Final Capstone Project Report: Force-Sensing Swimming Starting Block

Voltage Voyagers, **ECE 4440/4991** - December 6 2024

CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. STATEMENT OF WORK

1) Preston Borden

Preston was the test / integration lead for this project. He helped to make sure that connections between the project's subsystems were all in sync and dealt with the troubleshooting of those unions. Preston also worked on deploying the software application to the cloud using Amazon Web Services, as well as offloading the compute resources to the cloud. Preston was involved in creating portions of the software application's back-end/API in Django and Flask, and some of the front-end development work in React/JavaScript. Preston assisted in the procurement and manufacturing of the mechanical portions of the diving block apparatus.

2) Andy Chen
   Andy was the mechanical lead for this project, and led the design of the sensing system. This included researching and presenting options for force sensors, sensing surfaces, and mounting mechanisms. Andy presented multiple options for force sensors, and helped make the decision to choose an analog force sensitive resistor sensor based on it's scalable force resolution and humidity and head resistance. Andy then presented ways to translate force onto the sensors and proposed the mechanical design. Andy produced the CAD designs and worked with Preston to contact local and corporate vendors to get mechanical parts manufactured. Andy then helped with system integration to mount and integrate the electronics wiring with the mechanical system.
3) Liam Colbert
   Liam was electrical lead for this project, initially designing the two sensor PCBs to connect the MyRIO Microcontroller to the force sensitive resistors (FSRs) on the block. Once fabricated, Liam soldered the components to two of the sensor PCBs and fully tested each one to ensure functionality. When the sensors were able to send the analog voltage signal to the Microcontroller correctly, Liam worked on designing custom 3D printed mounting pieces to house the portable battery and PCBs within the water-proof enclosure. Liam then worked with Preston to mount the water-proof enclosure onto the block and wired the sensors to the PCB, completing the last of the physical mounting of components and ensuring all mechanical components were robust enough to support repeated use.
4) Meghana Guttikonda
   Meghana was the Software Lead for the project. She worked on designing and implementing a mobile application that would receive data recorded by the MyRIO so that the data can be viewed, recorded, and analyzed by the user. The front-end of the app, which is the interface the user interacts with, was created with the java script library React.js because of the simplicity in transforming a web application written with React to a mobile application. The backend of the application, which is where the databases are created and managed, was done using the Python framework Django. Django was utilized because of its simplicity and vast collection of resources. Together, these parts function together and with the MyRIO to provide a service that streamlines the collection of data. The web application was hosted using Amazon Web Services and will soon be downloadable from the Apple Store.
5) Samuel Knorr
   Sammy was the lead for the Microcontroller section of the project. He first determined which market controller worked best for the project and future considerations. Eventually landing on the NI MyRIO 1900, he moved on to configuring the controller and then writing the code. Sammy connected the controller to the hidden network to allow data transmission to the Web application. Additionally, he coded the controller so that it polled the Web app to determine when the force should be recorded. When the MyRIO detects that it should record, it measures the highest force and sends the data to the web app via HTTP requests when prompted by the application. After completing the coding portion, Sammy worked with Liam to mount it within the apparatus.

II. Abstract

In this project, we worked with a customer (Coach DeSorbo of the UVA Swim and Dive team) to design and build a custom training tool to gather information used to analyze a swimmers start from a starting block. The customer's specifications focused on determining the force exerted upon the starting block, with additional features such as data visualizations in graphical formats being implemented. The modified starting block was retrofitted with two arrays of FSRs that would measure the magnitude of force exerted on the front edge and back fin of the starting block upon a "go" signal coming from the mobile application that was built. When the "stop" signal was sent by the mobile application, the data was instantaneously displayed to the user. When the data is displayed, the options appear to keep or ignore the data. If the data is kept, it is saved to a specific user created profile. The mobile application also contains a database that stores information from previous trials for all created users with options for both table-formatted and graphical viewing options to display all recorded data.

III. Background

Accurate data measurement is essential in sports science for performance analysis, injury prevention, and training optimization. Modern athletics depends on precise metrics to refine techniques and enhance competitiveness, especially in swimming, where milliseconds matter. This project addresses these needs by creating a custom training tool for the UVA Swim and Dive team. The system measures the key parameter, force exerted and during starts, enabling reliable and user-friendly data collection. This highlights technology's growing role in advancing sports performance through evidence-based training.

Coach DeSorbo approached the Electrical and Computer Engineering department to design a custom training tool modeled on features from commercial devices. Through a competitive proposal process, the Voltage Voyagers team was selected, motivated by a shared background in competitive swimming and a passion for contributing to the UVA community. Collaboration with mentors like Professor Ono and Coach DeSorbo inspired the team to deliver a tailored solution.

The project drew inspiration from existing devices, including a starting block with piezoelectric force plates for biomechanical analysis and a device with dual front/back force plates and a pool wall force plate for start and turn measurements. The first was one that Coach DeSorbo had initially wanted us to recreate, consisting of a starting block and turn plate with individual piezoelectric force plates to separately measure the force from each hand and each foot, alongside with five high-speed video cameras for a biomechanical analysis of the kinetic and kinematic information [1].

The second device was one we found in research of prior art, similarly consisting of Dual front/back force plates analyze individual feet separately and a submersed pool wall force plate to measure backstroke start and turns. This device was more focused on gathering force information from both starts and turns as opposed to incorporating the high-speed video cameras like the previous design [2].

Our project stands out from existing commercial training tools with its customized design and features tailored to Coach DeSorbo's specifications. It utilizes strategically placed force plates on the starting block's front edge and back fin to measure critical forces, sending analog voltage signals for precise data capture. The system also includes a custom database for swimmer-specific performance tracking, enabling detailed analysis through visual and tabular formats. Completed on a tight budget and timeline, the tool prioritizes the coach's key objectives, offering practical and targeted insights to enhance the UVA Swim and Dive team's performance.

A. *Relevant Coursework*

TABLE I: LIST OF COURSEWORK UTILIZED

Course	**Skills/Knowledge Applied**
Fundamentals of Electrical Engineering I, II, and III	Circuit design and analysis used to develop the PCB
Software Development Essentials	Web-application and database development
Introduction to Embedded Systems	Microcontroller configuration
Data Structure and Algorithms	Database design

IV. Project Description

A. *Performance Objectives and Specifications*

Our project can be broken down into four subsystems that all must be properly tested. The first subsystem is the Software. The software portion has a front-end portion responsible for displaying information to the user and handling user input, a back-end portion that is responsible for processing HTTP requests from the MyRIO and user, and the cloud portion that hosts the entire web-application and handles the security of the application. The next subsystem is the Microcontroller which is the National Instruments MyRIO. Next is our PCB System that processes the force values generated by the sensor arrays, and the final system is our Mechanical portion (Dive Block structure) which is what the swimmer pushes off of.

The project starts at a mechanical level with a swimming starting block. These blocks adhere to strict NCAA requirements for competition, but for training purposes in a non-competition setting, we do not need to fit all shape and form requirements [3]. Great care was taken to ensure the design was as similar to a normal starting block as possible, with the objective of not making a noticeable difference in the feel of our training block and the typical starting blocks. The block also had to be fitted in a grip tape that was course enough to provide traction for the athletes, while also not causing injuries to any part of the swimmer.

The secondary part of this project is the software application and user interface for the customer. The group wanted the design to be user friendly and simple to understand due to the fact that athletes would want to get as many reps in as possible. A confusing design would lead to difficulty in resetting the application for the next swimmer. The Magnitude Recorder page will show the maximum force read by the MyRIO during the time the swimmer reacts to the starting signal. The coach can enter the athlete's name so the data can be recorded and stored into a database table that holds previously captured data of the swimmer's force off the block. The Swimmer Stats page will allow the athlete and the coach to analyze the athlete's progress overtime by collecting data from the database table associated with the athlete's name and output helpful statistics that will make the data more readable. The backend of the application will be linked to a database with tables that are associated with each of the inputted athletes names. This will make it easy to access previously recorded data so that it can be used for various functionalities that will provide performance feedback to the athlete and coach.

B. *System and Component Designs*

1) *Electrical*

Both the front edge and the back fin of the block were retrofitted with an array of 10 configurable force sensitive resistors (FSR) designed to take an input of 0-90 Newtons. This range was experimentally determined through a trial-and-error process and testing. Increasingly larger amounts of force placed upon the sensor cause the resistance to decrease, which increases the output voltage in a simple operational amplifier negative feedback loop (seen Fig. 1) in connected to each sensor. The 10 analog voltage signals were then all sent to a summing amplifier with $\frac{1}{2}$ gain (to limit output voltage in worst-case scenario) which was then connected to the input of the MyRIO Microcontroller.

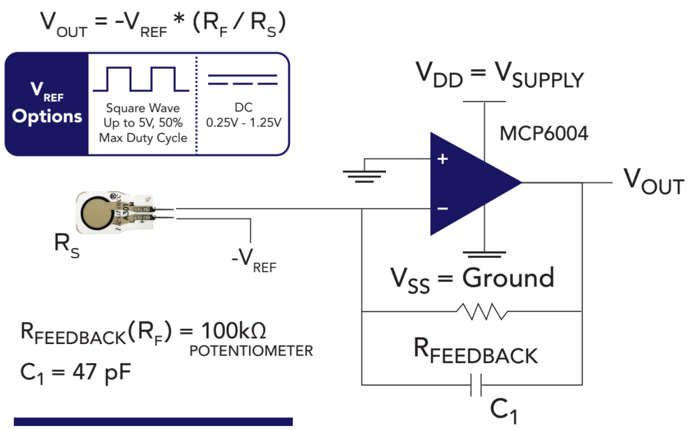

Fig. 1: FSR Feedback Configuration Circuit

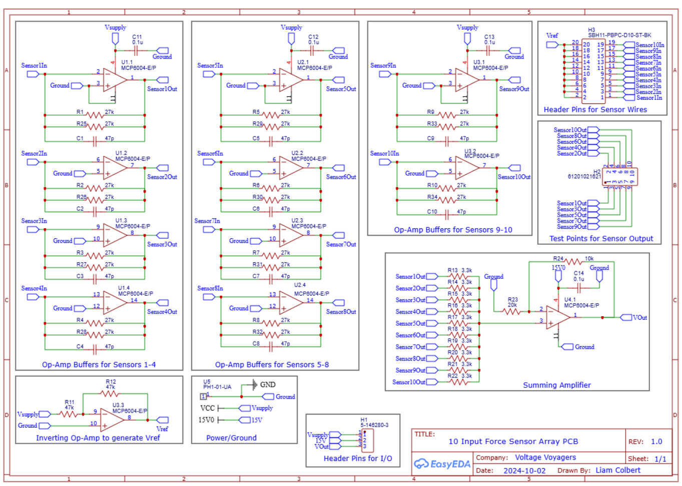

Fig. 2: PCB Schematic for 10-Sensor Array

Two Printed Circuit Boards (PCBs) were designed, each to take 20 input leads (positive and negative terminals of each sensor) which would then feed into the summing amplifier and have an output port to connect to the Microcontroller. In addition, the PCB needed power inputs, specifically a 1V, 10V, -1V, and GND pin. All of these power supplies came from the Microcontroller to simplify the powering system for when the block is in use on the pool deck. The schematic for the PCB can be seen in Fig. 2 while the layout can be seen in Fig. 3

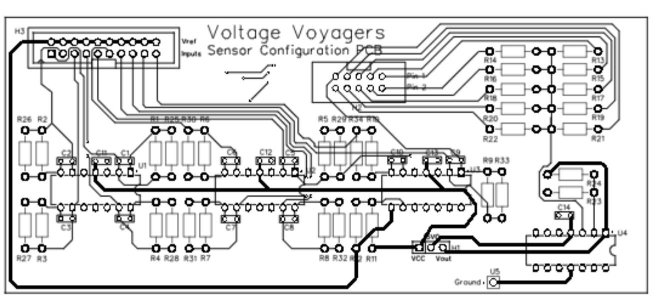

Fig. 3: PCB Layout for 10-Sensor Array

The electrical components can be simplified into the system flowchart shown in Fig. 4 that demonstrates the connections between the sub-systems.

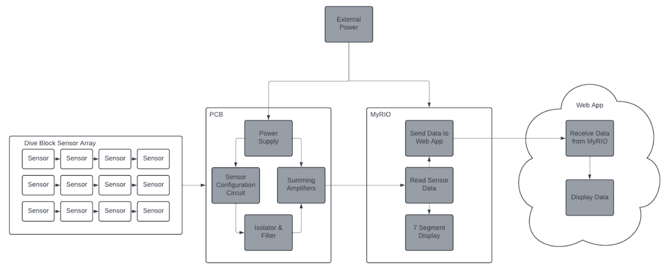

Fig. 4: Systems Flow Diagram

2) *Mechanical*

Mechanical Design:

The mechanical portion of our system involved designing the physical surfaces that swimmers would interact with to get force data to our sensors. The priority is to seamlessly integrate these sensing surfaces into the start block so that swimmers feel little to no difference in the integrated training block from the normal NCAA standard block. Designing the surfaces presented challenges: mounting the surfaces without detracting force, maintaining rigidity and stability, and including the adjustable fin.

We addressed these problems by splitting our surface into two regions. The first surface represented the front of the swim block that swimmers put their hands and one foot on to propel themselves forward seen in Fig 5

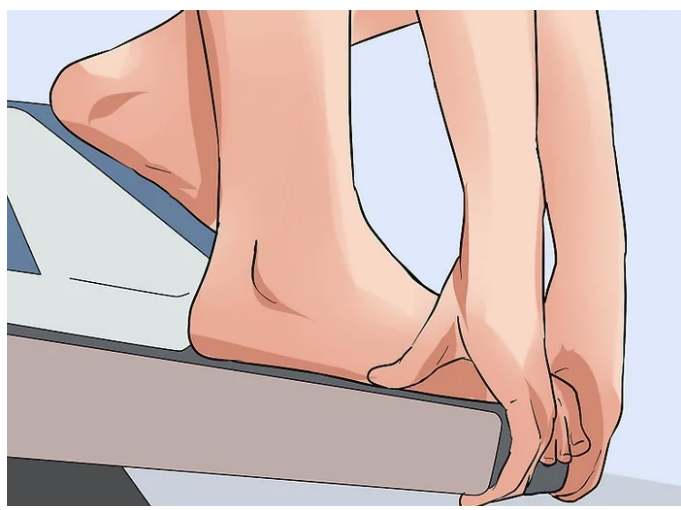

Fig. 5: Front Start Position

The front portion is designed as a rectangular prism surface that slots into the front of the starting block where it presses against the front sensors. The top and bottom lips prevent the surface from shifting up and down. Two metal tails slide along the sides of the block and is mounted with screw that prevents the piece from sliding off the the block, but gives it room to move backwards from a force exertion.

The second surface represented the back fin of the swim block that swimmers use their other foot to push off of seen in Fig X 6

Fig. 6: Back Start Position

This piece is a rectangular slab that sits on the sensor arrays on the fin, and is mounted via metal hook tabs, and bolts that keep the surface stable.

Mechanical Construction:

We chose to construct our two sensing surfaces with 5000 grade aluminum. Aluminum was chosen because of its high machinability, high humidity and corrosion resistance, and high rigidity to weight ratio. This choice was highly applicable since we needed to machine complex parts, perform in humid environments, and be lightweight and robust to be placed on the sensors.

For our Back Fin Plate, we reached out to multiple vendors and manufactured the part through a sheet metal process. This process involves cutting a sheet of aluminum to our specification and bending the aluminum under heat to match the design.

For our Front Plate, the part was too complex to submit a CAD file to a manufacturer. We decided to go with two different method to have options to fit our system. Our team reached out first to the Department Mechanical and Aerospace Engineering to produce our front sensing surface. Our approach was to create modular pieces that could be connected with screws. This required us to break down our front surface into three parts with threaded through holes that lined each piece together. We purchased a 90 degree aluminum corner to implement the top and front portion, and slabs of aluminum to create the side tails and bottom surface. This can be seen in Figures 7, 8, and 9

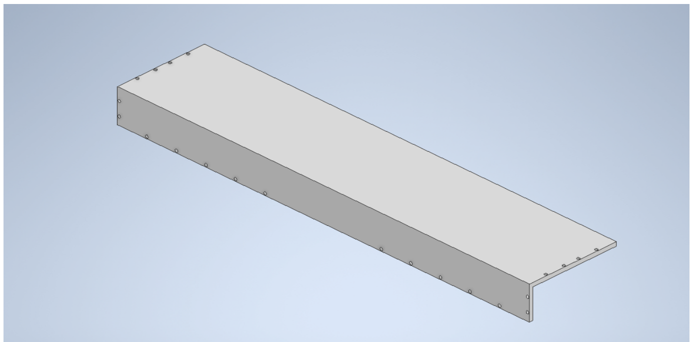

Fig. 7: Back Start Position

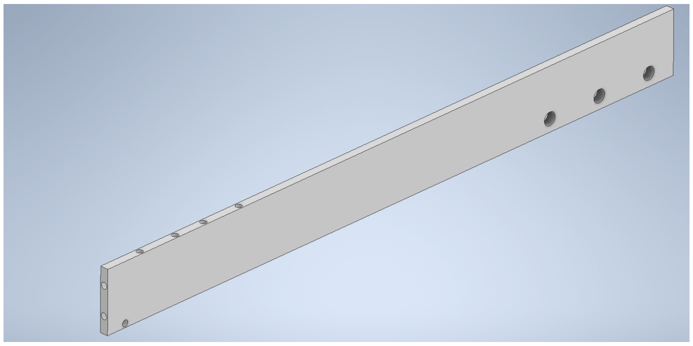

Fig. 8: Back Start Position

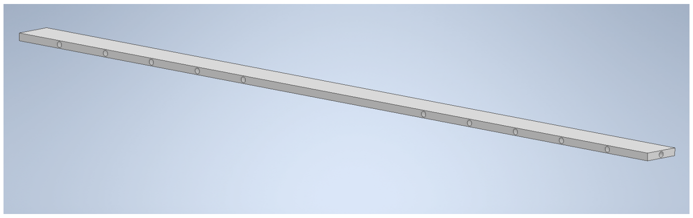

Fig. 9: Back Start Position

We also reached out to a local welder that used a similar construction method with laser cutting aluminum to specification, then welding the components together to make a finished piece.

3) *Microcontroller*

The National Instruments myRIO-1900 is a portable reconfigurable I/O (RIO) device that students can use to design control, robotics, and mechatronics systems. The NI myRIO-1900 provides analog input (AI), analog output (AO), digital input and output (DIO), audio, and power output. The NI myRIO-1900 connects to a host computer over USB and wireless 802.11b,g,n.[4]

The Microcontroller is the link between the analog sensors and the digital web app. It supplies the voltages that drive the PCBs and reads the resulting force values from them. Additionally, the controller polls the web app and listens for when it's told to record and send data to it. Once the user clicks record on the web app, the Microcontroller reads this change and begins to record the maximum force from the sensors. Once the user then stops recording, the

MyRIO detects the update and sends the force data to the web app. Fig.10

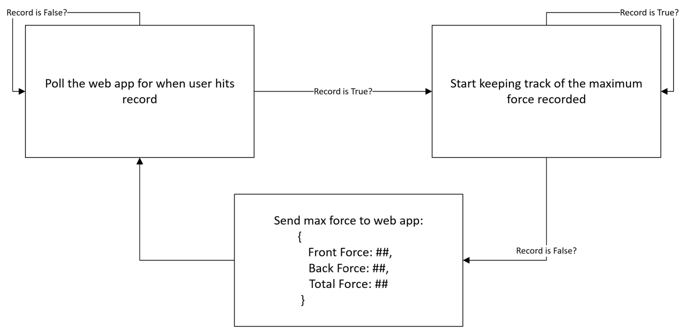

Fig. 10: MyRIO Flow Diagram

4) *Software*

The software application was designed to provide an intuitive and functional interface that facilitates efficient swimmer performance tracking. Its core features are streamlined to ensure ease of use while integrating seamlessly with the physical components of the system. Thus, to map out the design of the application, multiple wire frame designs, which are essentially high level layout of each page of the application, were created before settling on a simple, yet effective design approved by Coach DeSorbo shown in Fig. 11. The three key features and functionality of the software application are listed below.

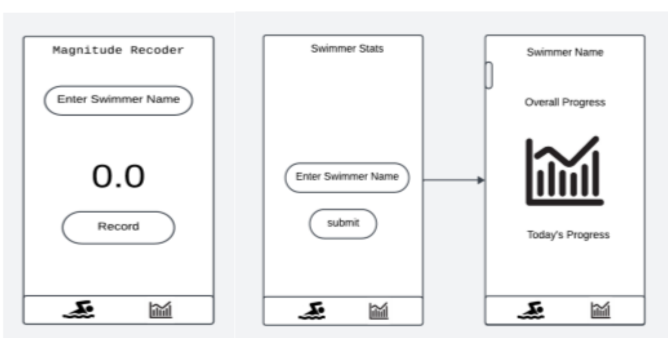

Fig. 11: High Level Application Design

As shown in the Fig. 11, there are 3 main components of the application – the swimmer registration page, the force magnitude recorder page, and the swimmer progress page.

Swimmer Registration: The Swimmer Registration page allows a coach using the application to log a swimmer into their program so that he or she can keep track of all the swimmer's recorded starts. The functionality on this page is simple - the user will just enter in the swimmer's name, year of graduation, and whether or not they are active. These metrics are preliminary metrics that can help keep track of the swimmer's in a more systematic format. When a swimmer name is submitted on the application page, the data that was submitted is sent back to the Swimmer table stored in the backend so that it can be retrieved when needed. An improvement to the registration page, that is not pictured in the wire frame, is the inclusion of an update option for updating existing swimmer data. This is essential in the case where the coach might've hastily entered a swimmer's information incorrectly or needs to update the information for each swimmer at the beginning of a new season. This is one of the many additional features that were added onto the original wire frame once receiving more feedback from Coach DeSorbo, the computer and electrical engineering faculty, and peers.

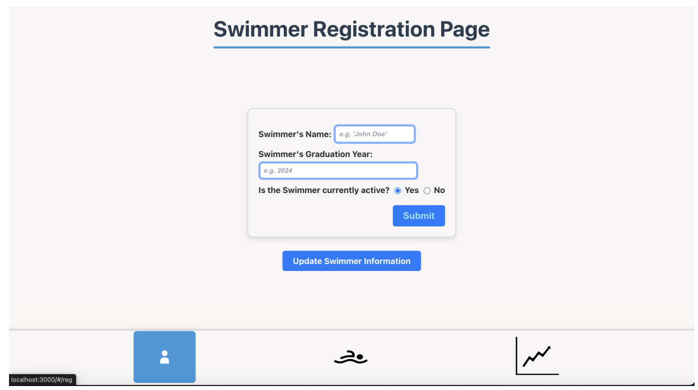

Fig. 12: Swimmer Registration Page

Force Magnitude Recording: The Magnitude of Force Recorder page functions with the Microcontroller to produce real-time results for the magnitude of force exerted by the swimmer on their dive. It pulls and sends data to the Microcontroller through a Flask app. The Flask app acts like a middleman between the software application and the Microcontroller and helps fulfill two functionalities. The first functionality is sending start and stop signals from the software application to the Microcontroller. Start signals should be sent to the Microcontroller when the 'Start' button is clicked on the recording page. Once the 'Start' button is clicked, a value of 'true' is posted to a text file located on the Flask app that will be read by the Microcontroller. This is what starts the recording of data with the Microcontroller. When the coach wants to stop the recording, suggesting that the swimmer has completed their dive, he or she will click the 'Stop' button, which will post 'false' on the same text file. Once the Microcontroller reads this command, it will stop recording. Additionally, it is important to note that once data in the text file is read by the Microcontroller, it is deleted from the file to ensure that confusion that can by caused by multiple values being stored to the file is eliminated. The second functionality that is assisted by the usage of the Flask app is posting data that has been collected by the Microcontroller to the recording page.

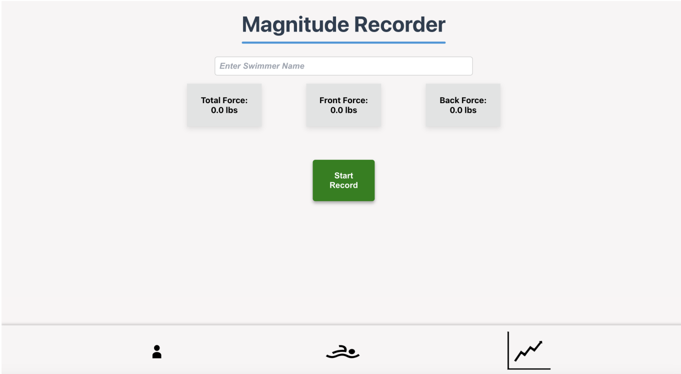

Fig. 13: Magnitude Recorder Page

Performance Tracking: The progress page enables coaches to monitor swimmer performance over time. This includes accessing historical data and visualizing progress to make informed training decisions. Coaches are able to visually understand the swimmer's progress overtime through the implemented chart feature. Additionally, an "export to excel" allows coaches and data analysts to view and analyze data in an excel format.

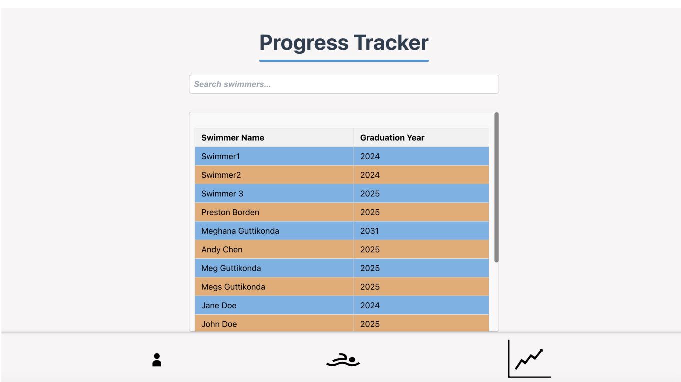

Fig. 14: Progress Tracker Page

The application was hosted on AWS to utilize capabilities of the cloud so the app can be accessed by non-local users. This allows the application to be accessible to anyone who is given access permissions.

C. Technical Details

The block was modified to support an array of sensors placed between custom aluminum plates and the surface of the starting block to measure the force magnitudes of both the hands and feet of a swimmer on the front lip of the block, as well as the back foot on the fin (see Figures 2, 3). These sensors need to be able to measure sustained forces up 1200N [5]. We chose a sensor, the FlexiForce A301 for its ability to a wide range of forces from 4N to over 4000N [6]. This configurability combined with its high humidity and temperature resistance make a perfect, robust candidate for a high action high force application.

Two custom-designed aluminum pieces were manufactured in order to provide a covering over the sensors to both protect them from water splashes and to direct the force from the surface onto the sensors. The CAD design for the Back fin is shown in Fig. 15 while the CAD design for the Front Edge Sleeve is shown in Fig. 16.

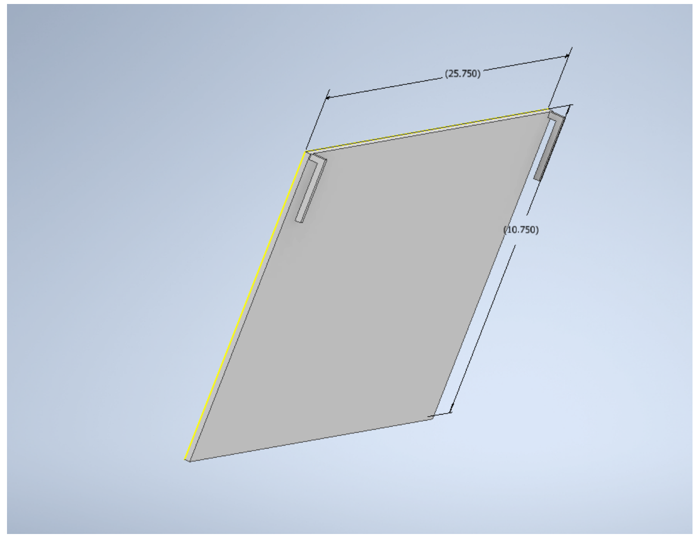

Fig. 15: Aluminum Plate for the Back Fin

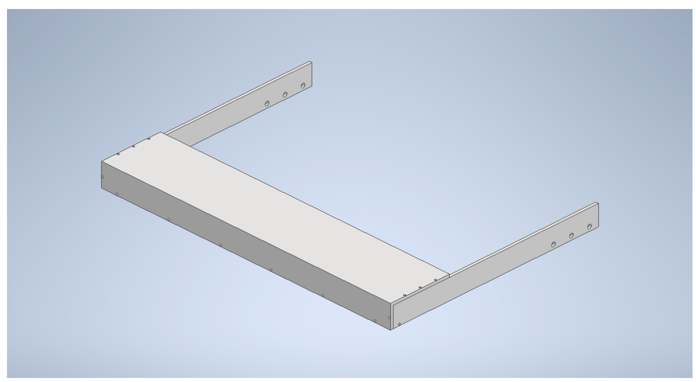

Fig. 16: Aluminum Sleeve for the Front Edge

Each sensor was attached to the underside of the aluminum pieces using a high-quality industrial adhesive tape. The image of the sensor array being attached to the Back Fin can be seen in Fig. 17. On the outward facing side of each sensor a piece of high tensile-strength rubber that was used as a spacer to prevent the plate from resting upon the existing block and give the wires room to run out the far end of the block. A similar process was performed for the front sleeve as seen in Fig. 18

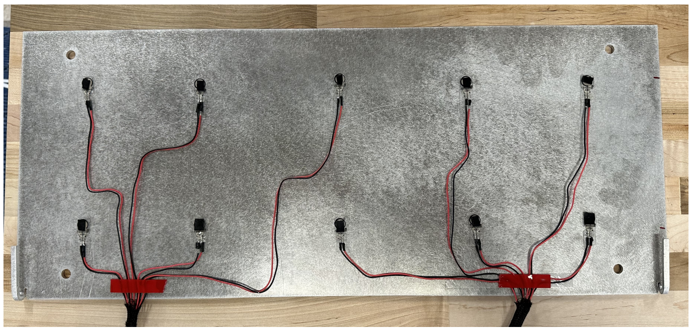

Fig. 17: Sensor Array attached to the Back Fin

Fig. 18: Sensor Array attached to the Front Edge

Each of the sensors had a red and black wire, for the positive and negative terminals respectively, which were connected into a ribbon cable snap connector that plugged into the PCB. The soldered and tested PCB can be seen in Fig. 19. As seen in this figure, there are empty resistor connections that were intentionally left blank. These extra resistor positions were designed with the intention making it easier to change the resistor values by simply installing new resistors and cutting the old ones. The feedback resistor is crucial to determining the force range of the sensors, which was entirely done experimentally due to a lack of an accurate force measuring and benchmarking device to test these sensors. The original testing to determine what range would be necessary was done with an 11lb handheld force sensor in combination with a slow-motion camera to plot the voltage outputs at given force inputs (3lb, 6lb, 10lb) and then plotting a line of best fit to determine the maximum force that could be determined from the sensor with the given resistor. An example of this calculation is shown here in Fig. 20

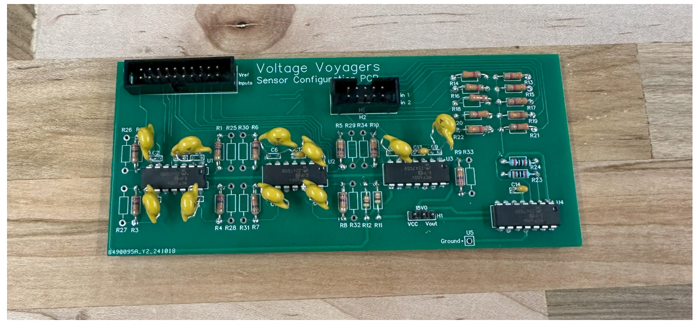

Fig. 19: Soldered and Tested PCB

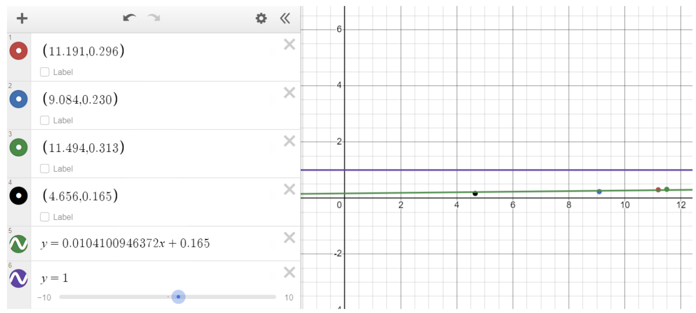

Fig. 20: Scaling Factor Determined from Line of Best Fit

This method of determining the scaling factor was highly imprecise and inaccurate, but was used just as a benchmark to ballpark the resistor values we would end up needing. When the Back Fin aluminum plate arrived and we were able to perform testing on the block, it was determined that the resistor range was too small, so 100K resistors were soldered in into the intentionally blank spaces with the already-installed 180K resistors to create a parallel value of 64.285K for the feedback resistors. When tested in combination with the Microcontroller, we were able to place a 20lb weight on the sensor and adjust the scaling value digitally until we accurately read a 5lb, 10lb, and 20lb dumbbell on the sensor. This gave a final range of 0-30.14 lb-force per sensor or a total of 301.4 lb-force for each of the two arrays.

To house the wiring and electrical components underneath the starting block and ensuring that the housing unit would be water-proof, a 14”x12”x7” acrylic box was purchased and mounted to the underside of the starting block using L brackets and screws. Re-sealable Velcro straps were purchased and adhered to the closable lid section of the block to ensure a water-proof seal when closed. Two mounting pieces were 3D printed to provide an obvious location to place the battery within the house, and to hold the 2 PCB boards. Since the block is expected to be used in forceful, repeated motion, the upmost care was placed into these designs to ensure no components would become loose. The MyRIO Microcontroller was mounted to the ceiling of the box using #3 metric screws, and a screw-terminal bus was installed in the back portion of the block since the power signals coming from the Microcontroller needed to be split to go to both PCBs. An image of the CAD design of the enclosure can be seen in Fig. 21 and the finalized physical version can be seen in Fig. 22.

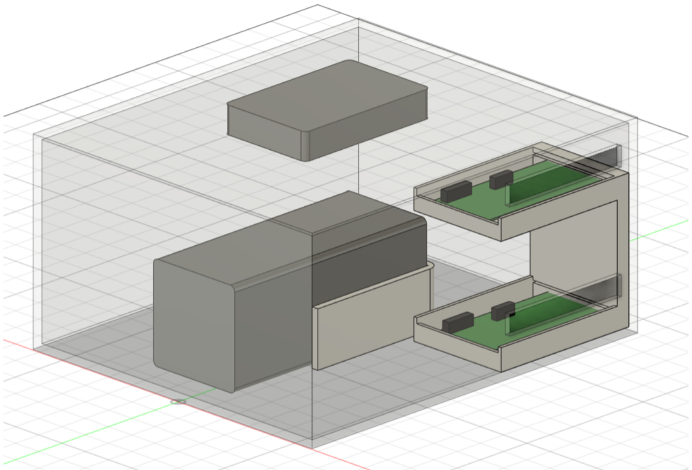

Fig. 21: CAD Design of Water-proof Mounting Enclosure

Fig. 22: Final Water-Proof Mounting Enclosure

The bottom PCB is connected to the Back Fin while the top PCB is connected to the Front Sleeve. The wiring diagram for the Screw Serial Bus can be seen in Fig. 23. The wiring diagram for the Microcontroller can be seen in Fig. 24. PCB1 refers to the top PCB which connects to the front sleeve while PCB2 refers to the bottom PCB which connects to the back fin. Refer to Fig. 26 and Fig. 25 for the official NI MyRIO documentation on these ports. All wiring was done with solid-core green wiring due to the availability of it within the NI lounge and its physical sturdiness. For the two wires connecting to A2 and A4 on as seen in Fig. 25, both cables are yellow due to availability but the yellow cable wrapped in black electrical tape connects to A4 while the cable without any tape connects to A2.

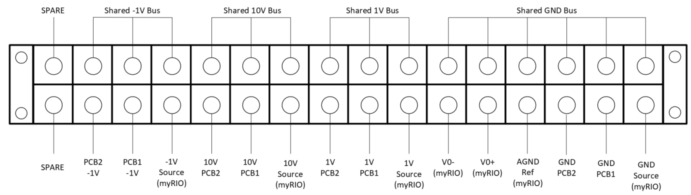

Fig. 23: Screw Terminal Wiring Diagram

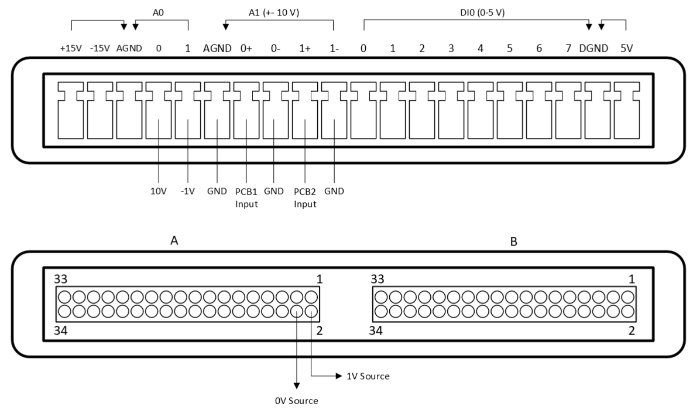

Fig. 24: Microcontroller Wiring Diagram

When choosing which controller would work best with the project, its CPU power, IO connectors, and future-proofing were considered. This led to the selection of the MyRIO 1900. It had the computing power required to consistently read the signals. Additionally, using a more powerful controller allows for future designs to be added to the project. Future capstones may add video processing because of the MyRIO. Finally, the abundant IO connections allowed for the Microcontroller to be the power source for the two PCBs. All of these factors made the MyRIO the ideal choice. The Microcontroller fits into the overall design as the middleman between sensors and the web app. The controller also provides the voltage required to run the sensor PCBs. A 10V, 1V, and -1V signals are produced and connected to both sensor arrays. Additionally, the ground reference is produced by the MyRIO. One challenge that we discovered during testing, was that the -1V supply was dropping to -.58V when the PCBs were connected. This happens because the PCBs are pulling more current than the Microcontroller can supply. The MyRIO is limited to a 2 mA current drive which causes this discrepancy in voltage. The result of this is that the sensors are maxing out at 30 lbs instead of 50 lbs. However, because there are 10 sensors on the front and 10 on the back, this impact is not detrimental to the project. The 10V, -1V, and 1V signals are produced via pin AO0, AO1, and A2 respectively. The outputs of the sensor arrays are then read through the AI0+ for the back array and AI1+ for the front array. Both AI0- and AI1- are connected to ground along with the AGND pin. Fig. 26 The 0V ground reference is produced by pin A4. Fig. 25

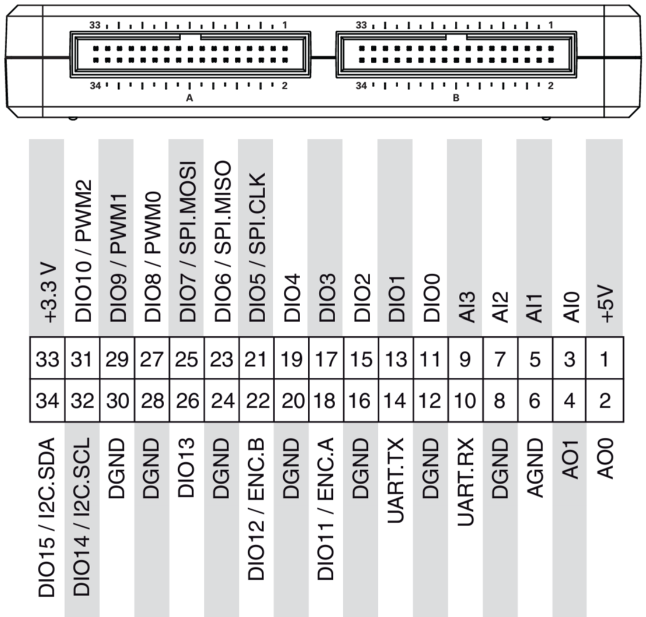

Fig. 25: MyRIO MXP Connectors A and B

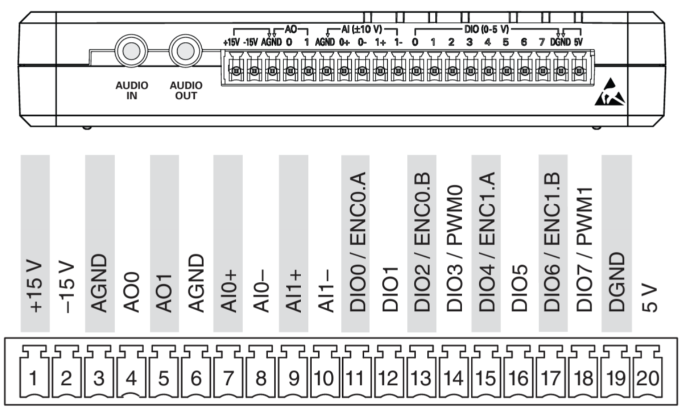

Fig. 26: MyRIO MSP Connector C

With the analog sensors being read, the voltages can be manipulated into actual force data. This is done by multiplying the voltage by 541, the scaling factor which converts the analog voltage signal to lbs-force. All of the Microcontroller code for the MyRIO is written in LabView, NI's proprietary coding language. The connection between the Microcontroller and the web app is made via HTTP requests. The Microcontroller polls the website every 500ms to see if the user wishes to record a dive. Once the Microcontroller detects a true value, it starts to read the sensors and keeps track of the greatest total force applied. Once the user hits the stop recording button on the software, the Microcontroller detects that false value and sends the front and back forces to the web app via a JSON package in a separate HTTP request. The MyRIO is connected to UVA's hidden network, the wahoo network. This was necessary as the network functionality is required to send and receive data from the web app. Since the Microcontroller cannot pass security checks beyond a password, the existing eduroam and guest networks were not viable. After it sends this data, the Microcontroller then idles until it is told to record again.

D. *Test Plan*

Because of the multitude of unrelated subsystems, there was a need to test both the individual systems and the entire system separately. Some subsystems required more testing than others and this section will first describe the individual testing measures taken for the subsystems and then the debugging procedure the group went through for final integration and testing.

Electrical Subsystem - The PCB required the most testing of any of the subsystems due to the nature of PCBs and physical hardware. The first step was to test the functionality of the PCB which was achieved in multiple steps. The first step was soldering on each of the components in sub systems, starting by testing all of the power supplies and then putting in all of the op-amps, feedback resistors, and capacitors to test that each individual sensor circuit worked. This was accomplished with test pins that were placed on the outputs of each of the sensor circuits before they were summed together. Once that was fully confirmed, the resistors for the summing network were added and that was tested and confirmed. Once functionality for each individual sensor was confirmed, a test using 3 sensors was done to ensure each signal was recognized and positively added to the total force when pressure was simultaneously applied. With all aspects working, the PCB was confirmed to have functionality.

Mechanical Subsystem - The Mechanical system did not have much testing due to the nature of physical installation and mounting. Dimensions for the fin and front sleeve were confirmed with machinists and several versions were made until one was satisfactory to both the group and the machinists.

Microcontroller Subsystem - The Microcontroller troubleshooting was mostly done with the assistance of the NI support team and individual research. Testing the web app connection was done by sending repeated post requests to the web app for 10 minutes and ensuring the expected results were observed. For instance, the MyRIO read that the record force button had been hit. Testing the MyRIOS polling of the max force was done by letting it run for 15 minutes and ensuring that the low-pass filters were stopping any noise. Additionally, the controller's CPU usage was observed at all points to make sure it was staying below 75%. Finally, unit testing was done to test individual sections of code. For instance, the HTTP polling section was tested while disconnected from the rest of the code. I used an LED indicator to make see that the post requests were being sent when desired. Finally, the max force recording code was tested by hard-coding a true value in place of the HTTP polling code. This allowed me to simulate the record button being clicked and test the behavior accordingly. This resulted in the max force correctly being stored and then sent when a false value was set.

Software Subsystem - To test the front-end portion of the software subsystem we had to test each individual page on the application and ensure it ran as intended without any errors displayed on any of the web pages. We also checked that the front-end application was displaying the correct data for any given swimmer. The back-end was concurrently tested by entering in fabricated information on the front-end application and submitting it onto the back-end and ensuring this data was populated into the database hosted on Amazon Web Services. The Cloud portion of the software was tested by using secure shell to log onto the Elastic Cloud Compute (EC2) hosting the web server and ensuring that it was running. We also tested whether it was accepting traffic from the allowed IP addresses and on the specified ports using HTTP requests.

Entire Integrated System - To begin testing the integrated system, power on the bank supplying energy to the Microcontroller. After approximately 15 seconds, the Microcontroller (MyRIO) should display three illuminated blue lights. These lights indicate a successful connection to the web application and readiness to receive data. If the MyRIO does not display the lights or shows an incorrect sequence, unplug and reconnect the power supply, then wait at least 30 seconds before rechecking the lights. If the issue persists, connect to the MyRIO using a laptop on the ”Wahoo” network and open LabView. In LabView, connect to the MyRIO and verify that it is functioning properly.

Once the MyRIO is confirmed operational, navigate to the ”Magnitude Recording” page in the web application and enter a registered user name. If no names are available, use the ”Registration” page to create a user. Return to the ”Magnitude Recording” page, press the ”Start Recording” button, and apply force to either the front or back sensing interface of the diving block. After releasing the pressure, press the ”Stop Recording” button and verify that the displayed force data is realistic. If the displayed forces are inaccurate or fail to appear, troubleshoot potential issues with the MyRIO, PCB, or web application.

To ensure the Amazon Elastic Compute Cloud (EC2) instance running the web server is active, execute an HTTP request in a shell. If there is no response, log into the AWS account to verify the operational status of the EC2 instance. If the EC2 instance is functioning correctly, the issue likely lies within the Microcontroller or the PCBs.

To verify the PCB and Microcontroller connections, first check that the MyRIO is supplying the correct voltages to the PCBs. Use a multimeter to test the voltage bus pins at the back of the enclosure. Refer to the wiring diagram (Fig. 23) to confirm the correct pin configuration: the leftmost pin should be disconnected, followed by three pins at -1V, three pins at 10V, three pins at 1V, and six pins for ground. After confirming the voltages, ensure that the ribbon cables are securely attached to the PCBs and that the sensors are correctly wired into the ribbon cables.

V. Physical Constraints

Several physical constraints were carefully considered during the development of this project. The primary constraint was the potential interaction between water from the pool and critical systems. To address this, all wired connections were secured with heat shrink tubing, and all cables were insulated to prevent water ingress. Key components, including the PCB and Microcontroller, were housed in a plastic, water-resistant enclosure to ensure protection from moisture. Similar waterproofing approaches have been highlighted in prior work, emphasizing the importance of robust sealing for electronic components in aquatic environments [7].

Another critical constraint was the risk of corrosion from pool water affecting the metal surfaces that swimmers push off to transfer force to the sensors. To mitigate this risk, aluminum was selected over steel for all metal surfaces due to its superior corrosion resistance. These surfaces were further wrapped in a ”non-slip,” slightly abrasive material that resists corrosion while providing swimmers with sufficient traction to generate force. This choice aligns with corrosion-resistant material studies that advocate for encapsulation methods to protect sensitive electronic components and structural elements from harsh environments [8]. Importantly, this material retains its non-slip properties even when wet, ensuring safety and reliability for users. Additionally, all screws and fasteners were made from corrosion-resistant materials such as zinc and aluminum.

The weight and rigidity of the mechanical components were also carefully analyzed. Heavier, more rigid materials could exert excessive pressure on the sensors, hindering accurate force transfer, while lighter, more flexible materials risked bending or breaking under high forces. An optimal balance between weight and durability was achieved by selecting materials that maintained structural integrity without compromising sensor performance. Finally, the size and shape of the diving block influenced the design of all machined components and the water-resistant enclosure. These elements were carefully sized to fit seamlessly with the block while accommodating all necessary internal components.

VI. Societal Impact

Our project’s design prioritizes the safety and welfare of all stakeholders, particularly the high-class athletes who will rely on the system for critical performance insights. Given the physical intensity of swimming starts and the potential for injury from improper equipment use, ensuring the structural integrity and reliability of the starting block modifications was paramount. The inclusion of force plates on the front edge and back fin required rigorous testing to confirm that they would not compromise the block’s stability or alter its performance characteristics. Furthermore, the software application was carefully developed to minimize latency and ensure real-time feedback, reducing the likelihood of misinterpretation or delayed reactions during training sessions. These measures underscore our commitment to upholding the athletes' safety and overall well-being.

Personal data integrity was a critical ethical consideration in the design of our web application, particularly given the sensitive nature of the performance data collected from high-class athletes. The application stores information about individual swimmers, including metrics such as force exertion, which are tied to user profiles. To protect this data, we implemented robust security measures, including user authentication to restrict access, and administrative controls to ensure only authorized personnel can manage the database. These safeguards help prevent unauthorized access, breaches, or misuse of the athletes' personal and performance information. Recognizing the potential reputational and psychological impacts of exposing such data, we prioritized privacy throughout the project to build trust with our stakeholders and comply with ethical standards for data protection.

Equity and inclusivity were essential considerations in our design, recognizing the diversity in athletes' body types, including differences in height, weight distribution, and strength. The force plate placement and data collection methods were designed to accommodate these variations, ensuring that the tool provides accurate and meaningful feedback for all users, regardless of physical characteristics. This inclusivity not only enhances the tool's usability but also aligns with broader social and cultural imperatives to promote fairness and accessibility in sports technology. By focusing on universal usability, the project contributes to fostering an environment where athletes of all backgrounds can achieve their full potential.

Economic and environmental factors were also carefully considered throughout the project. The budgetary constraints required us to select cost-effective yet durable materials, balancing affordability with functionality to ensure a high-quality product within the financial scope of the UVA Swim and Dive team. Additionally, by designing a reusable and modular system, we minimized waste and extended the equipment's lifespan, contributing to sustainability goals. The project's customization to Coach DeSorbo's specific needs further enhances its economic value by avoiding unnecessary features typical of generic commercial devices. These considerations collectively highlight our ethical responsibility to deliver a product that supports public health and safety while remaining sensitive to global, social, and environmental impacts.

VII. External Standards

During the development of this project, several external industry standards were considered to ensure the device's functionality, safety, and regulatory compliance. The primary standard addressed was the IPX4 water resistance standard, which specifies that a device must be resistant to splashing water from any angle. Testing for compliance with this standard was conducted following ASTM D870-15, the Standard Practice for Testing Water Resistance of Coatings Using Water Immersion [9]. This standard was applied to verify that the device meets the necessary water resistance criteria to function effectively in a wet environment as defined in the IEC IP ratings [10].

Given the electrical nature of the device and its interaction with water, compliance with the NEMA/IEC Type 1 standard was also essential [11]. This standard ensures that the device is protected from environmental factors such as dust and light while safeguarding athletes from electrical shock hazards.

Furthermore, the myRIO Microcontroller incorporated into the device features Bluetooth and WiFi connectivity. These wireless functionalities classify the device as an intentional radiator, necessitating adherence to IEEE and FCC regulations [12]. While these standards were not directly addressed during the project, as they were likely met during the design of the myRIO module, their relevance was acknowledged in maintaining the device's compliance with wireless communication standards.

VIII. Intellectual Property Issues

The diving block apparatus presents a unique solution for capturing key metrics of swimmers. This system incorporates force sensors, a custom PCB for data summation, a Microcontroller for processing, and a user-friendly application. The project shows its potential patentability by leveraging its specific features, such as data transmission, integration with mobile applications, and modularity to existing diving blocks. Other solutions are entirely new blocks, this device is a cheaper solution that transforms an existing block into a smart block.

Several existing patents highlight similar applications of force sensors and performance analysis in sports. Patent US20230390625A1[13] describes a swimming starting block with built-in force or motion sensors that collect data for performance measurement, including parameters like start dynamics and foot positioning. Another relevant patent, US20120192346A1[14], outlines a swimming starting block with sensors embedded in the push-off plate to detect force and pressure changes during starts. These technologies provide foundational support for our project's feasibility while showcasing the need for a more tailored, cost-effective solution. Finally, US8795140B2[15] details a method for measuring force and pressure in various applications using pressure-sensitive sensors, reinforcing the technical foundation of our project's sensor-based approach.

To ensure patentability, designs must demonstrate novel and non-obvious improvements beyond these existing patents. Our project is a more modular and budget-friendly design that would be patentable. To increase patentability, potential innovations would include optimizing sensor placements for both hands and feet to capture comprehensive force vectors and incorporating video integration capabilities.

IX. Timeline

Figures 34, 35, 36 in Appendix XV-A present the initial timeline for our group's project, depicted as a Gantt chart developed at the start of the semester. The division of labor was strategically planned to enable team members to work in parallel, minimizing bottlenecks and ensuring steady progress. As is common with engineering projects, unforeseen challenges and necessary adjustments arose, requiring modifications to the original Gantt chart throughout the semester.

One significant delay occurred due to the late arrival of the aluminum front sleeve and back fin plate, which postponed the assembly of the block until the final weeks of the semester. Additionally, several miscommunications regarding the mechanical components for mounting led to functional discrepancies in certain aspects of the design. These issues necessitated urgent trips to Lowe's to procure necessary parts, as waiting for shipped items was not feasible given the tight timeline. Despite these challenges, the project was successfully completed on schedule, demonstrating the team's adaptability and commitment to meeting deadlines. This is reflected in the Phase 3 timeline being shifted significantly behind schedule which can be seen in Final Gantt charts in Figures 37, 38, 39.

X. Costs

The total out-of-pocket development cost was roughly \$4300. This included all of the materials and construction costs that were used and unused. The percent cost breakdown is shown below in Figure 27

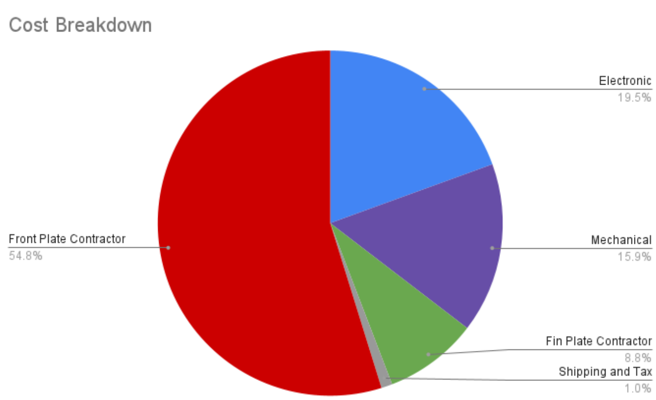

Fig. 27: Total Cost Breakdown

The cost for electrical components was \$851. This included the PCB printing cost, resistors, capacitors, electrical connectors, wiring, force sensors, and battery. There was some non-productive costs that were incurred from testing the system, mainly the size and type of wires that were purchased. We were looking for the perfect size wire gauge and jacket diameter in order to fit underneath the sensing surfaces to not detract force vectors from the sensors. We purchased a set of wires that were too thick, as well as a set of wires that were two thin and were not single strand which we realized was necessary later. This amounted to around \$140 that could be avoided in the future.

The costs for Mechanical components was \$685. This included all purchases relating to hardware including our physical mounting systems, screws and bolts, waterproof encasement, rubber buffer, tape, and aluminum for our in house design. Some non-productive costs were from purchasing screws and mounting systems that were later did not fit functionality of the device. These costs were relatively minimal at around \$30, but could be avoided in the future.

The cost of the Fin Plate construction was \$378. This component was constructed from a sheet metal process through an industrial parts manufacturing vendor, Xometry. We selected this vendor's quote after comparing multiple quotes, based on competitive pricing and speed of production.

The cost of the Front Plate construction was \$2363. This was the largest cost of our project. This construction was performed by a Charlottesville based professional welder that laser cut aluminum sheets to specification and welded the pieces to form our front sensing surface.

The costs of shipping and taxes were around \$45 for components that needed to expedited. These cost could be avoided in the future by ordering with other components and avoiding the need for expedite fees.

There were also non-measured costs of our project. Some portions of our project were given by the ECE department that included our MyRio micro-controller, 3D Printing Capabilities, and many electrical component.

For future production, we believe that the total cost to bring our system to market could be significantly less. The cost from manufacturing our mechanical parts from outside contractors made up around \$2800 of our total cost. From working with a machinist in the Mechanical and Aerospace Engineering Department, we found that material costs for aluminum could be conservatively around \$400 and labor costs to also cost around \$400, estimating 8 hours work at \$50 per hour. Non-productive spending also made up around \$215. With our knowledge of what works and what did not work, we can cut costs from manufacturing, prototyping, and over-engineering. A realistic cost could be around \$2100 (\$4300 total cost - \$2000 saved manufacturing cost - \$200 saved non-productive costs), or around \$2950 if we include the cost of purchasing an NI MyRio (\$850). Mass production and automation would be harder to achieve, since our system was designed specifically for a UVA specified start platform, so fitting system to every slightly different version of a start block would be difficult.

XI. Final Results

The final results of the project were highly successful, as all intended objectives were achieved, and the block performed as expected. The final design ensured the block was entirely waterproof, with all electronic components securely encased within the enclosure. Any additional openings in the box were sealed using a durable polymer adhesive. The Microcontroller was successfully powered by a portable source and reliably received transmission signals from the web application, enabling it to poll and transmit the analog data it captured. For the front sleeve, the CNC-manufactured version was selected due to its superior fit on the block and the beveled edge, which enhanced user comfort. The web application was completed with all initially planned features and included additional functionalities such as exporting data to an Excel CSV file, implementing a login authentication page, and adding color coding and animations to several buttons for an improved user experience.

Based on our evaluation criteria, we believe the project merits an A grade. The primary setback encountered during the semester was the delayed arrival of the block and front sleeve, which was largely beyond our control. If the process had been initiated earlier, the timeline could have been maintained as originally planned. Despite this challenge, all proposed objectives outlined in the project proposal were successfully accomplished.

Fig. 28: Front of Completed Block

To understand the final results of the software application, images that depict a walk through of the application on the users end are provided. The following image presents the result of the Magnitude Recorder page once the user stops the recording.

Fig. 29: Side of Completed Block

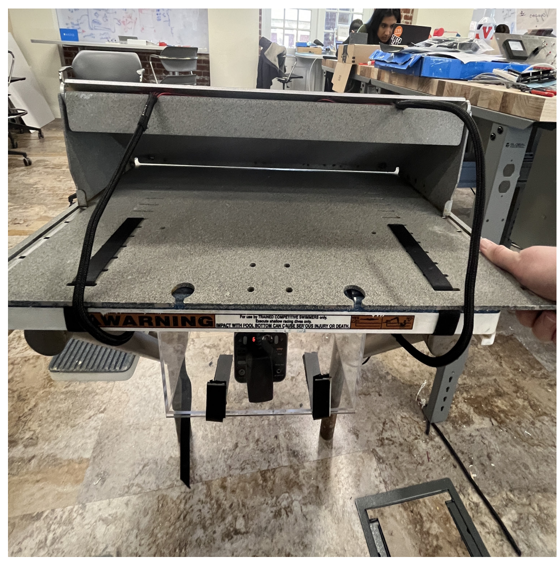

Fig. 30: Back of Completed Block

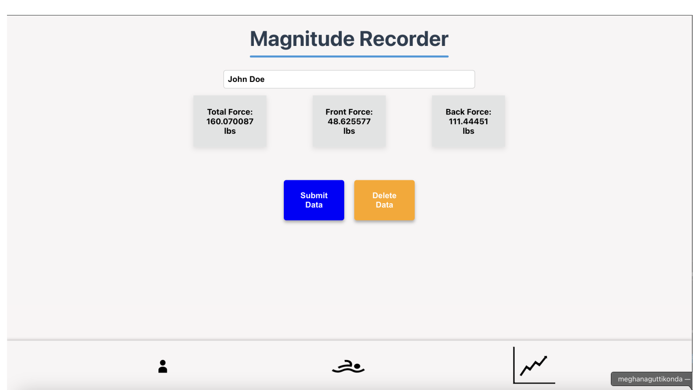

Fig. 31: Magnitude Recorder Results

Fig. 31 shows the total force, front force, and back force recordings collected from the Microcontroller. From here, the user can choose to keep or discard the data.

Figures 32 and 33 represent the start data for the swimmer "John Doe". The performance analysis features that were added were adjusted to the preferences of the various coaches on the swim team. Some prefer to see the data raw, while others prefer a visual to help them understand swimmer performance over time. Another helpful feature was adding the swimmer's best start, which was decided to be the start with the greatest total magnitude, so that the user can easily access useful information without having to scour through the data to find it.

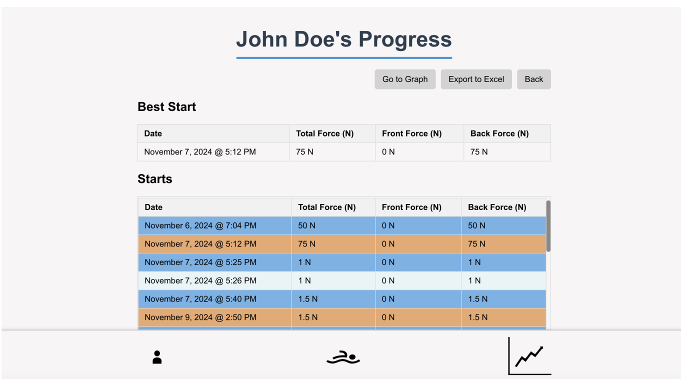

Fig. 32: List of Raw Data of Swimmer's Starts

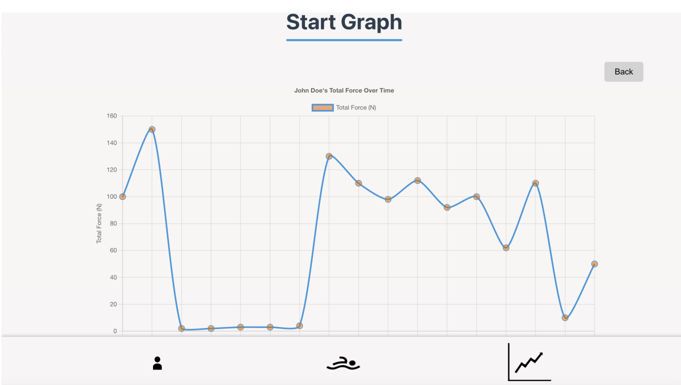

Fig. 33: Progress Chart

The final result of the software application highlights the seamless communication between the force sensor arrays, Microcontroller, and software as it provides a mean for the user to utilize the capabilities of the device.

XII. Engineering Insights

During this project, we developed several new technical skills, particularly in software development and mechanical design. On the software side, we gained proficiency in NI LabView, learned how to host a website, and established communication between a Microcontroller and a web application. These were critical skills for integrating the system's components effectively. Additionally, we collaborated with a machinist to design and manufacture large aluminum components that required welding—a process entirely new to our team. This project also highlighted the importance of time management and accountability in the engineering process. While we initially felt ahead of schedule, we found that even a brief period of neglect could set us back significantly. Maintaining consistent effort and attention was essential to keeping the project on track, a factor we had underestimated at the outset.

Teamwork and communication were also vital to our success. Although we did not formally assign a team leader, the need for someone to integrate different roles, maintain accountability, and ensure clear communication became apparent. This coordination was crucial to managing the complexity of the project effectively. One of the largest challenges we faced was external delays. The swim team delivered the diving block later than expected, and the manufacturing of the front sleeve encountered additional delays. These setbacks demonstrated that external factors could significantly impact timelines, emphasizing the need for contingency planning and adaptability. For future Capstone students, we recommend maintaining consistent communication among team members, setting clear milestones, and anticipating potential delays from external collaborators. Proactive planning and regular progress reviews are invaluable in managing both time and resources effectively while maintaining team morale.

XIII. Future Work

This project meets all the requirements defined at the beginning of the semester. However, there are features which can be added to improve the product. One enhancement is video processing. Adding a camera that records where the swimmer enters the water and when. A swimmer is fastest right when they enter the pool, therefore, the farther they can get from the block, the better chance they have at winning the race. This camera would detect the distance from the block they enter the pool and compare their entry time to when they dove. However, this feature does come with its own difficulties. First, it would be an interesting task to find or design a device that effectively detects entry into the water and connects it with the existing MyRIO controller. Fortunately, the MyRIO does have a high computing power and many IO ports that could be used to interface with such a device. An additional challenge would be how this device would connect to the MyRIO. While it does have many IO ports, the Microcontroller is stored beneath the block. Connecting a camera to it would require running wires along the pool deck, which is less than ideal. Finding a way to transmit the data wirelessly would be a more elegant, albeit far more challenging, solution.

Another future improvement would be recording the angle of the foot placement. The angle at which the diver jumps from the block is key to knowing where their force is being applied. A greater force exerted on the horizontal plane would result in a further entry point, while a vertical force may be wasted energy. The biggest challenge with this feature is implementing it without completely changing the current sensors. Finding a solution that uses the existing design will the a key challenge. This feature would integrate well with the web app and provide helpful data for the swim team. Both of these improvements would be interesting challenges that would greatly benefit the UVA swim and dive team.

XIV. References

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XV. Appendix

A. *Initial Gantt Chart*

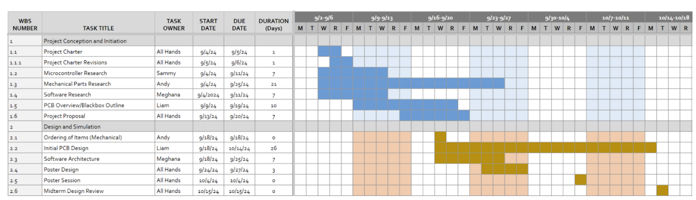

Fig. 34: Initial Gantt Chart Phases 1 and 2

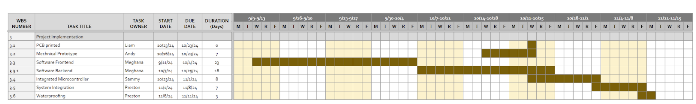

Fig. 35: Initial Gantt Chart Phase 3

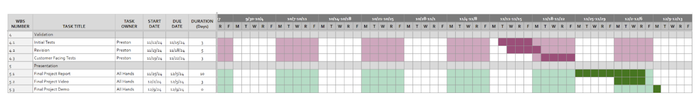

Fig. 36: Initial Gantt Chart Phases 4 and 5

B. *Final Gantt Chart*

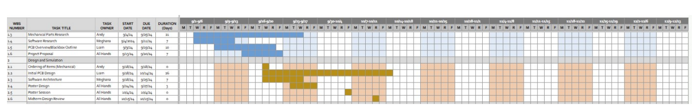

Fig. 37: Final Gantt Chart Phases 1 and 2

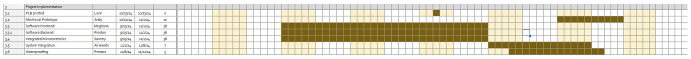

Fig. 38: Final Gantt Chart Phase 3

Fig. 39: Final Gantt Chart Phases 4 and 5

C. *Finances*

Description	Part Number	Cost
A301 Force Sensor	3718-A301-100-ND	32.30
A301 Force Sensor	3718-A301-100-ND	253.00
Rubber Sheet	1310n33	19.38
47pf Capacitor	VY1470K31Y5SQ63V1	5.22
0.1uF Capacitor	C322C104M5U5TA	3.28
Connector Header Through Hole 3	5-146280-4	1.02
Connector Header Through Hole 10	61201021621	0.94
Connector Header Through Hole 20	SBH11-PBPC-D10-ST-BK	1.28
27K ohm resistor	CF14JT27K1	0.07
47k ohm resistor	CF18JT47K1	0.40
3.3k ohm resistor	CF14JT3K31	1.06
20k ohm resistor	RNF14FTD20K0	0.20
10k ohm resistor	CF14JT10K0	0.20
General Purpose Amplifier 4 Circuit	MCP6004-E/P	5.20
10 Position Rectangular Receptacle Connector	61201023021	0.96
100 ft black 22awg wire	3071 BK005	50.03
101 ft red 22awg wire	3071 RD005	51.05
Connector Header Through Hole 1	PH1-01-UA	0.23
Fin Plate		377.79
Heat Shrink	2328-1/8PVCHSBLA2-ND	35.12
USB Connector for Ground	1568-1300-ND	4.95
Sensor Connector	S9197-ND	2.74
Battery		115.82
Acrylic Container		224.50
PCB		26.70
3M Fasteners		27.40
Heat Shrink Tubing	2328-1/8PVCHSBLA2-ND	35.12
USB A Break	1568-1300-ND	4.95
20 Position Header Connector	S9197-ND	2.74
USB 2.0 Cable A Male to A Male	2057-CA-USB-AM-AM-3FT-ND	5.60
M3 Pan Head Machine Screw Phillips Drive	1188-SCREW-DIN7985-M3X35-ND	1.00
Aluminum Bars	89755K49	77.80
90 Degree Alumnium	8982K46	125.65
Binding Screws	99637A303	24.88
Anti-Slip Tape	6970T142	38.46
34 AWG Red Wire	CN570B-100-ND	20.81
34 AWG Black Wire	CN573R-100-ND	20.81
100K Ohm Resistor	RNF14BTE100KTR-ND	12.48
Elevator Bolts	94650A424	10.76
10x Alloy Steel Socket Head Screw	92220A123	17.66
Binding Barrel Screws	99637A440	36.30
Ultra Low Profile Socket Head Screw	90357A026	39.28
Shipping and Tax for Screws		14.61
WIRE 22AWG BLACK SOLID FEET	1175-10981-22-1-2000-001-1-TD-DS-ND	41.10
WIRE 22AWG RED SOLID FEET	1175-10981-22-1-2000-004-1-TD-DS-ND	41.10
Shipping for Wires		29.99
Adhesive Tape		44.44
Screw terminal		21.12
Sullind Snap Connector		20.82
Ribbon Cable		20.83
Contractor Solution		2,363.36

Fig. 40: Purchases