DIGITAL COACHING FOR FIGURE SKATING

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Abstract

The Digital Coaching for Figure Skating project aims to reduce the barrier to entry for the sport by cutting the cost of instruction and allowing for a redistribution of coaching resources into underserved areas. It also provides an alternative teaching method for students who are visual learners. Although we were unable to connect and aggregate the wearable electronics and object tracking data, we fully developed the wearable system mechanically and demonstrated capable wireframe projection over the skater.

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1. Introduction

1.1 Problem

Coaching for figure skating costs $50+ / 25 min of instruction. With the costs of ice time and skate maintenance outside of this, the cost of figure skating is significant if you are looking to improve your skills in any way. This makes it impossible for many who would like to improve or begin figure skating to do so based solely on cost. For two years of twice-weekly coaching, the cost would be $10,400 for coaching alone. Our solution attempts to reduce this barrier to entry.

Aside from the cost, ice rinks are not always easily accessible physically, especially in more rural areas where people have to travel farther to reach their nearest rink. Enabling the possibility for a remote coaching element in our solution could connect a higher number and quality of coaches to areas that are underserved in that regard and increase popularity of the sport. Moreover, some students are unable to find coaches that teach with respect to their style of learning. Those who are visual learners struggle to find coaches who can explain complex movements in a way they can understand. This only increases the struggle of understanding what they are doing wrong when they reach a point of confusion or misunderstanding.

1.2 Solution

With a system consisting of wearable electronics, a camera setup, and access to a computer, each ice rink could be equipped for digital coaching and encourage skaters to improve without needing to invest significant amounts of money into coaching. The system would function as the wearable electronics can record accelerations in 3 dimensions, and the software can synthesize this information and the input from the camera in order to create a model of the skater and compare it directly with an ideal model. This is so the skater can directly see what they are attempting and make specific changes to their motion in order to perfect their form. Furthermore, this solution would aid the coaching of those who have a different style of learning (visual, tactile) as opposed to auditory to understand the corrections made.

1.3 Visual Aid

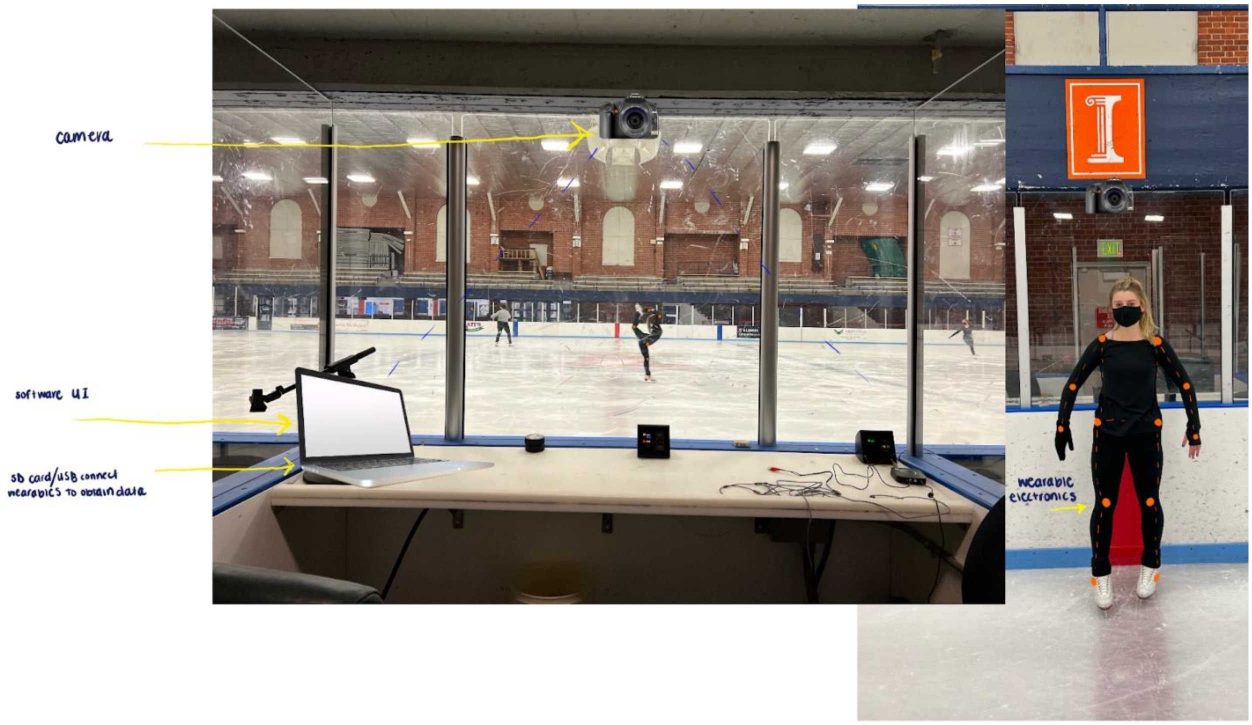

Figure 1. Visual aid demonstrating the different components of the project.

1.4 High-Level Requirements

Our high-level goals are as follows:

1) Design and build a wearable electronics system to measure the acceleration data of an ice skater performing the Biellmann (a skating skill in which the skater lifts the leg above their head and grabs onto the blade with their hands).

2) Utilize camera input to align with acceleration data and create a full depiction of the skater in terms of kinematics (position, velocity, acceleration).

3) Use aggregated data to generate a visualization of the skater and quantify the difference between an "ideal" move versus the skater's move. An ideal movement is an element which an experienced skater can perform at a high grade of execution.

2 Design

2.1 Block Diagram

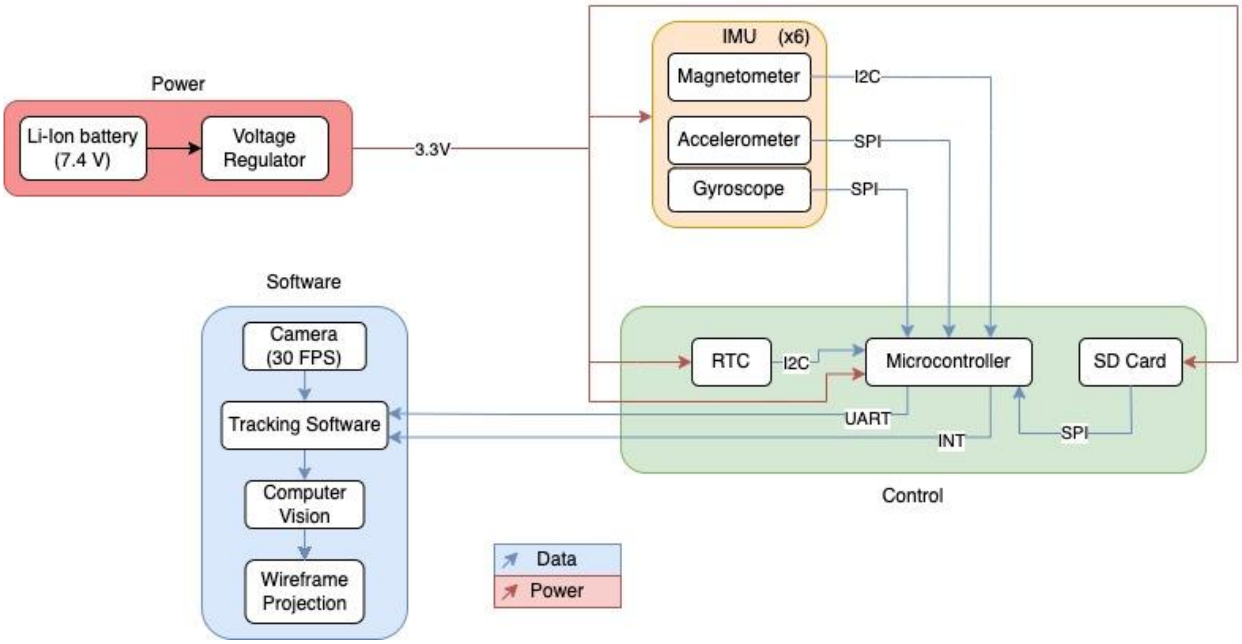

Figure 2. Block diagram breaking down the subsystems of the project.

2.2 Physical Design

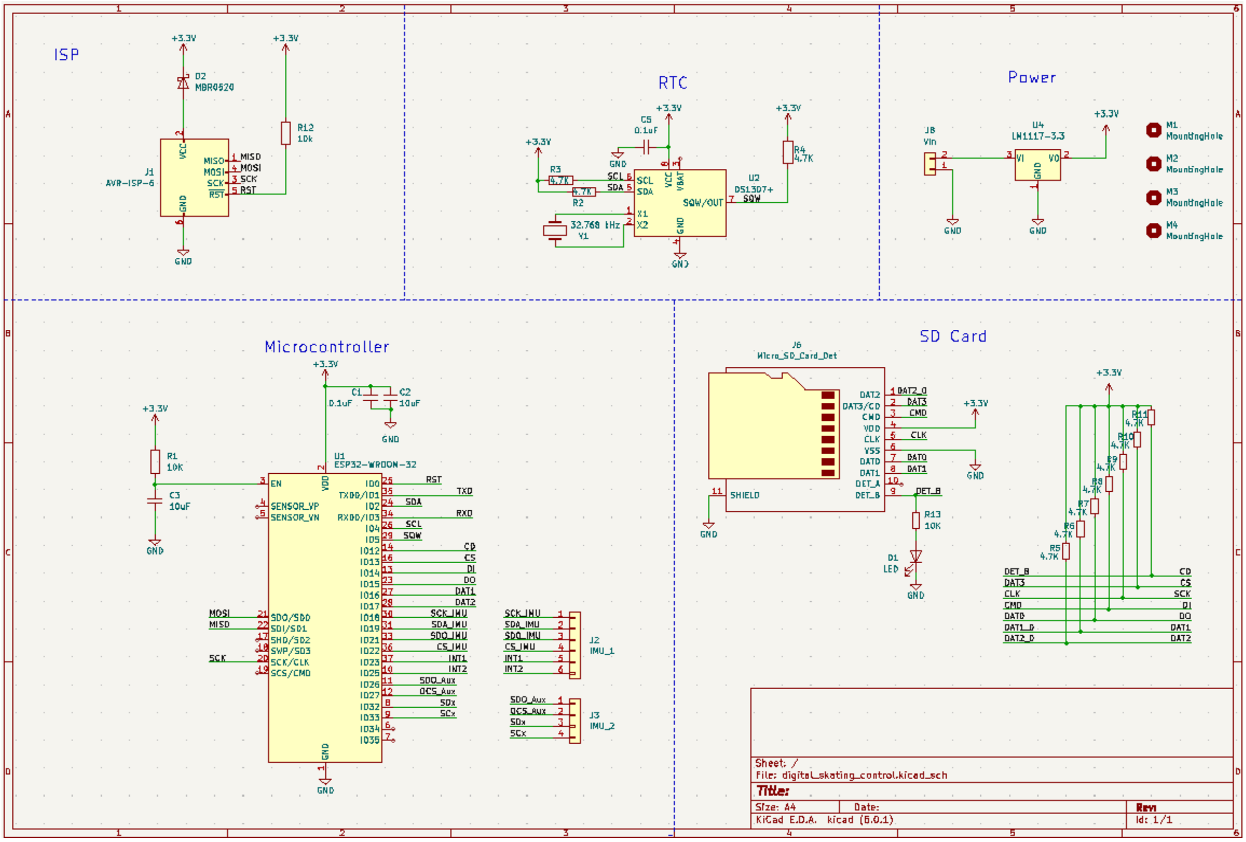

Figure 3. Schematic of the control subsystem.

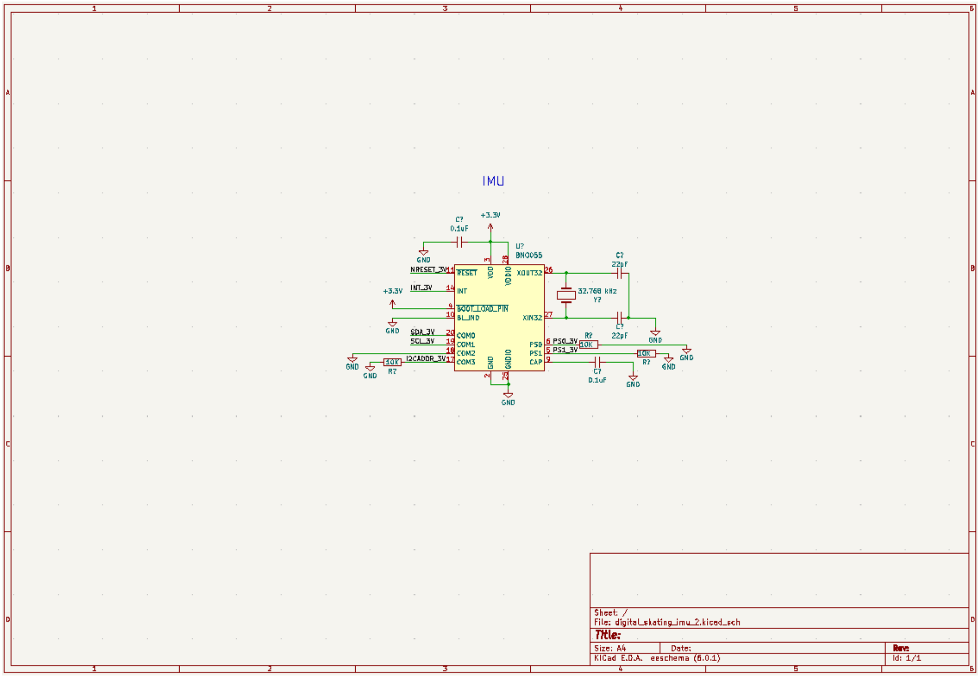

Figure 4. Schematic of the IMU subsystem.

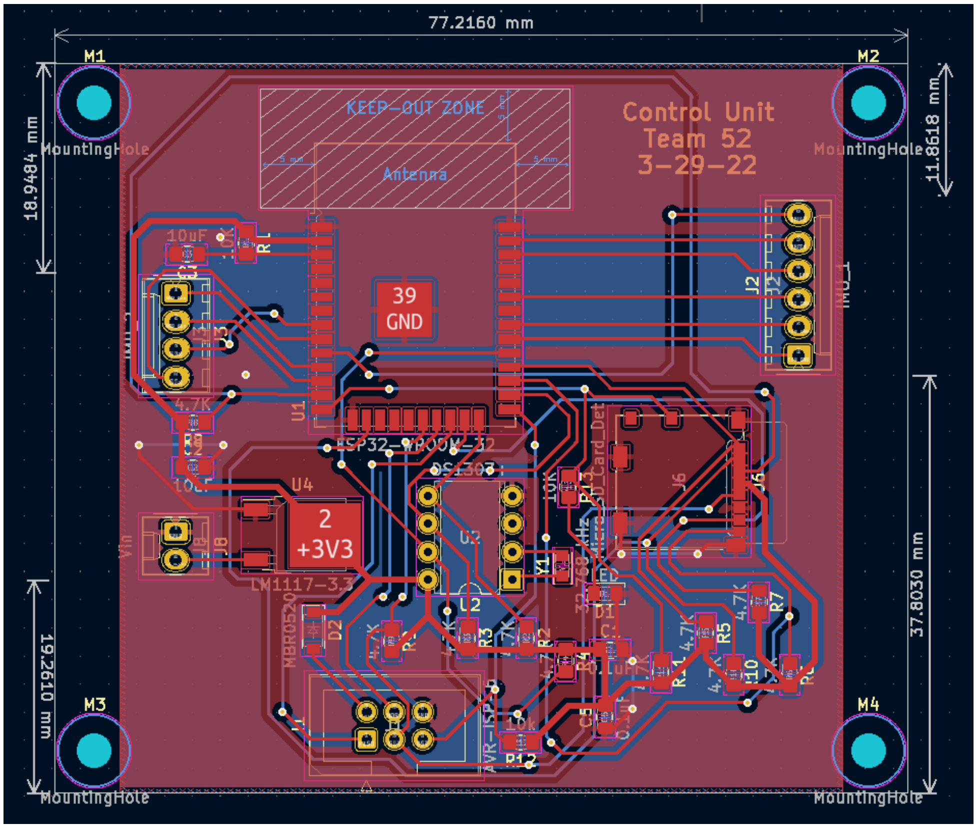

Figure 5. PCB of the control subsystem.

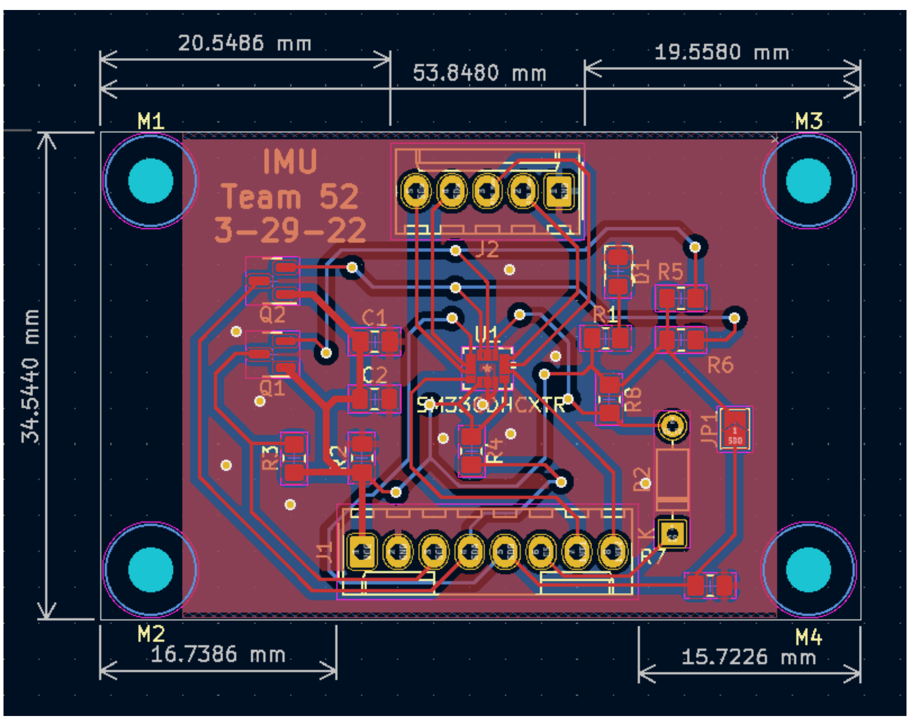

Figure 6. PCB of the IMU subsystem.

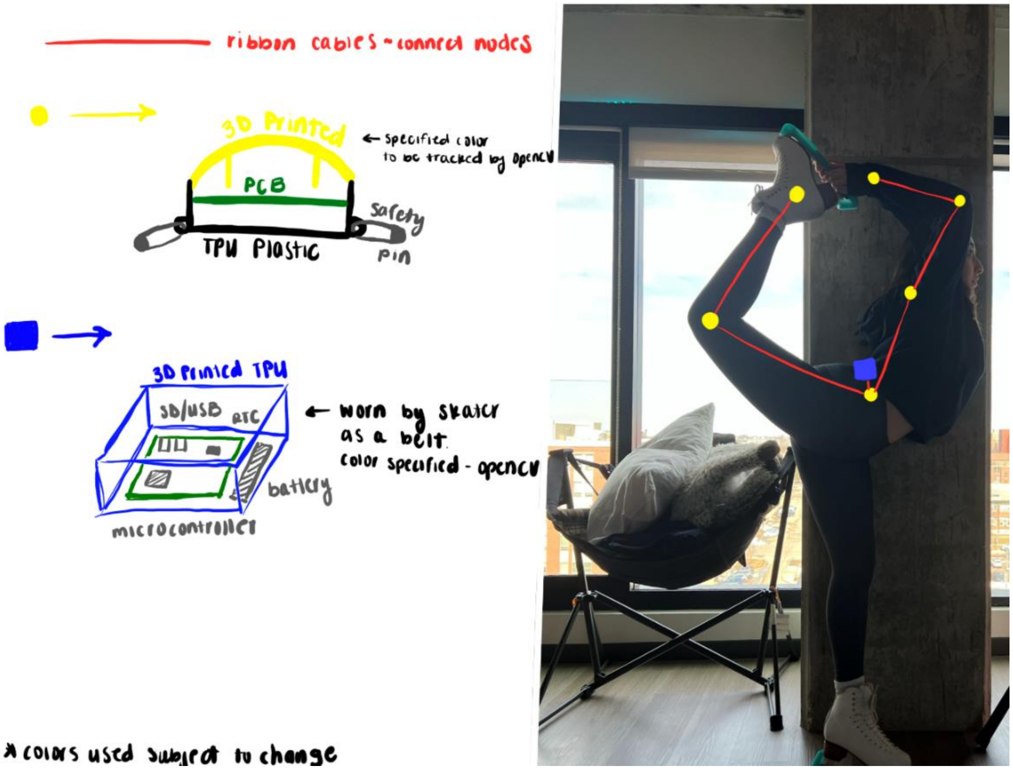

Figure 7. Visual aid with a more detailed breakdown of the wearable electronics system.

2.3 Subsystems

2.3.1 Power Regulation

Our wearable design needs to consistently power each IMU node strapped to the body. The main voltage provided will be set to 7.4V to provide efficient power and will use a voltage regulator to maintain stable power through multiple IMUs. While each IMU sensor could be powered individually, they will all be connected by ribbon cable to a central node, so they can share the same power source to model a more reliable system.

2.3.2 IMU Nodes

We will manufacture multiple IMU nodes consisting of an accelerometer, gyroscope, and magnetometer to be outfitted on an individual at important body joints. These nodes will be able to record acceleration data from the wearer and subsequently transmit through a wired connection to the master microcontroller node that is collecting data. The IMUs make up half of the wearable electronics. In order to attach these nodes to the skaters, we will CAD and 3D print a protective case, and pin the electronics onto the skater via a safety pin to ensure maintenance of a precise location. The node on the skate will be attached via a safety pin to a sleeve (commonly sold as a skate protector to freestyle skaters) that goes over the boot of the skate. We originally had planned to use the BNO055 sensor for our IMU nodes. Upon learning that they had run out of stock, we switched our design to use the BHI260AB sensor. However, we were unable to utilize this sensor as well as we were informed of another stock shortage of this sensor. We made our third implementation of the design with the ISM330DHCXTR, which is the least optimal IMU sensor of our choosing, as it does not aggregate data, and only contains 6 degrees of freedom (DOF) instead of 9 DOF in total.

2.3.3 Control Unit

We will also manufacture a custom microcontroller that serves as the master node for the wearable electronics system. This microcontroller will need to be wired to all of the IMU nodes in order to receive and aggregate the wearer's acceleration data. It will also require a storage system, in this case an SD card, in order to later transfer the accumulated data to the software component of the project. It is easiest to use compatible IMUs which operate on the same communication protocol as the microcontroller, allowing an easier transaction of information. We will also need to incorporate an RTC in order to later sync the data accurately with the camera recording. The microcontroller makes up the second half of the wearable electronics.

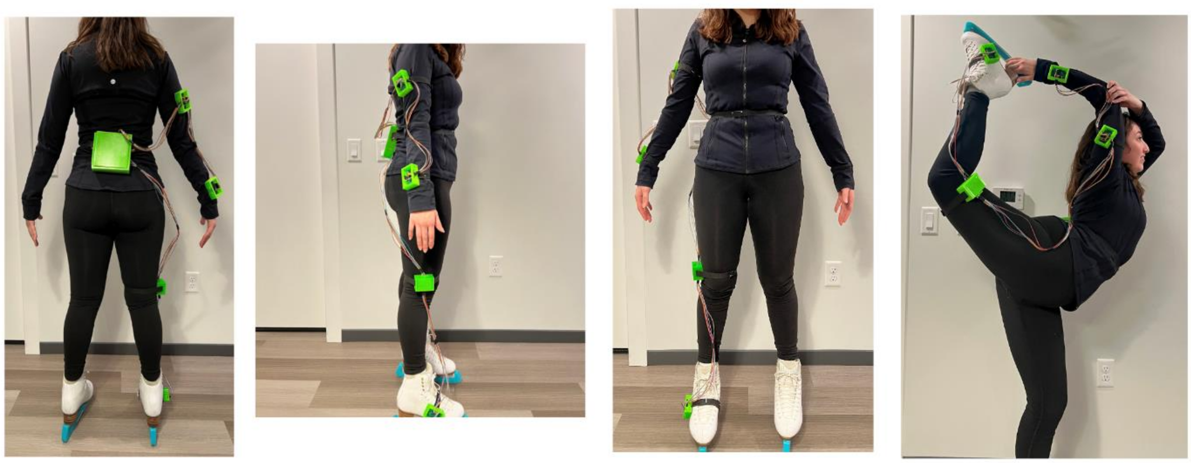

Figure 8. Full assembled wearable electronic system on a skater.

2.3.4 Camera and Software

We will need to connect a camera to a computer in order to accomplish the computer vision aspect of this project. The camera will capture the motion of the skater as well as track the world position of the IMU nodes to provide visual data. This will be paired with the IMU data to generate a model of the skater's movement as they execute skill moves. We can compare these models with "ideal" models based on skilled figure skaters to both quantify the difference between a performed move versus an "ideal" move and to provide visual feedback to the skater as to how they can improve their performance. We plan to use OpenCV or some similar library to accomplish this. In addition to the object tracking functionality, we want to have wireframe projections on the skater's body to give a better sense of how specific limbs and joints are moving during move execution. We originally wanted to accomplish this with the OpenPose library, but we ended up implementing this through the Xbox Kinect camera and Java 4 Kinect library.

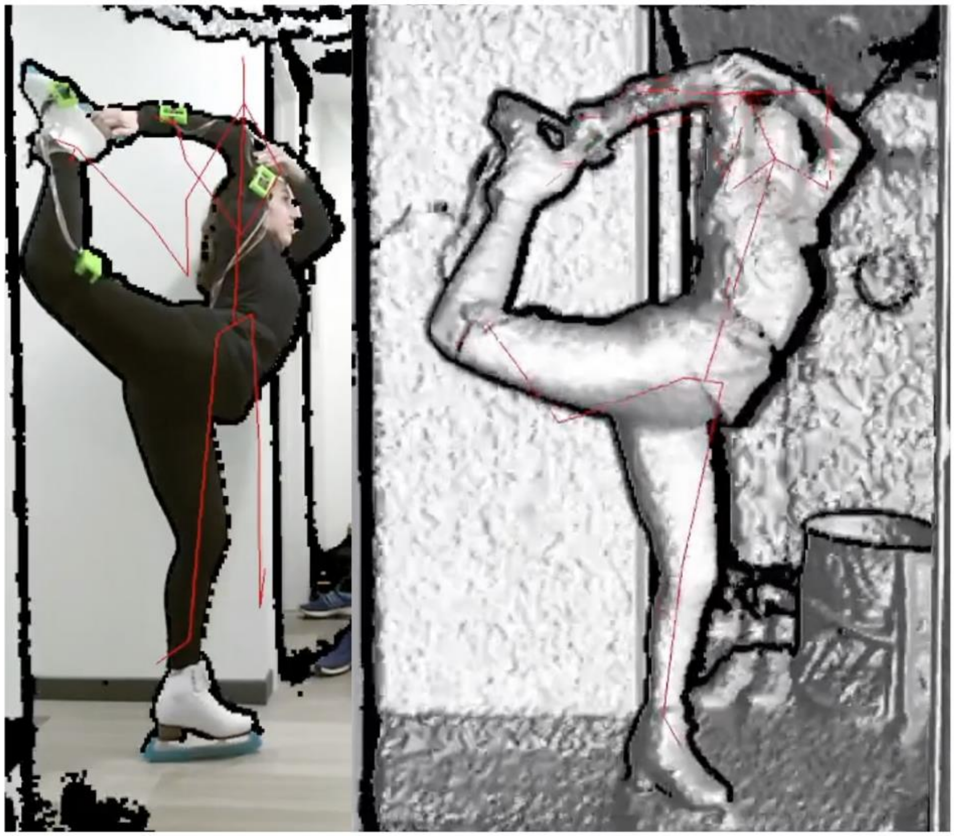

Figure 9. Wireframe projection from different camera views using the Xbox Kinect.

3 Verification

3.1 Power Regulation

The 7.4V battery we used was strong enough to provide both voltage and current to all the necessary components on the control unit board, along with each individual IMU node. Our requirement for the power regulation subsystem was to verify that each individual electrical component, such as the microcontroller, RTC clock, and IMU nodes, was consistently receiving a supply voltage of 3.3V and a current of at least 300 mA for operation standards. However, we encountered an issue where our voltage regulator was shorted due to electrical connections crossing and touching. This caused our voltage to not be regulated when running to other components on the PCB boards, so the components on our board were being supplied with a much higher voltage of 7.4V. This caused many of those components to overheat and not perform in an optimal manner. As a result, the voltages read with the multimeter were either much higher than 3.3V, and the currents were also out of range.

Table 1 Power Regulation Requirements and Verifications

Requirements	Verification
1. The power regulation subsystem must be able to supply at least 300mA to the rest of the system continuously at 3.3V ± 0.1V.	A. Measure the output current from the regulator with a multimeter and ensure that it does not fall below 300mA. B. Measure the output voltage from the regulator using an oscilloscope and confirm that it is 3.3V ± 0.1V.

3.2 IMU Nodes

Our first requirement was to essentially test the accuracy of the IMU data to be within 15% of the true values. The test that we devised would use our camera system as the ground truth values to which we would compare our collected data. Due to the previously described issues surrounding our power regulation subsystem, we were unable to program our IMU nodes and perform the first verification test.

Our second requirement was to verify the structural integrity of the protective cases that we 3D printed for the IMUs. We arrived at the 110 lb. figure based on two pieces of research. We found that the average weight for a female U.S. Olympic figure skater was 108 lb., which we rounded up. We also learned that 64% of members of the U.S. Figure Skating organization are under the age of 18. It stands to reason that children would generally weigh less than an Olympic athlete, so we feel this number accurately covers the majority of potential users for the project. We were able to successfully verify this requirement through a force test, but we feel that the cases' capabilities exceed our required weight, and with further research and testing, we would be able to shift the weight much higher to encompass even more users.

Table 2 IMU Node Requirements and Verifications

Requirements	Verification
1. Record acceleration data in the x, y, z planes within 15% accuracy.	A. Mark a predetermined distance in which the user will traverse a straight line across the frame of the camera. B. Run the object-tracking program as the user traverses the line. Upload IMU data to software program after completion. C. Use camera data as ground truth and compare measurements to ensure accuracy falls within 15%.

3.3 Control Unit

The control unit was a major piece of the hardware as its purpose was to capture all of the data provided by the IMU units. Our requirement for the control unit was to ensure that at least 90% of the data was received from the IMUs and stored in the SD card. We were not able to verify this as the ESP32 WROOM would overheat when we attempted to interface it. Our attempt to interface it was using a supplied voltage of 5V from the laptop, which leads us to believe that there was a short somewhere on the board, not allowing the current running through the microcontroller to dissipate as quickly as it should have been. While we were able to connect to the ESP32 WROOM chip via connection, the chip itself overheated in a quick manner, which was concerning enough that we would not maintain the connection for too long.

Table 3 Control Unit Requirements and Verifications

Requirements	Verification
1. Ensure at least 90% of IMU data has been received and stored in the SD card.	A. Confirm the expected number of data points matches (within tolerance) with the actual recorded within the timeframe of data collection. B. Confirm the number of data points that has been collected from each individual IMU stays within the tolerated limit.

3.4 Camera and Software

Our first requirement was to sync the IMU data from the hardware with the camera output from the software. Again, we were unable to verify this as we could not collect IMU data from the wearable system. This requirement theoretically could have been verified by pairing dummy data for the IMUs with our wireframe videos as a proof of concept, but we did not have the time to implement this.

Our second requirement was to track the IMU nodes on the skater using OpenCV. We were also unable to verify this due to issues with connecting the camera firmware to our OpenCV software. We tried implementing OpenCV code in multiple languages without any breakthroughs, but we believe the biggest issue with fulfilling this requirement was choosing to specify that we wanted to use OpenCV. This limited us from branching out to other possible object tracking libraries during the development of the project which may have yielded better results.

Table 4 Camera and Software Requirements and Verifications

Requirements	Verification
1. Sync hardware output with camera output to create a full quantitative depiction of the skater.	A. Access RTC values to timestamp accelerometer data. B. Compare frequencies of IMU data and video frames in order to determine proper sampling rate. C. Pair IMU readings with corresponding video frames.
2. Track all nodes on the skater using OpenCV.	A. Attach nodes to the user on one side of the body. B. Connect the camera feed to OpenCV and run object-tracking program, setting the program to follow the color and size of the node cases.

4. Cost and Schedule

4.1 Cost Analysis

Our total labor cost is calculated to be $90,000. This figure was found using equation 1 as shown below:

$$\$40/hour\ x\ 20\ hours/week\ x\ 15\ weeks\ x\ 3\ people\ x\ 2.5\ =\ \$90{,}000 \quad (1)$$

Table 5 Cost Analysis

Part Name	Part Number	Manufacturer/Supplier	Quantity	Cost
IMU Sensor	ISM330DHCXTR	Bosch	6	$9.99
Microcontroller	ESP32- WROOM-32	Espressif	1	$3.25
I2C Real Time Clock	DS1307	Maxim Integrated	1	$2.99
Battery	2S LiPo Battery (7.4V)	Liperior	1	$4.99
Ribbon Cable Spool	16-pin	Amazon	1	$9.99
Filament	1.75mm 250g TPU	Amazon	1	$15.99
Voltage Regulator	LM1117-3.3	Texas Instruments	1	$1.00
MicroSD Module	MicroSD Socket	4UCON	1	$1.95
Header Pin Row	1x24 Connector	DigiKey	10	$0.10

Capacitor (SMD)	0.1 uF	DigiKey	14	$0.70
Capacitor (SMD)	10 uF	DigiKey	2	$0.50
Resistor (SMD)	4.7k Ω	DigiKey	10	$0.44
Resistor (SMD)	10k Ω	DigiKey	51	$0.76
Diode	1N4148	MOUSER	6	$0.10
Diode (SMD)	MBR0520	MOUSER	1	$0.34
Diode	LED	MOUSER	7	$0.74
N-Channel Logic Gate	BSS138PW,115	DigiKey	12	$0.31
Total Cost				$164.90

Grand Total: $90,164.90

4.2 Schedule

Table 6 Schedule

Week	Steph	Lionel	Ethan
2/21	Research OpenCV for object tracking	Research software for data modeling	Finalize parts list and PCB layout
2/28	Research camera data analysis - frame by frame	Research hardware communication standards and data input	Finish PCB layout and get TA approval
3/7	Development of software for analysis of data obtained from camera and from hardware		Test and develop ESP32 & sensors
3/14	Spring Break		
3/21	Software development and debugging	CAD case for electronics and debug software	Hardware assembly
3/28	Software development and debugging		Hardware testing
4/4	Begin testing system as a whole		
4/11	Prepare for mock demo		

4/18	Final testing and adjustments for hardware and software
4/25	Demo, system testing, and begin final report
5/2	Work on final report

5. Conclusion

5.1 Accomplishments

From our original three high-level requirements, we were able to partially fulfill two of them. We successfully designed and built our wearable electronics system, but we could not actually test the collection of acceleration data. However, we have no reason to believe this would not be functional if our control unit had been programmable. We also succeeded in creating a visualization of the skater which could be used to compare user moves to ideal moves, but this visualization did not incorporate all of the data that we originally planned to integrate.

5.2 Challenges

While we were able to have some success in testing and verifying different parts of our project, there were many that we were not able to fully implement, especially in regards to functionality. One of the main problems we encountered was the failure of the voltage regulator. Not having a reliable voltage running through all of the hardware components was unfortunate as in many cases, too much voltage and current will prevent electrical components from working properly.

Another issue we faced, though much less of an obstacle, was getting our hardware design and cases to complement each other. The case was originally too bulky, and then too short to withhold the wiring, but if we had planned ahead, we could have compromised with a design that optimized a less bulky case, with more ideal wire management.

5.3 Ethics and Safety

We do not believe that there are any serious ethical concerns associated with our project. Neither the wearable electronics system nor the camera and data analysis components could be altered or misused in a way that would pose a threat to the safety or welfare of the users [1]. The only potential issue would be in data privacy of the user, but we feel that there is negligible risk of abuse. The camera recordings of the user would be filmed publicly in an ice rink, where other people would be present and there is minimal expectation of privacy. The video would also be stored locally on a laptop, so it could be immediately deleted after the coaching session if the user felt uncomfortable leaving a video record of themselves. Furthermore, there is no ethical risk in the development of our product as human testing will be limited to the members of the group.

We have however identified some safety concerns relating to our project. There is an inherent bodily risk associated with participation in ice skating. To address this, we are exclusively having Stephanie test the system. She has skated for many years and is on the University's synchronized skating team, so she possesses the experience and ability to safely ice skate. She is also familiar with the specific skill move that we aim to demo, so we are not putting her in increased danger of injury. In the case that an injury does occur, Stephanie has already signed a liability waiver with the ice rink that covers incidents on ice. This applies similarly to all product users, who assume a certain amount of risk by choosing to ice skate. Our project does not generate any additional risk in this regard.

The other area of safety to address is the wearable electronics system. Because these electronics will be in close proximity to the human body, we incorporated multiple features into our design that will ensure the safety of the user. We plan to power the system with a 2S LiPo battery which will deliver currents low enough to prevent shocking a person. We also plan to insulate all wiring between components as well as encase IMUs and the control unit in 3D printed boxes. With the addition of the clothes worn by the user, these layers of protection will keep the user from coming in contact with any current, barring extreme mechanical failure. We plan to print our electronics boxes using thermoplastic polyurethane (TPU) filament, which is more flexible and impact resistant compared to commonly used filaments like PLA and ABS. This design choice mitigates risk of damage to the electronics and better protects the user in case of falling. It would also be simple to add padding between the user's body and the boxes to further increase comfortability and protection.

5.4 Future Work

If we were to continue working on this project in the future, there are multiple improvements that could be made to optimize the product. We would have liked to use the original BNO055 chip over our current IMU as the additional DOF and integration of sensor fusion in the BNO055 would have allowed for a more comprehensive as well as simplified electronics system. We would also ideally add more IMUs to the overall design as there are still some key joints such as the elbow and hip which were not fitted with sensors. We would also want to add sensors to the other side of the body in order to have more comprehensive data collection and allow for other skating moves such as spins to be performed.

A dramatic improvement would have been to design our project so that the nodes would behave wirelessly with the microcontroller. This would be useful in taking advantage of the ESP32 WROOM's wireless features, and would prevent electrical problems between each node and the control unit. Another benefit would be the physical factor, as the user would be able to move more freely without concern of accidentally tearing a wire or adding tension stress to the system. Ideally, this would be best as people have different bodies, and this would be a solution to account for that.

We also would like to explore other software such as OpenGL, which would enable us to display a better wireframe projection of the body along with other graphical improvements to the final interface of the product. Specifically, it would be able to integrate our 2D camera data into a 3D frame, and efficiently provide a frame of reference and to base the wireframe projection throughout the samples of movements.

References

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