DIGITAL COACHING FOR FIGURE SKATING

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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

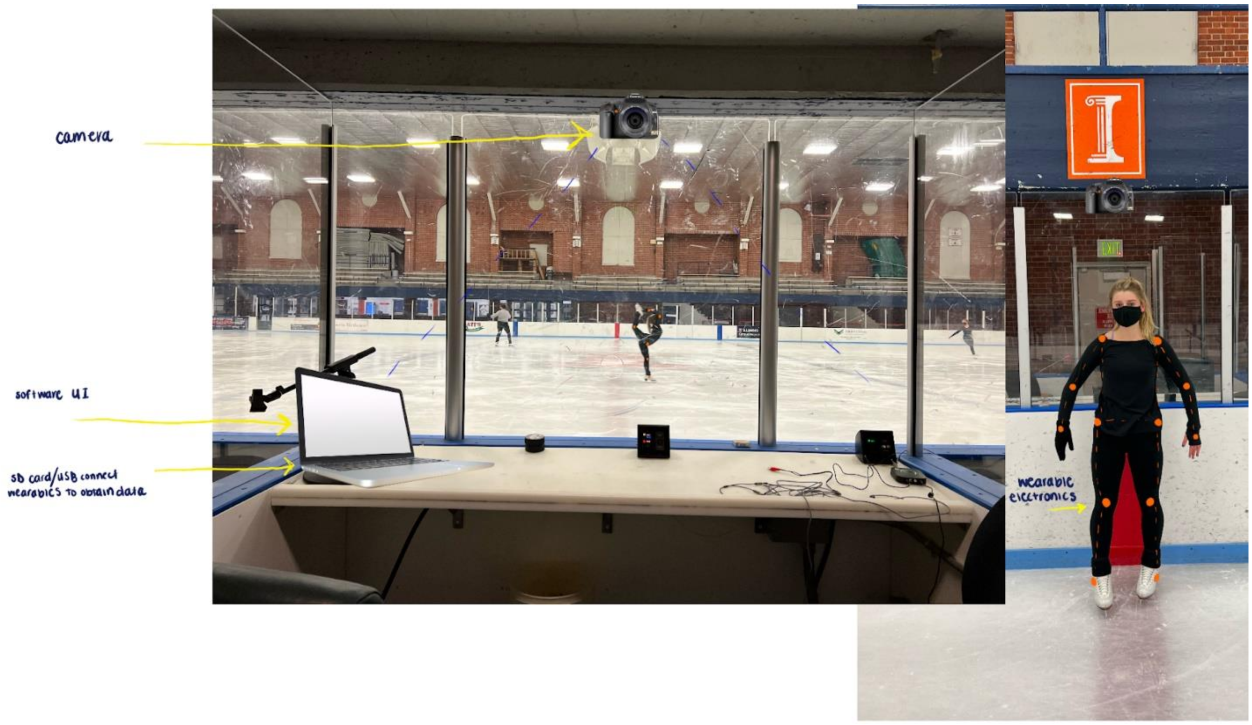


Figure 1. Visual aid demonstrating the different components of the project.

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

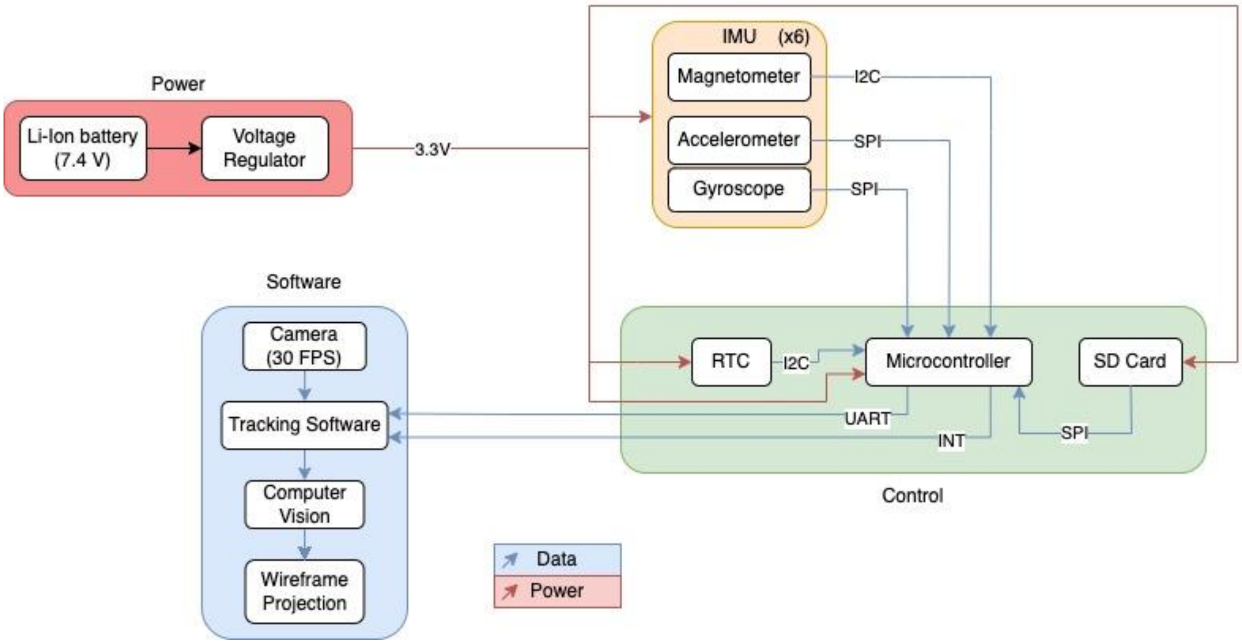


Figure 2. Block diagram breaking down the subsystems of the project.

2.2 Physical Design

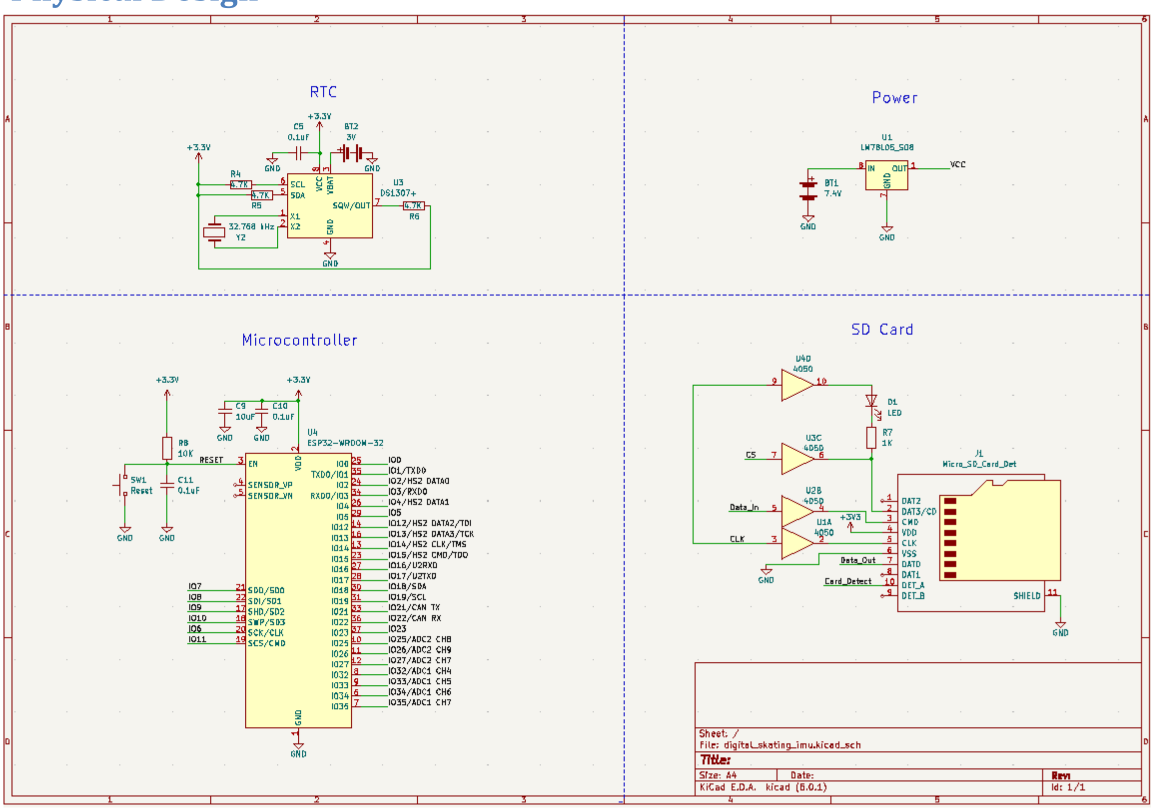


Figure 3. Schematic of the control subsystem.

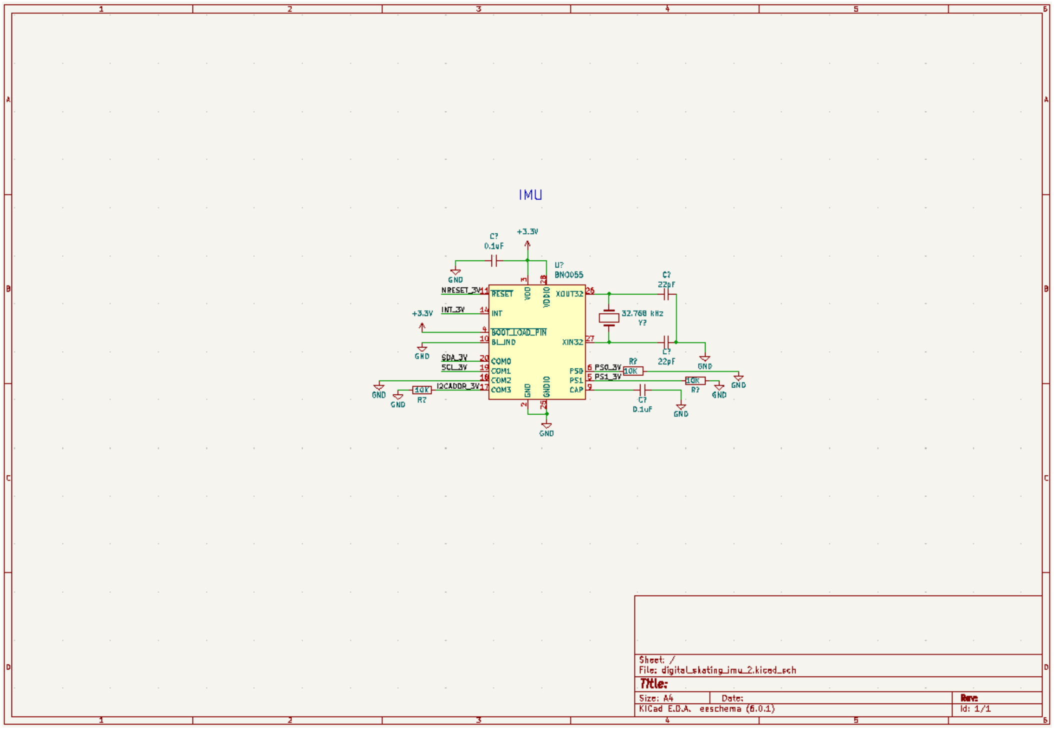


Figure 4. Schematic of the IMU subsystem.

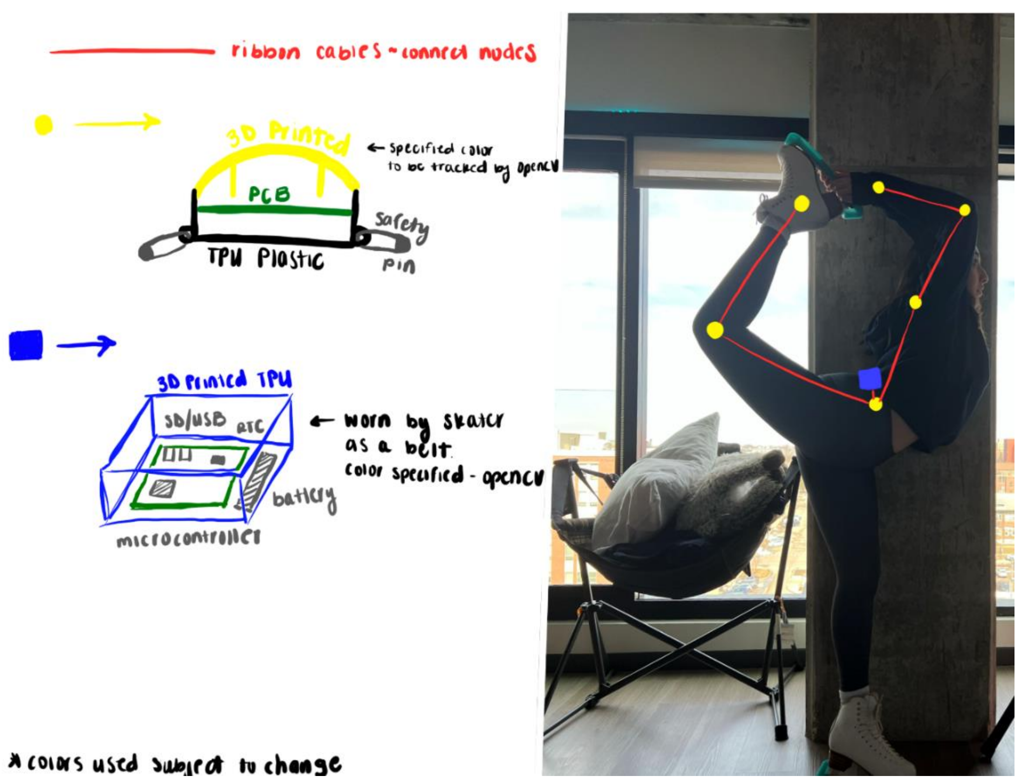


Figure 5. Visual aid with a more detailed breakdown of the wearable electronics system.

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.

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.

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 one 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 plan to use the BNO055 sensor for our IMU nodes.

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%.

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.

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.

2.3.4 Camera and Software

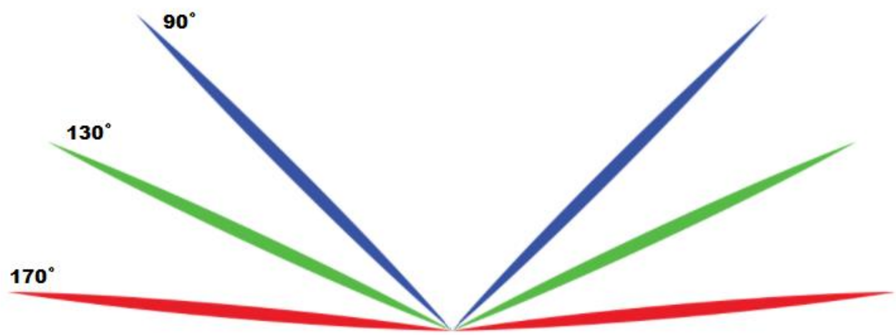
We will need to connect a camera to a computer in order to accomplish the computer vision aspect of this project. The camera will capture the motion of the skater as well as track the world position of the IMU nodes to provide visual data. This will be paired with the IMU data to generate a model of 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.

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.

2.4 Tolerance Analysis

For the BNO055 sensor, the typical accelerometer sensitivity tolerance is ±1% with a temperature drift of ±0.03%/K. The gyroscope also has a typical sensitivity tolerance of ±1% with a temperature drift of ±0.03%/K. The standard environmental temperature for the BNO055 sensor is about 25°C, and an average ice rink is maintained at -4.4°C. To make things simpler, we'll say that it's a difference of about 30°C (or 30 K).

This project is meant to be used in any ice rink setting, but we will use the UIUC Ice Arena setting as it will be the location we use to test and experiment. The Ice Arena has dimensions of 192' x 115', and we would be setting up the camera to monitor across the width of the rink. Through our software, the camera will be monitoring for the color of the IMU cases, which should be visible against the background of the ice rink. GoPro cameras have 3 different fields of view: 90° (Linear), 130° (Wide), and 170° (Superview).



$$View\ Width = 2 * \frac{115ft}{\cos(45°)} * \sin(45°) = 230ft * \tan(45°) = 230ft$$

Using the Linear setting of 90°, the field of view from 115 feet away provides a wide perspective of up to 230 feet.

$$Tolaccel\ =\ \pm 1\%\ +\ (\pm 0.03\%/K)\ x\ (30\ K)\ =\ \pm 1.9\%$$
$$Tolgyro\ =\ \pm 1\%\ +\ (\pm 0.03\%/K)\ x\ (30\ K)\ =\ \pm 1.9\%$$

Ideally, the person skating will not be skating on the other side of the rink away from the camera, so to keep a consistent margin of error, we can allow our code up to a 2% range (±1%) for color detection tracking of the IMU nodes. This amount should be generous enough to allow us to focus on the location of each node, but not misplace from camera perspective. The BNO055 unit is a 9 degree-of-freedom sensor, so working with its data and the camera's tracking should help synchronize location and movement detection.

$$2\%\ x\ 230\ ft\ =\ 4.6\ ft$$
$$1080p\ =\ 1920\ x\ 1080\ pixels$$
$$2\%\ x\ 1080\ =\ 21.6\ pixels$$
$$2\%\ x\ 1920\ =\ 38.4\ pixels$$

If we use a 1080p resolution, a 2% margin of error would provide an area of about 22 x 38 pixels of tracking error, which while far away would be 4.6 feet, but close up would be scaled down to a couple inches. The total tolerances of the IMU data do not directly affect the position of the skater, but rather their acceleration and angular velocity. The effect on location would be very minimal and would be easily fixed and synchronized by the data from the camera.

Overall, the error that would incur from motion detection and the tolerances of the IMUs would provide very small mistakes in tracking the skater and should be a concern. We also have two sources of data: the camera and the IMU sensors, so combining the data received from both devices, we can recover from many misplacements in the location data.

3. Cost and Schedule

3.1 Cost Analysis

For each design engineer, a $40/hour salary with a project completion time of 300 hours gives $12,000. With 3 design engineers, this comes out to $36,000.

Part Name	Part Number	Manufacturer/Supplier	Quantity	Cost
IMU Sensor	BNO055	Bosch	6	$1.99
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	10 pin	Amazon	1	$9.99
Filament	1.75mm 250g TPU	Amazon	1	$15.99
Voltage Regulator	LM78L05	Texas Instruments	1	$1.00
MicroSD Module	MicroSD Socket	4UCON	1	$1.95
Total Cost				$52.10

Grand Total: $36,052.10

3.2 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		

4. 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.

References

[1] IEEE, “IEEE Code of Ethics.” [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html

[2] Bosch, “BNO055 Intelligent 9-axis absolute orientation sensor.” [Online]. BST-BNO055-DS000-12, Nov. 2014.

[3] Espressif Systems, “ESP32-SOLO-1.” [Online]. June 2018 [Revised Feb. 2021].