

**ECE 445**  
**Spring 2022**  
Design Document

# **Pacer Runner**

**Team 12**

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# 1. Introduction

## 1.1 Problem and Solution Overview

Beginner runners know how difficult it is to keep a constant pace during a long run. Using a smartwatch or a smartphone, they can measure their pace and heart rate. However, an issue associated with these devices is that the runner doesn't receive any feedback until their training has ended, resulting in the runner not having any convenient way to maintain their pace throughout the run. Thus, they need a solution which can provide them with feedback instantly.

The solution involves a laser device that will be worn by the runner on their chest which would be capable of tracking their pace and giving real-time feedback on their performance. To do this, we will design a line laser device that changes the projection angle depending on whether the runner's pace is too fast, too slow or ideal. Thus, the pointer will move further if the runner decreases their pace and closer when they increase it.

## 1.2 Visual Aid

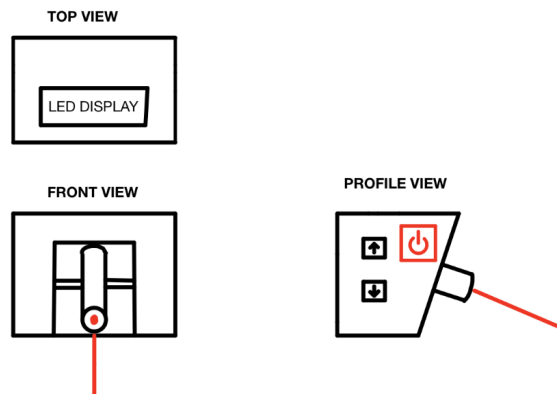


Figure 1: Orthographic Projection

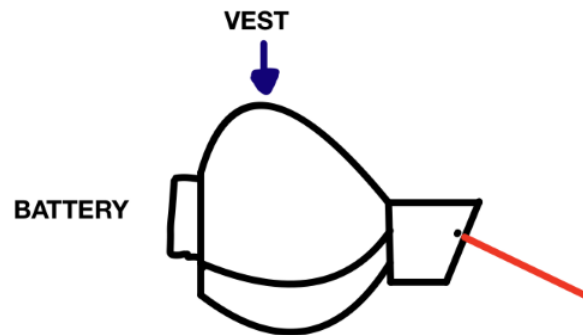


Figure 2: Vest Design

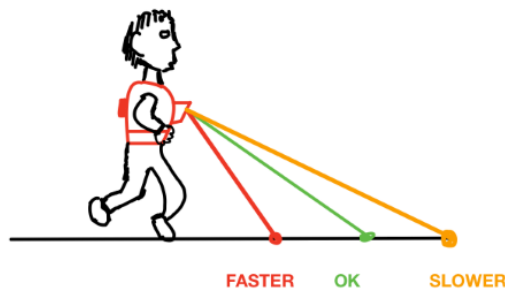


Figure 3: Working Illustration

### 1.3 High Level Requirements

- The servo-motor changes the angle of the laser in response to the runner's change in pace. (as shown in *Figure 3*)
  - ◆ There will be three possible positions with 0 degrees being vertically down (Refer to 2.6.2 *Angle-Control Tolerance*):
    - slower than target pace: servo-motor at 56 degrees
    - ideal pace: servo-motor at 45 degrees
    - faster than target pace: servo-motor at 27 degrees.
- The GPS module will calculate the runner's pace accurate to 1 mi/hr.
- The physical input buttons change the target pace, and the LCD display output will reflect these changes. The changes will be:
  - ◆ Increase pace button should increase the target pace by 0.5 mi/hr.
  - ◆ Decrease pace button should decrease the target pace by 0.5 mi/hr.
 The LCD display should always show the target pace.

## 2. Design

### 2.1 Block Diagram

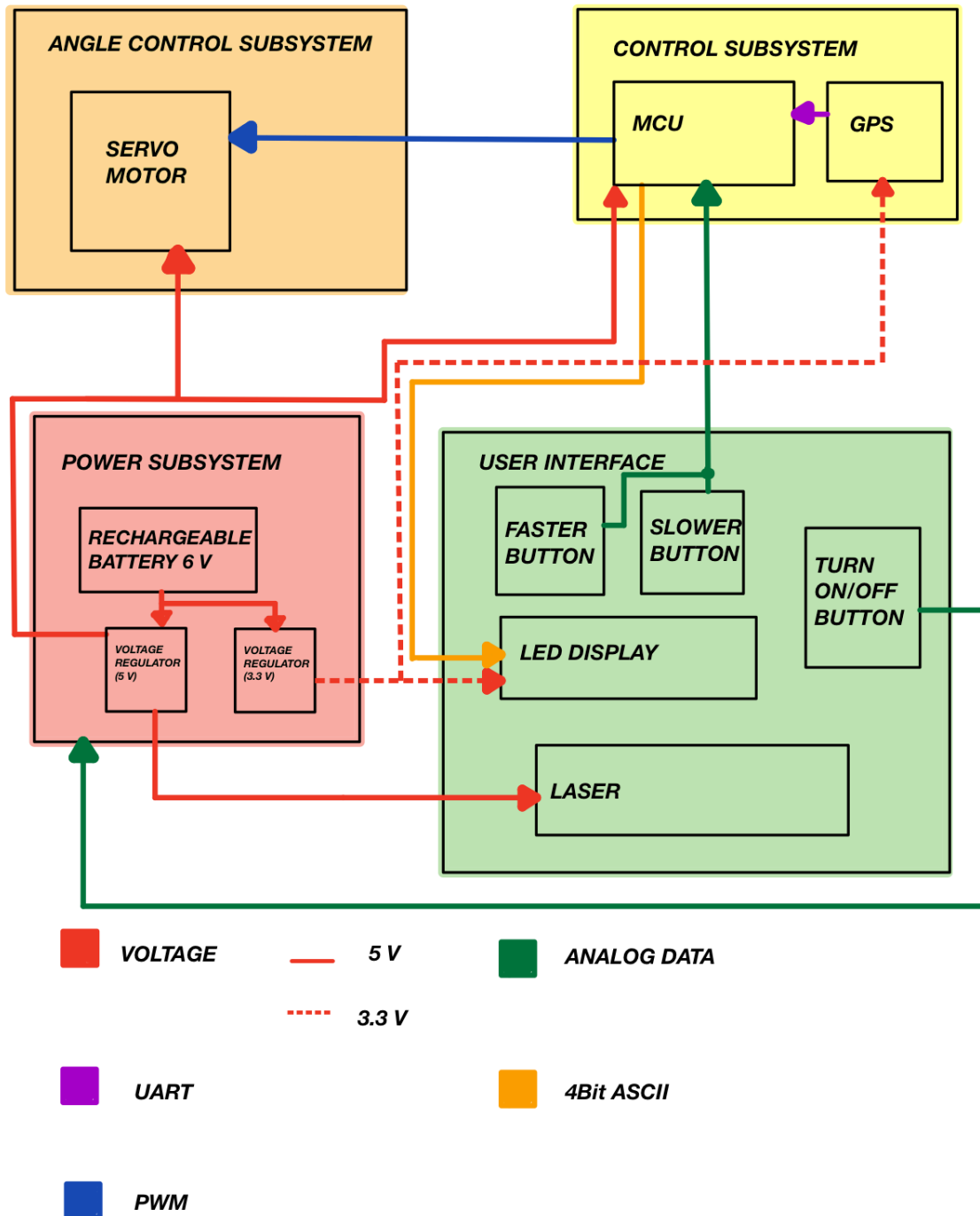


Figure 4: Block Diagram

## 2.2 Power

The power subsystem provides energy to the components based on their individual needs and requirements. The voltage from the main battery is regulated by one of two regulators, and then provided to all the other subsystems.

To ensure that our device operates to its utmost potential we have to provide an adequate source of power and a voltage regulator. We will be using a Nickel Cadmium rechargeable 6 V battery with a power capacity of 1800 mAh which weighs 245 g. This is extremely light, and should not be uncomfortable to wear. We chose the battery because our two main components, the laser and the servo-motor, both require a minimum voltage of 5 V for ideal functionality.

We chose the battery with a capacity of 1800 mAh since the overall power consumption of our device is 500 mAh which gives us a battery life of ~3.5 hours.

We would also require two voltage regulators to bring the voltage down to 5 V and 3.3 V for different components in our device. We will use LP5907 for the 3.3 V regulator, and LM1117 for the 5 V regulator.

<b>Requirements</b>	<b>Verification</b>
1. . Voltage Regulator 1 provides fixed 5.0 V +/- 0.5 V from 6 V source.	1. Measure the output voltage using an oscilloscope, ensuring that the output voltage stays within 0.5 V of 5.0 V.
2. Voltage Regulator 2 provides fixed 3.3 V +/- 0.33 V from 6 V source.	2. Measure the output voltage using an oscilloscope, ensuring that the output voltage stays within 0.33 V of 3.3 V.
3. The battery should provide at most a current of 500 mA +/- 50 mA. Since our device has an overall consumption of less than that amount.	3A. Connect the battery with a resistor of 12 Ohms.  3B. Measure the current using a multimeter to make sure that the current stays within 50 mA of 500 mA.

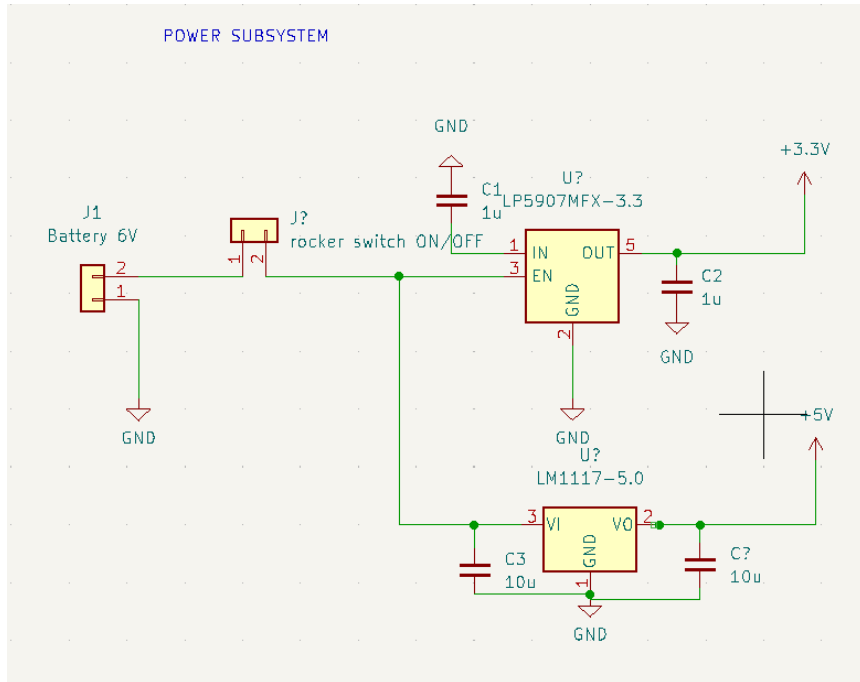


Figure 5: Power Subsystem Schematic

## 2.3 Angle Control

The purpose of this subsystem is to rotate the servo-motor (on which the line laser is mounted) to project the line laser in different positions based on the pace of the runner.

The motor in this subsystem gets power from the Power subsystem and receives commands to rotate from the Control subsystem. Lastly, it is connected to the User Interface as the line laser is mounted on this subsystem.

This subsystem consists of a servo-motor (HS-311) which has an operating voltage of 4.8 to 6.0V. This motor has a maximum rotation of 202 degrees which meets our requirements. Based on the pace of the runner, the motor toggles between 27 degrees, 45 degrees, and 56 degrees. (Refer to 2.6.2 *Angle Control Tolerance*)

Requirements	Verification
1. Set the target pace to be 5 mi/hr. Run at a pace of 5 mi/hr. The angle of the laser should be 45 degrees.	1A. Set the target pace as 5 mi/hr using the faster/slower buttons.  1B. Map out a lap that is 0.05 miles long, ask the runner to run this lap in 0.01 hrs / 36 seconds.  1C. Run this known lap, and verify that the servo motor angle is 45 degrees.
2. Set the target pace to be 6 mi/hr. Run at a pace of 5 mi/hr. The angle of the laser should be 56 degrees.	2A. Set the target pace as 6 mi/hr using the faster/slower buttons.  2B. Map out a lap that is 0.05 miles long, ask the runner to run this lap in 0.01 hrs / 36 seconds.  2C. Run this known lap, and verify that the servo motor angle is 56 degrees.
3. Set the target pace to be 4 mi/hr. Run at a pace of 5 mi/hr. The angle of the laser should be 27 degrees.	3A. Set the target pace as 4 mi/hr using the faster/slower buttons.  3B. Map out a lap that is 0.05 miles long, ask the runner to run this lap in 0.01 hrs / 36 seconds.  3C. Run this known lap, and verify that the servo motor angle is 27 degrees.



## 2.4 Control

The Control subsystem will:

- take in the target pace from the User Interface
- calculate the runner's pace using a GPS module
- compare the runner's pace with the target pace
- and finally, adjust the servo-motor's angle based on this information.

The control receives power from the Power subsystem, processes input data from the User Interface subsystem, and outputs data to the Angle Control subsystem as well as the User Interface subsystem.

This subsystem consists of two main components:

- The microcontroller (ATMEGA165PV-8AUR) allows us to link and control various parts of our project. It has 32 x 8 registers with 130 powerful instructions which provides us with sufficient computing power for this project.
- The GPS module (SAM-M8Q) will be used to calculate the runner's pace. It has a 72-channel u blox M8 engine. The velocity accuracy is listed as 0.05 m/s while the heading accuracy is 0.3 degrees.

Requirements	Verification
1. The microcontroller sends and displays data on the LCD screen.	1A. Connect the LCD display to the microcontroller using SPI.  1B. Verify that the LCD is capable of displaying the 3 digit speed of the runner.
2. The GPS module can track the user's location within 5 m.	2A. Program the GPS module to track a lap around the track for our runner.  2B. For the same lap use Strava, a running app on your phone to record the run which is known to give accurate data.  2C. After the run, compare the data side by side .If the margin of difference is within a circle of 5m radius around the runner the GPS is successful.
3. The GPS module can track the user's speed within 0.5 mi/ hr .	3A. Set the target pace as 5 mi/hr using the faster/slower buttons.  3B. Map out a lap that is 0.05 miles long, ask the runner to run this lap in 0.01 hrs / 36

seconds.

3C. Run this known lap, and verify that the speed on the LCD display sent by the GPS is within 0.5 of 5 mi/hr.

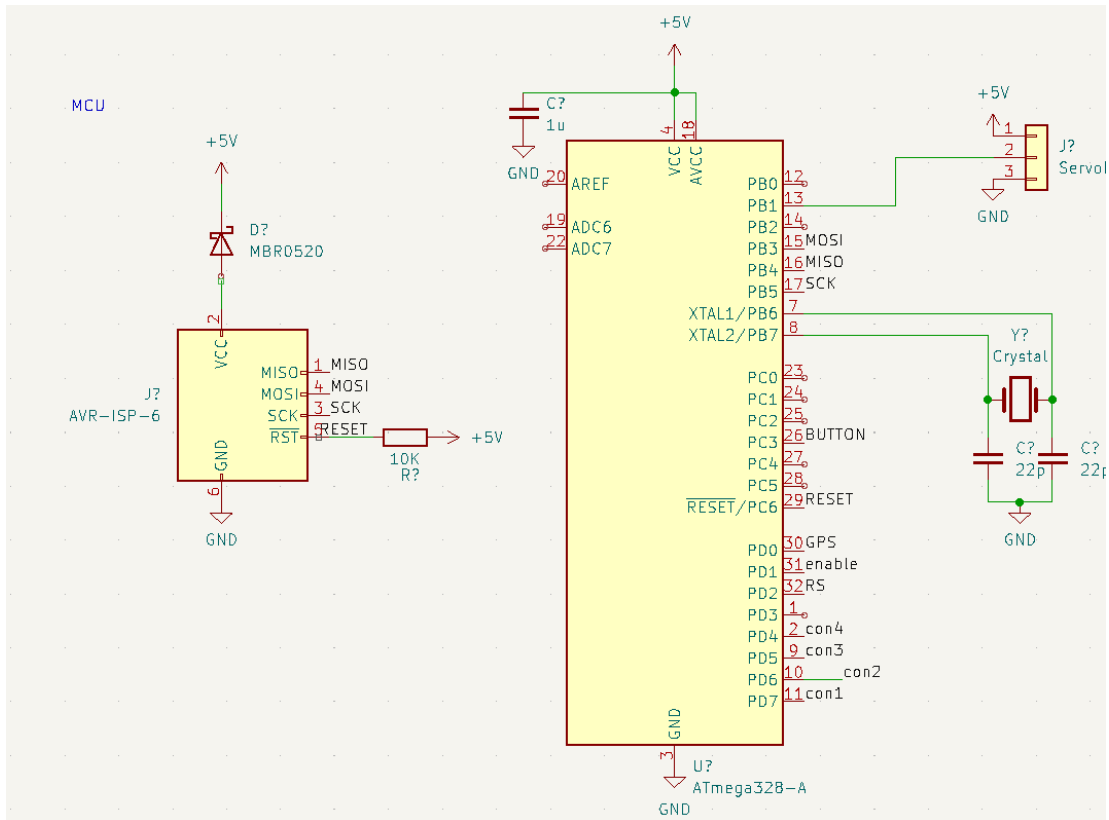


Figure 6: Microcontroller Circuit Schematic

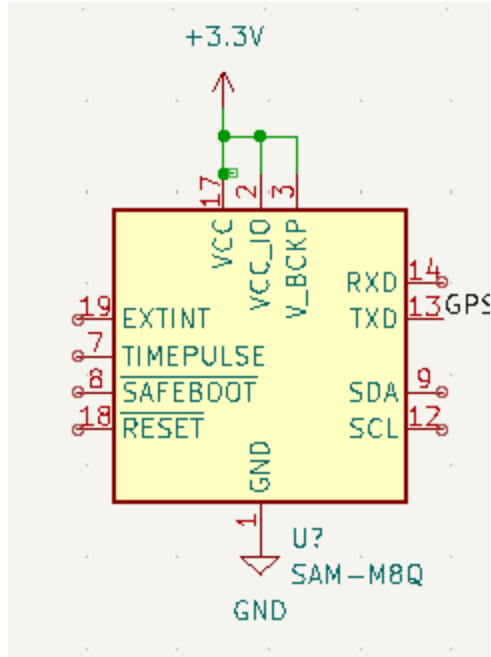


Figure 7: GPS Module Schematic

## 2.5 User Interface

The User Interface subsystem allows the user to interact with the device.

It receives inputs that are sent to, and processed, by the Control subsystem. A component in this subsystem, the line laser, is mounted on the Angle Control subsystem. Finally, it also receives output data (for the LCD display) from the Control subsystem.

This subsystem consists of three components:

- the LCD display,
- the physical buttons (turn on/off button, increase target pace button, decrease target pace button),
- the line laser.

Requirements	Verification
1. The LCD displays the target pace set by the user.	1A. Using the increase/decrease pace button, set the target pace to 5 mi/hr.  1B. Verify that the LCD display displays 05.0
2. The line laser should be visible in ideal conditions (indoors with dim lighting).	2A. Turn on only half of all the lights in the senior design lab room.  2B. Verify that the line laser is visible when projected to the ground.
3. The right button should increase target pace by 0.5.	3A. Note the number shown on the LCD display. Click the increase pace button.  3B. Verify that the number shown on the LCD display was incremented by 0.5.
4. The left button should decrease target pace by 0.5.	4A. Note the number shown on the LCD display. Click the increase pace button.  4B. Verify that the number shown on the LCD display was decreased by 0.5.

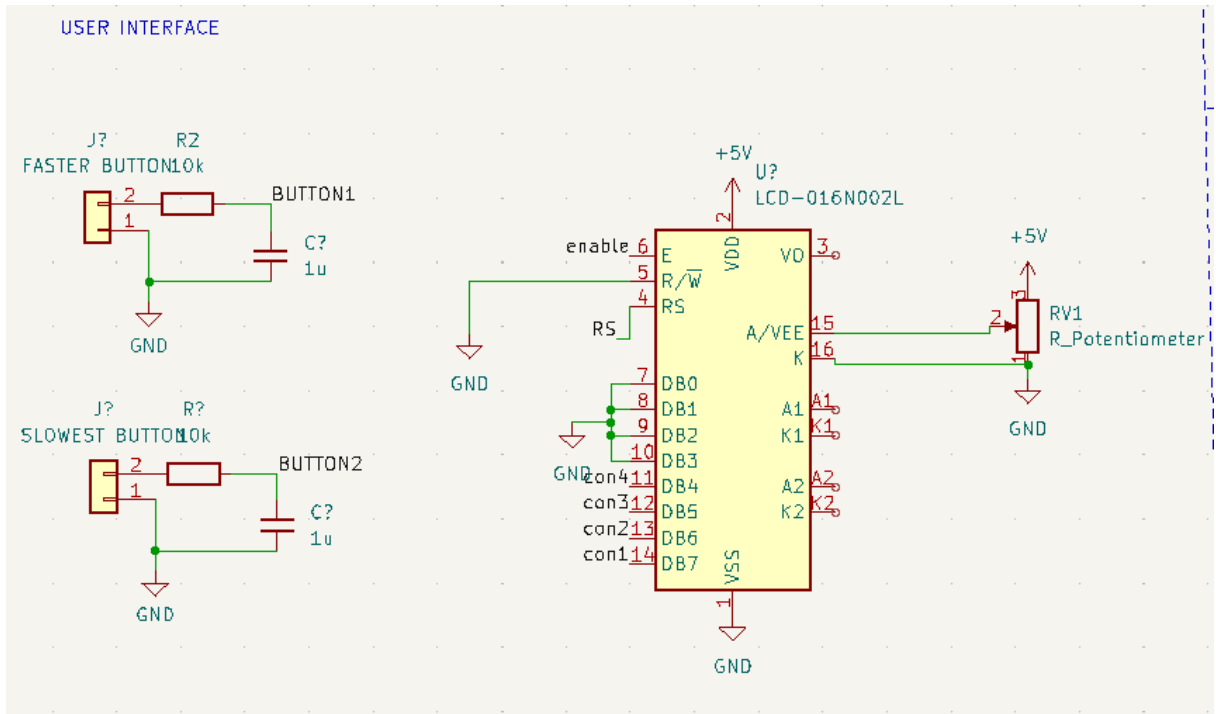


Figure 8: Buttons and LCD Display Circuit Schematics

## 2.6 Tolerance Analysis

### 2.6.1 GPS Accuracy Tolerance

For this project, the component which poses the highest risk of failure is the GPS system. This project requires that the GPS module can be used to successfully compute the runner's pace at any given moment. However, knowing the current limitations of a GPS module (i.e. **within 4.9 m**)[1], we will only be able to calculate the runner's location every ~5 m.

Now let us make some assumptions to calculate how to navigate this limitation.

$$\begin{aligned} \text{Average speed of runner} &\geq 2 \text{ m/s} \\ \text{GPS location updates every} &5 \text{ m} \\ \text{Time between GPS updates} &\leq 5/2 = 2.5 \text{ s} \\ \text{So we need to update our laser's position every} &3 \text{ s} \end{aligned}$$

By moving to this non-instantaneous approach, we can navigate this issue in a practical manner. It is also more reasonable for the project overall, since we need not concern ourselves about overloading the motor in constant changes.

Another consideration regarding the GPS is how long it takes the module to ping off a satellite and be available to use. Based on this GPS module datasheet, the hot/cold starts can take anywhere from 1s - 32s, which means our project will require at least **45s** after turning on before it can be used.[2] This is something we need to consider, but a 45s start time is **not impractical**.

### 2.6.2 Angle-Control Tolerance

#### 1. Glossary

- ***angle***: the angle the servo-motor (mounted with the laser) must be set to, considering 0 degrees to be facing straight down.  
In other words, at 0 degrees, the line laser will point straight down, and at 90 degrees, it points straight ahead
- ***laser horizontal***: it means the horizontal distance between the runner and the laser line projection.  
In other words, the distance between the runner's feet and the laser line. (projected by our laser)
- ***actual pace***: the pace at which the runner is currently running at calculated by our device. In units of miles/hour or mi/hr.

- target pace: the pace at which the runner wants to run at, inputted by them through the user-interface subsystem. In units of miles/hour or mi/hr.

## 2. Introduction

Another important part of this project is the angle-control subsystem, and the exact angles we need to consider for each position.

The three different situations a runner can be in are:

1. **slow**: *actual pace* < *target pace* - 0.5 mi/hr
2. **fast**: *actual pace* > *target pace* + 0.5 mi/hr
3. **ideal**: *actual pace* is within 1 mi/hr of the *target pace*

Henceforth, we will just be referring to the above positions as *slow*, *fast*, *ideal*.

## 3. Requirements

There are two requirements for the angle-control subsystem:

- A. The line laser can be seen clearly by the runner.
- B. The actual length difference between the laser line in the three positions should be equidistant, so as to not be confusing for the runner.

## 4. Calculation

Let us begin this calculation by making a few assumptions, along with their necessary justifications.

- A. the height of the device from the ground is  $x$  m
- B. the distance between consecutive positions should also be  $x/2$  m. (*fulfilling requirement B*)
  - a. If we take the average height of a runner to be 160 cm, then we can assume  $x$  to be ~125 cm.
  - b. Now based on our assumption of the line laser, the three positions it can be in will be :
    - i. 0.625 m from the runner ( $1x/2$ )
    - ii. 1.250 m from the runner ( $2x/2$ )
    - iii. 1.875 m from the runner ( $3x/2$ )
  - c. These three positions for the line laser will be comfortable for the runner to view, thus justifying our assumption. (*fulfilling requirement A*)
- C. the three positions should be as illustrated below

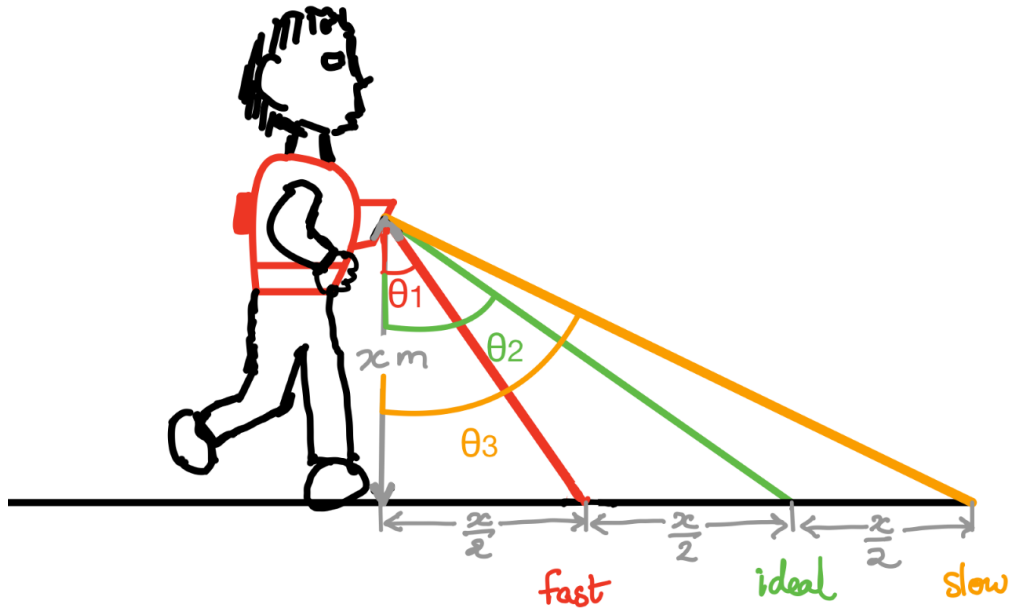


Figure 9: Sketch

Let us find the angles:  $\theta_1, \theta_2, \theta_3$

$$\theta_1 = \tan^{-1}\left(\frac{x/2}{x}\right) = \tan^{-1}\left(\frac{1}{2}\right) = 26.56^\circ \approx 27^\circ$$

$$\theta_2 = \tan^{-1}\left(\frac{x}{x}\right) = \tan^{-1}(1) = 45^\circ$$

$$\theta_3 = \tan^{-1}\left(\frac{3x/2}{x}\right) = \tan^{-1}\left(\frac{3}{2}\right) = 56.31^\circ \approx 56^\circ$$



## 5. Findings

Thus, we should set up our servo motor such that:

- **fast:** servo-motor should be set at 27 degrees,
- **ideal:** servo-motor should be set at 45 degrees,
- **slow:** servo-motor should be set at 56 degrees.

This requires us to buy a servo-motor which only needs 60 degrees of motion.

## 3. Cost and Schedule

### 3.1 Cost Analysis

#### 3.1.1 Labor

The average salary of a Computer Engineer graduate from UIUC is \$ 96,992. [3]

Based on that figure, if we consider there to be 261 working days in the year, and a normal work day to be eight hours, then the average hourly salary computes to: \$ 46.45.

Number of workers = 3  
Hours per week = 10  
Weeks required = 10

Labor costs = 2.5 x (#workers) x (hrs/ week) x (weeks required) x (avg salary)  
= 2.5 x (3) x (10) x (10) x (46.45)

**= \$ 34,837.5**

#### 3.1.2 Parts

Table 1: Costs

S.No.	Part	Unit Cost	Quantity	Total
1.	Voltage Regulator- <i>LP5907MFX-3.3/NOPB</i>	\$ 0.69	1	\$ 0.69
2.	Voltage Regulator- <i>LP5907MFX-5.0/NOPB</i>	\$ 0.78	1	\$ 0.78
3.	Microcontroller - <i>ATMEGA165PV-8AUR</i>	\$ 5.64	1	\$ 5.64
4.	Servo Motor - <i>HS-311</i>	\$ 13.49	1	\$ 13.49
5.	GPS Module - <i>SAM-M8Q</i>	\$ 31.50	1	\$ 31.50
6.	LED Display - <i>QBT56IB0</i>	\$ 3.23	1	\$ 3.23
7.	Push Buttons - <i>R-667845</i>	\$ 0.42	3	\$ 1.26
8.	Rocker Switch - <i>RF1-1A-DC-2-R-1</i>	\$ 1.17	1	\$ 1.17
9.	Laser- <i>VLM-650-28</i>	\$ 24.53	1	\$ 24.53
10.	Battery - <i>BGN1800-5DWP-41REC</i>	\$ 27.95	1	\$ 27.95
	<b>Total</b>			<b>\$ 110.24</b>

### 3.1.3 Grand Total

The grand total of the project comes out to \$ 34,947, with most of the cost in labor, and only \$ 110.24 to build the prototype.

### 3.2 Schedule

Table 2: Schedule

<b>Week</b>	<b>Aditya</b>	<b>Mustafa</b>	<b>Carlos</b>
2/28	PCB Design/ Design Review	PCB Design/ Design Review	PCB Design/ Design Review
3/7	Solder PCB	Solder PCB	Solder PCB
3/14	Break	Break	Break
3/21	GPS Code	PCB Design (2nd)	PCB Design (2nd)
3/28	GPS Testing	Test Subsystems	Test Subsystems
4/4	Assemble Prototype	Assemble Prototype	Assemble Prototype
4/11	Full Device Test	Full Device Test	Full Device Test
4/18	Fix Issues / Mock Demo	Fix Issues / Mock Demo	Fix Issues / Mock Demo
4/25	Demo	Demo	Demo
5/2	Presentation/ Final Paper	Presentation/ Final Paper	Presentation/ Final Paper

## 4. Ethics and Safety

### 4.1 Ethics

One specific ethical issue to consider is the collection of the runner's GPS data. We need to make sure that this data is not distributed, nor used in any manner outside of the runner's knowledge.

More generally, we need to make sure we follow the ACM and IEEE code of ethics to the best of our ability. [4][5]

Since this project will include software components, care is needed to properly credit all the resources we utilize. We must also be careful not to infringe on anyone else's copyright/intellectual property.

### 4.2 Safety

Our project utilizes a laser which is potentially dangerous to the human eye, thus we must make sure that we do not use a laser which is unsafe outside laboratory conditions. Specifically, we should use a Class 1 or 2 laser since they are deemed safe for unsupervised use. [6]

Additionally, we must add some safety constraints (for example: a turn off button/killswitch which completely turns off the device) to properly shut down the component in case of any harmful situations.

Because our project involves designing our own PCB, along with soldering, we need to make sure we follow all the lab's safety guidelines.[7]

Additionally, we must properly use and maintain all the lab equipment.

## 5. References

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