



# GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO  
PACER RUNNER

Autor: Carlos Sánchez Albertí

Director: Jonathon Schuh

Madrid

Julio 2022

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

Pacer Runner

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el

curso académico 2021/22 es de mi autoría, original e inédito y

no ha sido presentado con anterioridad a otros efectos.

El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido

tomada de otros documentos está debidamente referenciada.

Fdo.: Carlos Sánchez Albertí

Fecha: 10 / 06 / 2022



Autorizada la entrega del proyecto

COORDINADOR DE TFGs



Fdo.: Aurelio García Cerrada Fecha: 26 / 08 / 2022





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**Autor: Sánchez Albertí, Carlos.**

Director: Schuh, Jonathon.

Entidad Colaboradora: University of Illinois at Urbana-Champaign

## **RESUMEN DEL PROYECTO**

**Palabras clave:** Pacer Runner, PCB, hardware design

El objetivo de este proyecto es el de diseñar y construir un dispositivo capaz de indicar el ritmo del corredor en todo momento, teniendo este una referencia visual durante todo momento. El funcionamiento del aparato será el siguiente, primero el usuario indicará el ritmo el cual quiere seguir durante la carrera, a continuación, una vez el corredor comience la carrera, el láser se irá acercando, alejando o manteniéndose a una distancia constante en función de si el ritmo coincide o no con el establecido (si va más rápido se acercará la línea láser y si va más lento se alejará). Este proyecto se centrará en la parte electrónica del aparato, siendo primordial el desarrollo de la placa de circuito impreso. Además, será muy importante el desarrollo de un producto comercial, esto significa que una vez finalizado el proyecto el prototipo del aparato tiene que ser ligero, portátil y fácil de usar.

### **1. Introducción**

Actualmente, existen muchos dispositivos capaces de medir la velocidad de un corredor como pueden ser los smartphones o los relojes inteligentes con GPS. Sin embargo, todos ellos tienen un problema en común y es que estos aparatos no son capaces de dar una respuesta inmediata al corredor, sino que tiene que ser este que mire expresamente el reloj o el smartphone. Esto provoca que cuando la velocidad del corredor decae, el usuario no se dé cuenta hasta que mire el dispositivo. Para solucionar este problema se ha diseñado y construido un dispositivo capaz de marcar el ritmo deseado al corredor en todo momento, este dispositivo se llama Pacer Runner.

Pacer Runner consiste en un dispositivo capaz de dar una referencia visual al corredor de su ritmo de carrera. La referencia visual se consigue utilizando una línea láser proyectada en el suelo justo enfrente del corredor. Según la posición del láser el corredor sabrá si tiene que aumentar, mantener o disminuir la velocidad.

La idea del diseño y creación de este aparato surge de la tecnología usada durante el récord mundial de maratón, donde se usaron varios coches con láseres montados en el

techo de estos [1]. Estos láseres eran los encargados de marcar el ritmo al corredor Eliud Kipchoge para que bajará de las dos horas. El objetivo de este invento es hacer de esta tecnología disponible para el público general. En la Figura 1 se puede observar el láser montado encima del coche y proyectado en frente de los corredores.



*Figura 1. Tecnología usada durante el récord del mundo de maratón [2]*

## **2. Diseño del Proyecto**

Antes de explicar los objetivos es conveniente tener una visión general del diseño del sistema, para así comprenderlos mejor. El Proyecto se dividirá en varios subsistemas con el objetivo de facilitar el diseño de estos y localizar rápidamente los posibles errores. Estos subsistemas serán cuatro, el subsistema de control, el de control del ángulo, el de energía y el de la interfaz del usuario. En la Figura 2 se aprecian las interconexiones entre ellos.



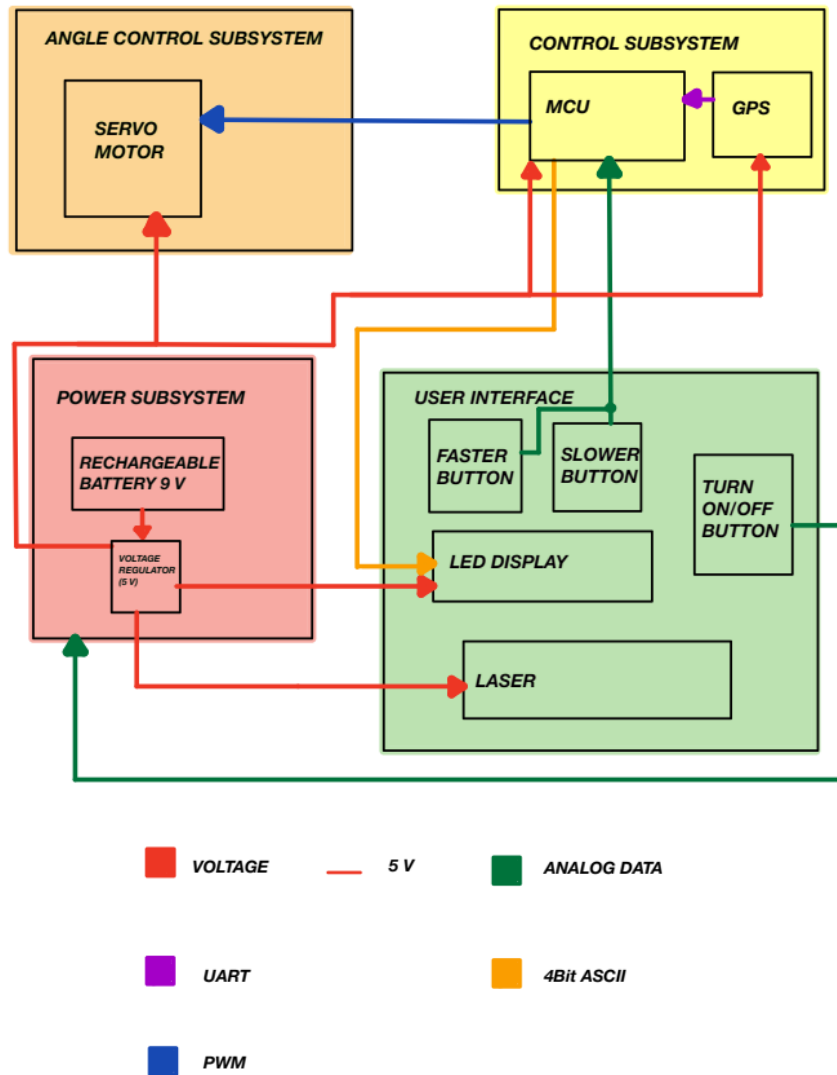


Figura 2. Diagrama de bloques

A continuación, se procederá a explicar la función que tiene cada subsistema y la forma en la que interactúa con el resto de subsistemas.

- **Subsistema de Control del Ángulo:** Este subsistema estará formado por el servomotor, su función es la de cambiar el ángulo del láser de línea cada vez que sea necesario. Le llegarán 5 V del subsistema de energía, además, recibirá una señal PWM del microprocesador (subsistema de control) que le indicará a que posición moverse.
- **Subsistema de Control:** Tendrá dos componentes, el microcontrolador y el módulo GPS. El microcontrolador será el encargado de controlar todo el sistema y el módulo GPS proporcionará los datos necesarios para calcular la velocidad de movimiento. El subsistema de Control tomará el 'target pace' (ritmo al cual quiere correr el usuario) del subsistema de la Interfaz del Usuario, a parte, calculará la

velocidad del corredor usando el módulo GPS. A continuación, las comparará y cambiará el ángulo del servomotor en función del resultado de la comparación.

El subsistema recibirá 5 V del subsistema de Energía, además recibirá señales analógicas de los botones de la Interfaz del Usuario, y a este le enviará una señal de 4Bit ASCII para controlar la pantalla LCD. Como ya se ha dicho antes, enviará una señal PWM al subsistema de Control de Ángulo.

- **Subsistema de Energía:** Estará formado por una batería recargable de 9 V y un regulador de voltaje a 5 V. Será el encargado de proveer de energía a todo el sistema. La batería de 9 V estará conectada a la PCB mediante un interruptor oscilante con el cuál se puede apagar todo el sistema. Por otra parte, el regulador de voltaje se encargará proporcionar los 5 V necesarios para los distintos componentes del sistema.
- **Subsistema de la Interfaz del Usuario:** Estará compuesto por los dos botones para incrementar o disminuir el 'target pace', el interruptor oscilante, la pantalla LCD y el láser de línea. Mediante este subsistema el usuario será capaz de interactuar con el aparato. La pantalla LCD mostrará el ritmo al que va el usuario, 'Actual Pace' y el objetivo, 'Target Pace', este se regulará mediante los botones de incrementar o disminuir ritmo. Por último, el láser de línea será proyectado en el suelo delante del usuario y es la referencia visual que tendrá para saber si tiene que aumentar, mantener o disminuir el ritmo.

### 3. Objetivos del Proyecto

El Proyecto busca cumplir los siguientes objetivos:

- El módulo GPS calculará la velocidad del corredor con una precisión de +- 1 mi/hr.
- El servomotor cambia el ángulo del láser en función del cambio de ritmo del corredor. Habrá tres posibles posiciones, siendo 0 grados en sentido vertical hacia abajo.
  - Más lento que el ritmo establecido por el usuario: Servomotor en 56 grados.
  - Ritmo ideal: Servomotor en 45 grados.
  - Más rápido que el ritmo establecido por el usuario: Servomotor en 27 grados.
- Los botones podrán cambiar el 'target pace' y la pantalla LCD mostrará este cambio, además del ritmo actual del corredor, el 'actual pace'. Los cambios serán:

- El botón que aumenta el ritmo objetivo deberá incrementar el ‘target pace’ en 0.5 mi/hr.
- El botón que baja el ritmo objetivo deberá disminuir el ‘target pace’ en 0.5 mi/hr.
- El diseño del aparato ha de ser compacto y cómodo de llevar. Además, tiene que ser ligero para no disminuir el rendimiento del corredor.

#### 4. Implementación del diseño

Una vez diseñado los diferentes subsistemas se procedieron a integrar todos juntos con el uso de una PCB. El diseño de la PCB se realizó usando el software de KiCad 6.0. A continuación en la Figura 3 se muestra el esquema del sistema completo.

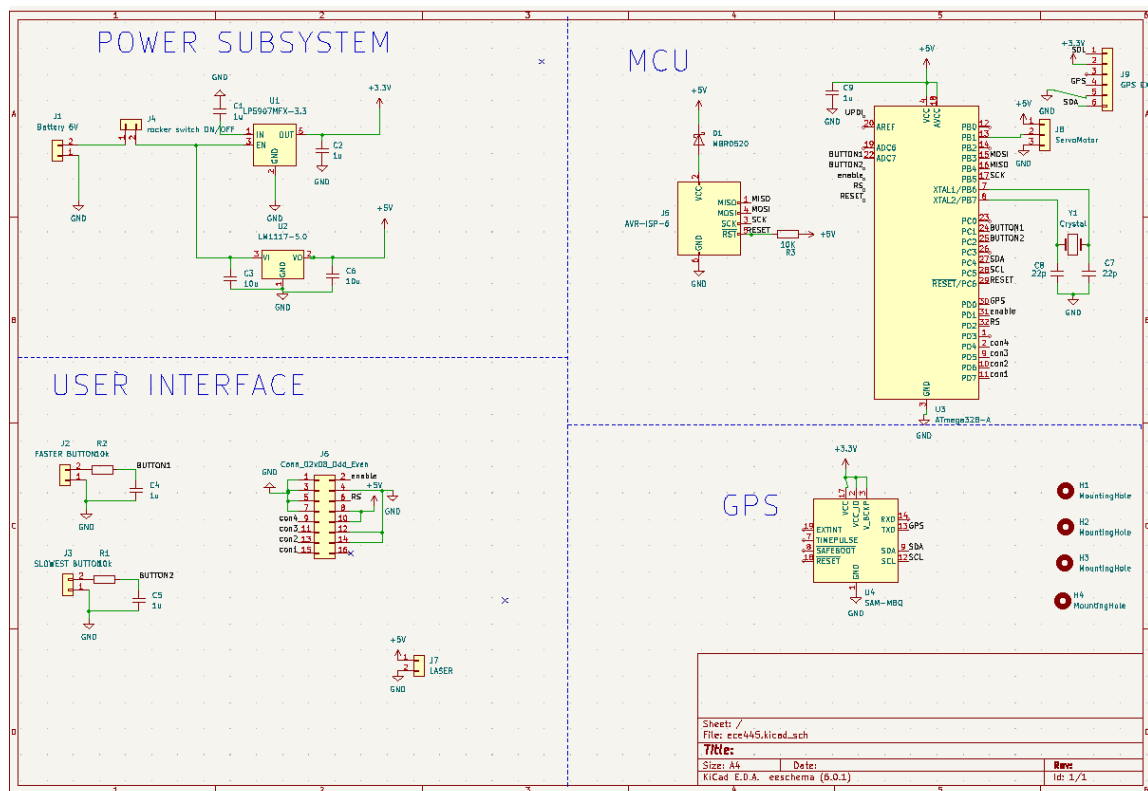


Figura 3. Esquema de la PCB

Una vez diseñada la circuitería de la PCB era hora de diseñar la disposición de esta. Esta disposición es clave porque el exceso de cables por una mala distribución de los elementos puede provocar fallos en el sistema e incrementar la presencia de ruido. A continuación, en la Figura 4 se muestra la distribución escogida para la PCB.



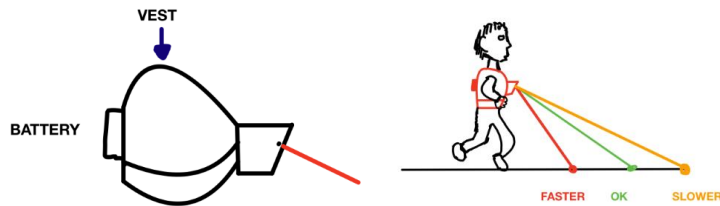


Figura 6. Diseño del chaleco

## 5. Resultados

Lamentablemente, el diseño no funcionó correctamente debido a un fallo en el subsistema de Control de Ángulo. A continuación, se explicarán los resultados obtenidos de cada subsistema.

- Control:** Este subsistema funcionó correctamente, ya que se consiguió flashear el microcontrolador y además cargar el código del proyecto en este. Por otra parte, el módulo GPS también funcionó correctamente, recibiendo datos de la posición y enviándoselos a el microcontrolador. En la Figura 7 se puede observar los datos recibidos del GPS y en la Figura 8 el sistema de Control funcionando.

Sats	HDOP	Latitude (deg)	Longitude (deg)	Fix Age	Date	Time	Date Age	Alt (m)	Course --- from GPS ---	Speed	Card ----
0	100.0	*****	*****	****	00/00/2000	00:00:00	628	*****	*****	*****	*****
0	100.0	*****	*****	****	00/00/2000	00:00:00	634	*****	*****	*****	*****
0	100.0	*****	*****	****	00/00/2000	00:00:00	640	*****	*****	*****	*****
5	1.3	40.114356	-88.226860	245	04/21/2022	20:56:00	375	365.70	0.00	0.09	N
5	1.3	40.114360	-88.226860	442	04/21/2022	20:56:01	559	365.50	0.00	0.04	N
5	1.3	40.114364	-88.226860	450	04/21/2022	20:56:02	566	365.40	0.00	0.02	N
5	1.3	40.114364	-88.226860	459	04/21/2022	20:56:03	575	365.40	0.00	0.02	N
5	1.3	40.114364	-88.226860	467	04/21/2022	20:56:04	584	365.40	0.00	0.04	N
5	1.3	40.114364	-88.226860	476	04/21/2022	20:56:05	593	365.60	0.00	0.06	N
5	1.3	40.114364	-88.226867	484	04/21/2022	20:56:06	600	365.80	0.00	0.07	N
7	1.2	40.114364	-88.226867	472	04/21/2022	20:56:07	589	366.00	0.00	0.02	N
7	1.2	40.114364	-88.226867	497	04/21/2022	20:56:08	613	366.00	0.00	0.07	N
7	1.2	40.114364	-88.226867	499	04/21/2022	20:56:09	615	366.10	0.00	0.06	N
7	1.2	40.114364	-88.226875	513	04/21/2022	20:56:10	629	366.30	0.00	0.06	N
7	1.2	40.114364	-88.226875	511	04/21/2022	20:56:11	627	366.30	0.00	0.11	N
7	1.2	40.114360	-88.226875	528	04/21/2022	20:56:12	645	366.50	0.00	0.06	N
7	1.2	40.114360	-88.226875	531	04/21/2022	20:56:13	648	366.50	0.00	0.04	N
7	1.2	40.114360	-88.226882	546	04/21/2022	20:56:14	662	366.70	0.00	0.30	N
7	1.2	40.114360	-88.226882	546	04/21/2022	20:56:15	663	366.80	0.00	0.89	N
7	1.2	40.114360	-88.226875	561	04/21/2022	20:56:16	677	366.80	0.00	0.37	N
7	1.2	40.114364	-88.226882	564	04/21/2022	20:56:17	681	366.00	0.00	0.24	N

Figura 7. Datos recibidos del GPS



Figura 8. Subsistema de Control en funcionamiento

- **Energía:** El subsistema funcionó correctamente, el único problema que hubo fue que, al conectar todos los dispositivos, la tensión de salida del regulador de voltaje era significativamente menor a 5 V como se puede ver en la Figura 9.

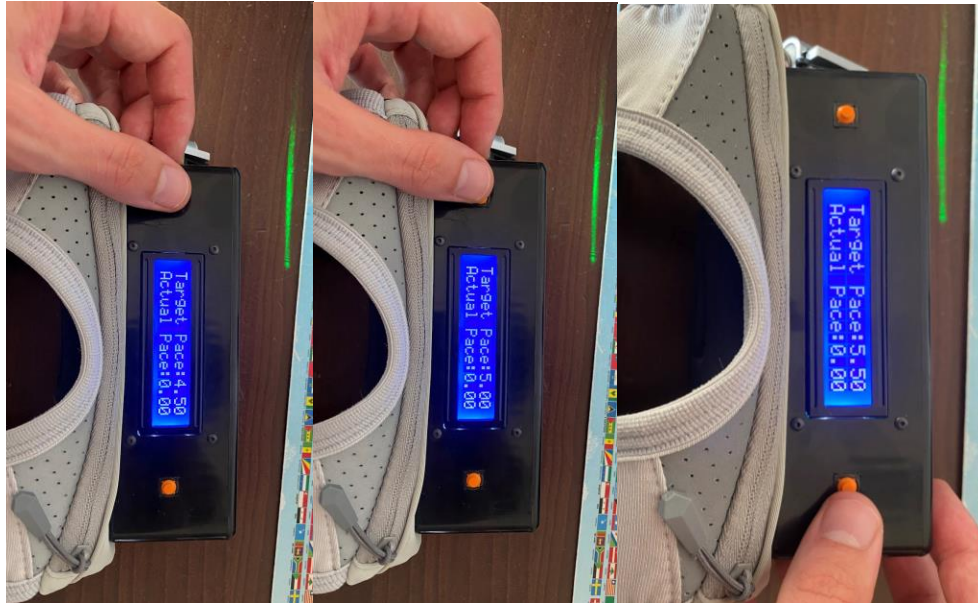


Figura 9. Tensión de salida del regulador de voltaje

Esto provocará que el servomotor no esté alimentado dentro de su rango de voltaje que es de 4.8 V a 6 V [3], por tanto, este no funcionará correctamente. El resto de los componentes funcionan correctamente a esta tensión.

- **Interfaz del Usuario:** El resultado fue muy bueno, este subsistema cumplió con todos los requisitos previamente establecidos. Los botones cambiaron correctamente el ritmo objetivo, ósea el 'Target pace', disminuyendo o aumentándolo en 0.5 mi/hr. La pantalla LCD mostraba correctamente todos los datos y actualizaba la velocidad del corredor, el botón oscilante encendía y apagaba

todo el sistema. Por último, el láser se veía correctamente en condiciones de laboratorio, ósea bajo luz artificial.



*Figura 10. Resultados de la Interfaz del Usuario*

Como se aprecia en la Figura 10, el ‘Target Pace’ cambia cada vez que se presiona un botón. Además, se puede ver también al láser y a la pantalla LCD funcionando correctamente.

- **Control de Ángulo:** Este subsistema no funcionó correctamente. En el momento de cambiar de posición, el servomotor se empezaba a mover descontroladamente. Esto se debe principalmente a dos causas. La primera fue que no recibía el voltaje suficiente para su correcto funcionamiento, es por eso que se le conectó una fuente de tensión exterior con 5 V y se añadió un convertidor de nivel lógico para aumentar la tensión de salida del microprocesador de 3.3 V a 5 V. Esto redujo las oscilaciones del servomotor, pero no las consiguió eliminar. La segunda causa fue el ruido, este ruido provenía de que el módulo GPS estaba situado al lado del servomotor, y los cables en la PCB se cruzaban en varios puntos.
- **Diseño del sistema:** Los resultados del diseño fueron buenos, ya que el dispositivo tiene un diseño cómodo y sencillo de llevar. Además, es intuitivo y fácil de usar para el usuario. En la Figura 11 se muestra el resultado.



Figura 11. Prototipo del aparato

## 6. Conclusiones

A pesar de que el resultado final no haya funcionado, no significa que el proyecto sea inviable. De hecho, el fallo de diseño es relativamente fácil de arreglar, simplemente con una nueva distribución de la PCB ya estaría solucionado. Además, los beneficios de este invento son notables, ya que se soluciona el problema de mantener el ritmo constante durante la carrera con un aparato fácil de usar y asequible de precio. Este invento eliminaría el uso de liebres para marcar el ritmo, ya que éstas serían menos precisas que el Pacer Runner y tienen un coste más elevado.

## 7. Referencias

- [1] “Aiding the sub two hour marathon challenge with lasers,” *Event Projection*, Oct. 21, 2019. <https://eventprojection.co.uk/case-studies/design-content/two-hour-marathon-challenge-lasers/> (accessed May 22, 2022).
- [2] “History is made as Eliud Kipchoge becomes first human to break the two-hour marathon barrier,” *INEOS 1:59 CHALLENGE*. <https://www.ineos159challenge.com/news/history-is-made-as-eliud-kipchoge-becomes-first-human-to-break-the-two-hour-marathon-barrier/> (accessed May 22, 2022).
- [3] “HS-311 Standard Economy Servo,” *HITEC RCD USA*. <https://hitecrd.com/products/servos/analog/sport-2/hs-311/product> (accessed Jul. 26, 2022).





# **PACER RUNNER**

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**Supervisor:** Schuh, Jonathon.

**Collaborating Entity:** University of Illinois at Urbana-Champaign

## **ABSTRACT**

The goal of this project is to design and build a device capable of always indicating the runner's pace with a visual reference. The operation of the device will be as follows, first, the user will indicate the pace he/she wants to follow during the race, then, once the runner begins the race, the laser will be approaching, moving away, or staying at a constant distance depending on whether or not the pace coincides with the target pace. This project will focus on the electronic part of the device, with the development of the printed circuit board being essential. In addition, the development of a commercial product will be very important, this means that once the project is finished the prototype of the device has to be light, portable, and easy to use.

**Keywords:** Pacer Runner, PCB, hardware design

## **1. Introduction**

Nowadays, there are many devices capable of measuring the speed of a runner, such as smartphones or smartwatches. However, they all have a common problem and that is that these devices are not able to give an immediate response to the runner. It has to be the runner who specifically looks at the watch or smartphone. This causes that when the runner's speed drops, the user does not realize it until he looks at the smartphone. To solve this problem, a device has been designed and built capable of showing the desired pace to the runner at all times. This device is called Pacer Runner.

Pacer Runner consists of a device capable of giving a visual reference to the runner of his or her running pace. The visual reference is achieved by using a laser line projected on the ground just in front of the runner. Depending on the position of the laser, the runner will know whether to increase, maintain or decrease speed.

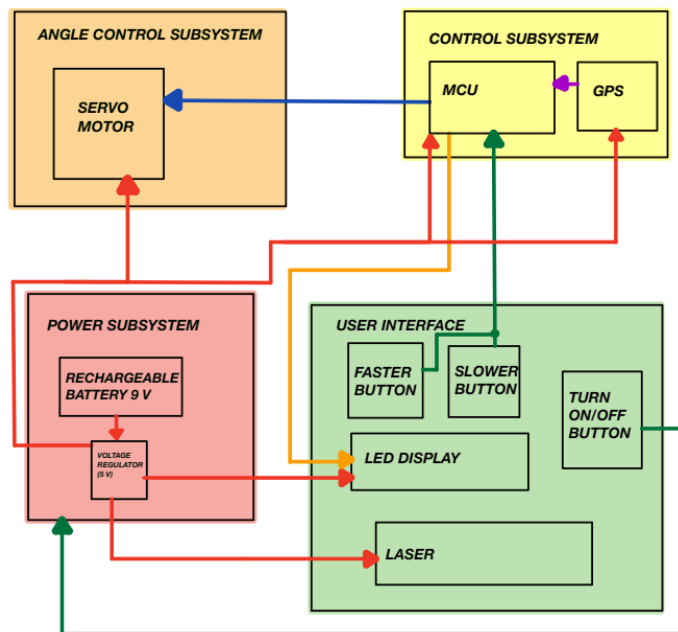
The idea for the design and creation of this device comes from the technology used during the marathon world record, where several cars were used with lasers mounted on their top [1]. These lasers were in charge of pacing the runner Eliud Kipchoge so that he would run under two hours. The goal of this invention is to make this technology available to the general public. In Figure 1 can be observed the laser mounted on the top of the car and projected on the floor.



Figure 1. Laser mounted on a car used during the marathon world record [2]

## 2. Design of the Project

Before explaining the objectives, it is convenient to have an overview of the system design in order to better understand them. The project will be divided into several subsystems in order to facilitate the design of these and to locate possible errors easily. These subsystems will be four, the control subsystem, the angle control subsystem, the power subsystem and the user interface subsystem. Figure 2 shows the interconnections between them.



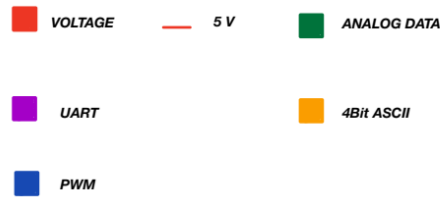


Figure 12. Block Diagram

Next, it will be explained the function of each subsystem and the way in which it interacts with the rest of the subsystems.

- **Angle Control subsystem:** This subsystem will be formed by the servomotor, its function is to change the angle of the line laser every time it is necessary. It will receive 5 V from the power subsystem. In addition, it will receive a PWM signal from the microprocessor (control subsystem) which will indicate to which position to move.
- **Control subsystem:** It will have two components, the microcontroller and the GPS module. The microcontroller will be in charge of controlling the whole system and the GPS module will provide the necessary data to calculate the speed of movement. The Control subsystem will take the 'target pace' (pace at which the user wants to run) from the User Interface subsystem. Then, it will calculate the speed of the runner using the GPS module, and finally, it will compare them and change the angle of the servo motor based on the result.

The subsystem will receive 5 V from the Power subsystem, it will also receive analog signals from the User Interface buttons, and it will send a 4Bit ASCII signal to the User Interface to control the LCD display. As mentioned before, it will send a PWM signal to the Angle Control subsystem.

- **Power subsystem:** It will consist of a 9 V rechargeable battery and a 5 V voltage regulator. It will be in charge of supplying power to the whole system. The 9 V battery will be connected to the PCB with a rocker switch that can be used to turn off or turn on the whole system. On the other hand, the voltage regulator will be in charge of providing the 5 V needed for the different components of the system.
- **User Interface subsystem:** It will consist of two buttons to increase or decrease the target pace, the rocker switch, the LCD display, and the line laser. Through this subsystem, the user will be able to interact with the device. The LCD display will show the pace at which the user is going, 'Actual Pace' and the target, 'Target Pace', this will be regulated by the increase or decrease pace buttons. Finally, the line

laser will be projected on the floor in front of the user and is the visual reference to know whether to increase, maintain or decrease the pace.

### **3. Goals of the Project:**

The Project seeks to meet the following objectives:

- The GPS module will calculate the runner's speed with an accuracy of  $\pm 1$  mi/hr.
- The servomotor changes the angle of the laser according to the runner's change of pace. There will be three possible positions, with 0 degrees being vertically down.
  - slower than target pace: servo-motor at 56 degrees
  - ideal pace: servomotor at 45 degrees
  - faster than target pace: servo-motor at 27 degrees.
- The buttons will be able to change the 'target pace' and the LCD display will show this change. In addition to the runner's current pace will also be shown on the LCD display. The changes will be:
  - The button that increases the target pace should increase the target pace by 0.5 mi/hr.
  - The button that reduces the target pace should decrease the target pace by 0.5 mi/hr.
- The design of the device must be compact and comfortable to wear. Furthermore, it must be lightweight so as not to compromise the runner's performance.

### **4. Implementation of the design**

Once the different subsystems were designed, they were integrated together with the use of a PCB. The PCB was designed using KiCad 6.0 software. Figure 3 below shows the schematic of the complete system.

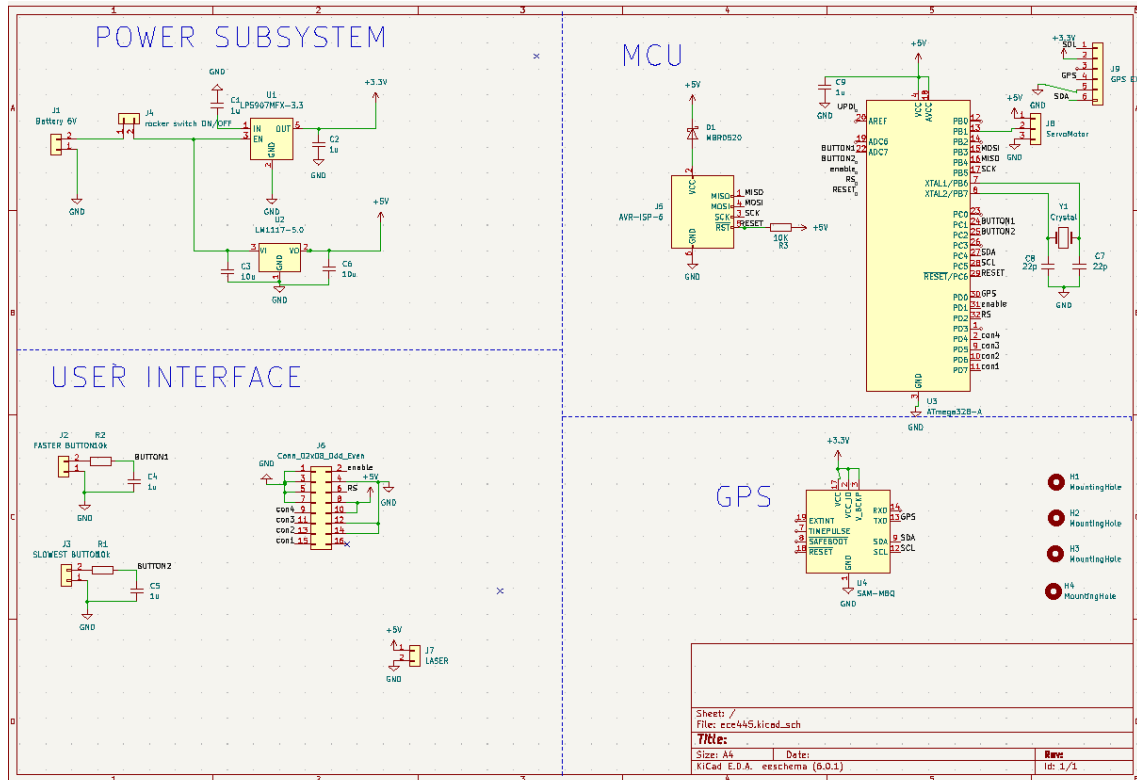


Figure 13. PCB schematics

After designing the PCB circuitry, it was time to design the PCB layout. This layout is key because the excess of cables due to a bad distribution of the elements can cause failures in the system and increase the presence of noise. Figure 4 below shows the layout chosen for the PCB.

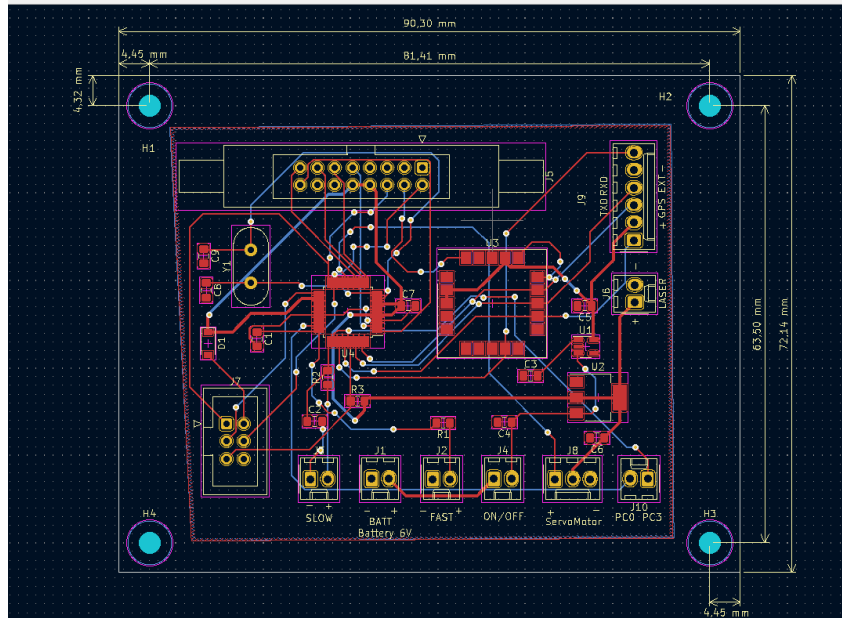


Figure 14. PCB Layout

Once the PCB dimensions were determined, it was time to design the electronics packaging. To do this, it was necessary to take into account which components are used and the position of these to make an intuitive and easy to use device. The final box design is shown in Figure 5 below.

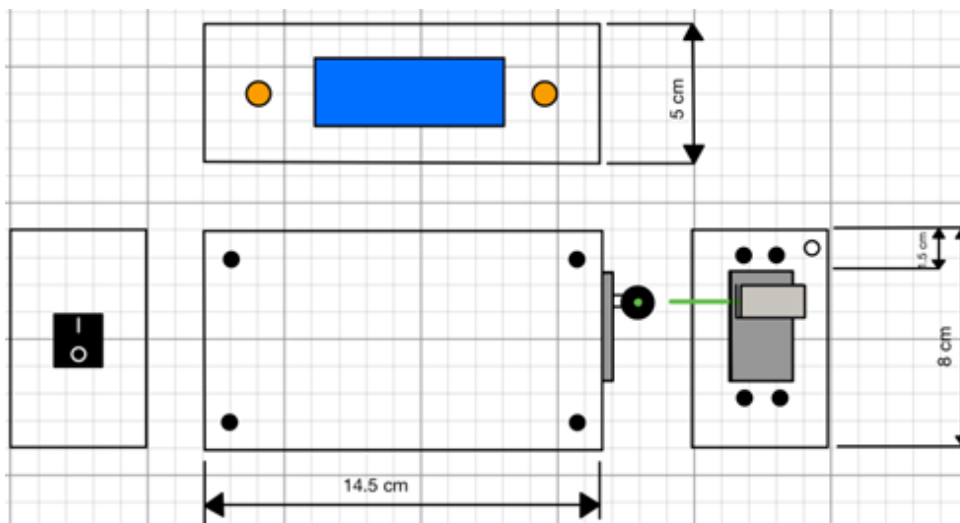


Figure 15. Final case design

This box will be attached to the front of a vest to distribute the weight on the runner's body and also ensure that the laser is always positioned in front of the user's body. A sketch of the idea is shown in Figure 6.

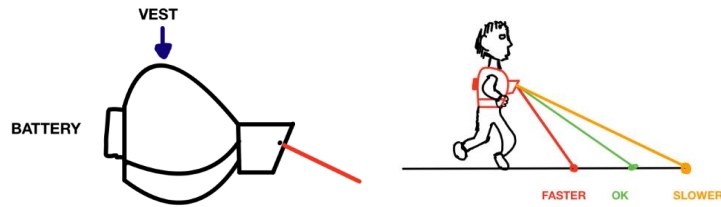


Figure 16. Vest design

## 5. Results

Unfortunately, the design did not work properly due to a failure in the Angle Control subsystem. The results obtained from each subsystem will be explained below.

- Control:** This subsystem worked correctly, since it was possible to flash the microcontroller and also upload the project code to it. On the other hand, the GPS module also worked correctly, receiving position data and sending it to the microcontroller. Figure 7 shows the data received from the GPS and Figure 8 shows the Control system working.

Sats	HDOP	Latitude (deg)	Longitude (deg)	Fix	Date	Time	Date	Alt (m)	Course	Speed	Card
				Age			Age	--- from GPS		----	
0	100.0	*****	*****	****	00/00/2000	00:00:00	628	*****	*****	*****	***
0	100.0	*****	*****	****	00/00/2000	00:00:00	634	*****	*****	*****	***
0	100.0	*****	*****	****	00/00/2000	00:00:00	640	*****	*****	*****	***
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5	1.3	40.114364	-88.226860	459	04/21/2022	20:56:03	575	365.40	0.00	0.02	N
5	1.3	40.114364	-88.226860	467	04/21/2022	20:56:04	584	365.40	0.00	0.04	N
5	1.3	40.114364	-88.226860	476	04/21/2022	20:56:05	593	365.60	0.00	0.06	N
5	1.3	40.114364	-88.226867	484	04/21/2022	20:56:06	600	365.80	0.00	0.07	N
7	1.2	40.114364	-88.226867	472	04/21/2022	20:56:07	589	366.00	0.00	0.02	N
7	1.2	40.114364	-88.226867	497	04/21/2022	20:56:08	613	366.00	0.00	0.07	N
7	1.2	40.114364	-88.226867	499	04/21/2022	20:56:09	615	366.10	0.00	0.06	N
7	1.2	40.114364	-88.226875	513	04/21/2022	20:56:10	629	366.30	0.00	0.06	N
7	1.2	40.114364	-88.226875	511	04/21/2022	20:56:11	627	366.30	0.00	0.11	N
7	1.2	40.114360	-88.226875	528	04/21/2022	20:56:12	645	366.50	0.00	0.06	N
7	1.2	40.114360	-88.226875	531	04/21/2022	20:56:13	648	366.50	0.00	0.04	N
7	1.2	40.114360	-88.226882	546	04/21/2022	20:56:14	662	366.70	0.00	0.30	N
7	1.2	40.114360	-88.226882	546	04/21/2022	20:56:15	663	366.80	0.00	0.89	N
7	1.2	40.114360	-88.226875	561	04/21/2022	20:56:16	677	366.80	0.00	0.37	N
7	1.2	40.114364	-88.226882	564	04/21/2022	20:56:17	681	366.00	0.00	0.24	N

Figure 17. GPS data





Figure 18. Control subsystem working

- **Power:** The subsystem worked correctly. the only problem was that, when connecting all the devices, the output voltage of the voltage regulator was significantly lower than 5 V as can be seen in Figure 9.



Figure 19. Output voltage of the 5 V voltage regulator

This will cause the servomotor to not be powered within its voltage range which is 4.8 V to 6 V [3]. Therefore, it will not function correctly. Note that the rest of the components operate correctly at this voltage.

- **User Interface:** The result was very good, this subsystem met all the requirements previously established. The buttons correctly changed the target pace, i.e. the 'Target pace', decreasing or increasing it by 0.5 mi/hr. The LCD screen correctly displayed all data and updated the runner's speed, and the rocker button turned the

entire system on and off. Finally, the laser was visible under laboratory conditions, i.e. under artificial light.



*Figure 20. User Interface Results*

As shown in Figure 10, the 'Target Pace' changes each time a button is pressed. In addition, the laser and LCD can also be seen to be working properly.

- **Anlge Control:** This subsystem did not work properly. At the moment of changing position, the servomotor started to move uncontrollably. This was mainly due to two causes. The first was that it was not being supplied with enough voltage for proper operation, so an external voltage source with 5 V was connected to it and a logic level converter was added to increase the output voltage of the microprocessor from 3.3 V to 5 V. This reduced the servomotor oscillations but did not eliminate them. The second cause was noise, this noise came from the GPS module being located next to the servo motor, and the wires on the PCB crossed at several points.
- **Sistem design:** The design results were good, as the device has a comfortable and easy to wear design. In addition, it is intuitive and easy to use for the user. Figure 11 shows the result.



Figure 21. Device prototype

## 6. Conclusions

Even though the final result did not work, it does not mean that the project is unfeasible. In fact, the design flaw is relatively easy to fix, simply with a new PCB layout it would be solved. Furthermore, the benefits of this invention are remarkable, as it solves the problem of maintaining a constant pace during the race with a device that is easy to use and affordable in price. This invention would eliminate the use of pacemakers for pacing, as they would be less accurate than the Pacer Runner and have a higher cost.

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## **CHAPTER 1. INTRODUCTION**

In Chapter 1 will be given a description of the project. In the first instance, the problem to be solved is presented, explaining why it is necessary to find a solution. Furthermore, in this chapter it will be explained why the product is beneficial to the user, so the purpose of the project will be better understood.

### ***1.1 PROJECT MOTIVATION***

The human being can run both short and long distances. There are big differences when it comes to sprint or run for a long distance. The key to success is to understand the variables that take place in this process, these variables could be intensity, speed and above all distance. Probably, the biggest challenge that the amateur runners have at the beginning is to dose their energies to keep the same pace during all the run.

In Figure 2. Eliud Kipchoge pace during the marathon with pace assistant [1], there is a graph of the pace that the marathon runner Eliud Kipchoge had during the marathon. During all the race he kept a constant pace, as can be seen in the data, his average pace was of 2:51 minutes per kilometer with small variance of +- 2 seconds per kilometer. Furthermore, there are two anomalies in the graph. The first one is in the initial kilometers, where Kipchoge increases his pace to 2:49 min/km. The second one is in the last part of the race when fatigue is high. He decreased his pace to 2:53 min/km. Even if the changes in pace are small, in the long run, the differences are bigger at the end of the race.



Figure 2. Eliud Kipchoge pace during the marathon with pace assistant [1]

It should be noted that these times were achieved with external assistance. In every moment he had a car in front of him going at the optimal speed to reach the 2 hours barrier. Using this assistance Kipchoge was able to do the marathon in 2:00:25, improving his own official world record (without any external help), which was 2:01:39 [2]. In conclusion, finding a constant pace during a long run is the best way to improve the results.

## 1.2 PROBLEM

As commented before, to improve the performance in a long run, the runner should keep a constant pace. But this is not an easy task, especially for amateur runners. Usually, they have the tendency to run faster in the firsts kilometers and decrease sharply their pace during the last part of the run. Usually, during popular races they have pacemakers to set a determined pace, but they are not as precise as a car. To solve this problem, the goal is to design and develop a device that will give constant feedback on the runner's pace.



It is true that exists different electronic devices that can measure the running pace like smartphones or running watches with GPS. But they have a common problem, they do not give feedback until the run has ended. This is where Pacer Runner comes in. Pacer Runner is a portable device that will provide the runner with visual information about his pace through a line laser that will be projected on the floor. This line laser will act as the car that Kipchoge used. Depending on how far the laser is projected from the runner's body will mean that the user should increase, maintain, or reduce the pace.

## **CHAPTER 2. STATE OF THE ART**

As said before, there exists different ways of measuring the pace of a runner and obtain all the data, but they do not solve the problem of the constant feedback to their users. Furthermore, there are some expensive solutions like the use of a car for setting the pace or even a pacemaker (a runner that is used to run at a determined speed).

### ***2.1 SMARTWATCH***

As shown in Figure 3, the smartwatches can be used to measure the time, pace, and distance of the run. But they do not solve the problem of constant feedback. The user is not going to know his/her current pace, unless he/she look at it specifically, and usually while a person is running, they are not focused all the time on the watch. Moreover, the user has to do an additional effort by changing the running posture during the time he is using it. This change of posture will affect to the technique, making him decrease the pace and lose some seconds.



*Figure 3. Smartwathch [3]*

## 2.2 LASER SYSTEM MOUNTED ON A CAR

This project was inspired by the technology used during the record of the marathon, where they used a car with a laser on its top, setting in all moments the optimal pace to beat the 2 hours barrier [4]. Unfortunately, this technology was only used during this race because adapting a car to mount a laser on it is not easy and is expensive. What is more, the organizers of the event had hired the specialist race engineering company, RML Engineering to customize the cars [5]. In Figure 4 can be seen the laser mounted on the car.



*Figure 4. Laser System used during the Marathon [4]*

Apart from that, there is no other technology or projects focused on solving this problem.



## CHAPTER 3. PROJECT DEFINITION

Chapter 3 will explain the motivation of the Project. In addition, the goals to be accomplished are going to be defined. And lastly, the work methodology is going to be explained, making a schedule that should be followed during the process.

### 3.1 MOTIVATION

During the last decades the number of runners has increased exponentially [6]. In a society where sedentary lifestyles predominate due to the increasing number of hours workers spend in front of the computer, running is the ideal solution to combat it.

Usually, these amateur runners start with medium distances of 5 or 10 Km, as can be seen in Figure 5. Furthermore, as can be seen in the same article, the runners in average are slower than ever, and that is because there are more inexperienced runners.

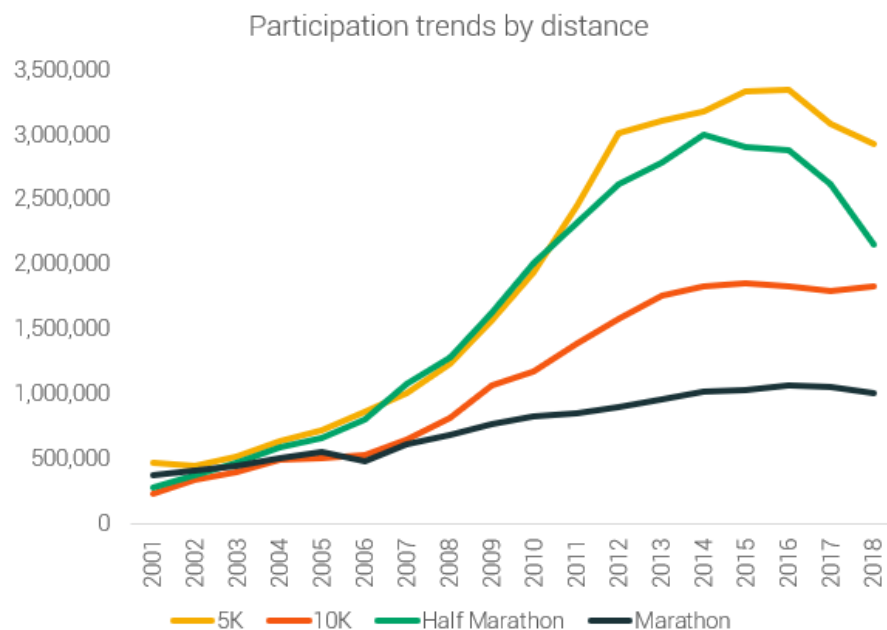


Figure 5. Number of runners by distance [6]

In conclusion, there is a big number of untrained runners that will need help to improve their performance. That is why the main goal of this project is to create a technology available for everyone that helps to improve the runner's performance. The project will consist in a device that is going to act as a pacemaker, indicating the runner to increase, decrease, or maintain his/her pace. Although, unlike the pacemaker the device will be more accurate to set the correct pace. Furthermore, it will be affordable and easy to use for all the runners.

In addition, in the economical aspect, the market capitalization of the running industry reached a value of US\$ 36.8 Billion in 2021 [7] and is expected to increase in the next years. So clearly, the running industry is very lucrative, and with this device we could take a part of the cake.

### ***3.2 HIGH-LEVEL REQUIREMENTS***

Before explaining the goals of the project, there will be a short introduction to how the system will work. This project will be composed of four subsystems, each with its own function. Figure 6 shows the block diagram of the device, where the four subsystems can be clearly distinguished. These are, in first place, the Control subsystem, which is composed of the GPS module and the microcontroller. The function of this system is to compute the pace of the runner and send the data from the microcontroller to the user interface subsystem. Next, there is the Angle Control subsystem which is composed of the servomotor, and its main function is to change the angle of the laser line. In addition, there is the Power subsystem, which is integrated by the 9 V rechargeable battery and the 5 V voltage regulator. This subsystem is in charge of supplying power to the whole device.

Lastly, there is the User Interface subsystem, which is integrated by the buttons, the LCD display, and the laser line. This subsystem will be in charge of displaying the data of the GPS, using the LCD, and also setting the target pace using the faster and slower buttons. What is more, this target pace will be also displayed on the LCD, as well as the current pace of the runner. And finally, the laser will be projected on the floor, and

depending on the angle the runner will know if he/she has to increase/maintain/decrease the pace.

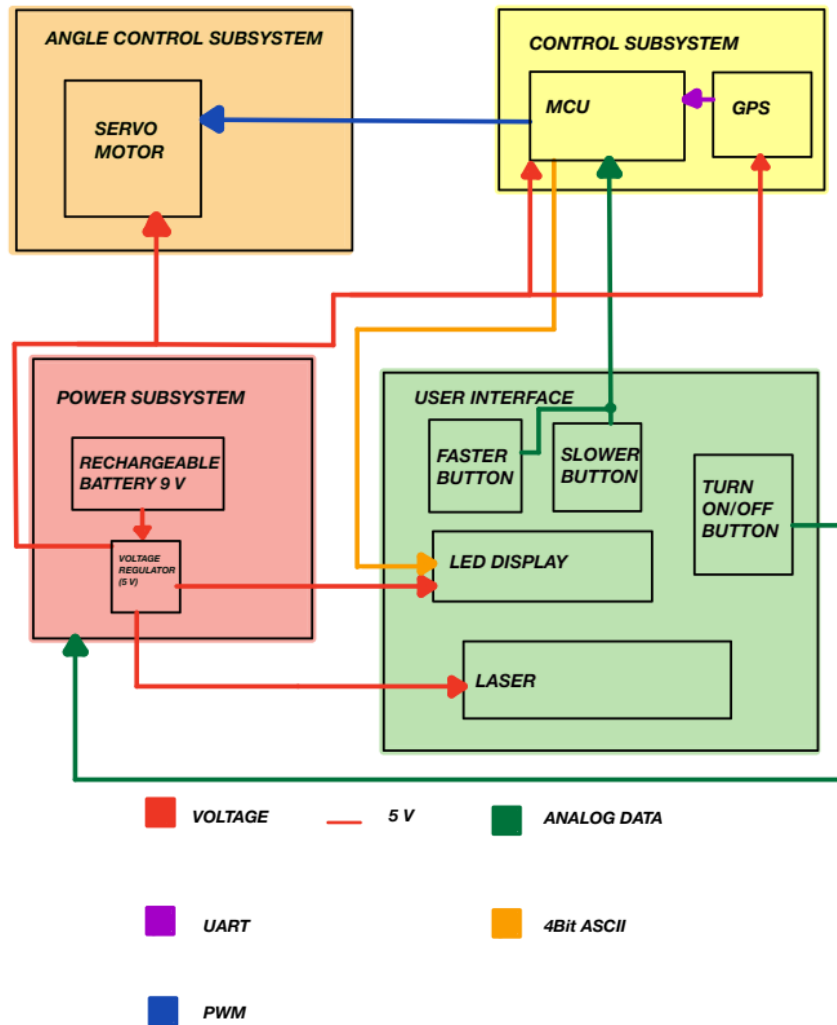


Figure 6. Block Diagram

Now that the reader knows the structure of the project, the objectives will be explained. These objectives are the following:

- **Control subsystem:** The GPS module will compute the speed of the runner with an accuracy of 1mi/hr.<sup>1</sup>
- **Angle Control subsystem:** The servomotor changes the angle of the laser in response to the runner's change in pace. There will be three possible positions with 0 degrees being vertically down.
  - Slower than target pace: Servomotor at 56 degrees.
  - Ideal pace: Servomotor at 45 degrees.
  - Faste than target pace: Servomotor at 27 degrees.
- **User Interface subsystem:** The physical input buttons change the target pace, and the LCD display output will reflect these changes and the current pace of the runner. The changes will be:
  - Faster button should increase the target pace by 0.5 mi/hr.
  - Slower button should decrease the target pace by 0.5 mi/hr.
- **Design:** The design of the device should be compact and comfortable to wear for the runner. Furthermore, it has to be lightweight so that it does not put extra strain on the user.

### **3.3 WORK METHODOLOGY**

The path followed to meet the goals was to divide the project into three main stages. The first step was doing a brainstorm to develop and improve the initial idea, starting with the first drafts of the device and planning which will be the steps to develop the project. The next stage consisted of the design and development of the hardware device. The most important aspect of the hardware was the design of the PCB, since it is the heart of the project. Overall, the budget given by the UIUC may not be exceeded, then in the design of the hardware it must be taken into account. At the same time, the code will be developed. Once finished this step, work on building and testing the subsystems will begin. In addition, the work needed for debugging the PCB will be done in the Senior

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<sup>1</sup> The values of the angles and accuracy of the GPS may be subjected to future changes



Project Design Laboratory at the ECE building, including all the soldering and the tests. Lastly, all the subsystems will be tested by their own using an Arduino UNO as the control system, and once all the components are working separately, the whole system will be assembled.

### 3.3.1 WORK PLAN

In the following Table 1. Work Plan, it is shown how the workload will be distributed. And which exact actions will be taken during the three different stages.

Table 1. Work Plan

Project goals and initial design	January – February (2022)	<ol style="list-style-type: none"> <li>1. Goals definition</li> <li>2. First drafts of the device</li> <li>3. Initial PCB design</li> <li>4. Order of the necessary parts</li> </ol>
Hardware and Software design	March – April (2022)	<ol style="list-style-type: none"> <li>1. Soldering PCB</li> <li>2. Code development</li> <li>3. Debugging and redesigning the PCB</li> </ol>
Debugging and Testing	April – May (2022)	<ol style="list-style-type: none"> <li>1. Final subsystems test</li> <li>2. Assembly of the device</li> </ol>

### 3.3.2 RESOURCES

The following resources will be used during the project development process:

- **Software:** Two main programs will be used during the development of the project.
  - Kicad 6.0: This will be the software used for the design and development of the PCB.

- Arduino ISP: It will be used for debugging the code.
- **Machine Shop:** It is located at the ECEB and it will be used to build and assembly the physical device. They assembly the mechanical parts needed for the project. In addition, they will provide some materials needed for the project like screws or plastic boxes to put inside the electronic components.
- **ECEB shop:** It will be used to buy the different electronic components needed for the project.
- **Senior Design Laboratory:** This laboratory, located at the ECEB, will be used for soldering, testing, and debugging the PCB and the rest of the hardware parts needed for the project. It is equipped with different machines like multimeters or soldering machines that will be used for the project.

## CHAPTER 4. IDEA DEVELOPMENT

In chapter 4, the different design alternatives will be developed and how they evolved towards the final version. It will be analyzed in depth why they were discarded, and which were the alternatives that were taken into account.

It must be considered that in this chapter we will talk exclusively about the design of the product, and not about the design of the electronic circuits. The design of the electronic components will be discussed in the following chapters.

### 4.1 INITIAL DRAFTS

As can be seen in Figure 7, the first idea was to create a device similar to a headlamp. Thus, the runner would wear the device on his/her head, and so the runner could see the laser projected in front of his feet at a distance of more than 1.5 m (4 ft). But after reconsidering the idea, it was concluded that there could be several problems with this configuration.

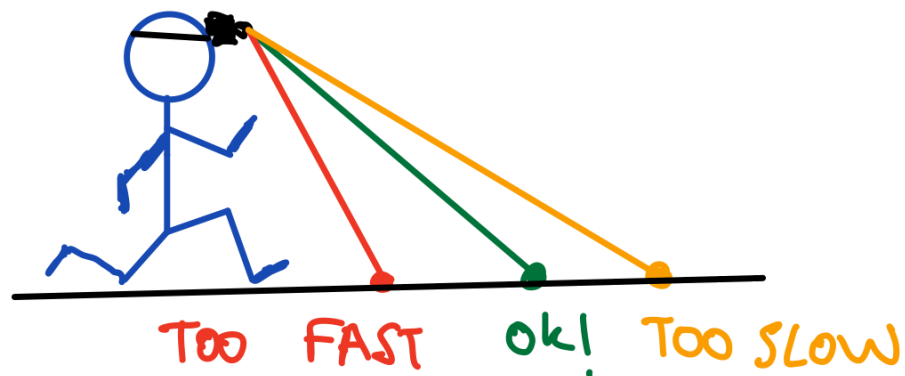


Figure 7. Initial Idea

The first problem was safety, since the device is mounted with a line laser instead of a flashlight, it could be harmful to the human eye. What is more, since the laser was worn on the head, it was very likely that when crossing paths with people, they would be directly exposed to the laser, increasing the risk of an eye injury. To solve the problem there are two factors to consider. Firstly, the position where the laser will be carried from the head to the chest, so that direct contact of the laser with the eye will be more unlikely. Secondly, the laser cannot be unsafe outside laboratory conditions. So the laser must be of Class 1 or 2 since they are deemed safe for unsupervised use. [8]

The second problem is laser stability. As the laser is placed on the head, every time the runner moves it to look up or down, even sideways, the laser line will move with it making it confusing. To solve this, the same idea used for the safety problem will work. The laser will be moved from the head to the chest. This way, the laser will always point to the ground.

Lastly, as can be seen in Figure 7, the color of the laser would change every time the servomotor position changes, but this had several issues. The most important one was the visibility. After several experiments in the laboratory, it was concluded that the green laser was much brighter than the red one with the same voltage source, making it more visible during sunlight conditions. More generally, the green laser can be five times brighter than the red one [9]. Additionally, the implementation of a system capable of changing the color of the laser is complicated and would considerably increase the volume of the device, making it less practical and heavier. Thus, this feature of the system was ruled out, using only the green light laser.

## **4.2 CASE DESIGN**

In this section, the case design is going to be explained. The case consists of the box where all the electronic components are located, including the laser and the servomotor. It is an important part of the project because it has to be good enough to bring

it to market. In addition, it has to be light, reasonably small in size and it has to be good looking.

### 4.2.1 3D PRINTED CASE

Initially, it was planned to design a specific case for the product and then 3D print it to minimize the size of the device to a minimum and save unnecessary weight. As can be seen in Figure 8, a first design was made.

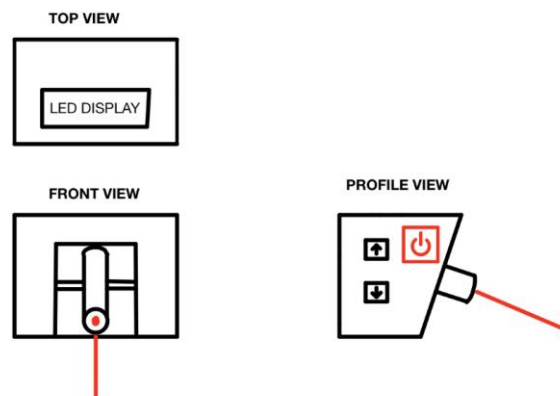


Figure 8. Initial Case Design

This first design was done before the designing of the electronics that is why it doesn't have any measures in it. It had several problems both in terms of design and complexity. First of all, since the laser had part of it inside the case, it would make the box larger than necessary. In addition, the lateral shape of the box will have to have an inclination so that the laser can be projected on the ground, making it more difficult to manufacture. Thus, after talks with the workers of the Machine Shop, it was decided that it was better to use an already built box and adapt it to the project.

### 4.2.2 STANDARD CASE

After ruling out 3D printing, it was decided to purchase the box from the ECEB store. This box had to be large enough to fit the PCB and the rest of the components. That's why it was chosen a larger box than necessary to fit all the elements including some

unexpected ones. In the next Figure 9 can be seen the new design of the case using this new box. It should be noted that each square corresponds to one millimeter.

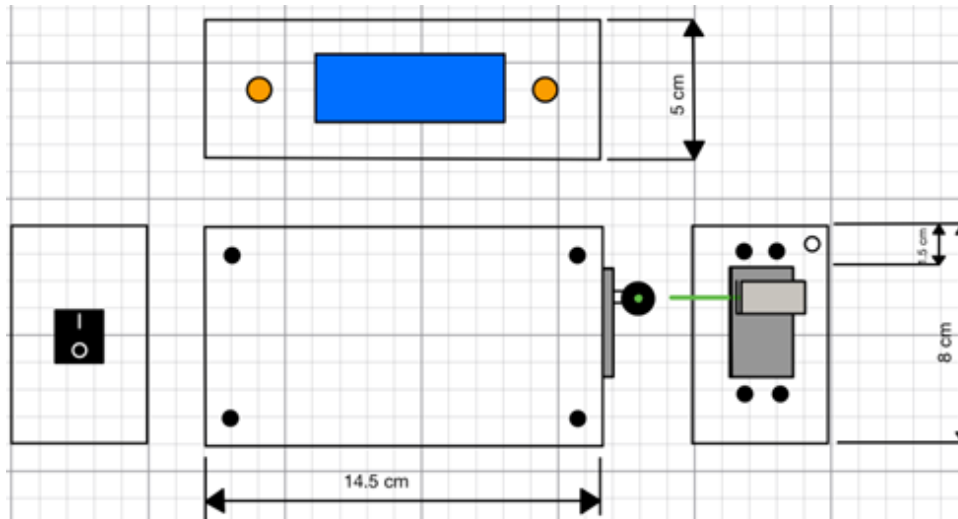


Figure 9. Final Case Design

Several changes were made with respect to the first design. The laser is now placed on the side of the box, while in the initial idea it was in the center. This decision was made because the PCB and all the wires take up more space than expected and they would be visible if the box had a hole for the laser in the middle. The other change was the location of the faster and slower button. Now, they are on the top of the box on the sides of the LCD screen. This change was made because it is easier for the runner to press the buttons if he/she is able to see them.

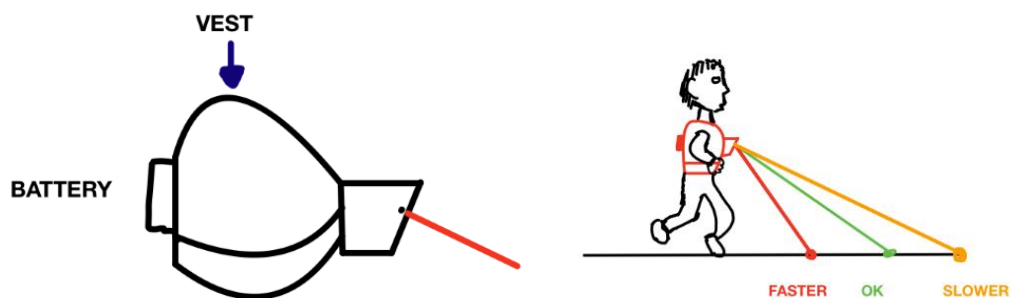
Finally, emphasize that the rest of the design is similar to the initial one. The rocker switch to turn on or off the system is located in one side of the box and the LCD screen is also on the top.

### 4.3 DEVICE DESIGN

Now that the case where all the electronic components is explained, a way to wear it comfortably has to be designed. As shown in Figure 7, the initial idea was to wear it like

a running flashlight but now that the case is carried on the chest another way of wearing it is needed.

After several ideas, it was concluded that wearing it with a vest was the best option. The main reason was because it is a cheap product and easy to find. Also, a lot of runners use them to wear their belongings while doing sport. Moreover, it is also very easy to modify to attach the box with all the electronics. In Figure 10, it is shown the sketch with appropriate modifications to the vest.



*Figure 10. Vest Design*

Note that the battery would be placed at the back of the vest for better weight distribution.





## **CHAPTER 5. HARDWARE DESIGN**

The hardware design is the heart of this project. This chapter will explain in detail all the decisions taken at the time of designing the hardware. Furthermore, each section of this chapter will correspond to a subsystem, which will be explained in detail.

To introduce with, the system is composed of four subsystems, where each subsystem has its own function. These subsystems are the angle control, control, user interface and power subsystem. In section 3.2 on Figure 6, can be seen an illustration of how each subsystem are connected between each other and what are they internal components in a high-level domain. The decision of breaking the system in several subsystems was made because it will simplify the design process, since it would be easier to find bugs if the project is tested by small parts. Moreover, it makes the design and building process much simpler and easier to understand. The criteria used to form a subsystem is that they have a common function, and that this function is clearly different from the one performed by other subsystems.

Before going into an in-depth explanation of each of the subsystems, a summary of what each one consists of will be given. The first subsystem is the angle control. It consists of the servomotor that is in charge of changing the position of the laser. The second one is the control subsystem and is composed by the MCU and the GPS module. This subsystem is in charge of giving orders to the rest of subsystems. In addition, is responsible of computing the pace using the GPS data. The next one, is the user interface, which is composed by the pace buttons, the rocker switch, the laser, and the LED display. This subsystem corresponds to the electronic components with which the user is going to interact. Lastly, the power subsystem will be in charge of providing power to the system and it will be composed of a rechargeable battery of 9 V and a voltage regulator of 5 V.

## 5.1 ANGLE CONTROL SUBSYSTEM

The purpose of this subsystem is to rotate the servomotor, on which the line laser is mounted, to project the line laser in different positions based on the runner pace. It will be formed by the servomotor, and it will get power from the Power subsystem through the 5 V regulator, and it will receive the commands to rotate from the Control subsystem. Lastly, it is connected to the User Interface as the line laser is mounted on this subsystem.

### 5.1.1 SERVMOTOR

The servomotor used for this project was the HS-311. This model was chosen because a similar model was available in the laboratory and could be tested from the beginning. In Figure 11 is shown a picture of the servomotor.



Figure 11. Servomotor (HS-311) [10]

The important features of this servomotor are the operating voltage range from 4.8 V to 6 V, a weight of 43 grams, reasonable enough for the project even if it could be lighter, and a size of 40x20x36.5 mm [11]. Note that the voltage range is important because if the servomotor doesn't receive enough power, it won't work properly.

## **5.2 CONTROL SUBSYSTEM**

The control subsystem is the key to the project since it has the microprocessor, that will be in charge of controlling the system, and it will have the GPS module, which will get the data of the runner's pace. The control subsystem will take in the target pace from the User Interface, it will calculate the runner's pace using a GPS module, then 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.

### **5.2.1 MICROPROCESSOR**

At the time to choose a microprocessor for the project there were several problems related to the global shortage of this product. Initially, the MCU chosen for the project was the ATmega328 since is easy to program and there could be found a lot of information of how to use it on the internet. Moreover, it met all the necessary specifications for this project. It had enough pins to be able to connect all the other electronic components and was compatible with a large number of components.

But after choosing this MCU, the problems began. The ATmega328 was out of stock in almost all electronic stores, and those where it was available, the waiting time was too long to meet the project deadlines. That is why it was decided to change the MCU. The new processor chosen was the ATmega809 since it was on stock, and it met the requirements for the project.

#### **5.2.1.1 ATmega809**

Once the MCU was chosen, the PCB design was started. For this, the function of each pin of the microprocessor had to be considered. In the Figure 12 can be seen the function of each pin.

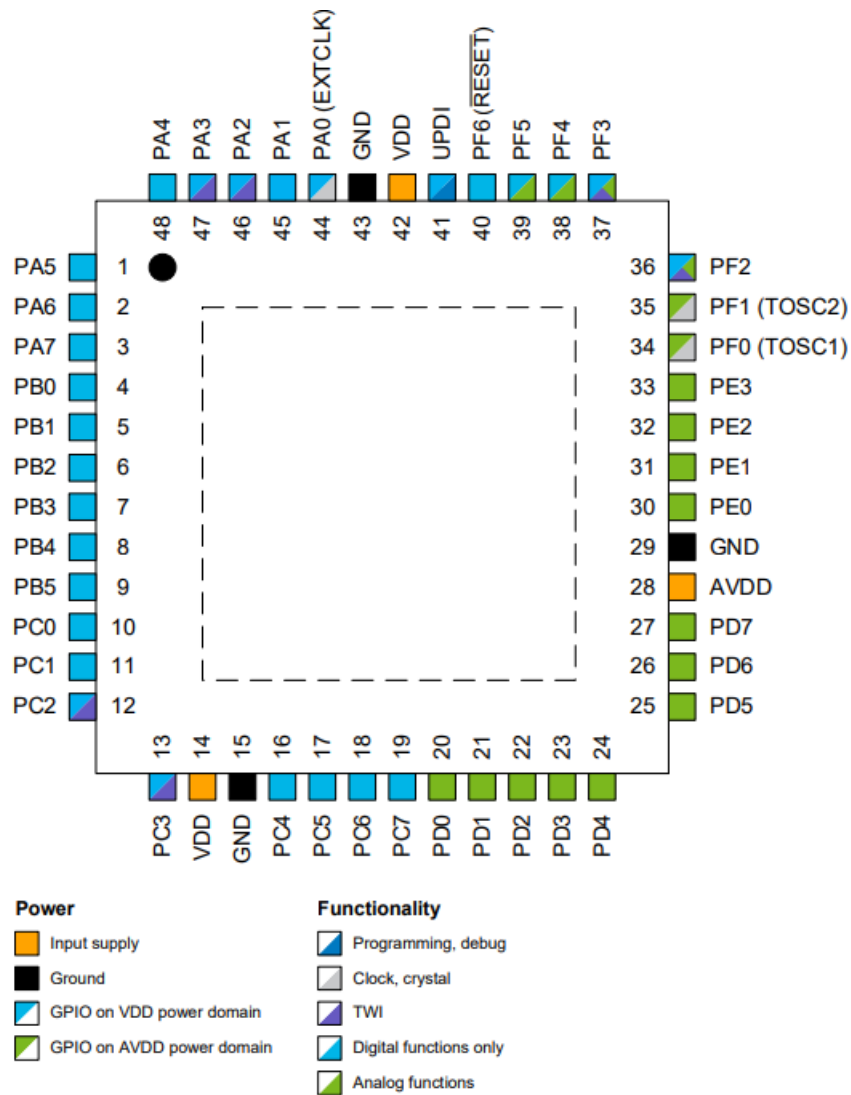
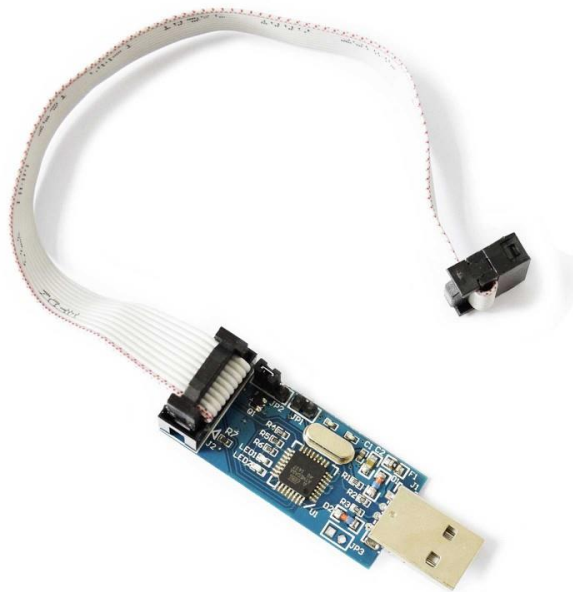


Figure 12. Pinout of the ATmega809 [12]

At this point is where the first major design flaw was made. The mistake was that there was a confusion in the choice of the pin in charge of programming the MCU. As shown in the image, the pin used to debug and program the microprocessor is pin number 41 or also called UPDI. However, this pin was never connected on the PCB. The reason of

this design error comes from the external programmer needed to program a new MCU, known as bootloader.

In the laboratory there were several USBasp external programmers (on Figure 13 can be seen an image of these external programmers) that they were used to upload the bootloader when the chip was first soldered. The USBasp used four pins to upload the bootloader in the MCU. These four pins were the MISO, MOSI, SCK and RST. Since this USBasp had already been used to program the ATmega328 previously, it was decided to try to use this same device for the ATmega809 without checking compatibility, thinking that they were from the same family.



*Figure 13. USBasp AVR used in the laboratory [13]*

The problem came once the ATmega809 was soldered on the PCB and an attempt was made to flash it. At the time to burn the bootloader in the MCU there was an error and the MCU was not flashing. After doing some research, it was concluded that the problem was with the USBasp AVR and its compatibility with the ATmega809. As can be found in the specifications of this USBasp AVR, the ATmega328 was compatible but not the ATmega809. [14]

Finally, once the bug was found, the Control Subsystem on the PCB design had to be modified. There were two options, the first one was to connect the UPDI pin and buy a new external programmer compatible with the ATmega809. The second option was to change the microprocessor to the ATmega328 and completely reconnect the Control subsystem.

The decision taken was to change the MCU to the ATmega328, since it was more probable to understand how to burn the bootloader because there were several tutorials on the internet, and furthermore, there was no need to spend more money on buying a new external programmer.

### 5.2.1.2 ATmega328

Once the decision was made to use this microchip, the same problem of shortage still existed. But there was the option of buying a motherboard with this MCU already soldered on it, and using hot air to desolder it, and extract the ATmega328. So, the Arduino nano board containing the necessary microchip was purchased. On Figure can be seen the Arduino board with the ATmega328.



Figure 14. Arduino Nano purchased for the Project [15]

On the other hand, the different subsystems had to be reconnected to the new MCU. In Figure 15 are shown the different types of pins.

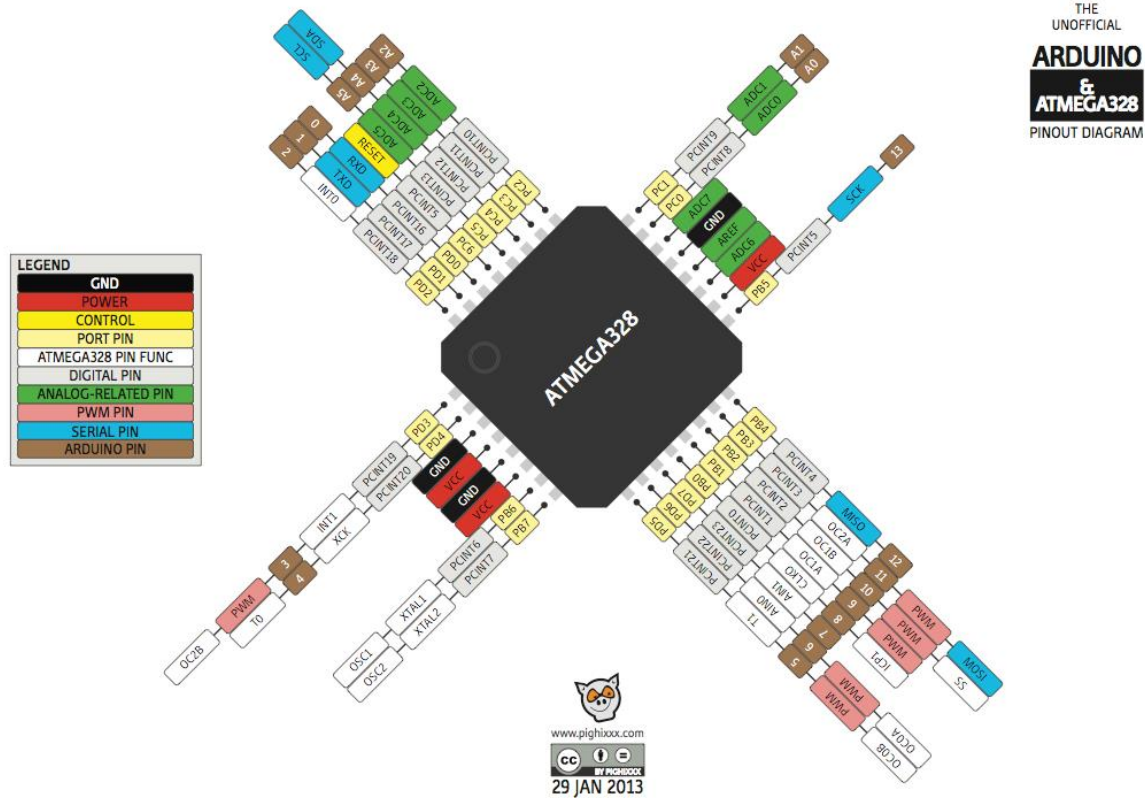


Figure 15. ATmega328 Pinout [14]

Furthermore, the connections needed to use the USBasp were given on the course web page. Thus, for the design of the Control System the schematic in Figure 16 was used. As can be seen, the MCU will be programmed using the MISO, MOSI and SCK ports. Moreover, the small schematic on the left corresponds to the port where the USBasp will be connected to upload the programs. Lastly, it is observed that an external 16 MHz crystal will be used. The main reason is because the internal clock is less accurate than the use of an external crystal. In addition, the cost of an external crystal is low, and it increases the accuracy of the system. [16]

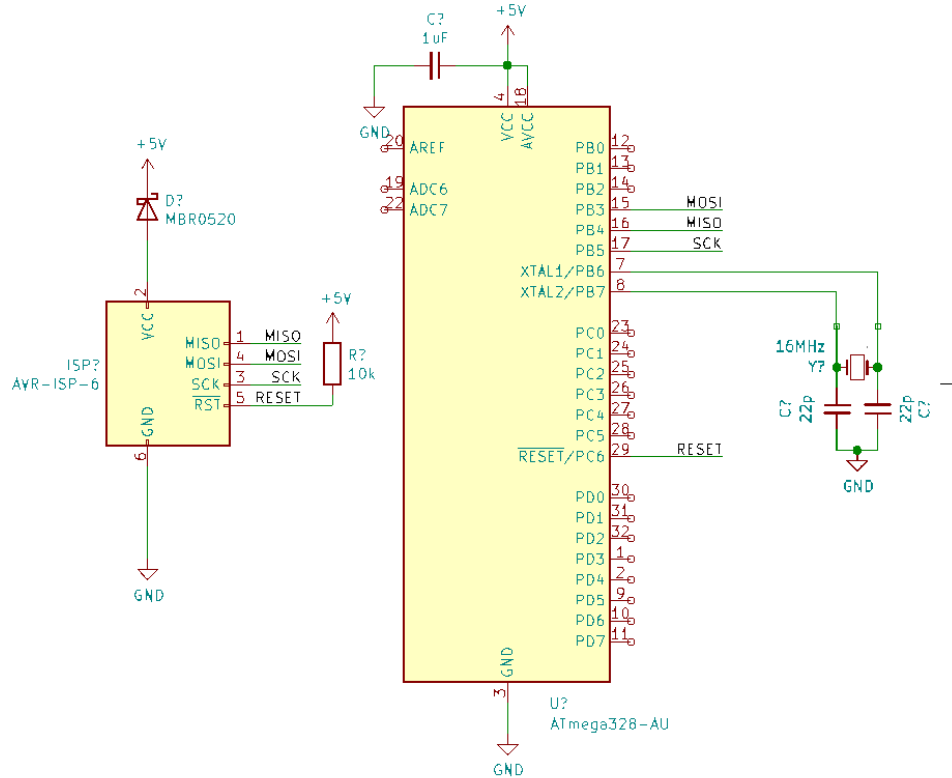


Figure 16. Basic schematic of the ATmega328 [14]

## 5.2.2 GPS MODULE

The GPS module was a key component for the correct operation of the project. A good GPS had to be chosen to avoid possible problems with the accuracy or connection. Thus, it was decided to spend a big percentage of the budget in this component.

The module chosen was the SAM-M8Q that met all the requirements of the project. As can be found in the datasheet, it has an accuracy of 0.05 m/s for velocity, it has a voltage range of 2.7 V to 3.6 V, and an average supply current while working at 3 V of 23 mA, this is low enough for the project.[17] Furthermore, this GPS can be surface mounted on the PCB, saving space that will reduce the size of the device. In Figure 16 can be see the SAM-M8Q.





Figure 17. SAM-M8Q module [18]

As will be commented in later chapters, due to the cancellation of the order this module never arrived, and a new one was needed. This cancellation happened after the order of the second PCB, but fortunately, for the second PCB there were added several pins to connect an external (not surface mounted) GPS module. The external GPS that was acquired was the BN-280 module, that has a velocity accuracy of 0.1 m/s versus the 0.05 m/s that had the initial module, and a voltage range from 3.6 V to 5.5 V. Furthermore, the supply current needed to use this GPS is 50 mA, more than the double of current consumed by the SAM-M8Q module. The advantage of this GPS module was its price that was around the 20 dollars. In Figure 18 is shown an image of the component.



Figure 18. BN-280 external module used for the Project [19]

### 5.3 POWER SUBSYSTEM

The power subsystem provides energy to the components based on their individual needs and requirements. The voltage from the main battery is regulated by the 5 V regulator, and then provided to all the other subsystems. Initially, this subsystem had two voltage regulators, one of 5 V and the other of 3.3 V but then when the GPS module was change to the BN-180, the 3.3 V regulator was unused because this new module works at 5 V. Thus, the 3.3 V regulator was not soldered on the PCB.

So, basically the power subsystem is composed by two elements. The first one is a 9 V rechargeable battery, and the second is the 5 V voltage regulator that will decrease the incoming 9 V to the 5 V that the system needs to work in a safe environment. Note that the 9 V battery was chosen because it was the only rechargeable battery on the ECEB shop. In Figure 18 can be observed the power subsystem schematic.

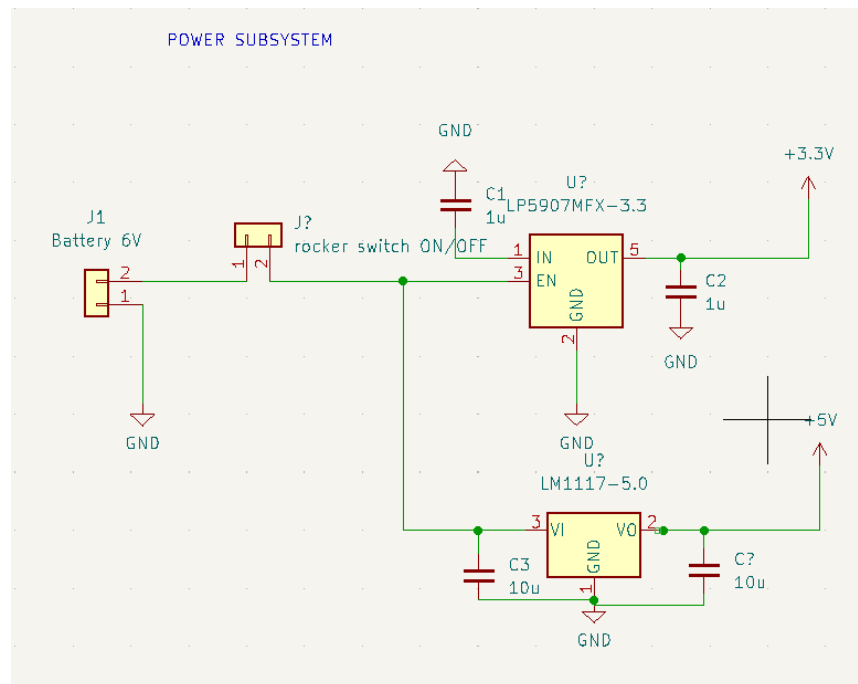


Figure 19. Power Subsystem schematic

To end with, as can be seen in Figure 19, there will be a rocker switch between the 9 V battery and the voltage regulators to turn on/off the device. It was placed in this position because it will be used as a safety measure in case any problem happens, just pressing this button everything will shut down including the line laser.

Note that initially, the voltage of the battery was 6 V since the 3.3 V regulator had a maximum input supply of 6 V. [20] But after removing the 3.3 V regulator from the system, it was decided to increase the battery voltage from 6 to 9 V to increase the input current, thus the laser will be brighter. [21]

## **5.4 USER INTERFACE SUBSYSTEM**

This subsystem will be the customer's first impression of the product. Thus, the finishes of this subsystem like buttons or the laser will need to have a good quality. The User Interface subsystem allows the user to interact with the device.

It receives inputs, like pushing a button, that are sent to and processed by the Control Subsystem. Furthermore, the laser will be mounted on the Angle Control Subsystem, and it also will receive output data from the Control Subsystem directly to the LCD display. In addition, this subsystem will be formed by three components. The first one is the LCD display that will show the current pace of the runner, and the target pace. The second one is the buttons, that will allow the user to change the target pace by pushing the increase/decrease pace buttons. And lastly, the line laser that will be projected on the floor.

### **5.4.1 LCD DISPLAY**

As said in the introduction of this subsystem, the LCD display will show visually to the runner his/her pace and the pace he/she want to set as the target pace. The LCD used for this project is the C162D-BW-LW65, this display has two rows of characters, and each row can represent sixteen characters. In Figure 20 can be seen an image of the LCD. In the case of this project, the first row will provide the target set by the runner and in the second row it will show the actual pace.



*Figure 20. LCD display used in the Project [22]*

The LCD was connected to the ATmega328 using only four data lines. This decision was taken because the MCU used for this project did not have enough pins to use eight data lines, the consequence of this choice is that the code will be more difficult. But the fact of using only four data lines will also reduce the number of cables used for the project, and so the package will be smaller. Moreover, the LCD will need two extra pins to connect the enable and the switching pins of the display, which will be in charge of activating and controlling the component. There are two more pins that will be connected to the 5 V source to control the contrast.

#### **5.4.2 USER BUTTONS**

The user buttons will be placed one on each side of the LCD, so the runner can access them easily. They will allow the runner to change the target pace, one will decrease by 0.5 mi/hr the pace, while the other will increase this pace by 0.5 mi/hr.

As can be seen in Figure 21, the filter will be implemented using hardware. For this, it will be used a 10 K resistor and a 1 uF capacitor, these are standard values to obtain a time constant of 10 ms which is enough to filter these perturbations.

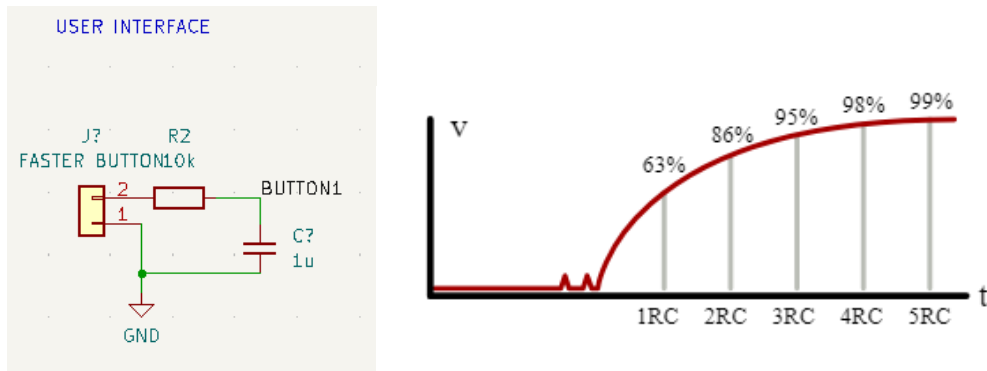


Figure 21. RC button filter [23]

### 5.4.3 LINE LASER

Several problems were found in determining which laser was most suitable for the project. In the first instance, it was thought to use three different laser each one of a different color to indicate the runner if he/she was following the optimal pace. This idea was discarded as can be seen in Chapter 4. Idea Development Then it was thought to use a point laser, but it was really hard to follow just a small point, so finally, it was decided to use a line laser.

The color of this line laser was also a challenge since it had to be bright enough to be seen at least in laboratory conditions. The two colors chosen were the green and the red color, but after doing several tests between them under the same conditions of brightness, it was determined that the green laser was more indicated for the project.

Finally, it had to be found a laser small enough to be mounted on the chest and not be harmful to the human eye. That is why after doing some research and calling some laser companies it was decided to use the VLM-650-28. This laser met most of the requirements, it was small, it had a diameter of 9 mm and a length of 26 mm, it can handle a voltage

supply of 5 V and it was bright enough during lab conditions.<sup>2</sup> [24] In Figure 21 can be seen a photo of the laser.



*Figure 22. VLM-650-28 LPT Laser [25]*

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<sup>2</sup> Lab conditions are referred to as close environments where there is not a high amount of natural light.

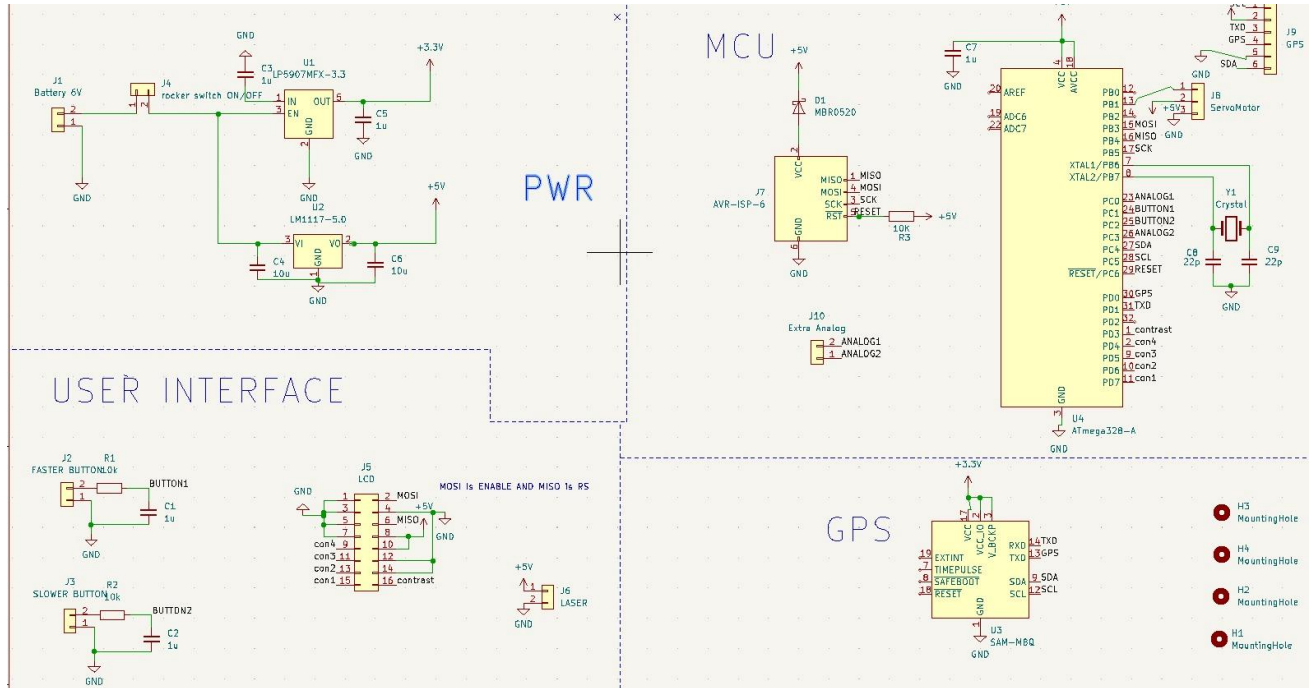
## **CHAPTER 6. PCB**

In Chapter 6, the design and development of the PCB will be discussed. The most important part to ensure the success of the project was that the PCB worked correctly. For this, it was necessary to be very careful with the design since a mistake could be costly. In the PCB the different subsystems will be put together in such a way that all of them work correctly. It is important that the size of the PCB is as small as possible because it will be possible to use a smaller housing to put all the electronics.

This chapter will begin by explaining how the different subsystems were connected to each other. In addition, it will show the changes made to the PCB throughout the project. Finally, the results obtained will be shown.

### ***6.1 SCHEMATICS***

The first step at the time to design the PCB is to draw the schematics of the whole system, for this purpose, the KiCad 6.0 software will be used. In Figure 23 a general view of the circuits designed for this project can be seen. As may be appreciated, the circuits drawn are divided into the same subsystems previously mentioned. Note that the labels indicate the existence of a wire between ports with the same label.



*Figure 23. PCB schematics*

Next, each subsystem will be zoomed in to better understand how they are connected. It must be said that the angle control subsystem will not have a specific section for it since its design in the PCB is no more than three pins in which the servomotor will be plugged. It will not have the power section either because it has already been discussed in depth in 5.3 Power subsystem and nothing else of interest can be contributed.

### 6.1.1 CONTROL SCHEMATICS

The Control subsystem is composed by the MCU and the GPS module. In this section the MCU and the GPS schematics are going to be divided in two parts for the better understanding of the systems. Firstly, MCU schematics that can be seen in Figure 24 will be discussed.



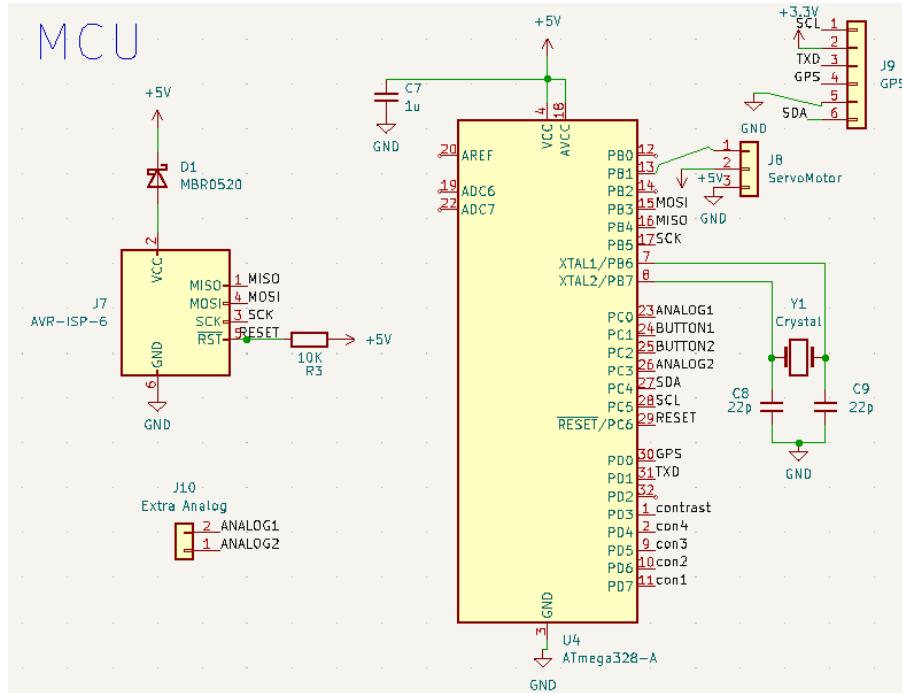


Figure 24. MCU schematics

As seen in the Figure 24, the MCU has a supply voltage of 5 V. Also, most pins of the MCU are used that is why the LCD is controlled with only four pins and not eight. These pins are labeled with the names: con1, con2, con3, con4. Furthermore, with PD3 the MCU can control the contrast of the LCD. The MOSI, MISO and SCK labels correspond to the connections made with the USBasp AVR connector. Finally, on the pin PB1 of the ATmega328 is connected the servomotor that is going to receive the information from this connection using a PWM signal.

The next component is the GPS module, that can be seen its schematic in Figure 25. This picture represents the footprint of the SAM-M8Q module. The GPS module will be connected with the pins SDA, SCL, TXD and RXD. It is important to say that the RXD pin of the GPS will be connected to the TXD pin of the MCU and vice versa.

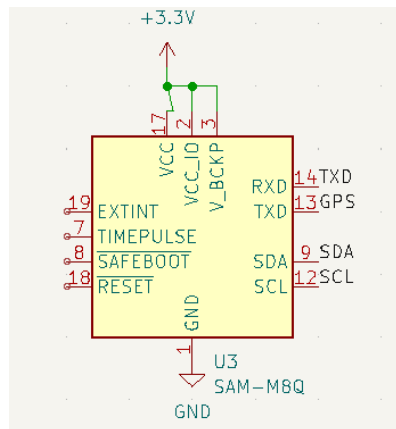


Figure 25. GPS module schematic

### 6.1.2 USER INTERFACE SCHEMATICS

In Figure 26 can be seen the User Interface subsystem. There are three circuits, two correspond to the increase/decrease buttons and the last one belongs to the connections of the LCD display. The buttons will be connected to digital pins of the MCU, in this case they will be connected to pins PC1 and PC2.

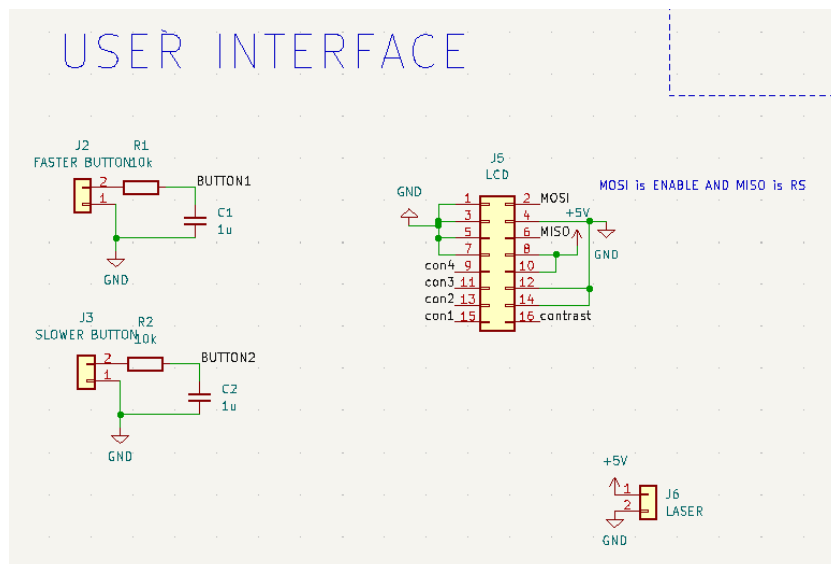


Figure 26. User Interface schematics

Note that the LCD will be connected to the pins MISO and MOSI, since the MCU will never be programmed at the same time as the LCD display is working, so the pins can be reused.

## 6.2 PCB LAYOUT

The next step after finishing the schematics is assigning the footprints to the electronic components like capacitors, resistors, crystals, etc. Then, it was time to display all the components of the PCB. This display had to be as clear as possible since a bad distribution of the components could increase the noise on the electronic circuits and create undesired behaviors. That is why the MCU had to be set in a strategical position to decrease the length of the wires. In Figure 27 can be appreciated the display chosen for the PCB.

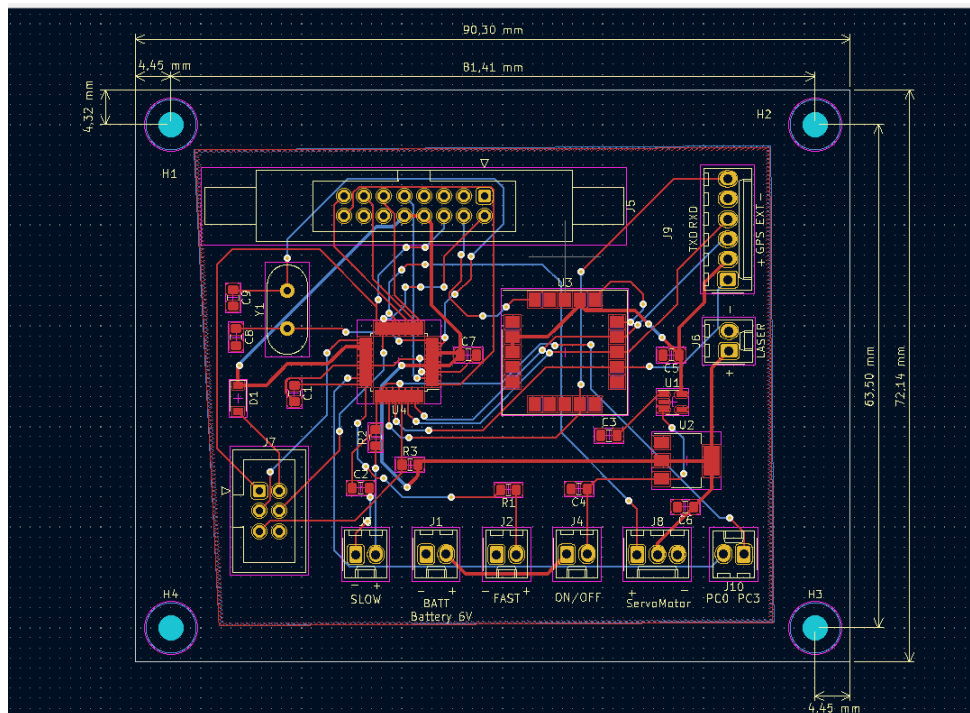


Figure 27. PCB Layout

Thus, the MCU was placed in a middle zone to try to decrease the number of wires that had to be crossed, since there are only two layers on the PCB, this means that there

cannot be a point where three wires cross each other. Note that there were added two layers of ground, so the ground connections can be left unwired. This simplified a lot the layout of the PCB.

Finally, all the connectors were placed on the edge of the board to facilitate the access to them. And the holes to screw the PCB to the case were added on each corner.

### 6.3 PCB RESULTS

After finishing the design of the schematics and the layout of the PCB, it was ordered. To order it, the Gerber files of the design were created with customized setting and then it was sent to PCBWay, the company that provided the PCB, and revised by their workers to find any possible mistake in the files. After the okay of the company, the PCB was sent between a period of ten days.

Once the PCB arrived at the lab, it was time to solder all the electronic components needed for it. This process was made in the lab using solder machines and a microscope to solder the smaller parts like the MCU. In Figure 28 can be seen the PCB with its components soldered.

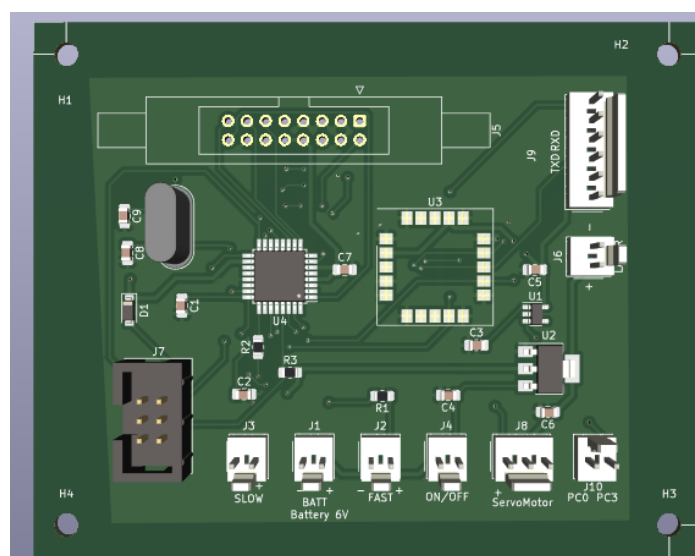


Figure 28. PCB results

## **CHAPTER 7. PROJECT RESULTS**

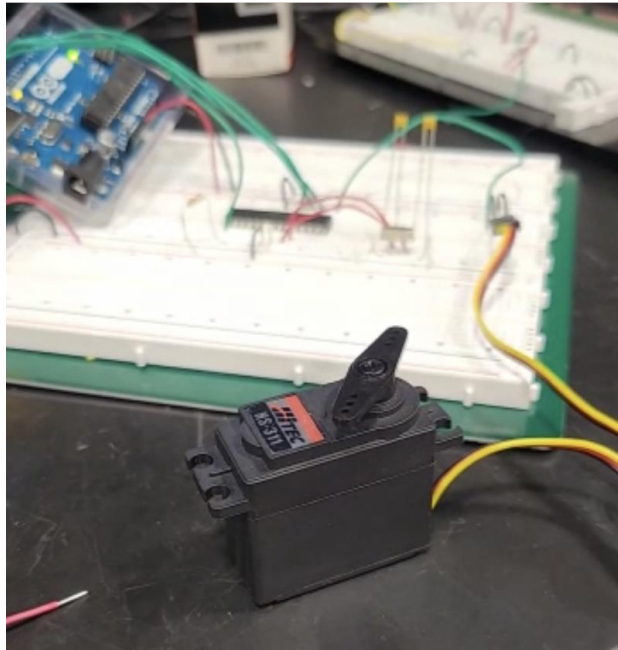
In this chapter, the final results of the design will be explained, including all the problems and challenges that appear during the project. As has been done in the previous chapters, the results will be explained by subsystems, and finally, the results of the whole device will be shown.

Note that all the electronic circuits were tested using an Arduino UNO and a breadboard where all the circuits were mounted, but they were tested separately in subsystems. The complete system was never tested until the PCB was soldered and all the components of the project were connected to it.

### ***7.1 ANGLE CONTROL RESULTS***

To recall, the angle control subsystem was formed by the servomotor. This servomotor was connected to 5 V and it receives information from the MCU to which angle it needed to move depending on the pace of the runner.

The requirements of this subsystem can be in Appendix A: Results and Verifications. To test this subsystem, a circuit equivalent to the one designed on the PCB was mounted on the breadboard. Then, a basic program is loaded in the MCU to change the angle that the servomotor receives. Figure 28 shows a picture of the breadboard used to test the servomotor.



*Figure 29. Servomotor tested in a breadboard*

Note that the MCU used for the test was the ATmega328 in its breadboard version, and the Arduino UNO was used to upload the code in it. The results were good, and the servomotor worked properly, changing its position every time a new angle was defined.

## **7.2 USER INTERFACE RESULTS**

The User Interface was tested before the Control subsystem because the LCD was needed to show the data of the GPS. This subsystem was composed by the buttons, the LCD and the laser.

The first component tested was the LCD display. It was connected to the Arduino UNO that had been previously upload with a simple code to show the phrase: 'Target: 5.0'. Then, the buttons were added to the breadboard, and the code was updated with a new one that included the buttons. This code will change the number displayed on the LCD only if the user presses the increase or decrease button. In Figure 30 can be seen the circuit on the breadboard.

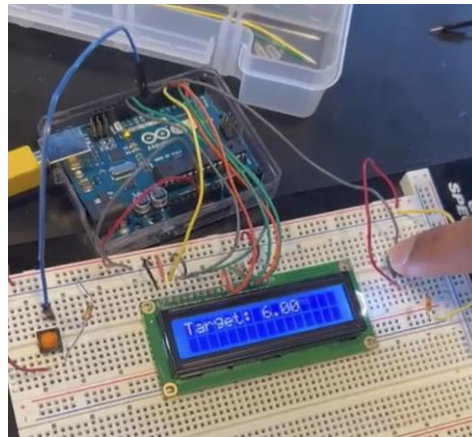


Figure 30. LCD and buttons test on a breadboard

The LCD worked properly displaying the phrase sent by the Arduino UNO, and the buttons changed the target pace by +/- 0.5 every time they were pressed. Once tested on the breadboard, they were connected to the PCB and tested there to see if there was any error. In Figure 31 can be seen a set of images showing the system working correctly.



Figure 31. LCD and buttons final test

Finally, the last part to test of this subsystem is the laser. To test the laser, it was simple since it just needs to be connected to a voltage supply. In this case it was connected to 5 V, and as can be seen in Figure 32, the laser worked as expected.



*Figure 32. Laser test*

### **7.3 CONTROL RESULTS**

Testing the Control subsystem was probably the hardest one, since the MCU can only be tested using the PCB. To do that it was necessary to solder the ATmega328 to the PCB and then check that all the connections were made correctly before turning on the power, since a short circuit between two legs could break the MCU. After checking that all the pins were connected properly and there were no shortcuts using a multimeter, it was time to burn the bootloader. This was made using the Arduino software and using the Arduino UNO as a USBasp programmer since the one that was provided in the laboratory didn't work properly. With the Arduino UNO the bootloader was finally uploaded on the PCB so that meant that the MCU it was flashed.



The second component of the Control subsystem is the GPS module. Since the SAM-M8Q didn't arrive, the one that was tested was the BN-280 module. This module was easy to test with the Arduino UNO, and furthermore, it could display the data on the computer. So, it helped a lot at the time to detect and solve problems like loss of connection. In Figure 33, there is a table of the data sent to the computer.

Sats	HDOP	Latitude (deg)	Longitude (deg)	Fix Age	Date	Time	Date Age	Alt (m)	Course ---	Speed from GPS	Card ----
****	*****	*****	*****	****	*****	*****	****	*****	*****	*****	***
0	100.0	*****	*****	****	00/00/2000	00:00:00	628	*****	*****	*****	***
0	100.0	*****	*****	****	00/00/2000	00:00:00	634	*****	*****	*****	***
0	100.0	*****	*****	****	00/00/2000	00:00:00	640	*****	*****	*****	***
5	1.3	40.114356	-88.226860	245	04/21/2022	20:56:00	375	365.70	0.00	0.09	N
5	1.3	40.114360	-88.226860	442	04/21/2022	20:56:01	559	365.50	0.00	0.04	N
5	1.3	40.114364	-88.226860	450	04/21/2022	20:56:02	566	365.40	0.00	0.02	N
5	1.3	40.114364	-88.226860	459	04/21/2022	20:56:03	575	365.40	0.00	0.02	N
5	1.3	40.114364	-88.226860	467	04/21/2022	20:56:04	584	365.40	0.00	0.04	N
5	1.3	40.114364	-88.226860	476	04/21/2022	20:56:05	593	365.60	0.00	0.06	N
5	1.3	40.114364	-88.226867	484	04/21/2022	20:56:06	600	365.80	0.00	0.07	N
7	1.2	40.114364	-88.226867	472	04/21/2022	20:56:07	589	366.00	0.00	0.02	N
7	1.2	40.114364	-88.226867	497	04/21/2022	20:56:08	613	366.00	0.00	0.07	N
7	1.2	40.114364	-88.226867	499	04/21/2022	20:56:09	615	366.10	0.00	0.06	N
7	1.2	40.114364	-88.226875	513	04/21/2022	20:56:10	629	366.30	0.00	0.06	N
7	1.2	40.114364	-88.226875	511	04/21/2022	20:56:11	627	366.30	0.00	0.11	N
7	1.2	40.114360	-88.226875	528	04/21/2022	20:56:12	645	366.50	0.00	0.06	N
7	1.2	40.114360	-88.226875	531	04/21/2022	20:56:13	648	366.50	0.00	0.04	N
7	1.2	40.114360	-88.226882	546	04/21/2022	20:56:14	662	366.70	0.00	0.30	N
7	1.2	40.114360	-88.226882	546	04/21/2022	20:56:15	663	366.80	0.00	0.89	N
7	1.2	40.114360	-88.226875	561	04/21/2022	20:56:16	677	366.80	0.00	0.37	N
7	1.2	40.114364	-88.226882	564	04/21/2022	20:56:17	681	366.00	0.00	0.24	N

Figure 33. GPS Data

The GPS was correctly tested with the Arduino uno as can be seen in Figure 33, where it can be seeing a variation of the speed and location. The next step was to test the GPS on the PCB. It should change the number of the second row that represents the actual pace of the runner in miles per hour. In Figure 33, there is a photo of the GPS working while the user is walking at 2 mi/hr, approximately. Note that on the code the speed is rounded to multiples of 0.5.



Figure 34. GPS test

This Figure 34 shows a user wearing the Pacer Runner while he is walking. In the top of the image can be seen what the runner sees when he is wearing the device. Clearly, the ‘Actual Pace’ is changing since the user is starting to run.

## 7.4 POWER RESULTS

The Power subsystem was easy to check since it was reduced to just one voltage regulator and a 9 V battery. A Keysight multimeter was used to measure the voltage on the 5 V voltage regulator, as can be seen in Figure 35. The regulator had an output volage of 4.53763 V that was significantly lower to the expected 5 V. Fortunately, the system could still work properly, since almost all the devices can work below 5 V, but as is going to be explained in the Project results section, the servomotor didn’t work as expected when the MCU sends a signal.



Figure 35. 5 V voltage regulator measurements

## 7.5 DEVICE DESIGN RESULTS

The device case had really good results thanks to the work of the Machine Shop. They assembled all the components together and adapted the case to the needs of the project. Furthermore, they attached the case with all the electronics to the vest and they did the proper holes to pass the wires. The results are shown in the next figures.



Figure 36. Front and Top view



*Figure 37. Lateral views*

Initially, the battery had to go on the back of the vest, but after receiving the vest, it was decided to hide the battery in the front pocket of the vest, so it is more accessible for the user and easier to replace the battery. The result is shown in Figure 38.



*Figure 38. Battery pocket*

## **7.6 SYSTEM RESULTS**

Once all the subsystems were tested separately, it was time to test the whole system together, and check if it worked properly. To perform the test, all the components were connected and the MCU was uploaded with the final code made by Aditya Singla and Mustafa Jamal. This code can be found in the Appendix B.

The result was disappointing, the whole system seemed to work but at the time of moving the servomotor, it didn't work as it should. Although everything worked properly by their own, when they were all connected to the PCB the system had issues. Specifically, the servomotor was the source of all the problems.

The problem was that when the servomotor received the order to change position, it did so but could not stay in that position. It would start to move uncontrollably once it had reached the indicated position. In the first instance, an attempt was made to solve this problem by changing the code, even adding an extra delay to avoid possible random noise, but this solution wasn't good enough.

### **7.6.1 INPUT VOLTAGE PROBLEM**

Then, after figuring out that the problem was not the code, it was decided to check if all the hardware components were working properly. It was then when there were found two main problems. The first one was that the servomotor is supposedly to work with a voltage between 4.8 V and 6 V. But measuring the output voltage of the 5 V voltage regulator, the voltage was below the 4.6 V as can be seen in Figure 34. This meant that it should be used a level shifter to increase that voltage. Furthermore, the ATmega328 pinout voltage is of 3.3 V that is also below the limit voltage of the servomotor.

To solve this problem, it was used the voltage source of the laboratory to provide the exact 5 V to the servo, and a 3 V to 5 V level shifter that can be seen in Figure 39. This level shifter was mounted on a small breadboard, and it was connected to the same power source as the positive wire of the servomotor to avoid extra problems.

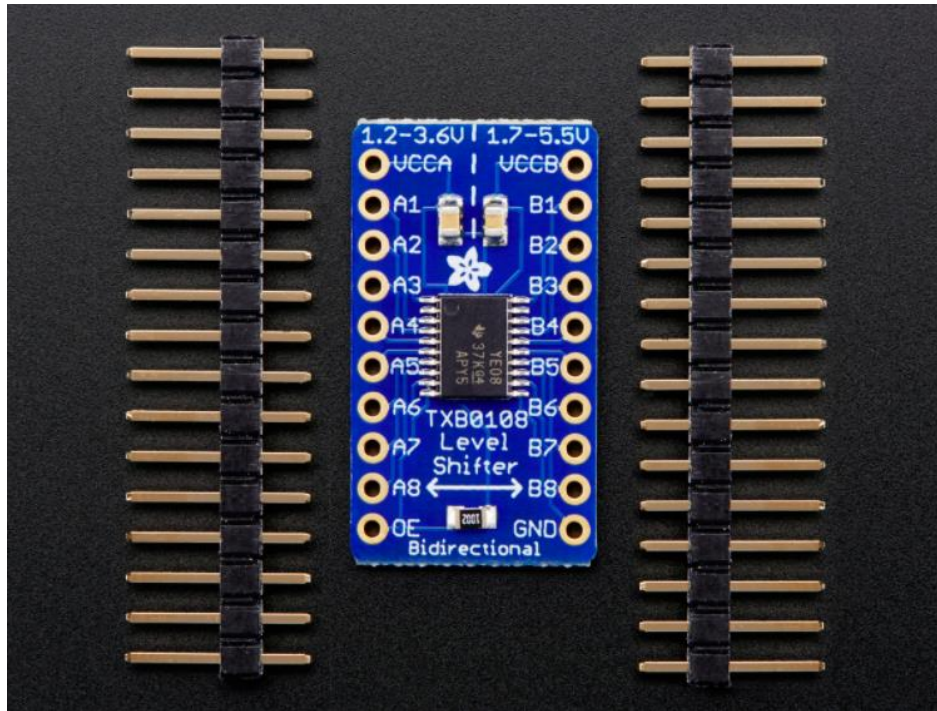


Figure 39. Level shifter used in the Project [26]

Once the breadboard circuit was mounted, it was connected to the rest of the system, and everything was tested again. Unfortunately, the servomotor didn't work as it should, even though there was a great improvement in its response. Now, due to the use of external circuitry as the breadboard, the noise in the system increased exponentially.

### 7.6.2 NOISE PROBLEM

This problem was critical since there was no time left to redesign the PCB and there were no short-term options to solve it. The noise came from mainly two sources. One was the external GPS that was really close to the servomotor and it produced interferences. In fact, when the GPS was disconnected the servomotor was stable in its positions, but when it was connected the servomotor started to make small random changes in its position.

The origin of this problem was in the design of the PCB since the wire of the servomotor and the wire of the GPS module were close and these actually cross at some point. The second source was the external breadboard, since adding external circuitry to the PCB is not the best way to avoid noise.

To sum up, the servomotor problem was determining factor in the failure of the project. Attempts were made to find a solution, but the time was too short to find the correct one, and ordering a new PCB with the proper changes was impossible due to the long shipping time. On the other hand, the other parts worked as expected, highlighting the correct functioning of the GPS. In conclusion, the project could have been achieved with a few more weeks to correct the servomotor problem.

## CHAPTER 8. PROJECT BUDGET

In Table 2 is shown the total cost of the project. Note that some parts are not included because they were available on the laboratory, or they were reused from another projects. This is the case of the resistors and capacitors used for the project.

Table 2. Total cost

S.No.	Part	Unit Cost	Quantity	Total
2.	Voltage Regulator- <i>LM1117DTX-5.0/NOPB</i>	\$ 0.78	1	\$ 0.78
3.	Microcontroller - <i>ATMEGA328P</i>	\$ 5.64	1	\$ 5.64
4.	Servo Motor - <i>HS-311</i>	\$ 13.49	1	\$ 13.49
5.	GPS Module - <i>Beitian BN-880</i>	\$ 31.50	1	\$ 31.50
6.	LCD Display - <i>Adafruit RGB Backlight 16x2</i>	\$ 8.58	1	\$ 8.58
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-520-28</i>	\$ 24.53	1	\$ 24.53
10.	Battery - <i>Energizer 9V Battery</i>	\$ 12.49	1	\$ 12.49
	<b>Total</b>			<b>\$ 94.78</b>

The total price of the project comes out to \$ 94.78. In this price is not included the cost in labor, that would significantly increase the cost of the project.



## **CHAPTER 9. CONCLUSION AND FUTURE WORK**

This is the last chapter of the memory, here are going to be explained the conclusions of the project, the technical skills developed, and the future work. Each part will have its own section where it will be developed in detail.

### ***9.1 CONCLUSIONS OF THE PROJECT***

As can be read throughout this document, the development of the product did not reach the expected result. However, this doesn't mean that the idea is unfeasible. As explained in section 7.6 System Results, the mistake was in the operation of the servomotor. That mistake was not difficult to solve doing some changes on the PCB like adding a level shifter converter and separating the servomotor from the GPS module. If the deadline would have been later, the final result of the project could have been another one, but the limited time was crucial to restrict the possible solutions.

Another key point is the device design. The prototype made had a great result and it met the established size and weight targets. On the other hand, it is possible to reduce even more the volume of the box and even the weight. This could be accomplished using a new PCB with all the components more compacted and saving the unnecessary pins or components like the 3 V voltage regulator, or the SAM-Q8M footprint that at the end were unused.

Lastly, the device is useful and can provide great benefits to the user, making his/her performance improve during the race. The device was easy to carry and more important easy to use, and it was also durable to be use in long runs which is what it was primarily designed for. The most complex part of the project that was the GPS module used to calculate pace work flawlessly. This allows the device to accurately calculate the runner's speed up to an accuracy of 0.5 mi / hr.

## ***9.2 TECHNICAL SKILLS DEVELOPED***

This project was crucial to learn about electronics and engineering in general. During the project, the different stages of an engineering project were developed, such as design, component assembly, or trial and error. This project also allowed the teamwork between engineers of different fields since one was an electrical engineer and the other two were from computer science. This situation demonstrated the relevance of teamwork and understanding the operation of the whole project, even if the engineer is only focus in one part of it. The coordination and cooperation between the members of the team made the project progress, and it was a key element to solve the problems that came across.

This project required a lot of technical skills, one of the most important was the design of the PCB. The PCB design required knowledge in the use of the KiCad 6.0 software, that was acquired in the first weeks of the project. Furthermore, it was not enough with just to know how to use the software, in addition, it was necessary to know how to design the circuitry of the device. This was the most import skill since the viability of the project depended exclusively on the correct operation of this electronic components. Moreover, it required the ability to solder the different electronic components of the project.

To sum up, this project required thinking outside the box to solve the problems that came up. It should be noted that not only did it take thinking of a good idea, but it was also necessary to develop it and choose the best way to achieve it. Furthermore, it was an unexplored path, full of challenges and problems that no one had before. This made it more complicated to find solutions to some problems, but it helped extrapolate solutions from other projects to solutions for this project.

## ***9.3 FUTURE WORK***

The product developed is still far away from the final product, many improvements can be made. In this section will be given some of them.

The first step would be to solve the servomotor problem, as can be read in previous chapters, there are some mistakes on the design that must be corrected. Once this problem is solved and the device is working properly, then it will be time to improve it. There are so many ways to improve it, one could be to add a Bluetooth modem and send the data to the smartphone. With this, the runner could have data of his/her performance during the race and the App could give him/her advice on his/her optimal pace. Another feature that could be added is a heart rate monitor, with this and some data of the user estimates of the person's optimal pace could be made.

What is more, since the laser may not be bright enough in high light conditions, a sound system could be added to warn the runner. This system could be deactivated and would be complementary to laser system.

To sum up, if the system is improved and the results are good, it could be a good idea to commercialize the product since it has a great potential to succeed among runners, especially among those who are more amateurs.



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## APPENDIX A. R&V TABLES

Requirements	Verification
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 600 mA +/- 50 mA. Since our device has an overall consumption of less than that amount.	3A. Connect the battery with a resistor of 10 Ohms.  3B. Measure the current using a multimeter to make sure that the current stays within 50 mA of 600 mA.

*Table 3. R&V of the Power subsystem*

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	1A. Set the target pace as 5 mi/hr using the



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

*Table 4. R&V of the Angle Control subsystem*

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

*Table 5. R&V of the Control subsystem*

<b>Requirements</b>	<b>Verification</b>
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.

*Table 6. R&V of the User Interface subsystem*

## APPENDIX B. CODE

```
#include <LiquidCrystal.h>

#include <Servo.h>

#include <TinyGPS++.h>

#include <TinyGPSPlus.h>

#include <TinyGPS++.h>

#include <SoftwareSerial.h>

static
const int RXPin = A3,
        TXPin = A0;
static
const uint32_t GPSBaud = 9600;

// The TinyGPS++ object
TinyGPSPlus gps;
SoftwareSerial ss(RXPin, TXPin);

int Contrast = 75;
const int incPin = A1; // pin 28 on mcu, top right
const int decPin = A2; // pin 27, below the top right
const int servoPin = 9; // pin 26
const int contrastPin = 3;

// Variables that change
float targetPace = 5;
float currentPace = 0;

int incState = 0;
int decState = 0;

// Servomotor variables
int pos = 0;
bool strike; // if strike, then change servo, otherwise consider warning
int currentAngle;

// variable for gps pace
int seconds = 0;
TinyGPSTime t1;
float spd1, spd2, spd3;
int counter = 0;
```

```
// Flags for logic
int decFlag = 0;
int incFlag = 0;

LiquidCrystal lcd(12, 11, 7, 6, 5, 4);
Servo motor1;

void setup() {

    // Set up Servo
    motor1.attach(servoPin);
    // pinMode(servoPin, OUTPUT);

    // Set up GPS
    ss.begin(GPSBaud);

    // Set up LCD
    analogWrite(contrastPin, Contrast);
    lcd.begin(16, 2);

    // Buttons
    digitalWrite(incPin, HIGH);
    digitalWrite(decPin, HIGH);

    // Variable for GPS Pace
    seconds = 0;
    spd1 = 0;
    spd2 = 0;
    spd3 = 0;
    strike = false;
    currentAngle = 0;
}

void loop() {

    // servoTimer --;
    // if(servoTimer < 0)
    //     servoTimer = 1000;
    lcd.setCursor(0, 0);
    lcd.print("Target Pace:");
    lcd.setCursor(0, 1);
    lcd.print("Actual Pace:");

    // checkButtonsAndUpdateLCD();

    // this function will be called based on what position we want to have our
    laser in
    // pos = servoAngle();
    // if(seconds == 0)
    //     servoMove(pos);
```

```
if (gps.time.isValid()) {

    if (seconds >= 2) {
        // update the reference time
        t1 = gps.time;
    }

    if (counter == 2) {
        spd3 = gps.speed.kmph();
        counter = 0;
    }

    if (counter == 1) {
        spd2 = gps.speed.kmph();
        counter = 2;
    }

    if (seconds == 0) {
        // we should calculate the average pace based on 3 previous pace values
        currentPace = averagePace();

        spd1 = gps.speed.kmph();
        counter = 1;
    }

    seconds = timeDiff(t1, gps.time);
}

// this function will be called based on what position we want to have our
laser in
pos = servoAngle();
// servoMove(pos);
if(seconds ==0 && pos != currentAngle){
    servoMove(pos);
//    lcd.setCursor(0,0);
//    lcd.print(pos);
}

    smartDelay(1000);
}

int timeDiff(TinyGPSTime & t1, TinyGPSTime & t2) {
    // t2 is future ALWAYS
    int t1_ss = t1.second();
    int t2_ss = t2.second();
    int t = 0;
    if (t1_ss > t2_ss) {
        t = 60 - t1_ss;
        t += t2_ss;
    } else {
```

```
t = t2_ss - t1_ss;
}

return t;
}

// for gps
static void smartDelay(unsigned long ms) {
    unsigned long start = millis();
    do {
        while (ss.available())
            gps.encode(ss.read());
        checkButtonsAndUpdateLCD();
        printPace();
    } while (millis() - start < ms);
}

float averagePace() {
    float pace = spd1 + spd2 + spd3;
    pace /= 3;
    pace = pace * 0.62;
    int paceINT = (int) pace;
    float paceDIFF = pace - paceINT;

    // round to nearest 0.5
    if (paceDIFF <= 0.25)
        pace = paceINT;
    else if (paceDIFF <= 0.75)
        pace = paceINT + 0.5;
    else
        pace = paceINT + 1;

    return pace;
}

// This Function Prints the Target and Ideal Pace on the LCD
void printPace() {
    if (targetPace < 0) {
        targetPace = 0;
    }
    lcd.setCursor(12, 0);
    lcd.print(targetPace);

    lcd.setCursor(12, 1);
    lcd.print(currentPace);
}

// Function that checks for button clicks, and updates LCD accordingly
void checkButtonsAndUpdateLCD() {
    incState = digitalRead(incPin);
    decState = digitalRead(decPin);

    // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
```

```
if (incState == LOW && incFlag == 0) {
    targetPace += 0.5;
    incFlag = 1;

} else if (incState == HIGH && incFlag == 1) {
    incFlag = 0;
}
if (decState == LOW && decFlag == 0) {
    targetPace -= 0.5;
    decFlag = 1;

} else if (decState == HIGH && decFlag == 1) {
    decFlag = 0;
}
}

// Servo-motor logic
void servoMove(int angle) {

    if (strike) {
        motor1.write(angle);
        if (angle == 45)
            strike = false;
    } else {
        if (angle != 45)
            strike = true;
    }
    currentAngle = angle;
}

int servoAngle() {
    float paceDIFF = targetPace - currentPace;
    if (paceDIFF == 0) {
        return 45;
    } else if (paceDIFF < 0) {
        // going fast
        return 27;

    } else {
        // going slow
        return 56;
    }
}
```



## **APPENDIX C. UN SUSTAINABLE DEVELOPMENT**

Pacer Runner is aligned with the next United Nations Sustainable Development Goals [27]:

- 1. Health:** Pacer Runner is aligned with the third goal since this project will help to improve the health of the users. This will prevent them from suffering illnesses like heart attacks or obesity. As can be seen in the study by the Journal of the American College of Cardiology [28], people who had run at least fifty minutes per week are less likely to die from cardiovascular disease.
- 2. Education:** Pacer Runner will help its users to find their optimal pace and improve their performances without the need for a personal trainer. That will suppose an increase in the number of people running because it will be cheaper than hiring a personal trainer.