in the main housing via a wireless connection, sending data to tweak sprint settings, and display times to the end user.**

***Index Terms* — microcontroller, LDR sensor, 802.11n, GUI, TCP, Socket**

I. Introduction

This project seeks to bring the accuracy of digital timing used at higher level sprint competitions to the practice routines of sprinters of all skill levels. Most lower level sprinters rely on some form of analog timing in practice to track improvement during training, typically another person timing with a stopwatch. Our goal is to remove the need for a second person timing the sprint while also improving on accuracy over this and other analog methods. Since our target audience is sprinters of all skill levels, we tailored the design as much as possible to accommodate all sprinters as potential users of our design. The design is lightweight as it's meant to be taken to and from a track, and housed in 2 pylons as to have minimal components for the end user to have to worry about when transporting the system. The design includes a rechargeable battery system, and consumes little power as to not require a recharge during a practice session. LEDs and a speaker are used in the design to simulate more realistic training environments where the user can hear and see the "go" signal. Within the design is a wireless-capable microcontroller, which controls the LED and speaker, reads from the LDR sensor, and times the user sprints. The microcontroller is sent requests to begin a sprint from the user's Android smartphone, using an app with ease of use in mind. The Android apps functionality is to communicate with the microcontroller when to begin a sprint and to receive the finishing time after the conclusion of the sprint as well as display to the user information relevant to their sprint. Overall our design provides a more accurate timing solution to all but the most expensive competitors on the market to improve the practice routines of sprinters.

II. System Components

A. Microcontroller

The microcontroller is considered to be the brains of this product. It controls all the subsystems including wireless communication (WI-FI), Trip sensors, LED and Sound drivers for visual and audible cues. To keep the cost down and integrate all of the separate subsystems the ESP32 chip by Espressif was chosen. This chip is fairly new and was released in early November of 2016, because it is in its early infancy and still in the development stage we have the opportunity to be the first to jump into the market with this specific chip. The Esp32 chip is recognized as one of the most powerful chip on the market as of now. This chip has two cores allowing us to run multiple threads to do calculations, processing, Wi-Fi stacks and run times. It has a high CPU clock speed in the range of 160 to 240 Mega Hertz (MHZ). This high clock speed allows the unit to keep a very precise running time down to the 100th of sec. While most controllers have a fixed memory/flash in the KB range the ESP-32 chip has the ability to allow for upgradeable flash up to 16MB, providing more than enough storage for the program and possibilities to expand on the code when needed. Apart from the chip being relatively inexpensive it has WI-FI already integrated into its small QFN package size of 6mm x 6mm. It has 32 GPIO pins and 12 ADC pins which allows for a plethora of peripherals to connected and controlled. The device is programmable in C++ language and will be using Eclipse and command terminal to test and debug each system independently.

B. Trip Sensor (Beam Break circuit)

To detect when a person crossing the finish line a light source will be utilized to create a beam across the finish line so when the runner breaks the beam a detection circuit can recognize the break and send the necessary information back to the user. This is a two-

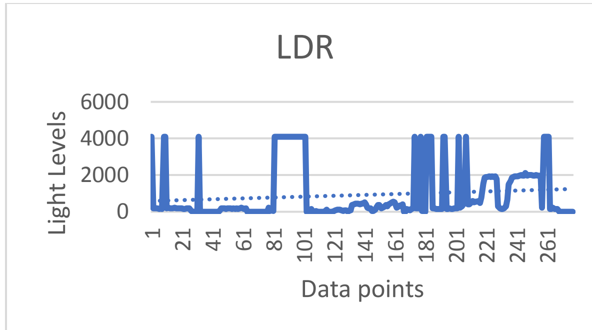
part system that requires a transmitter being the light source and the receiver being the microcontroller and detection circuit. The Light source will be a laser and/or IR LED to allow for range and easy setup. On the receiver side a IR receiver and/or a LDR (Photocell) will be used to detect the light source completing the detection circuit.
Photocells can change their resistance on a molecular level manipulating the flow of electrons. When light rays emit a frequency of visible light on a photocell the photons are absorbed by this semiconductor. This absorption gives electrons the ability to break free from its electron pair and enter the conduction band. This free electron and hole that is left provides the device with enough to reduce its resistivity and conduct electricity.

Looking at figure 3.3 you can see that Resistance vs light sensitivity is not linear which makes it difficult to use for accurate light readings. In our case however, we only need to pass a certain threshold measuring only extreme values e.g. Light present < (threshold) || 0 = "Sensor has been tripped". In order to integrate this into the microcontroller to recognize beam breaks a simple circuit divider will be used to detect the analog voltage values. The formula for the Voltage divider circuit is as follows

$$Vout = \frac{R2}{R2 + R3} \cdot Vin$$

R2 represents the LDR which acts like a variable resistor based on how much light is present on the sensor. The Vout is plugged into one of the 12 ESP-32 Analog to Digital pins and uses an internal Op-amp comparator circuit to compare its voltage divider circuit with its REF voltage supplied by the power to the microcontroller.

IR is short for Infrared and can be defined as infrared radiation in the electromagnetic spectrum found between microwave and visual light raging from 700nm to 100000nm in its wavelength. Typical IR control systems work within the wavelength of 870nm and 950nm. In this part of the spectrum Infrared is mainly invisible to human eyes. Thermal radiation in room temperature gives of infrared light that can only be seen through special camera's that come equipped with IR filters. Molecules that change their rotational movement can either absorb or emit infrared radiation of a certain frequency. These Infrared systems are divided into two main categories depending on the frequencies the light can produce or receiver can pick up. The first and main category we will use of IR's are near infrared systems which has a wavelength closest to the visible light spectrum meaning the wavelength are very short compared to the rest of the spectrum. These are your very common IR that are inexpensive. One or more IR sensors can be placed in pylon A and set our second pylon B at a distance with a IR receiver inside to create an invisible beam for our finish line. When a runner passes by the two pylons it will disrupt or break the beam notifying that someone has just finished. These typically have a transmission range of 1 to 3m. To increase the distance, we would need a high power led light with very low angle of 10° and use a photodiode with IR filter.



During testing, we connected our LDR to the Microcontroller and began to plot the points, varying the different light levels hitting the sensor to see if it was possible to get a readable data output. The results are shown in graph above. This test was done in sun light with sun at about 40 degrees above the horizon. Light levels reaching the 4000 mark indicates that the sensor is in complete darkness and light levels in the 0 range are saturated with full brightness from are laser light source. From these results, we can see that our average threshold is very low almost near 0 due to the interference with the sun. The typical range is from 300-800 without our light source. Two solutions to help combat this problem and bring our threshold up would be to first place our LDR sensor in a enclosed tube and add an ir filter to help reduce the suns exposure on the sensor. Second, it would be beneficial during the setup process before the race to take the average reading from the sun with no laser shining on it and a reading with the laser shining on it to compare and create a new threshold before the race is started.

C. Communications

To allow for easy access for the user to receive calculated vales such as race time and distance we will use WIFI to wirelessly send information back to the user's smartphone or laptop.

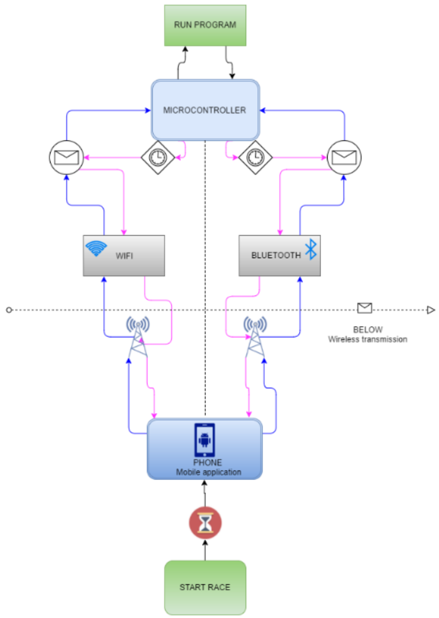


Figure 6.1.2 shows the flow chart of wireless communication between the phone and microcontroller. To begin, the microcontroller will have multiple access to the device through Wi-Fi. The microcontroller acts as an access point and accepts connections from devices that connect to it through Wi-Fi. Starting at the bottom of the flow chart, the user when set up at the start line and when ready will pair with the microcontroller using Wi-Fi. The user does not have to specifically connect due to those conditions, they may pair based on their preference of choice. Once the phone and microcontroller are connected and the user hits start the phone waits a random amount of time to send the command wirelessly to the microcontroller. Once the wireless message is received the microcontroller decodes the message and starts the timer. When the sprinter crosses over the finish line the MCU stops the timer and records the time. This information is then sent wirelessly back to the phone where the user can view their times. As seen in figure 6.1.2, an early goal was to allow connecting to the microcontroller through either Bluetooth, or Wi-Fi, as both are built onto the chip. Though since the esp32 is a relatively recently released board, it's libraries are still somewhat in infancy, with the Bluetooth libraries being too underdeveloped to be used in the context of this design. The communications are mirrored here since only one connection is needed, and they accomplish the same tasks. There will be slight downgrade in power consumption (with Wi-Fi consuming more power), but an increase in effective range (Wi-Fi having a longer effective range than Bluetooth Low Energy).

D. Battery

Since our project will be a standalone project a battery is the center of the power distribution for the system. Using a battery allows our project to be used on the track or other racing surface at a moment's notice, that mobility is our goal for this project. An important thing to note in this project is that there will be two batteries, one in each pylon on each side of the race finish line. The system in general is relatively low power in each pylon so that allows us to get away with a smaller battery which is to our liking.

The battery we will be using in each pylon are the same so charging will be identical. The battery itself is a Li-Ion 18500 Battery. The nominal voltage is 7.4V with 1400mah. Important related measurements would be its power at 10.36Wh, and its discharge current of 2A rate due to a poly-switch. The dimensions of 51mm (2.0") x 38.1mm (1.5") x 19mm (0.75") allow us to fit to the small pylons we plan to use. Also, it is relatively light weight at 70.8 grams (2.5 oz).

E. Power Distribution

In each of the pylons there will be two linear voltage regulators, one at 3.3V and the other at 5V. As such both regulators will be buck regulators.

For the 3.3V voltage regulator, TPS82130 from TI it has the following operating values and schematic to fit our needs in our 3.3V rail for our device.

Table 1: 3.3V Regulator values

TPS82130	Value	Description
Duty Cycle	46.20%	Duty cycle
Efficiency	92.44%	Steady state efficiency
IOUT_OP	1.1A	Iout operating point
Pout	3.3 W	Total output power
Total Pd	0.27 W	Total Power Dissipation
Vout p-p	2.425mV	Peak-to-peak output ripple voltage

Following is the schematic and the PCB layout for the 3.3V Regulator.

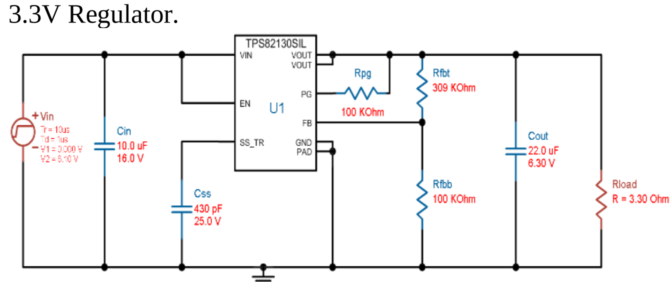


Figure 1: Schematic of 3.3V Regulator

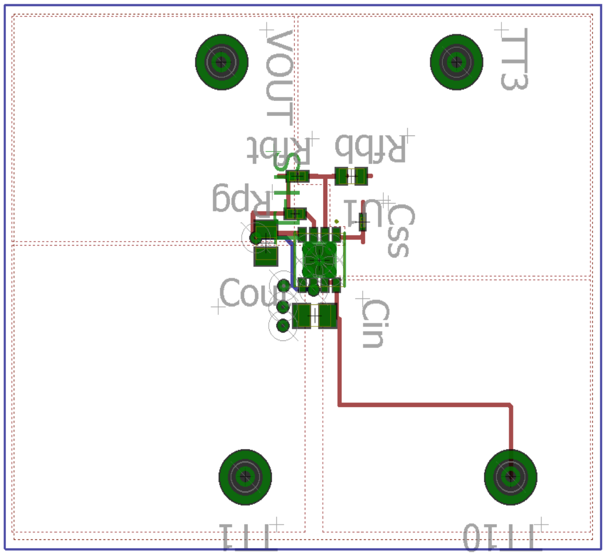


Figure 2: PCB Design

The PCB itself has two layers, with ample copper planes our regulator should have little problem with heat internally, as it fits snuggly into the pylons

For the 5V Regulator, the TPS6307 from TI it has the following operating values and schematic to fit our needs in our 5V rail for our device.

Table 2: 5V Regulator values

TPS63070	Value	Description
Duty Cycle	10.28%	Duty cycle
Efficiency	92.58%	Steady state efficiency
IOUT_OP	1	Iout operating point
Pout	5	Total output power
Total Pd	0.40W	Total Power Dissipation
Vout p-p	0.00135 V	Peak-to-peak output ripple voltage

Following is the schematic and the PCB layout for the 5V Regulator.

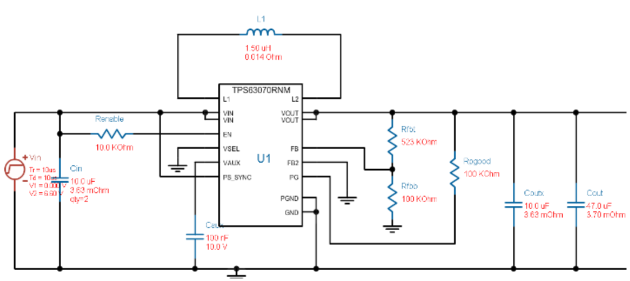


Figure 3: Schematic for the 5V Regulator

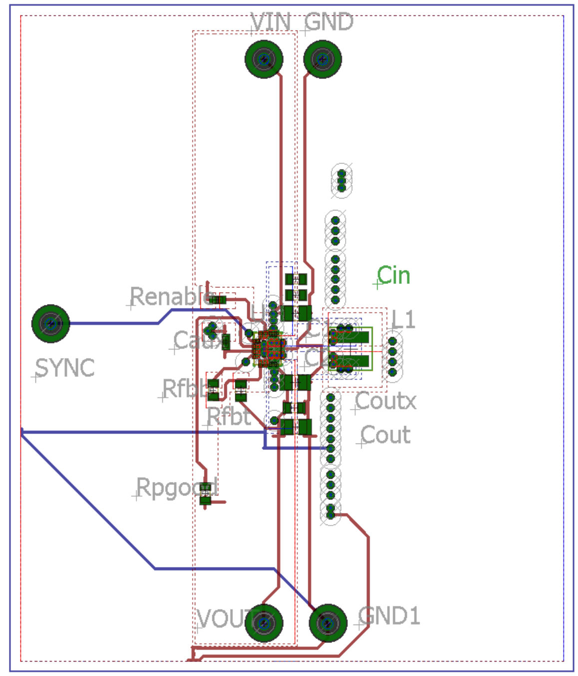


Figure 4: PCB Design for 5V Regulator

The PCB itself has two layers, with ample copper planes our regulator should have little problem with heat internally, as it fits snuggly into the pylons.

F. Battery Charging

For our charger design our main goal is for there to be an easy to use charging method for the two pylons. Our project has a high probability to be stored in a locker room or sporting equipment closet of some sort. In this setting the two pylons need to have easy access to get to the batteries in order to charge them.

For an easy charging solution we will use a smart charger designed for batteries with a nominal voltage of 7.4V. Simply put the battery charger is designed to charge 7.4V Li-Ion/Polymer battery with capacity >= 1600mAh. The battery charger Automatically cut-off power when battery pack is full at 8.4V. The status of the battery charging is indicated with an LED.

Table : Charger Characteristics

Charger Characteristics	
Input Voltage	100 -240VAC 50/60Hz / US AC power plug
Output Voltage	8.4VDC
Charging Current	1.2A Charge time = (Ah rate of the pack x 1.5) / 1.2A charge current
Protection	Reverse Polarity and over charge protection
LED Indicator	Red - Charging Green - Fully charged Dim Green/no LED - you are trying to charge a fully charged battery.
Dimension (LxWxH)	88mm(3.5") x 52mm(2.0") x 30mm(1.2")
Weight	4.9Oz (139grams)

For testing and backup charging we will simply use an additional smart battery charger designed to charge 7.4V Li-Ion/Polymer battery. This uses a basic wall outlet, and gives the necessary 8.4VDC with 1.2 A of current. This will allow us to have a relatively quick charge.

G. Microcontroller Programming

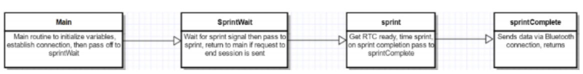


Figure G-1 – High-Level Microcontroller Programming Design

Since the esp32 can run at a high clock speed, we can meet our accuracy requirement when programming the timing of the microcontroller. As seen in figure G-1, the microcontroller programming is broken into a handful of functions that call each other in sequence. Since the microcontroller two tasks are communicating with the android device and timing a sprint, we can break the methods in a way to remove the latency of the wireless communication affecting timing. Since we need to manage a wireless connection with the device as well, we'll be passing the TCP socket to send and receive data to and from these functions. In our final implementation, we've stuck to using the 802.11n WI-FI protocol and the TCP transfer protocol to send data between the two devices. Our main routine as shown in figure G-1 initializes variables and establishes a wireless connection with the android device using the 802.11n Wi-Fi protocol. We chose to utilize the 802.11n wireless protocol as it's outdoor range can be approximated to about 250 meters, exceeding our requirements of a typical use case where the user is likely 100-150 meters from the microcontroller housing. Once the main routine has initialized the wireless parameters the microcontroller passes off control to the "sprintWait" routine.

The "sprintWait" routine does as the function name suggests: waits for a signal from the android device requesting for a sprint to begin. The android device must send over a request before the microcontroller can begin timing. The routine does this by reading from the TCP socket connecting the android APP to the microcontroller program, continuing once a specific sequence of bytes have been received indicating a sprint request. Once a request has been received, we pass off the request (which contains some sprint information such as warmup and timeout times) to the sprint function, where the timing happens.

All the sprint timing is handled on the microcontroller. Once the microcontroller receives a signal, we use the LED and speaker to signify the user of when to start sprinting this is shown in the android UI as well as to prevent users from starting too early. The sprint functions main timing method is by reading from the real-time clock of the microcontroller as the beam breaks. Once the speaker and LED signals are sent to indicate to the user to begin sprinting, we use a function call that converts clock cycles to real time and capture the time as the user crosses the finish line. To optimize timing accuracy, we'll be running the esp32 microcontroller at the clock speed of 240 MHz. The esp32s clock is more than capable of timing to 0.01 seconds of accuracy. In testing, we've found our timing method to be far below 0.01 seconds of error, we know this due to every cycle we capture a time, the delta in time from 1 cycle to another is no longer than 2 ms.

Once we've completed the sprint, we pass the sprint data to "sprintComplete", which is the function that handles sending the finished time to the android device to store and show to the user. While simple, this design of using function calls to pass data relevant to the sprint and TCP connection allows the development of the microcontroller software to be iterative and allow for easy debugging in case issues arise.

H. Android Application Programming

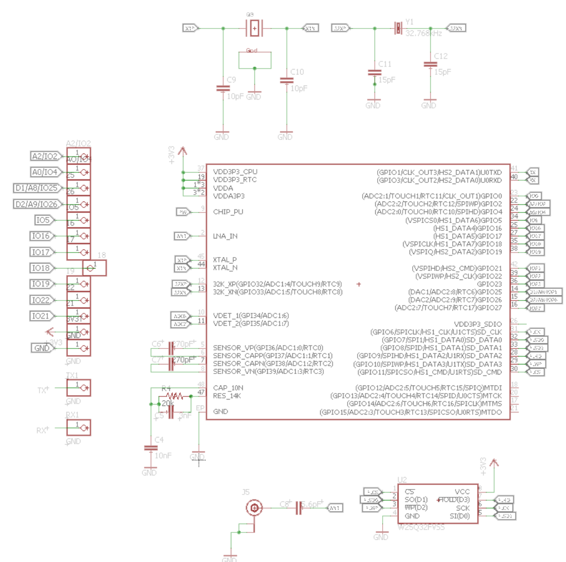
The Android application is the primary way in which the user is going to be interacting with the design, through its GUI, or graphical user interface. This interface must prioritize ease of use by showing as much necessary information as possible while minimizing the number of screens the user needs to navigate. The application must also display to the user after they've sent a sprint instructions on to wait for the signal from the main device, as well as their time at the completion of their sprint. With these key functionalities in mind, we've broken the android application into three subsections: Connecting to the microcontroller, sending a sprint, displaying a sprint.

Since the microcontroller is behaving as an access point in the connection between the 2 devices, the user can simply connect to the microcontroller from their system settings. The app must however keep track of its port and the socket connecting the microcontroller to the application through the TCP protocol. Besides the LED and speaker connected to the microcontroller, the app is the only way the user gets information relevant to the state of the system. The app must provide any information that isn't clear from the I/O devices attached to the microcontroller.

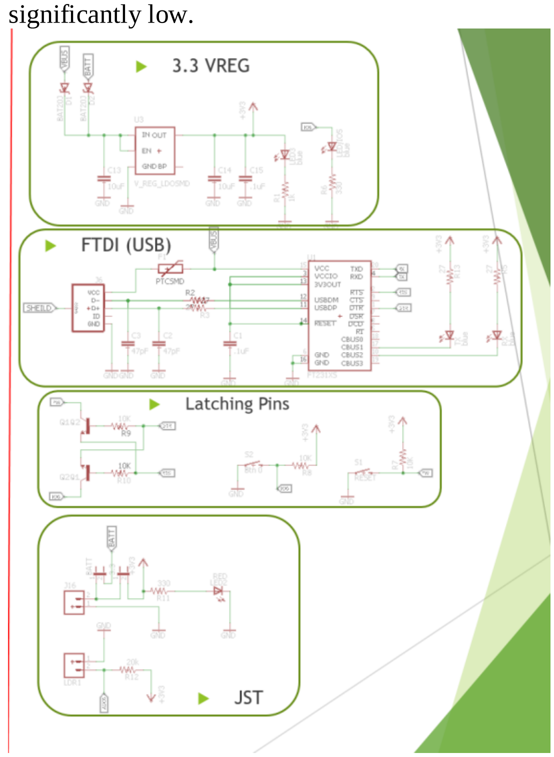
Upon requesting a sprint, the app displays instructions for the user to get ready during the warmup phase and "go" on the LED changing color and speaker sounding. Upon completing a sprint, the app displays the finishing time of the user's sprint. While this isn't much functionality we have to be careful as to make the workflow easiest to understand for the user as possible.

III. SCHEMATICS

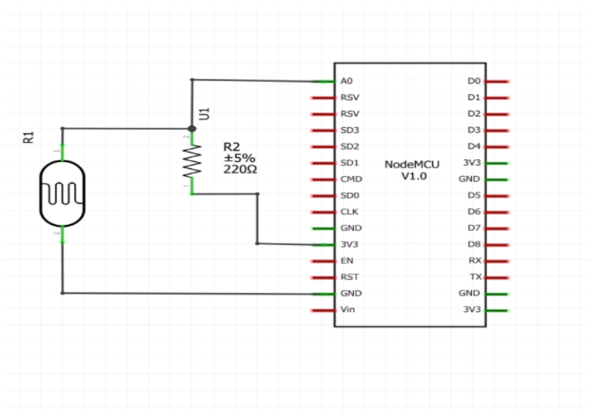
Microcontroller



The picture above represents part 1 of 2 of the full Microcontroller board. The main components for the ESP-32 contains Two clocks at 32MHZ and an external 26MHZ in case we would like to run a backup clock to keep track of peripherals. The rest of the components are a few capacitors, resistors and Flash to store variables and a compiled program. These are all the components needed to run the microcontroller at a bare minimum keeping the cost significantly low.



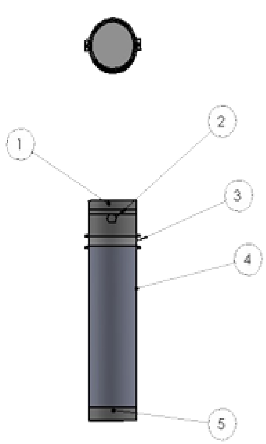
The figure above is part 2of 2 of the microcontroller board and is compartmentalized into 4 subsections listed above. An onboard regulator is used for when we debug the board and use external power sources. The FTDI will be used to program the board through USB, but once the proper firmware is flashed to the device it will be able to receive programs over the Air (OTA). Two buttons used to pull both the GPIO0 pin and the EN pin to ground to boot into the programming flash mode. JST connecters are for battery and contain are voltage divider circuit for reading the Analog voltage of the LDR.



Line laser/LDR circuit

The picture represents the LDR trip circuit using the voltage divider

IV. Build Design



The whole assembly is separated into 5 separate pieces as of now making all the electronics easily accessible for modifications and updates. Balloon one is the top cover that snaps on two part 2. Balloon 1’s purpose is to protect the electronics from any weather conditions that can affect operation, such as rain snow, wind, and the sun’s rays. Balloon 2 is where the trip sensor LDR is housed. The LDR is recessed in to the housing to minimize the amount of sun rays that can enter. The sun’s rays like the laser is also a source of light that can essentially affect the results from the LDR which is why we try to minimize the amount of sun rays from the cavity to allow the laser beam to produce most of the light source so we can establish a trip sensor for the system. This part of the assembly is also where the electronics for the main speaker is housed to provide an acoustic signal for when the race begins and ends. Balloon 3 is not 3D printed but is an acrylic piece to house the led lighting. This is to provide a visual que to the user to show when the laser is aligned and ready to start the race. It also shows the user when the race begins and when the race is finished. We will use a laser cutter to create a circular ring that can be placed directly on top of the Led ring circuit. The acrylic will also be sanded to make the light diffuse through the acrylic, making it easier for the user to see. Balloon 4 is the main body of the housing. This part of the assembly is where the main microcontroller is housed. This is where all the wires are routed from external circuits to the main MCU. This part also serves as the housing for the power and circuitry that must be distributed to all the other subsystems. Balloon 5 is the bottom cap that closes everything in from the bottom of the housing thus keeping all of the elements from destroying the internal components. Figure 6.4.1 (4) below is an exploded view to help the reader visually understand the different parts of the housing more in depth and visually see the construction assembly of the product.

V. Conclusion

The main goal of this project is to create a system that allows for an athlete to practice and compete in his/her track related events. With a combination of hardware in the finish line pylons and software communication through a mobile phone app, the user and other athletes should be able to use this project to practice and improve in race related events. Separating this project into multiple subsystems allowed the design and testing to be done in smaller chunks. Choosing a microcontroller that can integrate these subsystems was key to the success of the project. With our choice of microcontroller, it covered the need for wireless communications in the project through Wi-Fi. The high clock rate also covered the challenging task of timing accuracy. The microcontroller will communicate with an audio, LED and laser subsystems while wirelessly communicating with a smartphone app. The project plans on being easily used and mobile so as far as the power system goes battery is the only option, which will lead to needing two batteries (one for each pylon). The power distribution system following will include two voltage regulators making two rails of 3.3V and 5V rails. With all these subsystems working together and a minor aligning our project is ready for use.

This project also shows the group's design capabilities utilizing the tools taught through UCF's engineering program. This project expanded the group's engineering toolbox by forcing the group to learn new real world applications. Learning Eagle cad software and learning how to design and create PCB's will be an added benefit in future careers. Testing and troubleshooting real world design issues as a group also creates another invaluable skill set that can be used throughout the group's future career. The manipulating of the multiple deadlines, meetings, reports, and the need to achieve success in the prototyping of the project has given this group a small "taste" of the career that we have chosen.

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