Judo Sensor Vest

Design Document

Team 6

Max Baumgartner (mtbaumg2)

Alex Gaynor (bchmnng2)

Janak Mehta (jrmehta3)

TA: Samuel Sagan

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We would like to thank Dr. Manuel Hernandez of the Mobility and Fall Prevention Research Laboratory for his help as well as the use of his force plate in gathering data for our project;

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Our TA, Sam Sagan for his advice at every step of the project.

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1 Introduction

1.1 Objective

There are often controversial decisions made by judges and referees in competitive judo matches due to the limitations of distance and viewing angles, which can drastically affect the way that points are awarded in matches. Our solution that will mitigate this problem is a vest with force sensors that can accurately detect the forces from the moves and throws executed in order to help judges score matches with greater accuracy.

1.2 Background

This problem of controversial decisions has been persistent in judo even at the highest level of competition like the olympics. One recent controversy was the 2012 olympics in the 66kg division quarter-finals when Ebinuma Masashi fought Cho Jun-ho [1]. The controversy stems from a scoring decision by the referees whom after video review took away a *yuko* (quarter point-a now discontinued score as of 2017) from Ebinuma which turned a match that should have been over into overtime. Both players were unable to score and the match ended, Cho was declared to be the winner by decision after showing a dominant late game however, this call was rescinded to give Ebinuma the victory after the judges deemed his previous throw was significant enough for him to win. While the yuko score is currently being considered for removal, the fact remains that international level judges even with the help of video cameras had made huge blunders in scoring. The Judo Vest is a design that is intended for practitioners to better understand their throws and for judges to be able to make better calls during matches and to prevent further controversies in the wonderful sport of judo.

1.3 High-Level Requirements

1. The vest must be highly durable as well as compact and non-intrusive.
2. It must demonstrate properly for a handful of select judo moves such as *ogoshi* (hip throw), *osoto-gari* (leg sweep) and *kesagatame* (pin). We will also implement a feature that allows the wearer to tap out while on the receiving end of an armbar.
3. The vest must be able to detect forces distributed across several pressure sensors as well as a continuous force applied over a period of time which represents a pin, and transmit the appropriate data wirelessly to a computer for scoring purposes.

2 Design

The project consists of clearly-defined modules, each one accomplishing a specific purpose in the project. The vest itself will be made of a reasonably lightweight, resilient material. The force sensors will be able to withstand the full force of a throw (a couple thousand Newtons distributed across several sensors, while the pressure sensors will be capable of withstanding a pin (can be up to a couple hundred Newtons, spread across several sensors). With these, the vest will be capable of properly discerning whether a force was a throw, a pin or a tap-out, and there will be clear criteria for determining each of these. In addition, there will be a dedicated communications module that will allow the vest to broadcast its score remotely to a computer over a range of at least 14 meters. The microcontroller will take in the inputs from the sensors and decide which signal to broadcast to the communications module. The processing unit will take in the data and calculate whether a point should be awarded to the wearer's opponent and then display the score.

2.1 Block Diagram

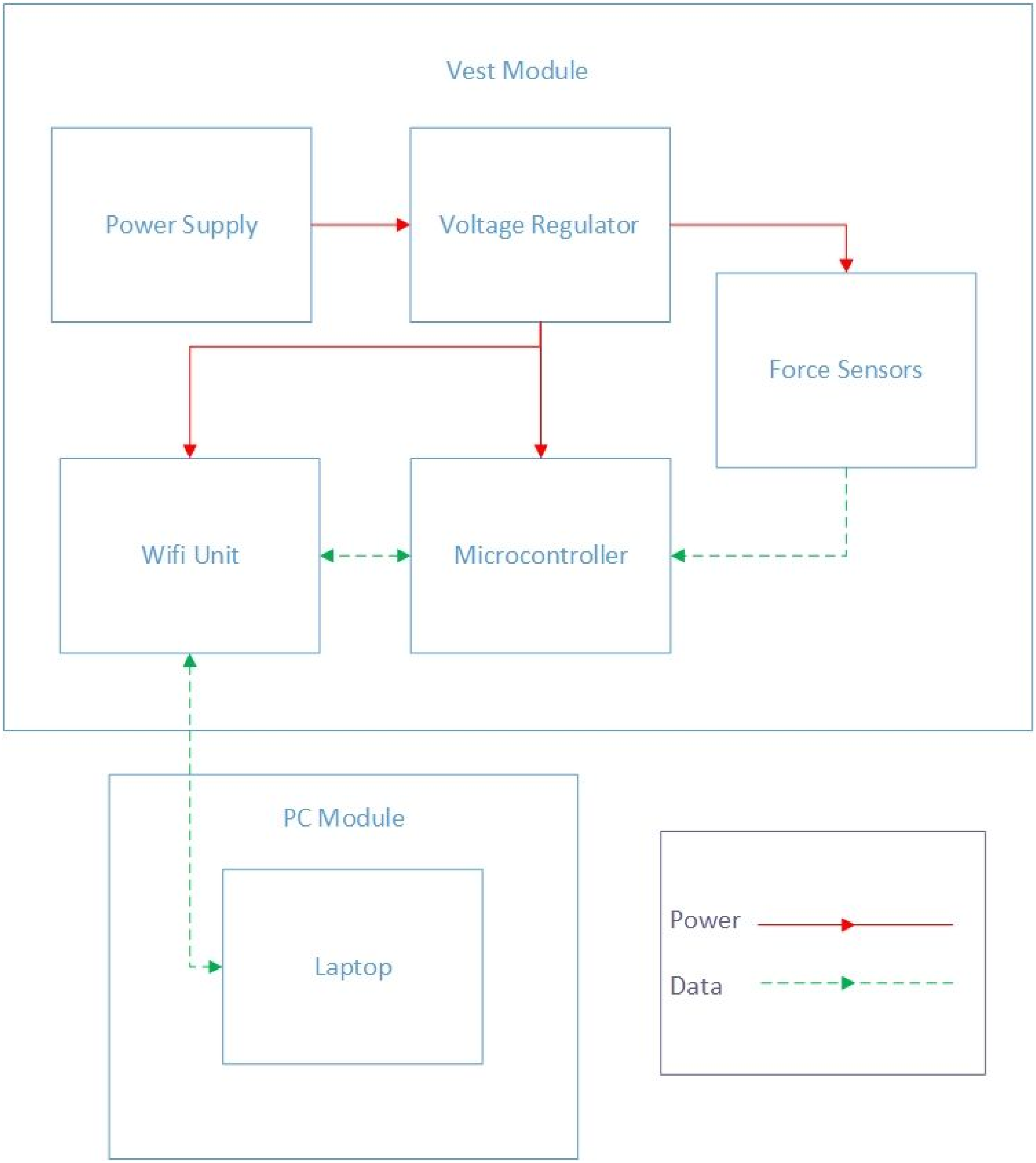

Fig. 1 : Block Diagram

2.2 Physical Design

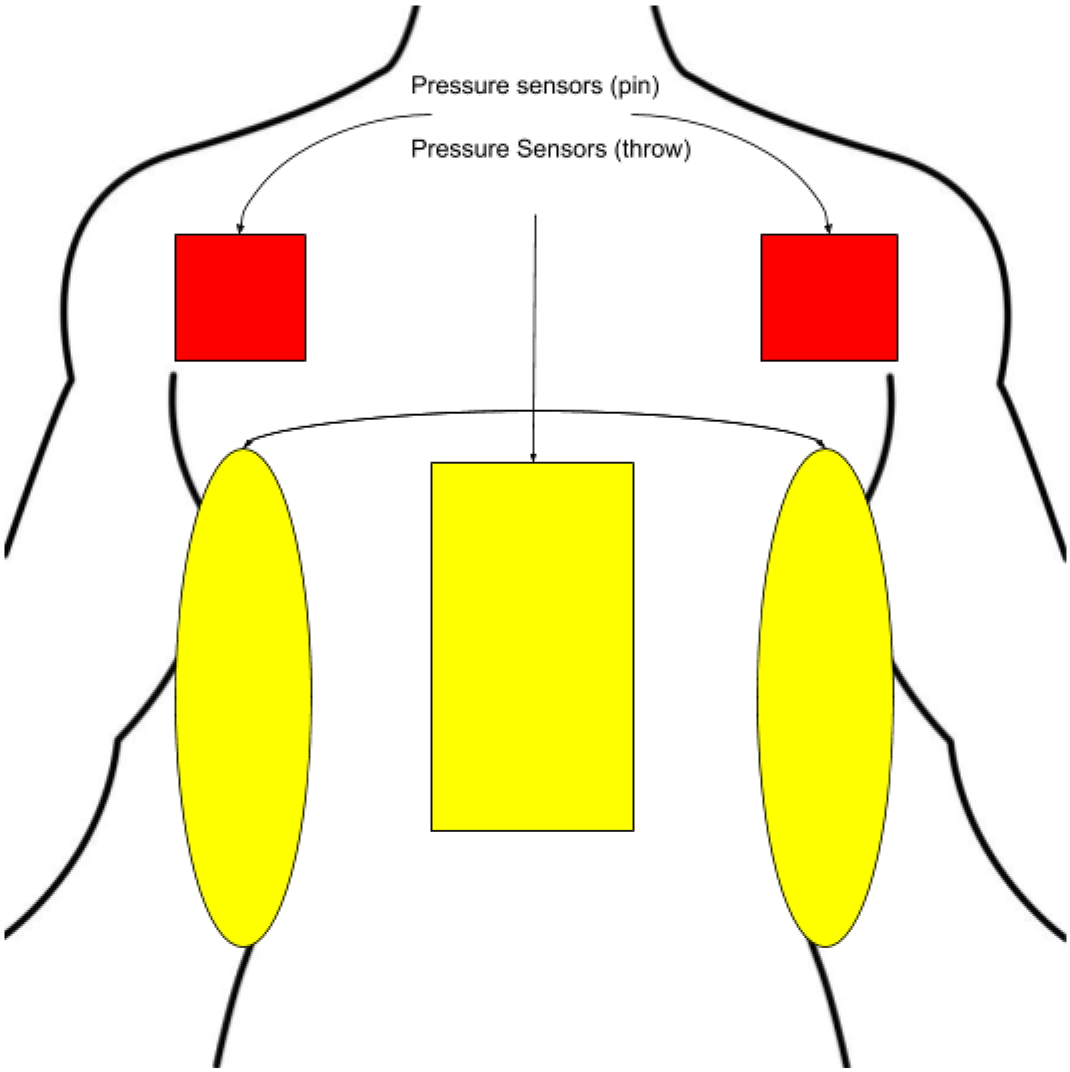

Fig. 2 : Diagram depicting the placement of sensors on the body

The sensors on the back should roughly fit a size 3.5 to 4 judo gi so roughly 45x60cm on the back. The ideal placement of the sensors would be 4 sensors on each latissimus dorsi with a cluster of 2 sensors placed along each side of the spine around the upper part of the thoracic region totalling to 10 sensors on the back dedicated to only determining the force of a throw. There will additionally be 2 sensors one on each shoulder blade, to confirm if a pin has occurred, and 2 in the upper chest region to allow the user to tap out during an arm bar. Ideally, all of the sensors could be placed on a modified rash guard or undershirt which would only add minor interference to the movement of the user. The control unit placed on the front of the thighs and no larger than 20x15cm vertical strip. This is to ensure that the microcontrollers as well as the communications unit does not get crushed when the user falls on their back and will not see too much physical contact with opponents during a match or sparring session.

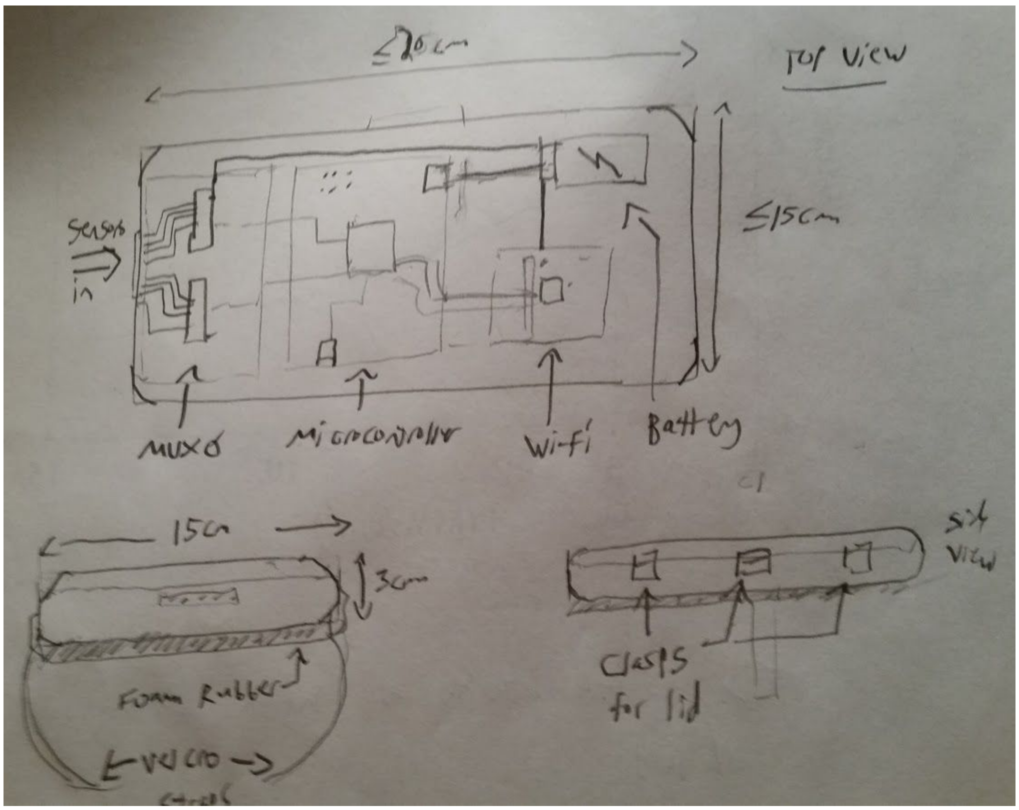

Fig. 3: Sketch of circuit protector assembly: Top, front and side views.

The batteries, microcontroller, wifi module and sensor multiplexers will be contained inside a protective sheath, sketched above. Each of these components will likely have their own PCB, to facilitate efficient packing and reduction of size. The PCBs will be contained a box with dimensions not exceeding 20cm x 15cm x 3cm.

2.3 Block Design

2.3.1 Power Supply

Input: 9V alkaline battery

Output: +5V±5% for ATmega328 microcontroller

+3.3V±5% for ESP8266 wifi module

+5V±5% for ShuntMode FSR sensors

Since the design needs to be wireless, a battery pack will provide the power to the worn circuitry, which includes power to the Sensor module, Control unit and the Wifi unit.

Devices	**Voltage Requirements**
ATmega328 microprocessor	Min voltage: 1.8 V Max voltage: 5.5 V
ShuntMode FSR	Min voltage: 0.2 V Max voltage: 5V
ESP8266 wifi module	Min voltage: 1.7 V Max voltage: 3.6 V
LM7805 Voltage regulator	**Input:** Min: 7.5 V Max: 35 V **Output**: Min: 4.8V Max: 5.2 V

Table 1: Voltage ranges for all components on vest

2.3.2 Voltage Regulators

Input: 9V from power supply

Output: 5V, 3.3V respectively

To protect the circuitry from burning out, a voltage regulator will reduce the battery voltage to a safer level appropriate for the model of microcontroller and sensors we use. We will be using the LM7805 voltage regulator, that will be capable of handling the voltage from the battery (7-9 V DC) and stepping it down to 5V, which is the optimum voltage for the Arduino. The wifi module requires a lower operating voltage of 3.3V, so it will have its own separate voltage regulator, the LM3940.

[10 Points]

Requirements	**Verification**
1. Provide a constant output of 5 V ±5% to be used by the microcontroller 2. Provide constant output of 3.3 V ±5% to be used by the wifi unit.	1,2. Use multimeter to measure the voltage at the terminals.

Table 2: Voltage regulator RV table

2.3.3 Sensor Module

Input: Physical force on sensors

Output: Resistance change of the sensor module

To try to attempt to get an accurate scoring of a fall and the validity of a pin, a series of force sensors will be used to measure how the user falls and if they have escaped/entered a pin or not. The sensors will be placed in locations most likely to be impacted when one of the moves within our scope is executed.

Due to the limited number of analog pins in the ATMEGA328 we will be using an analog multiplexer unit to choose which sensors to read for the pins involving the side of the back and the lower center spine. The select signals will be controlled by the atmega and cycled through at a rapid rate ensuring that when a throw does occur the microcontroller can detect it. Figure 5.1 shows the MUX unit for our dorsal sensors using the 4051 analog 8:1 MUX. The sensors represented by the 8 resistors, are connected to the 8:1 MUX, the select signals are governed by the digital I/O of the microcontroller. The MUX output is connected to two op amps as seen in Fig 6.1, the first acting as an inverting amplifier to differentiate between higher forces and the second acting as a buffer [4]. The circuit configuration is necessary due to the desire to use the resistance across the FSR to determine our voltage output and the desire for the ability to read forces exceeding 440N. The op amps are used because the resistance of the FSR becomes smaller as more force is applied making it more difficult to differentiate as seen in Fig. 4.1. The total gain across the two op amps can be expressed by the equation

$$V out = V in\frac{R_{REF} R_{BUFF1}}{R_{FSR} R_{BUFF2}} \qquad \textbf{eq.1}$$

The ideal would be to have a reference resistor equal to or smaller than the resistance given at the highest force readings as this would ensure a -4.5V output when maximum force is registered. The second op amp is used as a buffer to make our negative voltage to positive for the analog I/O to read. This is due to our desire to use the resistance across the FSR in our gain calculation. To accomplish this setting we once again refer back to figure 4.1 we can see that at high forces the FSR outputs a resistance close to 200kΩ. While it decreases minutely when more force is applied, the output resistance without an amplifier will hardly be usable and the minute difference in resistance would hardly be noticeable. The R_{REF} should ideally be smaller than this 100kΩ resistance with it ideally being around 180kΩ to ensure that R_{REF} will always be less than R_{FSR} to prevent any voltage exceeding 5V going into the microcontroller it also should prevent the output across the first op amp from exceeding 4.5V. This 4.5V limitation across the first op amp is in place in case the buffer does not give exactly unity gain. While R_{BUFF1} and R_{BUFF2} should be close to equal as possible as it may not be feasible this 4.5V limitation is set in place.

Of the 6 remaining sensors 4 of the sensors, used for pins and armbars, must be read 100% of the time to ensure that when tapping out the signal is always read, and that we never lose a force reading for when a player is pinned. This means that these 4 sensors will be connected directly without a MUX. The pin sensors will have the same op amp configuration as the throw sensors however, the tap out sensors will be a have a weaker force sensor due to the need to read minute forces. In comparison to the 440N sensors these can only get a max reading of 44N. These sensors will be represented by a voltage dividing circuit seen in figure 6.2.

The remaining two sensors used for the spinal area are identical to the 8x1 MUX except for the fact that the 8x1 MUX is replaced by a 2:1 analog MUX. To keep things consistent they will also have their select signals cycled at the same speed as the 8:1.

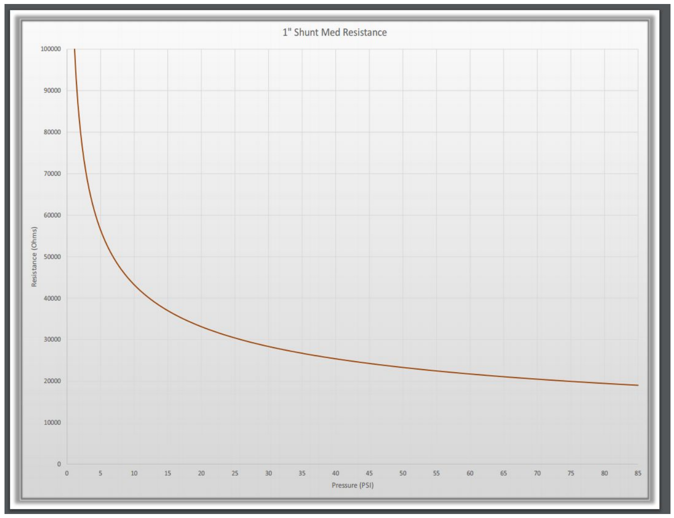

Fig. 4.1: Resistance Curve of ShuntModeFSR[8]

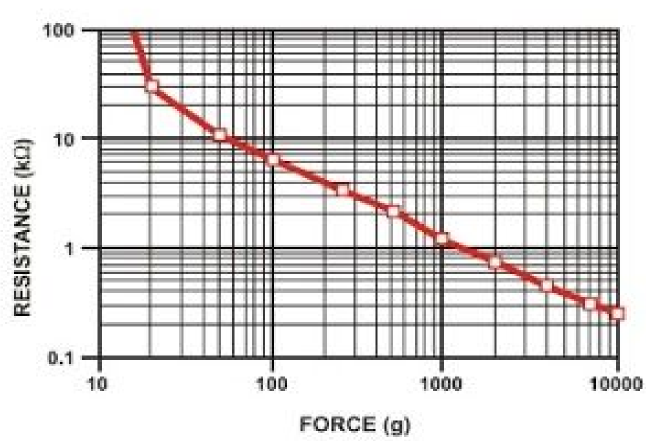

Fig. 4.2: Resistance vs force curve for SEN-09376 FSR [7]

[15 points]

Module	Requirement	Verification
Force Sensors	1. Must be able to detect up to 440N of force for throws. 44N for tap out.	1. Apply a force of 440N (44N for tap out sensors) onto the sensors and measure voltage to see how it corresponds to voltage vs resistance curve.

	2. Must be able to accurately detect a pin. To do this, it must detect a force of about 440N over a continuous period of 25 seconds.	2. Apply a force of 440N for 25 seconds on the sensor and measure voltage across the sensor and check if reading is accurate.
Analog Mux	1. The analog mux must not drop a signal.	1. Ensure the MC is reading all 8 outputs with the select signals set to cycle through the signals at 500Hz
Op Amps	1. Each op amp must operate with a delay no larger than 2µs 2. Buffer resistors must be within 5% of each other. 3. Reference resistor must be below 180kΩ 4. Max output voltage should not exceed 4.5V across the first op amp when a 440N force is applied to the FSR.	1. We will use an oscilloscope to measure the time delay across the op amps to ensure time delay is no greater than 2µs 2. We will use ohmmeter to measure resistances and compare results ensuring the two values differ no greater than 5% of each other 3. We will use an ohmmeter, however, this may be subject to further change depending on our max sensor resistance. 4. This will be done by reading

		output voltage across the first op amp with and seeing if it exceeds -4.5V

Table 3: Sensor module RV table

2.3.4 Microcontroller

Input: 5V power input, Voltage measurement from sensor module.
Output: Data packet sent to wifi unit.

We have considered a variety of options for the microcontroller that will control the wearable circuitry, with an emphasis on a model that is cheap, compact, reliable and able to interface with our chosen sensors as well as a wireless communications module. To that end, we chose to use the ATMega328p microcontroller along with some other components, to effectively build our own Arduino microcontroller capable of interfacing with any peripherals required [2].

[5 points]

Requirement	Verification
1. Microcontroller should be able to detect changes in the voltages across the force sensors when force is applied. 2. Should be able to collect sensor data and create data packet.	1. Place a 1kg weight on the sensor and check the value of the reading obtained by the microcontroller. The resistance registered read should correspond to 9.8 N on the force-resistance curve. (Approx. 600kΩ) 2. Feed sample sensor values to microcontroller and run code to check

	whether the data packet was correctly constructed.

Table 4: Microcontroller RV table

2.3.5 Wifi Unit

Input: 3.3 V power supply, Data packet from microcontroller.

Output: Data transmitted to pc module

Since judo requires a lot of movement in 3 dimensions, the sensor signals will have to be transmitted wirelessly. To this end, we will make use of a wifi module that is included in the circuitry worn by the user and will transmit the data packet created by the microcontroller when the sensors are activated. We will be using the ESP8266 wifi unit to send the data using TCP.

A TCP data packet contains the source port, the destination port, the length of the data packet and the encapsulated data. A new packet would be sent every second and the packet would be repeatedly sent every few milliseconds until an ack message is received. One second should be enough of a time window to send a packet, wait for an ack or to send it again multiple times. The sensor data would be sent in blocks. There are 12 sensors in total so there would be 12 blocks. Each block would contain the voltage across each sensor. There would be a header for a packet serial number to keep track of.

The ESP8266 cannot be directly connected to the 5V microprocessor so we will use a bi-directional logic converter to connect it to the microcontroller.

[10 points]

Module	Requirement	Verification
WiFi Unit	1. Should be able to send packets reliably without loss in data due to packet drops within a 4:00 minute period. Should send be able to send and receive ack from pc at the minimum rate of 2 packets per second. 2. Must be able to transmit data from a minimum range of 14m.	1. Send periodic sample data packets for 4 minutes (one every second) and compare the data sent and data received. 2. Conduct trials of transmitting sample data packets from a distance of 14, 15 and 16m and confirm that all the data packets have arrived without any corruption.

Table 5: Wifi module RV table

2.3.6 PC Module

Input: Data from wifi unit

Output: Score information

We will run a program on a computer to receive data from the communications module and process it into meaningful information. Depending on what sensors were activated, it will decide what kind of move was dealt and how many points are to be awarded to the opponent. The resultant information that can be gleaned from the data will be displayed on the computer in a visual format to show the score and sensor readings.

Data will be received at the rate of one new packet every second. Once a packet is received, an ack message is immediately sent in response. If a message has been received already, and an ack for that message has already been sent, then that packet will be dropped.

[10 Points]

Requirement	Verification
1. Should be able to receive data packet and send ack. 2. Should be able to parse data packet and figure out which sensors were activated and using the combination of the sensors, should be able to figure out what move was executed.	1. Send sample data packet to UDP socket and wait for ack response. 2. Send a sample data packet with known force sensor inputs and check if module outputs the correct information after parsing.

Table 6: PC module RV table

2.3.7 Circuit Protector

Most of the circuitry will be enclosed in a protective container worn on the inner thigh. It will be composed of a strong, lightweight material, such as polycarbonate, that will be able to withstand the force of a throw while also allowing wifi signals through so that the vest can wirelessly transmit data gathered. The protector will take the shape of a box no larger than 20 cm by 15 cm, and will contain the microcontroller, batteries, wifi module and sensor multiplexers. It will have a base made of foam rubber to help with wearer comfort and be secured to both the leg and vest by velcro straps. Ideally, it will also be modular and detachable from the vest. For that it will have ports that the wires running to the sensors will be able to plug in to.

Requirements	Verification
1. Must be smaller than 15cm x 20cm x 3cm. 2. Must be safe enough for user to wear on leg. 3. Must be durable enough to withstand multiple hits and falls and forces up to and exceeding 2000N.	1. Measure size with ruler. 2. Round off the edges to minimize risk of injury. Have it strap on with Velcro. 3. After the protective shell is procured there will be multiple trials where one of us will fall on top of the box on a mat before circuitry is placed inside.

Table 7: Sensor module RV table

2.4 Schematics and Flowcharts

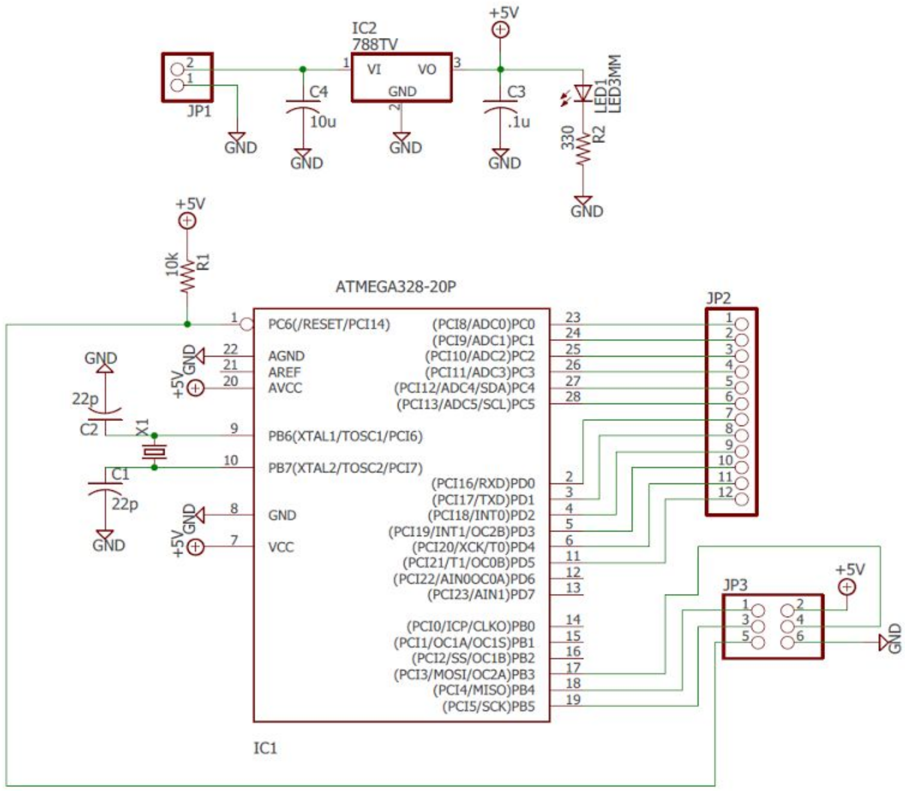

Fig 5: Schematic Diagram of Microcontroller unit.

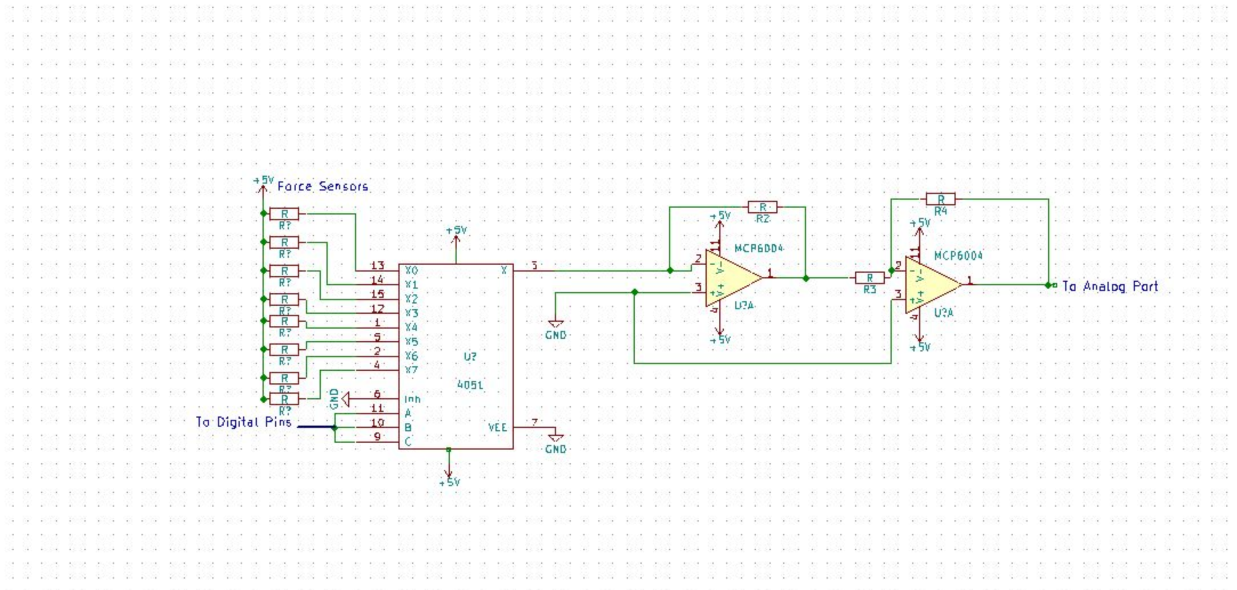

Fig 6.1: 4051 MUX sensor configuration

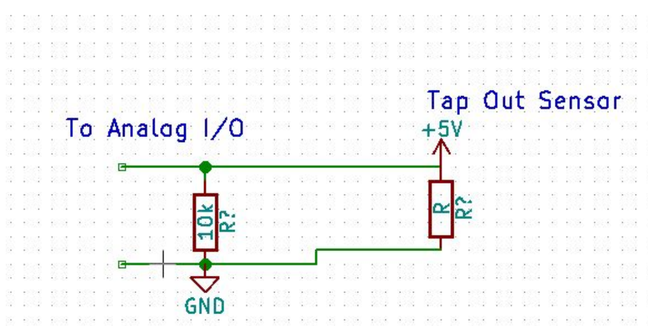

Fig 6.2: Tap Out voltage divider circuit

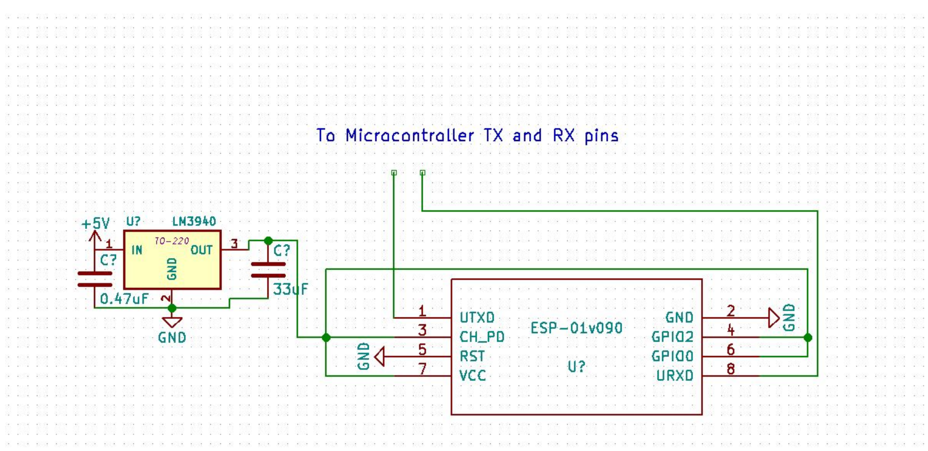

Fig 7: Wifi Unit with 5V to 3.3V voltage regulator

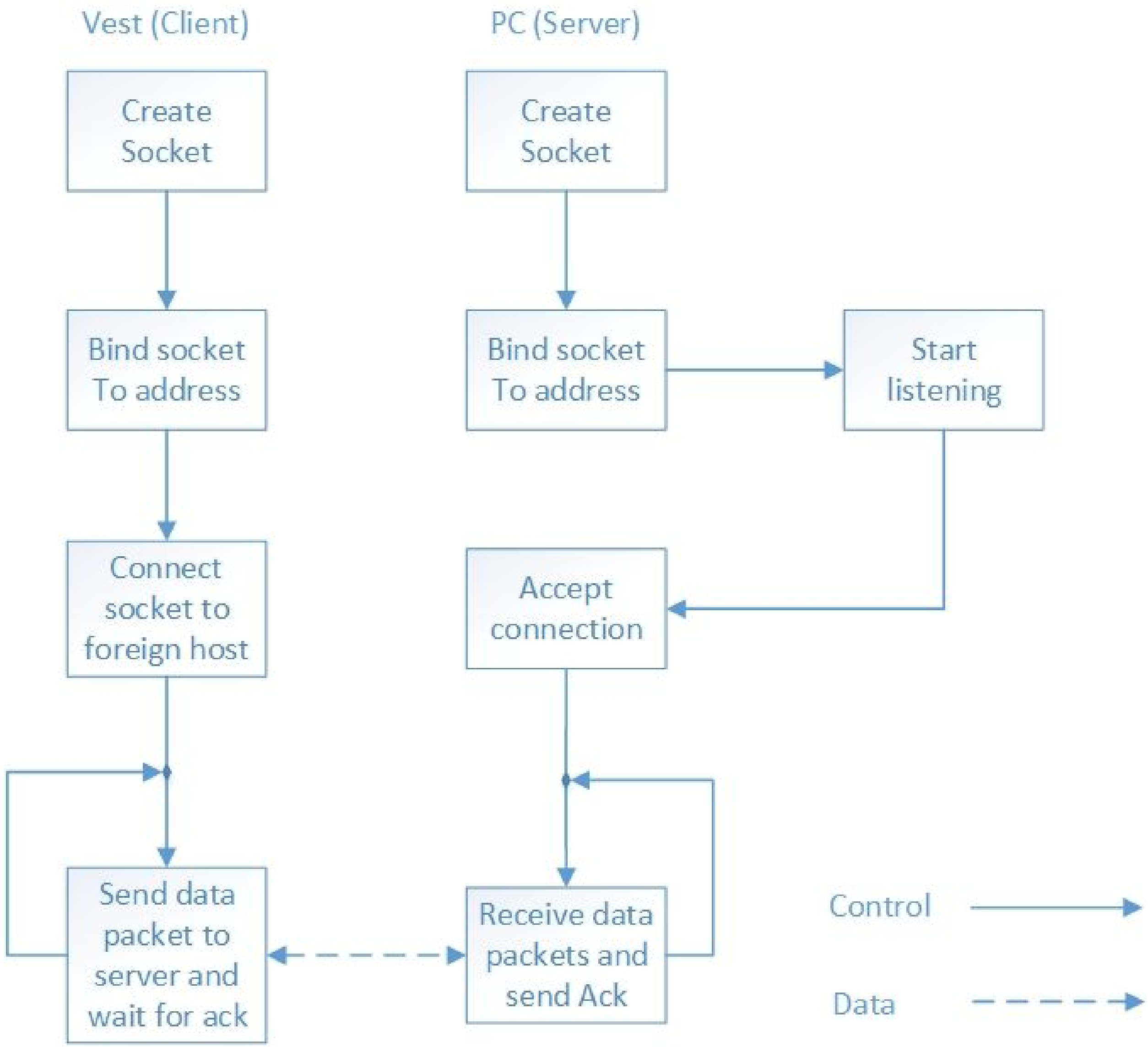

Fig 8: Flowchart depicting the operation of software to transfer data packets

2.5 Data collection

We performed some research with a force plate in one of the Kinesiology labs to gather data on the approximate force generated by a judo throw. We conducted several different kind of judo moves, each with 5 trials to get a good average of each to get an idea of what our force sensors should be able to detect. For reference, the mass of the subject in each of the below trials was 72.57 kg and forces generated are measured in Newtons.

Movement	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
Leg Sweep	1794	2343	1610	1191	1733
Hip Throw	2519	2365	2390	2075	1785
Backfall	1272	1052	1306	1081	1092
Forward Roll	1029	1143	1350	912	1113
Vertical Jump	2086	1900	1950	1950	1850

Table 8: Results of data gathered with force plate

2.5.1 Simulation results

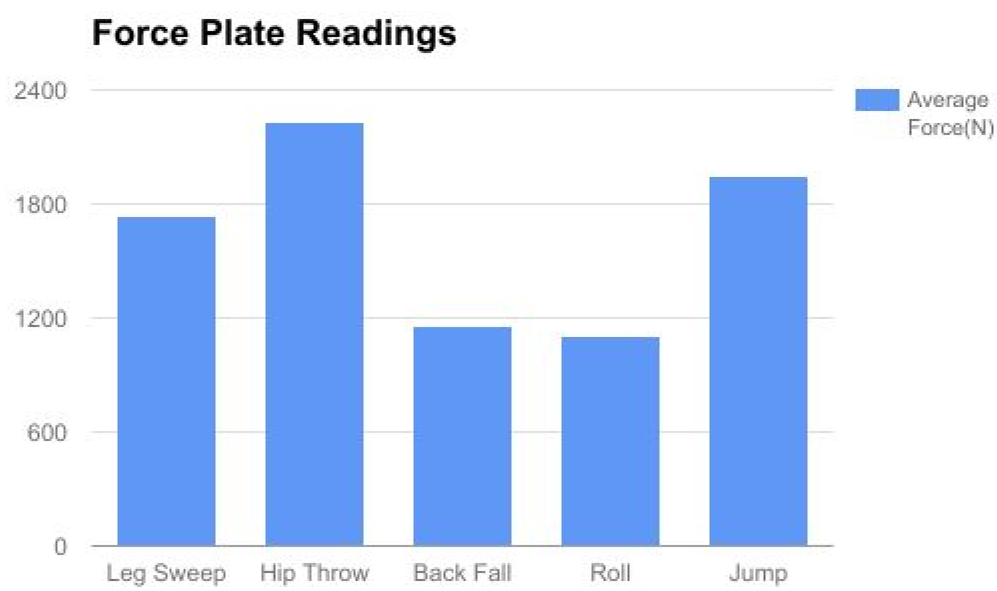

Fig. 9: Results from data trials

2.6 Tolerance Analysis

The most critical feature of our project is to be able to detect forces exerted on the user while he participates in a judo match. The readings that we made from our data trials give us a ballpark of 1000N minimum of force exerted on the body when the moves are executed. It is financially unfeasible to use sensors that can sense that amount of force as the cost runs upwards of $800 each. The sensors available on the market right now which can provide those readings cannot be used for wearable devices. As such we have had to compromise and simplify our design to make it more cost effective and also so that it can function as a vest. We will be using much smaller load sensors (rated for up to 100 lbs load on each)

One serious cause for concern is the total output voltage that is to be read across the sensors should be no larger than 5V with the voltage across the first op amp no larger than 4.5V. This is due to our voltage buffer circuit that must be included in our design to have a readable output voltage for the microcontroller to read. The equation for gain is reproduced below.

$$V out = V in \frac{R_{REF} R_{BUFF1}}{R_{FSR} R_{BUFF2}} \qquad \text{eqn.1}$$

The issue arrises when R_{buff1} and R_{buff2} are not equal to each other which could potentially increase our target voltage in the first op amp. For our worst case scenario we see a gain of either 1.1 or a gain of 0.9. This would be a cause for concern as high forces could potentially exceed 5V. Worst case, we see a gain of 1.1 meaning our voltage across the first op amp would need to be less than 4.5V. To accomplish this the reference resistance, under the assumption that the FSR would output ≈200kΩ when applied 440N of force, would need to be ≤ 180kΩ to ensure that no voltage output would exceed 5V with a worst case voltage buffer gain of 1.1 V. Looking to the reference sheets on surface mount resistors[6], this would translate to a ±5% error with all resistance values.

3 Cost & Schedule

3.1 Cost Analysis

3.1.1 Labor

We have estimated our costs for this semester to include salaries for 3 engineers at $40/hour each for approximately 12 hours per week for a semester of 16 weeks.

$$3 * (40 * 16 * 12) = \$23,040$$

Since we are also enlisting the help of the Machine Shop to build our circuit protector, we estimate it would take two of their guys, at an estimated rate of $50/hour each approximately 5 hours to build it assuming they have all the materials they need.

$$2 * 50 * 5 = \$500$$

Total Labor: $23,040 + $500= **$23,540**

3.1.2 Components

Part	**Cost**	**Supplier**
1 inch ShuntMode FSR x12	$72	Sensitronics
SEN-09376 x2	$19.90	Sparkfun
ATmega328 x3	$12	Amazon
AVR cable + Programmer	$8.56	Amazon
AVR pin adaptor	$6.99	Amazon
Assorted resistors, capacitors, LEDs	$5.00	Electronics Service Shop
16 MHz Crystal Oscillator	$0.49	Electronics Service Shop
ESP8266 Wifi Module ESP01	$6.95	Amazon
PCB x3	$50	PCBWay
CD4051BE Multiplexer x2	$1	Digikey
MCP 6004 x2	$0.80	Microchip
LM3940	$1.49	Digikey
Rash guard	$40	Dick's Sporting Goods
9V battery x2	$7.99	Duracell
Wiring (2 spools conductive	$6	Sparkfun

thread)		
Fabric Glue (waterproof)	$10	Sparkfun

Total components cost: $249.17

Total cost: $23789.17

3.2 Schedule

As a group, we intend to follow a weekly schedule in order to achieve maximal efficiency in completion of our project.

Week	**Max**	**Alex**	**Janak**
2/27/17	Design Review Investigate/order sensors order analog MUX	Design Review Breadboard the prototype microcontroller. Begin basic testing of microcontroller. Make circuit battery-powered. See about obtaining PCB for microcontroller. Peer Review 1	Design Review Create data packet structure and figure out exact relation to convert resistance/conductance information to force values.
3/6/17	Test single sensor Properly configure sensors	Soldering Assignment Start designing PCBs for the rest of the circuitry,	Write arduino code to collect force sensor data and create data packet for

	Establish the transconductance and resistance graph	allowing for modular design.	sending.
3/13/17	Test Sensors and MUX	Submit updated PCBs for manufacture.	Write code to create UDP client using wifi module to send packets.
3/20/17	Debug Sensors and MUX	Help with debugging and design.	Write code to create UDP server on pc to receive data packets.
3/27/17	Vest development	Finish all PCB design	Complete code to parse data packets and display results.
4/3/17	Test Vest and sensors w/throws	Get final PCB Integrate all electronics with vest	Live testing
4/10/17	Refine vest and sensors	Help to finish vest.	Last minute debugging and testing.
4/17/17	Mock Demo	Mock Demo	Mock Demo
4/24/17	Demonstration Peer Review 2 Mock Presentation	Demonstration Peer Review 2 Mock Presentation	Demonstration Peer Review 2 Mock Presentation
5/1/17	Presentation Peer Review 3 Final Paper Lab Notebook	Presentation Peer Review 3 Final Paper Lab Notebook	Presentation Peer Review 3 Final Paper Lab Notebook

4 Ethics and Safety

4.1 Ethics

Since users will use the vest while doing judo, the risk of injury is always present. We will aim for high safety standards and will provide sufficient warnings of the potential dangers that may be involved in the usage of our product. This aligns with IEEE code of ethics #1: "To accept responsibility..."[3]. We will be honest in our claims and estimates based on our data and will not make any false claims for the sake of the progress of the project. This aligns with IEEE code of ethics #3 We will work closely with the professors and the TAs and will use their constructive criticism and review for the improvement of the project. We will give credit to every person who contributes to the development of this project [3].

As we're creating a device used for full contact sport we will try to make the device as safe as possible for the user to prevent the device from harming people as well as preventing people from using the device for harm. This is evident in our desire to place the control unit in areas with low physical contact and ensuring that all components will be insulated in protective layers to prevent harm to both user and device. The conductive thread that will be used to connect the sensors to the control unit will be insulated with fabric glue so that it doesn't short out and give faulty readings.

The circuit protector will be made of polycarbonate, so as to be reasonably lightweight and highly durable and resistant to impact. This will also allow wi-fi signals to pass through, unlike a metal box. We will also have beveled edges on our shock resistant container to minimize cuts or other injuries resulting from the wearer possibly landing on the box during a match. Due to our scope of our project and the limitations of current force sensors, the prototype vest may not be able to properly accommodate people above the 66-72kg weight class though we will try to the best of our abilities to develop a device that can be used by anyone in compliance with the non-discrimination clauses in the IEEE code of ethics #8.

There is also a concern regarding competitive integrity. Since our device is meant to be used in the competitive scene, any unfair rulings made as a result of faulty information provided by our device may damage the reputation and integrity of the competition and may adversely affect the careers of the athletes. We will take steps to ensure that our product will give the most accurate results within the scope of our project. We will also try to get the most accurate results by placing the sensors in areas we believe will be the places first to see impact in a throw. If most of the sensors in the major areas of the back are activated with sufficient force (voltage across resistors) it will be considered a throw. To ensure that judges do not misinterpret our data an easy to understand representation of the data collected during a match will be displayed. However, our device is not meant to be the final judge for whatever happens on the judo mat. It is designed to provide supplementary data to help the judges and referees confirm and validate their decisions. The final say should always rest with the judges.

4.2 Safety

1. Since we are using a battery as a power supply for a wearable vest that will be sustaining impact, there is a danger of the battery getting damaged and hazardous materials being leaked. As such we will take extra precautions to ensure the protection of this battery so no harm may come. We will also provide sufficient warnings indicating the possible danger.
2. Our product also contains circuitry that cannot be exposed to water. Doing so may result in a short which may destroy the circuit or may even result in injuring the user. To ensure that such an event will not occur we will try to make the materials enclosing the circuitry and sensors to be sweat/water proof.
3. Given that judo is a full-contact sport we've decided to place the microcontroller in where we believe it will see the lowest amount of action. This is decision is further

solidified by the fact that it is currently illegal to grab an opponent's leg. Still, as it is a sport there is a risk that there will be rule breakers who will deliberately try to grab the legs. To ensure the safety of the circuits and the wearer there will be extra padding surrounding the thighs and bevel all edges to prevent any of the components potentially digging into the wearer's skin.

5 Citations

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