ECE 445

Senior Design Laboratory

Design Document

CfA Flying Area Accuracy Determination

Team No. 78

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March 24 2023

Abstract

This document describes the overall design plan for the remainder of the semester, including the parts needed, description of the test environment, and outline of testing processes. Ethics, cost, and tolerances will also be discussed and an estimation of the total workload will be given at the end.

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1. Introduction

1.1 Problem

The challenge faced right now is that the Intelligent Robotics Lab Facility would like to design a software that will analyze how consistently the position of a drone is able to be tracked throughout the Flying Arena based on the configuration of the motion tracking setup. The current motion tracker system used in the Flying Arena is the Vicon Tracker 3 which gathers up to mm position accuracy. However, in areas where the motion tracking camera's configuration does not allow for optimal observation, the accuracy has proven to decrease. The goal is to see how the accuracy changes when the drone would move higher, lower, and further away into the arena and away from the cameras throughout the entire volume of the arena. Ideally after testing, the camera locations can be recalibrated to get the best observation angle.

1.2 Solution

The goal is to see how the accuracy changes when the drone would move higher, lower, and further away into the arena and away from the cameras throughout the entire volume of the arena. Ideally after testing, the camera's locations and angles can be recalibrated to get the best observation angle.

Several subcomponents will need to be put in place. The first is the motion capture setup itself. This consists of the Vicon Tracker 3 software and the multiple Vicon Cameras which will record the position and is currently what the robotics lab utilized for their own experiments. Users are able to record real-time data on a created object's three dimensional position and stream it over WiFi to a supported third party software, such as MATLAB. Several objects can be analyzed in the software at once, each of which is organized and pre-determined by the user. In order to be measurable, the objects must either reflect or emit infrared light.

In order to adjust the configuration of the cameras, a calibration device must be designed. This will consist of a PCB, a microcontroller, switches, a power source, various resistors and capacitors, infrared LEDs (with wavelengths of either 780 nm or 850 nm), and reflective balls. The microcontroller we are choosing to use is the ATmega328P as it has enough programmable I/O ports to connect to eight infrared LEDs individually and three buttons that will control three main configurations of the LEDs. The PCB board will be shaped similar to the top-view of a drone, in which there are four different "wings". Four of the eight LEDs will be on the outer edge of the wings, and the remaining four will be closer to the center. On each wing in between the two LEDs, there will be a hole that allows for mounting a reflective ball. Two switches will control three different LED configurations, being that the outer four emit light (one switch), the inner four emit light (second switch), and all eight LEDS emit light (both switches at once).

Since reflective balls are normally used in the Flying Arena to reflect the infrared flashes from the cameras, these will act as the "true" location. Due to the balls reflecting instead of emitting, they are considered passive markers and will act as one passive object all together. Our design with the LEDs will act as the second object and will represent the measured location. From a performance perspective, since LEDs emit infrared light they are active markers and can be measured at a further distance than passive markers. By comparing the motion-captured location of the reflective balls and infrared LEDs at the same time, we will be able to analyze how accurate the two markers are in comparison in real time. Based on the result, we will reconfigure the camera setup until both the reflective balls and LEDs have similar position measurements on the x,y, and z axes all within six degrees of freedom.

The last subcomponent of the project is the software that we will write that will calculate the percent error between the two measured locations. Data recorded by the motion tracking sensors will be streamed over illininet WiFi in the form of a csv file that we can read and analyze on a personal computer using an approved third party system such as MATLAB.

1.3 Visual Aid

An example of a deck that includes a PCB and programmable LEDs is shown in Figure 1. An example of a deck that includes reflective balls is shown in Figure 2. We plan to reference both of these decks when designing our PCB, and combining the qualities to utilize the LEDs and reflective balls at the same time.

Figure 1. *Drone carrying a deck that has an LED-configured PCB [1].*

Figure 2. *Drone carrying a deck that has holes to attach the reflective balls [1].*

An example of the camera setup that we will be using is shown in Figure 3 below. As detailed by the Vicon user manuals, each camera will be connected to an ethernet cable [2]. The calibration object will either be flown on a drone or carried by one of us within the field of view of all the cameras.

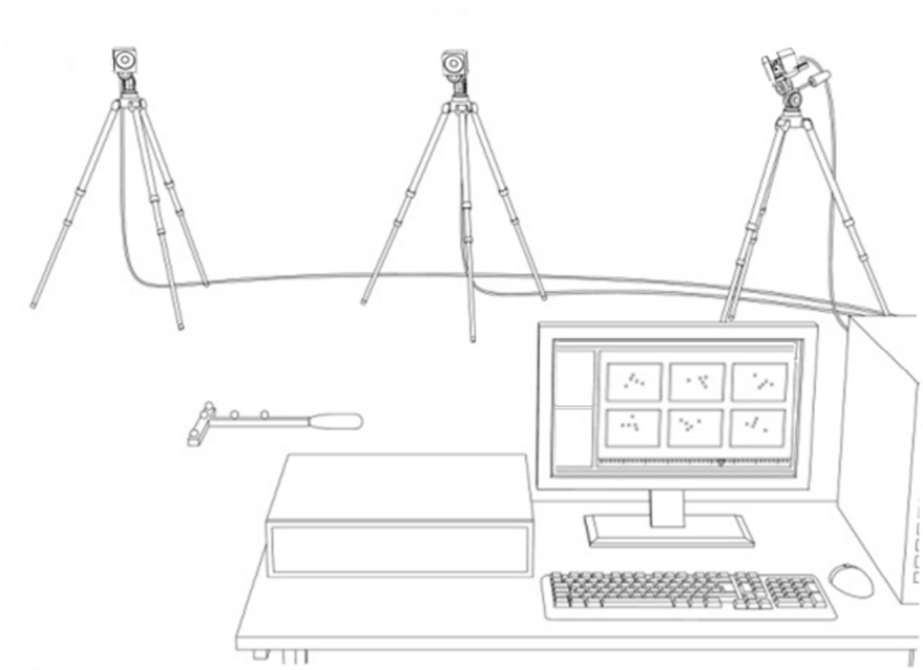


Figure 3. *Similar camera setup to what is in the Flying Arena [2].*

1.4 High Level Requirements

1. Design and create a PCB board with an ATmega328P as a microcontroller, eight programmable LEDs, two switches, and mounting holes to attach the reflective balls. The ATmega328P must be programmed to light up the LEDs in three different configurations.
2. Design an algorithm in the software to compare the locations of the reflective balls and the Infrared LEDs simultaneously.
3. Simultaneously track two objects, one being the 4 reflective balls and the other being the current configuration of LEDs, and stream the data over Illininet WiFi to MATLAB on a personal computer.

2. Design

2.1 Block Diagram

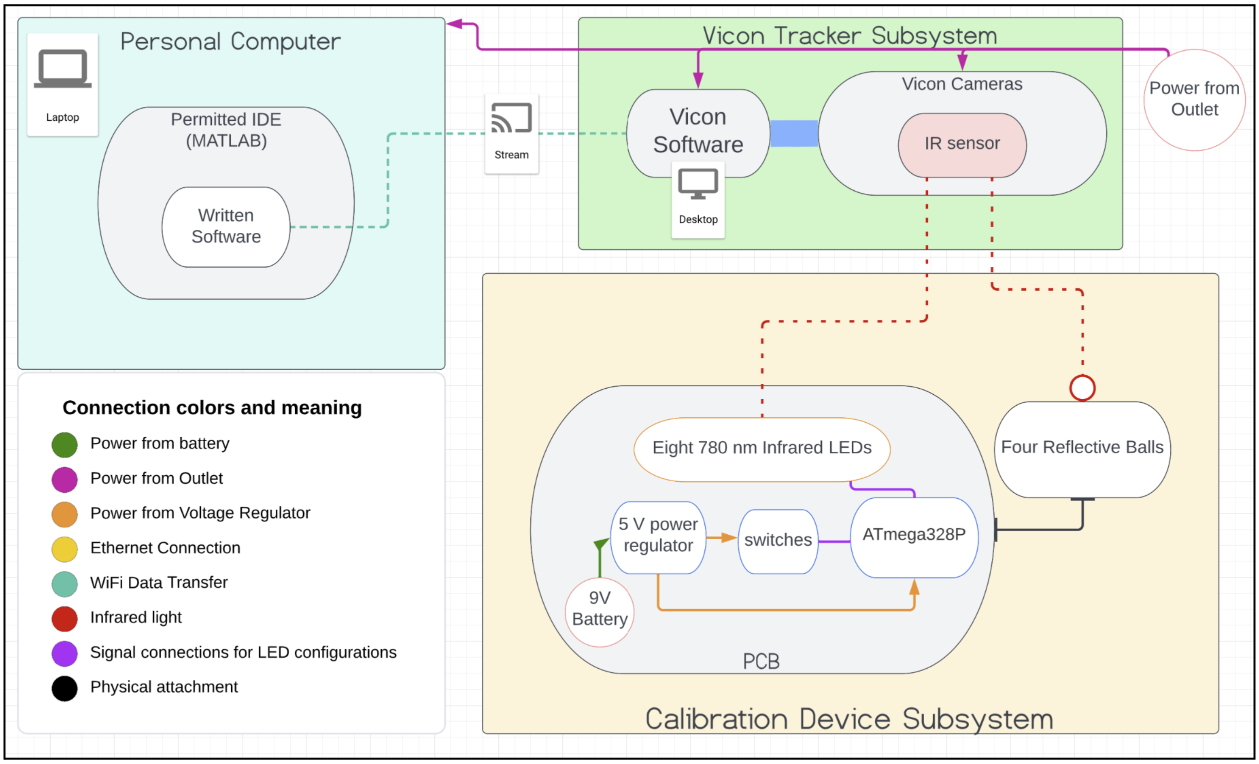


Figure 4. *Block Diagram of Configuration*

2.2 Subsystem Overview

- **Software:** The software will be designed to read data from a csv file that is sent from the Vicon Tracker 3 Motion Capture System to the personal computer we are working on via the local illininet Wifi. Using a compatible system such as MATLAB, the two main groups of data that we will have to analyze is the 3-dimensional measured location of the reflective balls and infrared LEDs. At each parallel recorded set of (x,y,z) points, the percent error will be calculated and used to determine the accuracy of the current Motion Tracking Camera configuration.

- **Motion Tracking Configuration:** The Motion Tracking Configuration consists of multiple cameras and the Vicon Tracker software. Both will be powered by the wall outlets, but the data collected by the multiple camera system will be sent to the software over an ethernet connection. The cameras record 370 frames per second, meaning that there will be 370 data points per second. The camera flashes a near infrared light of about 780 nm, which will be reflected by the reflective balls [3]. Using the Vicon Tracker 3 software, the user will be able to group multiple items into one "object". Since there can be multiple objects focused on at one time, two will be tracked for this project [2].

- **Drone/Test Object and Flying Arena:** The Flying Arena will be the test space, and the test object or drone will have the PCB board mounted onto it as well as the reflective balls. The PCB itself will need to have a 5 V power source that leads into both the switches and the Atmega328P, which is the microcontroller of our choice. Two I/O pins will be designated for the switches, while another eight I/O pins will lead to individual LEDs. There will be two switches, each one controlling four LEDs. There will also be several resistors so as to not overload the Infrared LEDs. During testing, the drone will either be carried around by one of us, or mounted onto a drone given that we have been through flight training.

2.3 Subsystem Requirements

- **Software:**
    - **Continuous Recording of Both Object Locations.** In order to properly analyze the data collected, it must be streamed from the desktops with the Vicon System to the designed software on our personal laptop. This will occur at the end of the given trial in the form of a csv file which can be immediately read and analyzed. The camera will capture 370 elements of data, each being (x,y,z) coordinates per second.
    - **Constantly Compare the Two Data Sets.** As the two groups of data will be sent and read in parallel, they must also be stored in a way that each respective set of points can be directly compared for the percent error on the x, y, and z axes.

Percent error will be determined by taking the infrared LEDs' location as the expected value, and the location of the reflective balls as the observed value.

$$\left|\frac{observed - expected}{expected}\right| * 100 = \text{percent error } \%$$

- **Motion Tracking Configuration:**
  - **Vicon Tracker 3 System.** The system will process the data collected from the cameras to determine a 3D image of the calibration object and determine the location of its center. The x, y, and z coordinates of each object's center will be the data. Both the reflective balls and the infrared LEDs will be tracked as separate objects, each of which will be manually grouped together by the user before each trial. Both sets of data processed by the system will be saved in a csv file and sent over WiFi to the designed software to further analyze for accuracy [2].
  - **Vicon Tracker 3 Cameras.** The Vicon cameras are a slightly older model that strobe an "near infrared" wavelength of about 780 nm - 850 nm. The strobes act as flashes that will be reflected by the reflective balls. Providing that the LEDs are within the proper bandwidth range, they will be registered by the cameras when illuminated [3]. The LEDs will stay illuminated throughout the entirety of the trial, instead of responding to the strobes like the reflective balls will. About 370 points of data will be collected per second, all of which will be transferred to the Tracker 3 software over an ethernet connection. The cameras can be moved around throughout the Flying Arena to gain optimal viewing angles of the markers.
  - **Routing Over WiFi.** The local Illininet WiFi will be the routing method when sending the csv file from the computer running the Tracker 3 software to the personal computer we will be using for testing.

- **Drone/Test Object and Flying Arena**
  - **PCB.** The PCB will resemble the shape of the drone, as shown in Figures 1 and 2 and it will include mounting holes for the reflective balls to be mounted. The required materials, including the microcontroller, the IR LEDs, the voltage regulator, and various other elements will be soldered onto it. The final PCB design will be mounted onto a deck that has a similar size and shape, which is shown in Figure 6.
  - **LEDs.** There will be eight Infrared LEDs in total, four of which will be closer to the center and the other four will be on the outer arms of the PCB. They need to have a wavelength of around 780 nm - 850 nm to mimic the strobe of the infrared Vicon Cameras. Since these emit light instead of reflect, it needs to produce a similar wavelength compared to what the camera will strobe. Various

configurations will be tested, particularly when the light emission is concentrated in the middle or spread out across the deck. This will test active marking and act as the more accurate location [3].

- **Switches.** There will be two switches connected between power from the voltage regulator and the ATmega328P microcontroller. One will control the innermost LEDs and the other will control the outermost LEDs. When both switches are closed all eight of the LEDs will be illuminated.
- **Atmega328P.** The Atmega328P is the microcontroller of our choice, as it has 23 I/O pins that can easily address the eight different LEDs. It will be programmed to turn on LEDs based on which switch is currently flipped. This will allow for different configurations to be tested on top of just the base ones stated previously, provided that there is more time after initial testing is complete. The programming will be done from the ISP, being the AVR-ISP-6.
- **Reflective Balls.** The reflective balls will reflect the flashes of the camera and can be mounted into the holes on the deck. There will be one main configuration of four different balls, as this is what is normally done in the Flying Arena. Having the reflective balls will test passive marking [2].

2.4 Subsystem Requirement and Verification Table

Requirement	**Verification**
Continuous Recording of Both Object Locations.	● Check the output file to ensure that all 370 frames captured each second have independent positional data for each LED/reflective ball and there are no gaps in data. ● Check that there is a stable connection to Illininet Wifi.
Constantly Compare the Two Data Sets using Vicon Tracker 3 System	● Construct a graph picturing the locations of each of the 4 or 8 LEDs (depending on the configuration) and reflective ball over the flight duration in Vicon Tracker 3. ● Ensure that the LEDs and reflective balls are grouped as two different objects. ● Verify that percent error can be calculated for the center of each object.

PCB	• The PCB functionality will be tested in both the senior design lab as well as the Robotics Lab, as there is a soldering station there. • The PCB at this time has passed an audit, but dimensions must be correct in order to function. • All components will be hand soldered, and thus more easy to work with an test.
Atmega328P	• This microcontroller is easily programmable for the purposes of keeping different configurations of IR LEDs illuminated [4]. • It will be tested by programming the code onto an Arduino first, then onto the ATmega used in our design.
LEDs	• The LEDs will first be tested alone, separate from the PCB, on a breadboard to ensure that the Vicon Cameras can register them. • On the PCB, the LEDs must successfully turn on when the remote switch is hit. This will be tested in the senior design lab after the ATmega is correctly working.
Reflective Balls	• Reflective balls must successfully be picked up by the Vicon cameras simultaneously as the leds are on. • The ability to properly fit into the mounting holes will be examined.

2.5 Schematic and PCB Layout

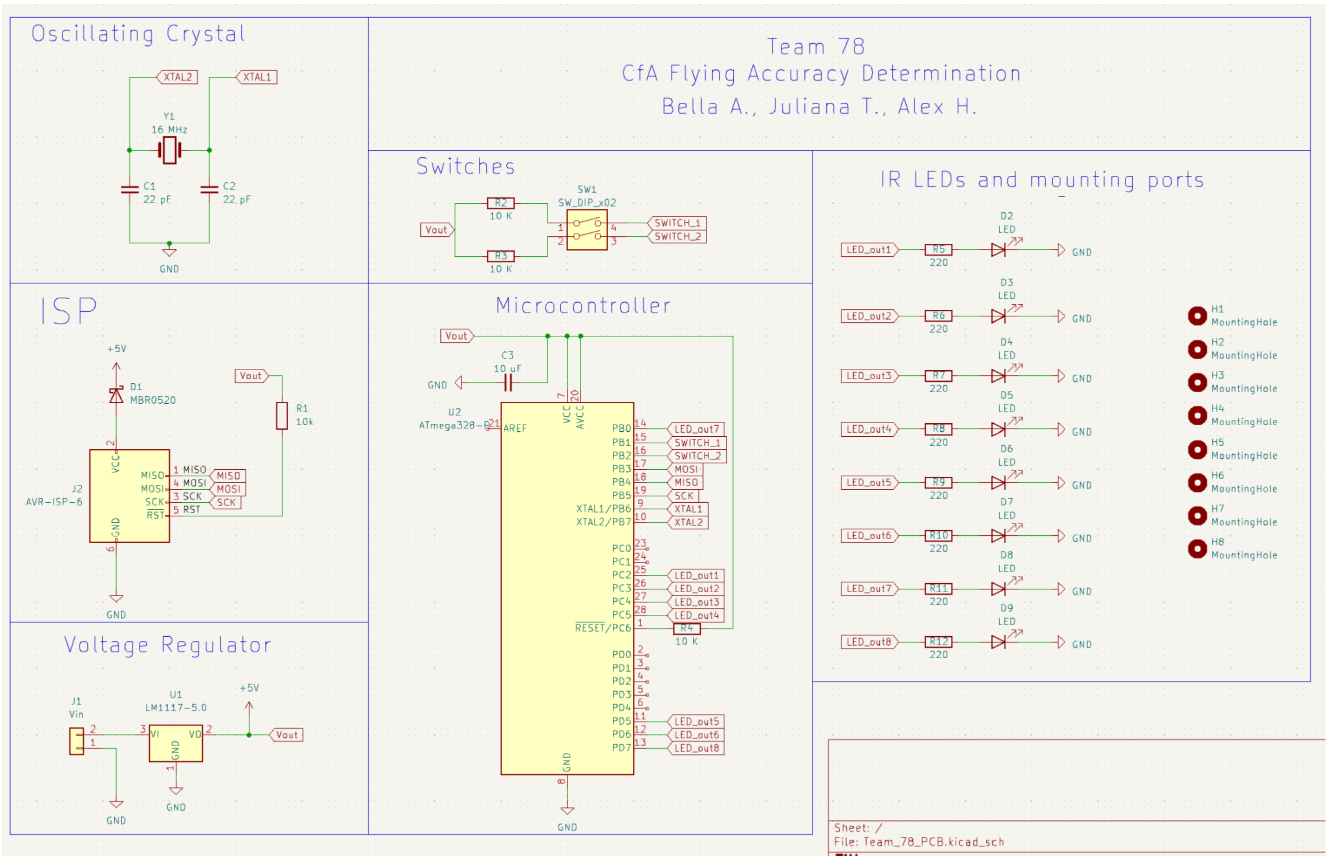


Figure 5. *This image displays the schematic layout in KiCAD*

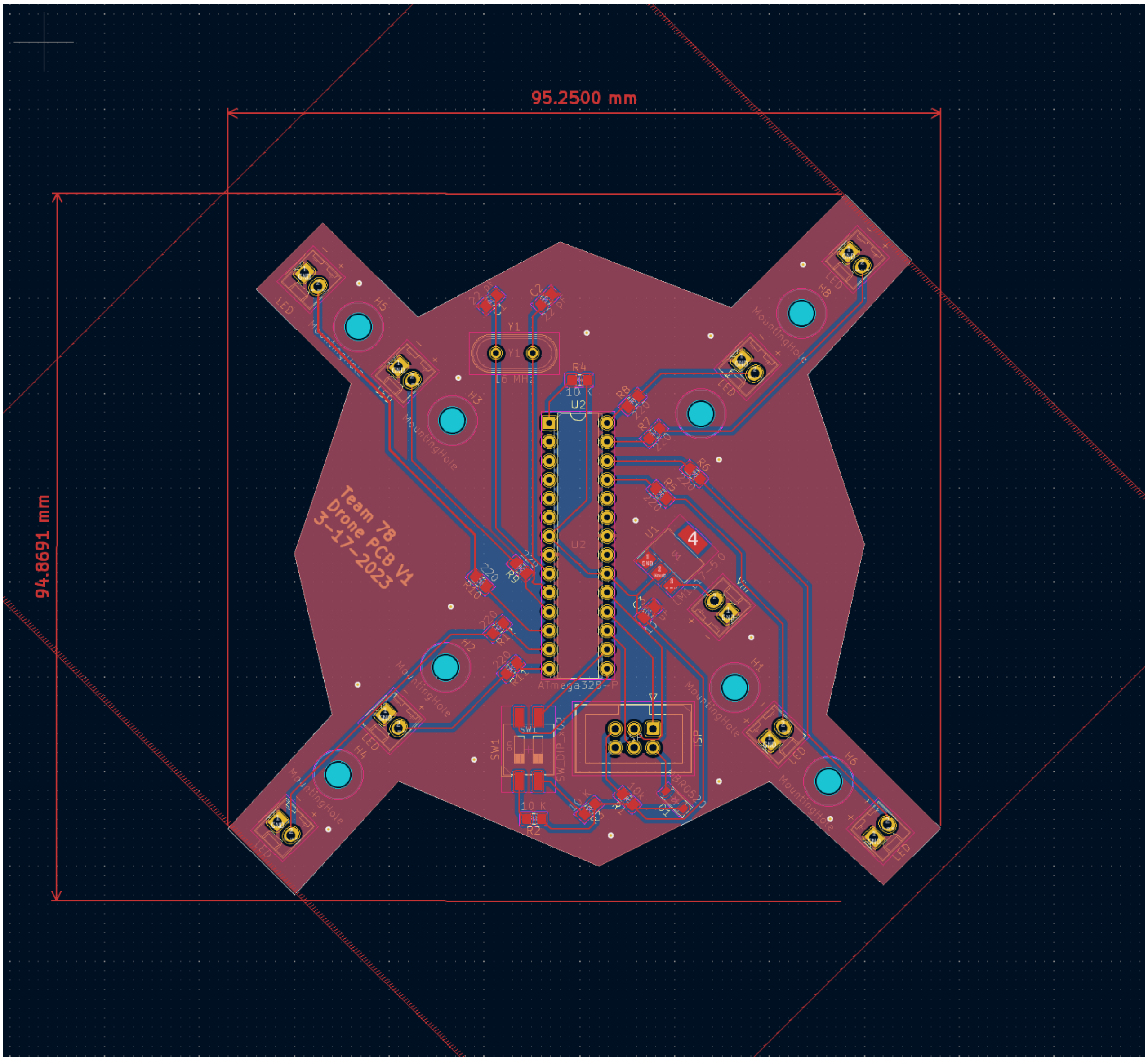


Figure 6. *This image displays the PCB layout in KiCAD*

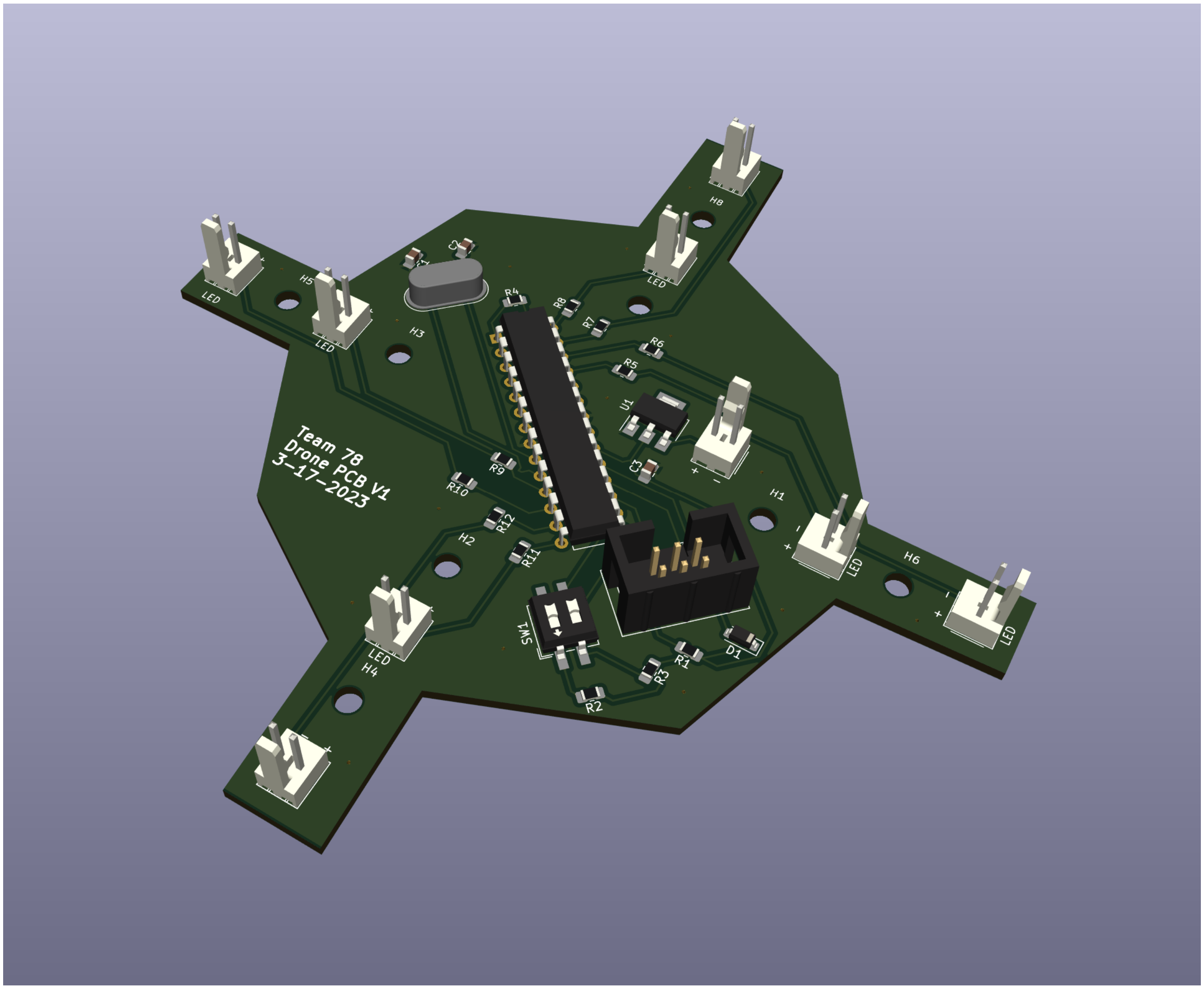


Figure 7. *This image displays the 3D view of the PCB layout in KiCAD*

2.6 Software Flowchart

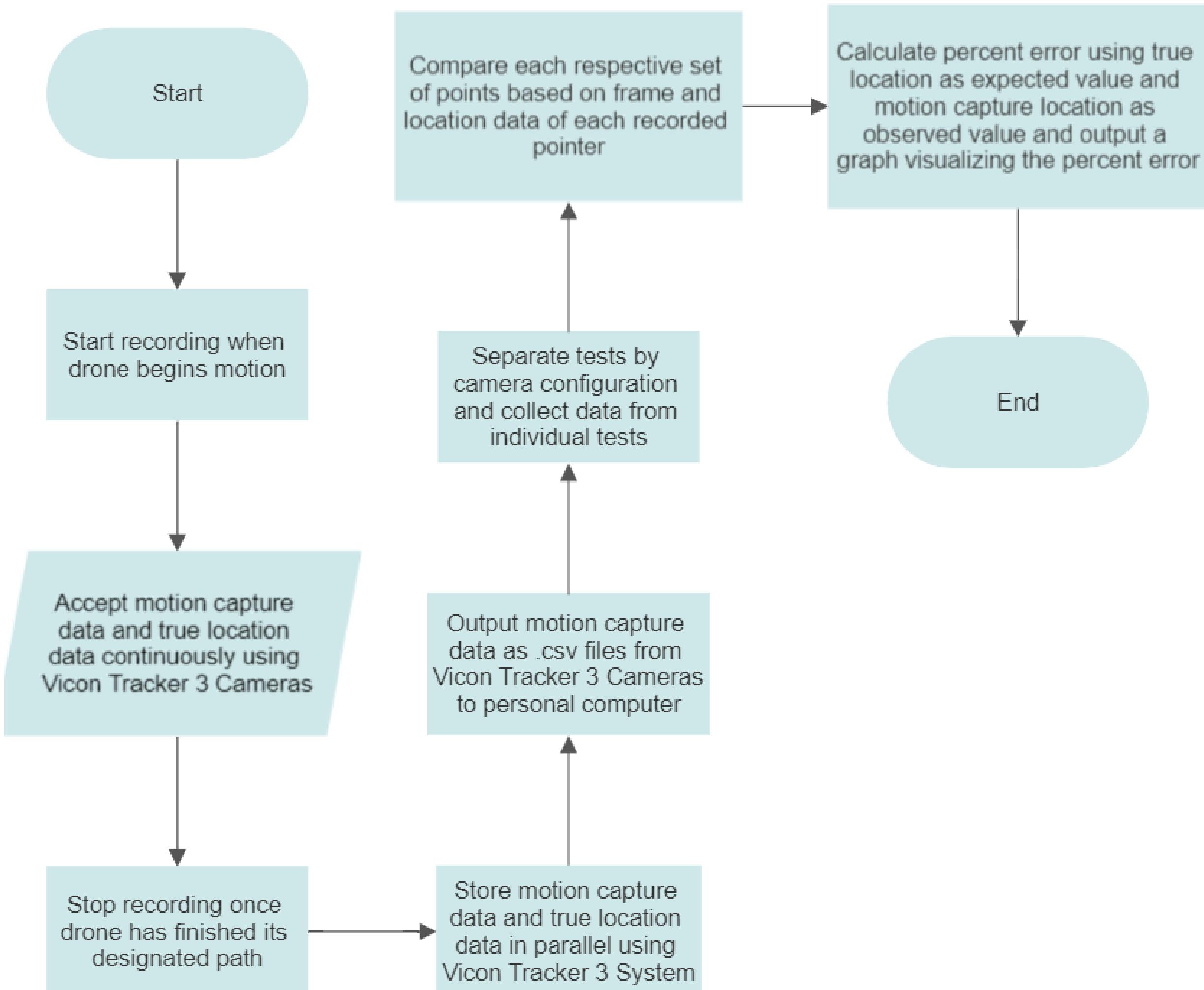


Figure 8. *This image displays the flowchart of the designed software. The "true location" is represented by the infrared LEDs. The measured location is represented by the reflective balls.*

2.7 Tolerance Analysis

Some of the risk involved in pursuing this project involves the Infrared LEDs and determining the wavelength that will function best with the cameras. As we cannot see Infrared light without proper equipment, it may take some trial and error and multiple types of IR LEDs to be purchased. This may take time, so it could impact the progression of the project.

Another risk that could be met throughout the experiments involves designing the software and taking the time to properly debug it. If the software does not work, the entire system may not function properly as a whole.

Bad data from inaccurate location measurements would lead to a larger percent error. The largest percent error that we will allow recording location is +-0.01%.

$$\left|\frac{observed - expected}{expected}\right| * 100 = 0.01$$

Providing that the expected value is at location 1 m in the x-direction:

$$\left|\frac{observed - 1}{1}\right| * 100 = 0.01$$

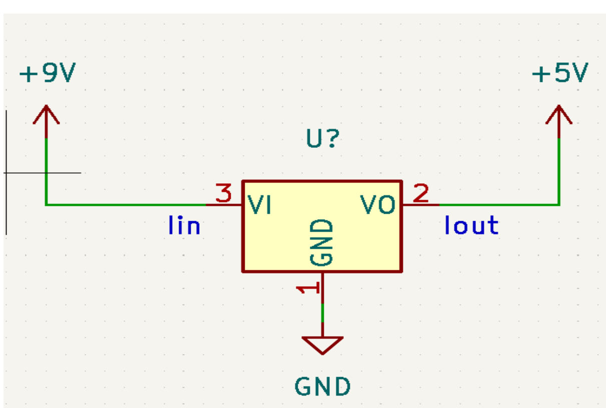
Observed - 1 = 0.0001

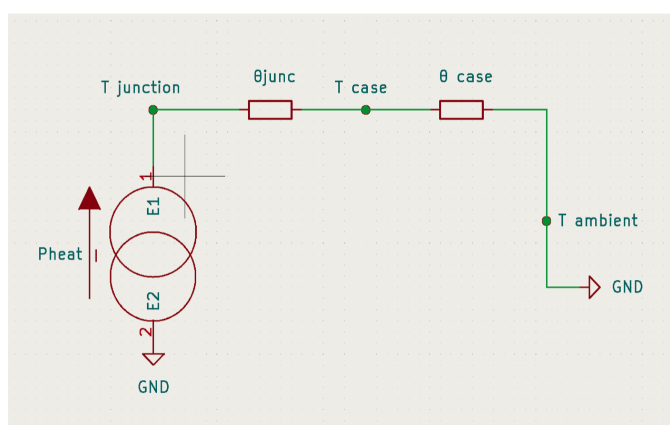
As a result the observed center can be at maximum 0.0001 m away from the center of the expected location.

An additional tolerance that we calculated out was the thermal circuit analysis in the voltage regulator on the PCB. Looking at a regulator we know that output current is approximately equal to the input current since the other path goes straight to ground. According to kirchhoff's law V=IR and Newton's law of cooling ΔT= kQ there exists a relationship between the following variables.

In = Iout Pin> Pout

I(A) → Q(w) V (v) → ΔT (°C) R(Ω) → θr (°C/w)





P heat= Pout- Pin= Iout(Vin-Vout) Tjunc-Tamb= Pin(θja)

Seeing this we must ensure that the temperature at the junction(Tjunc) will be lower than the temperature of the component 125 °C [5].

Another addition is to ensure that each LED is not being overloaded with current. According to the ATmega328P datasheet, the DC current per I/O pin is about 20 mA and 5 V [4].

According to the datasheet of the LEDs, the 2.0 V forward Voltage. This means that the resistors connecting to the LEDs must be around 100 - 150 ohms [6].

$$5 = (150 * 0.02) + 2$$

$$5 = 3 + 2$$

3.1 Cost analysis (parts and labor)

Description	Part number	Unit price	# bought	Total cost
780 nm IR LED [6]	**LED750L**	$10.40	8	$83.2
22 pF capacitor [7]	**CL21C220JBANNNC**	$0.10	4	$0.40
10 uF capacitor [7]	**TMK212BBJ106MG-T**	$0.18	4	$0.72
Diode [7]	**MBR0520**	$0.16	2	$0.32
Connector [7]	**0022232021**	$0.21	2	$0.42
ISP [7]	**61200621621**	$0.48	2	$0.96
Switches [7]	**219-2MSTR**	$0.63	2	$1.26
Voltage Regulator	**LM1117MPX-50NOPB**	$0.61	2	$1.22
16 MHz Crystal	**LFXTAL003240BULK**	$0.50	2	$1.00
Microprocessor [7]	ATMEGA328P	$2.89	1	$2.89
Vicon camera [2]	—----------	0	Given (3)	0
150 ohm resistor [7]	CFR-25JB-52-100R	$.068	8	$.55
PCB (4.5" x 4.5")	N/A	N/A	1	N/A
Total	//////////////////////////	//////////////////////////	41	$92.94

3.2 Schedule

Every member should contribute to the project approximately three days a week until the design of the pcb and understanding of the software for our purpose is complete. We will need to work on the board design one or two days a week and get into the lab two days a week to set up optimal camera positioning and become accustomed with software in the flying arena. Once the pcb design is complete our group will spend two days a week in the UIUC Robotics Lab in order to run sufficient amounts of tests and collect data as we fit our custom pcb board and discover the best way to compare accuracy.

JULIANA: available after 1 M,W,F   11am-2pm, after 4pm T, T

ALEX: available after 1 All Week

BELLA: available T,TR all day   Available after 1 PM W   Available on Weekends

Week	Objective
2/21	Check Design Document, Start building PCB
2/28	PCB Review, Finish up PCB design
3/7	Order parts and PCB, Complete teamwork evaluation
3/14	Spring Break
3/21	Finish ordering parts, Start assembly, Start software development
3/28	Finish assembling parts to be fit onto drone, Finish software, Begin testing in Flight Lab
4/4	Continue testing in Flight Lab
4/11	Work on hardware and software verification
4/18	Present mock demo to TA, Work on final presentation and paper
4/25	Work on any issues that occurred, Continue working on final presentation and paper
5/2	Work on Final Paper

4. Ethics and Safety

The main ethical concern of this project is if we irresponsibly were to fly the drone. According to rule number II.9 in the IEEE code of ethics, we must “avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses” [8]. If we irresponsibly fly the drone, it may cause damage to others or the lab environment/equipment. Regarding safety we must take the proper precautions and training when entering the robotics lab. Mechanically we run the risk of damaging lab equipment (drone), if it were to be operated improperly. Electrically we must design a PCB board that will have fully functioning connections, short circuits can damage the PCB board as well as the frame depending on the level of issue.

Furthermore, it is important to not overload the circuit, as if overheating occurs it could cause a fire in the robotics lab. This issue deals with lithium batteries being combustible and leading to dangerous electric fires. Due to this reason, we performed the thermal calculations in the tolerance analysis to make sure that specifically the linear voltage regulator is not overloaded when reducing a 9 V supply down to 5 V.

Regarding the lab space, it is important to keep the drone at a safe level within the arena and always announce when takeoff will occur. Otherwise, people may get harmed by the quickly moving propellers. This could also cause property damage, such as to windows or lightbulbs, if the drone were to be flown outside of the protective cage.

In the lab it is also important to respect the time of everyone who is also using the lab. Therefore, it is important to sign up for time slots a week prior and cancel with at least 48 hours remaining before the planned time. Therefore, other people can sign up for a slot that will no longer be attended by the users. When the time allotted to a slot is done, the users should make sure to pack up belongings and leave so that others can also use the lab.

The robotics lab has expensive equipment, and it is important to only go into the lab with your team and not hold the door for anybody else, even if they try to verify that they have access.

References

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