Electronic Martial Arts Paddle

ECE 445

Liam McBride, Alexander Lee

Professor: Arne Fliflet
TA: Jason Jung

Introduction

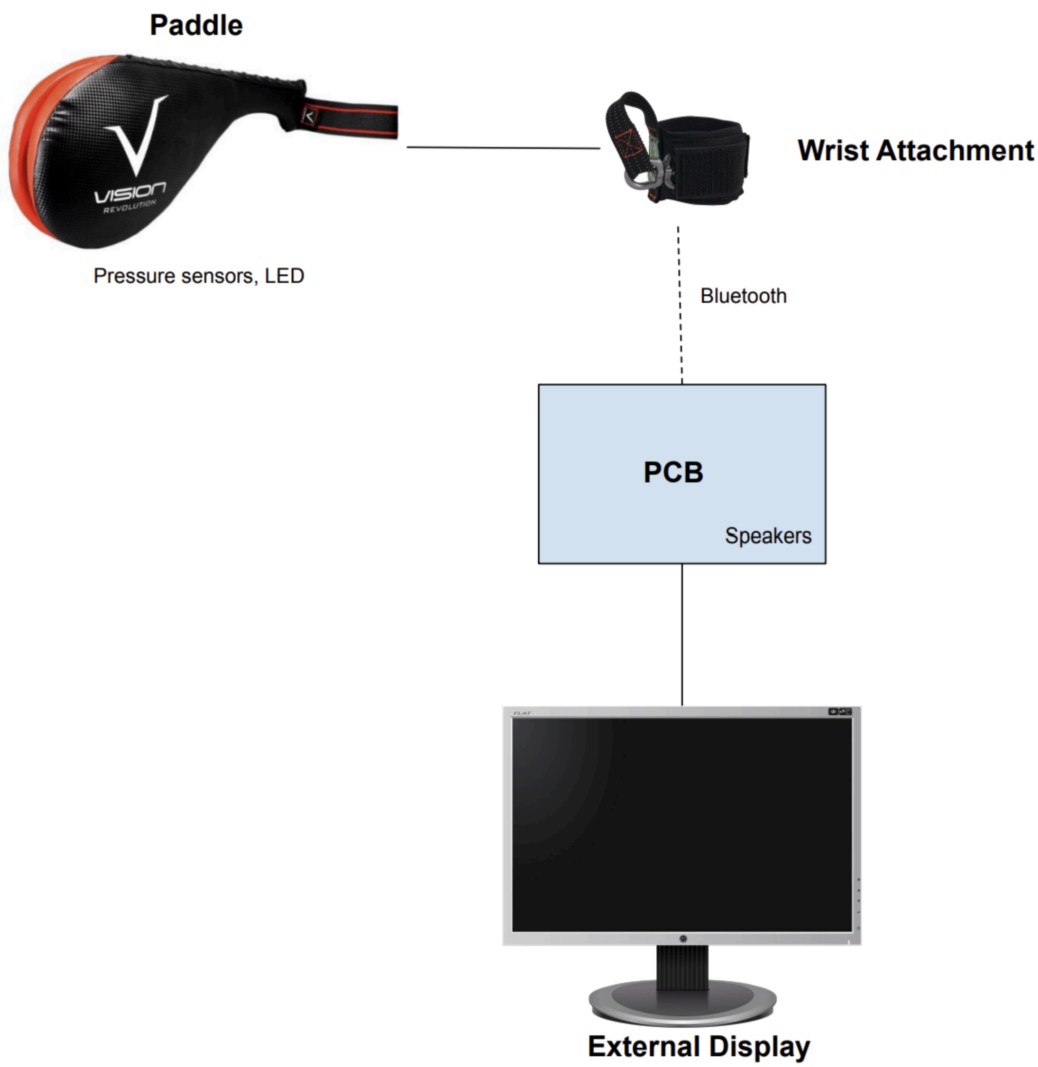
Problem:

Taekwondo is a Korean martial art and combat sport involving primarily kicking techniques and punching. When athletes train, they utilize what are called "paddles," equipment that are analogous to mitts in boxing. Athletes repeatedly hit the paddles to train their kicks and various strikes, and it is usually up to the holder to determine whether it was a good kick, or the athletes themselves will decide whether the kick was "satisfactory" or not. Currently there is no good way to accurately quantify performance in Taekwondo training for drills such as speed and power. There exists electronic gear called "Daedo gear" for automatic scoring by tracking the power and the location of the martial artists' kicks, but that gear is only used in competition and is prohibitively expensive, unrealistic both for everyday training and for accommodating every athlete.

Solution:

To solve the issue of accessibility, cost, and overall quality of training for athletes, we are proposing electronic target paddles. Our prototype will include pressure sensors at different locations of the paddle to measure power and speed for kicking during training. The paddle must be lightweight and flexible, which necessitates minimal attachments to the paddle itself, encouraging the use of a wrist attachment to handle the majority of the functionality and connections. We will also facilitate reaction speed/timing drills via sound or blinking of the LEDs. Example paddle here:
We would have our main system (pcb) be a separate box that would handle the inputs from the paddles through a bluetooth connection. Then using the information received from the strikes of the athlete, our prototype will output the results and statistics to an external monitor or an LCD screen.

Visual Aid:

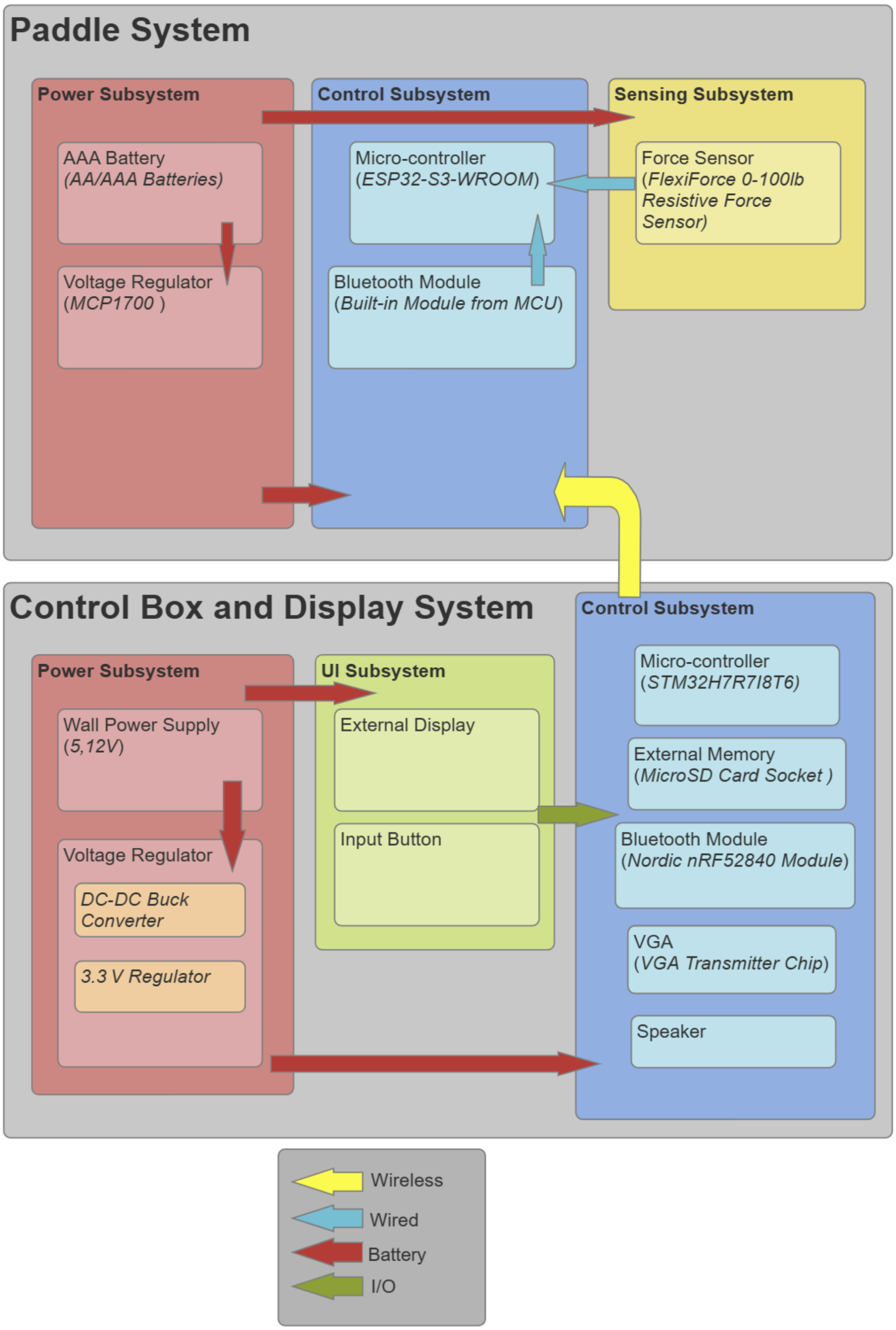


High-level requirements list:

1. System must be able to accurately differentiate between different strength strikes to the paddle.
2. Added weight to the paddle must not exceed 2 pounds so that the kicker can safely strike the paddle, and so the holder doesn't have to work noticeably harder than before to use the paddle.
3. Paddle must be able to last on its own power for more than thirty minutes.

Design

Block Diagram:



Block Diagram Description

Paddle System

1. Power Subsystem (Paddle)

This subsystem provides a stable voltage to the paddle's electronics using either small batteries (AA/AAA) or a Li-ion cell and a regulator. It ensures that the microcontroller, Bluetooth module, sensors, and LEDs receive a constant 3.3 V supply. Because the paddle must remain lightweight, the battery choice is critical: it must balance minimal added weight with sufficient capacity for at least 30 minutes of continuous operation. Proper voltage regulation also protects sensitive components from fluctuations and ensures consistent performance during intense training sessions.

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2. Control Subsystem (Paddle)

A microcontroller and Bluetooth module gather sensor data and wirelessly transmit it to the main control box. This subsystem also processes immediate tasks—such as recognizing valid hits and managing LED signals on the paddle. The microcontroller runs at a high enough sampling rate to accurately detect quick strikes, while the Bluetooth module must maintain a reliable, low-latency link for real-time feedback.

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3. Sensing Subsystem

An array of force sensors measure the intensity of each kick on the paddle. They must be robust enough to survive repeated strikes while still delivering accurate, noise-free data to the microcontroller. Appropriate padding or mechanical dampening helps protect the sensors and ensures consistent measurements.

Control Box & Display System

1. Power Subsystem (Control Box)

A wall power supply feeds the main PCB, which regulates voltage for the microcontroller, Bluetooth receiver, and any additional components (such as an audio amplifier). This ensures a stable operating environment and adequate current for the entire system. Safety-certified adapters (e.g., UL-listed) protect users from electrical hazards.

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2. Control Subsystem (Control Box)

A more capable microcontroller on a custom PCB handles incoming Bluetooth data from the paddle, calculates force and timing metrics, and coordinates outputs like audio cues or display updates. It manages pairing, data integrity, and any higher-level logic (e.g., storing scores or compiling statistics). Real-time processing is essential to minimize latency and keep up with fast-paced training drills.

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3. User Interface Subsystem

Connected via VGA, this subsystem visually presents performance metrics and scoring to the athlete or coach. An optional speaker or audio amplifier produces audible cues for reaction drills and hit confirmations. Physical buttons or other input mechanisms allow users to start/stop sessions, reset counters, or navigate settings quickly and intuitively.

System Description

Paddle System

1. Power Subsystem

Battery Source

- Option: One or two AA/AAA batteries in series (2–3 V), or a small Li-ion cell.

Voltage Regulation

- Choice: A 3.3 V LDO or switching regulator capable of supplying enough current for the microcontroller, Bluetooth module, sensors, and LEDs.
    - Example: MCP1700

Requirements

- Must supply stable 3.3 V (±5%) across the operating range of the battery/batteries.
- Must provide sufficient current for MCU, Bluetooth, sensors, and LEDs (e.g., 100–200 mA depending on design).
- Should support at least 30 minutes of operation per charge/set of batteries under typical use.

Verification

- **Test Equipment:** Multimeter, oscilloscope, electronic load simulator, battery capacity tester.
- **Test Procedures:** Use a digital multimeter and oscilloscope to monitor the voltage output under various load conditions (idle and during active sensor polling).

- **Presentation of Functionality:** Document measured voltage stability over time and current draw profiles. Provide runtime data showing continuous operation for at least 30 minutes, and compare against the design specifications

This subsystem is designed to provide a precise 3.3 V ±5% rail capable of delivering up to 200 mA under peak conditions, which is critical for maintaining sensor accuracy and reliable wireless communication during rapid strikes. The decision to use the MCP1700 is based on its low quiescent current and proven performance with battery sources, ensuring seamless interfacing with the MCU and Bluetooth module for at least 30 minutes of continuous operation.

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2. Control Subsystem (Paddle)

Microcontroller

- Choice: ESP32-S3-WROOM
- Clock/Memory: Enough flash/RAM to handle sensor reading, wireless communication, and LED control logic.
  - Arduino IDE compatible edge-castellated module with built-in WiFi and Bluetooth

Bluetooth Module

- Choice:
  - Integrated into the MCU (e.g., nRF52 series)
- Responsibilities:
  - Continuously poll force sensors (via ADC) and/or accelerometer (via I^2C/SPI).
  - Process sensor data, detect valid strikes, and handle timing logic

Requirements

- Must reliably detect hits at a sampling rate sufficient to capture fast strikes (e.g., 100 Hz or higher).
- Must maintain a stable, low-latency Bluetooth connection (e.g., <50 ms packet round-trip).
- Must operate at low power to maximize battery life; consider sleep modes when idle.

Verification:

- **Test Equipment:** Signal generator (to mimic sensor outputs), oscilloscope (for waveform and timing analysis)
- **Test Procedures:** Deploy test routines that simulate sensor inputs and measure ADC sampling rate. Use a Bluetooth tracker to verify packet transmission timings and latency.
- **Presentation of Functionality:** Provide logs and screenshots from the Bluetooth sniffer confirming a <50 ms round-trip delay and demonstrate ADC sampling performance at 100 Hz or above. Include power consumption data under idle and active modes.

The ESP32-S3 is chosen for its ability to sample sensor data at or above 100 Hz and maintain Bluetooth latencies under 50 ms, directly supporting the high-level requirement for real-time strike detection. Its integrated BLE and Wi-Fi interfaces are optimized for low power consumption—typically in the tens of milliamps during active transmission—and it communicates with the sensor array via ADC channels and I^2C/SPI at well-defined data rates.

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3. Sensing Subsystem

Force/Pressure Sensors

- Choice: 8″ FlexiForce 0-100lb. Resistive Force Sensor (id: 3102_0)
- Mounting: Must be robustly affixed to the paddle to survive repeated impacts.
    - padding in between

Requirements

- Must accurately measure forces in the relevant range (e.g., up to a few hundred newtons, or scaled by mechanical dampening).
- Must survive repeated strikes without sensor damage.
- Data must be stable enough for the MCU to distinguish real hits from noise/vibration.

Verification

- **Test Equipment:** Force gauge, data logger, camera
- **Test Procedures:** Calibrate sensors using a force gauge to apply known loads (such as weights) and compare sensor outputs. Conduct repetitive impact tests to simulate extended training use.
- **Presentation of Functionality:** Present calibration curves and error margins for force measurement. Document sensor performance over repeated stress cycles and provide statistical analysis of noise vs. signal consistency.

This block quantitatively captures forces up to 100lb with a resolution that can detect differences as low as 5% of the maximum force, ensuring the system can reliably differentiate between varying strike intensities. The integrated 5 in^2 memory foam pad and sensor mounting are designed to attenuate peak forces to approximately 22 lbs, directly contributing to the durability and precision required by the design specifications.

Control Box & Display System

1. Power Subsystem (Control Box)

Wall Power Supply

- Choice: A standard 5 V or 12 V DC adapter (UL-listed, 1–2 A capacity).

Regulators

- Regulate down to 5 V (if needed) and 3.3 V for the main MCU, Bluetooth module, amplifier, etc.

Requirements

- Must supply enough current for the entire control board, any attached display driver, and audio amplifier.
- Provide stable 5 V and/or 3.3 V rails.

Verification

- **Test Equipment:** Multimeter, oscilloscope, electronic load
- **Test Procedures:** Use an electronic load to simulate maximum current draw and monitor voltage outputs with a multimeter and oscilloscope.
- **Presentation of Functionality:** Display voltage regulation graphs under load conditions. Confirm that the system meets current draw requirements and stability criteria.

This subsystem uses a UL-listed 12 V adapter with an MP1584 buck converter to deliver a stable 5 V output, which is further regulated to 3.3 V via an AP2112; both regulators maintain voltage within ±5% and are capable of supplying up to 2 A to meet all load requirements. This design ensures that the high-performance MCU, audio amplifier, and display driver operate reliably under varying load conditions, as confirmed through quantitative ripple and load testing.

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2. Control Subsystem (Control Box)

Microcontroller

- Choice: STM32H7 that can handle:
  - Real-time data processing from the paddle.
  - Generating or buffering a video signal or controlling an external HDMI driver.
  - Audio signal generation.
- **STM32 (STM32H7) and incorporate bluetooth chip**

External Memory / Storage

- Potentially for bigger buffers or storing logs/scores, include an external SPI Flash or SD card slot.

Bluetooth Transceiver

- Could be the same type of module as in the paddle, or a complementary BLE module integrated on the board.
- If the MCU includes BLE, use that.

Requirements

- Must receive sensor data at an acceptable rate (e.g., at least 10–50 packets/sec) and update the user display quickly (<200 ms latency).
- Must handle calculations (strike force, average speed, reaction times) in real time.
- Provide a robust wireless link—lost packets should be detected, and the system should handle re-connections smoothly.

Verification

- **Test Equipment:** Bluetooth analyzer, oscilloscope
- **Test Procedures:** Run integration tests where the control box receives simulated Bluetooth data streams. Monitor data throughput and processing latency using diagnostic software.
- **Presentation of Functionality:** Provide latency measurement reports and throughput charts that demonstrate meeting the <200 ms display update requirement. Show recovery test logs for packet loss and reconnection events.

The STM32H7, operating at up to 400 MHz with extensive DMA and timer resources, processes incoming sensor packets at 10–50 Hz and computes performance metrics within a maximum latency of 200 ms, directly supporting the high-level requirement for real-time feedback. Its integrated Bluetooth (or dedicated external BLE module) interfaces quantitatively via UART/SPI at speeds between 1–10 Mbps, ensuring robust data transfer and reliable reconnection strategies in dynamic training environments.

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3. User Interface Subsystem

Display

- External Display: Any external display with a VGA input.

Speaker / Audio

- Audio Amplifier: a small Class D amp (PAM8403).
- Connection:
  - MCU generates audio signals via PWM or I^2S → Amp → Speaker.
- Audio Cues: Reaction drills, notifications, etc.

Input Buttons or Controls

- Let you start/stop drills, reset counters, etc.
- Connect to MCU GPIO with basic debouncing.

Requirements

- Display must show real-time stats (hit count, force, reaction time) within 200 ms.
- If using a speaker, volume must be sufficient for a noisy training environment.

- If using physical buttons, they must be straightforward for an athlete or coach to press mid-training.

Verification

- **Test Equipment:** Timing software, VGA signal analyzer, decibel meter, multimeter, and oscilloscopic analysis for button debounce.
- **Test Procedures:** For the display, run test patterns and measure response times using a timer software to ensure <200 ms update latency. For audio, use a decibel meter to verify that the speaker output meets the required volume in simulated noisy conditions. For buttons, conduct manual and automated debounce testing to confirm reliable operation under repeated presses.
- **Presentation of Functionality:** Provide video or time-stamped logs showing the real-time display performance. Include decibel measurements and user feedback reports on audio clarity. Show test logs confirming that button presses register correctly without false triggering, ensuring an intuitive and responsive interface.

The user interface subsystem employs an external display connected through VGA, ensuring real-time stats are updated within 200 ms of data reception. Additionally, the PAM8403 amplifier, capable of 3W per channel, and tactile buttons with a debounce time of approximately 20 ms, provide quantitatively verified, responsive feedback for both visual and audio outputs.

Cost and Schedule

Cost Analysis

Labor:

We are estimating a salary of $30/hour.

We are estimating roughly 112 man hours. 8 hours per week for 7 weeks, for two people, brings us to 112 hours.

Labor: $30/hour x 2.5 x 112 hours to complete = $8400

Materials:

Description	**Manufacturer**	**Part #**	**Quantity**	**Cost/u**

MCU	STMicroelectronics	STM32H7R7I8T6	1	$9
DC-DC Buck Converter	Monolithic Power	MP1584	1	$3
3.3 V Regulator	Diodes Incorporated	AP2112	1	$2
Bluetooth transceiver (in module form)	Raytac	MDBT42Q	1	$7
Audio Amplifier	Diodes Incorporated	PAM8403	1	$2
MCU	Espressif	ESP32-S3-WROOM	1	$6
Battery Voltage Regulator	Microchip	MCP1700		
Force Sensors	FlexiForce	3102_0	2	$25
Additional Resistors and Capacitors				~$3

TOTAL COST: $8457

Schedule

Week of 3/10: Putting together breadboard demo, finalizing pcb design and ordering

Week of 3/17: SPRING BREAK

Week of 3/24: Testing pcb with parts, iterating on design if necessary

Week of 3/31: Testing parts inside paddle, putting together control box, reordering pcb if necessary

Week of 4/7: Hooking up screens, speakers, connecting paddle to control box, reordering PCB if necessary

Week of 4/14: Final Assembly and Programming

Week of 4/21: Mock Demo and testing

Week of 4/28: Final Demo

Week of 5/5: Final Presentation, Final Paper, Returning Materials

Tolerance Analysis:

The biggest hurdle we must overcome is the robustness of the paddle system. Repeated strikes from trained martial artists will require a system able to handle it accordingly. Part of how we aim to solve this is having some of the more fragile components on the wrist of the holder, rather than in the paddle itself. The force sensors themselves are designed for taking blows. If we go with the Force Sensing Resistors like planned, they are flexible enough that we won't need to worry about them breaking. We also plan to pad the sensors to both dampen the strikes as well as help protect the sensors.

We plan to use the 0-100lb flexiforce force sensing resistor (8″ FlexiForce 0-100lb. Resistive Force Sensor (id: 3102_0))

The sensing area is a 0.375” diameter circle.

This gives us an area of 0.11045 in^2

We will have a pad of area 5 in^2 placed to distribute the force of the blows.

0.11045/5 = 0.022 = 2.2% of the force is directed to the sensor itself. However this is in a perfect scenario where all of the force is distributed evenly, however in most practical scenarios this won’t be the case.

This is why we are using a 5in^2 1in thick piece of memory foam to help reduce the force even further.

We can calculate the force reduced by the foam by treating it like a spring.

k = (E x A) / t

E = 30kPa (average compressive modulus for low-density memory foam)
A = 5 in^2 = 0.00323 m^2
t = 1 in = 0.0254 m

k = (30,000 x 0.00323) / 0.0254 = 3189 N/m

To calculate the force transmitted through we will use a linear spring model

F = k x t

3819 x 0.0254 = 97 N = 21.8 lbs

This means at full compression, the foam pad absorbs 22lbs of force, which will help dampen the peaks and reduce the likelihood of damage to the sensor.

Ethics and Safety

Ethical Concerns

We will follow all policies outlined by the IEEE and the ACM Code of Ethics. To avoid ethical breaches we will consistently check that our work always follows best practice.

We will maintain an open channel for reporting and discussing any ethical concerns that may arise during the development and testing process.
Regular internal reviews will be conducted to verify that our methodologies, data handling, and communications are fully transparent and in line with industry standards.

Honesty and Transparency

We will clearly communicate the limitations and capabilities of our prototype. We will not overstate or understate the performance metrics or sensor accuracy. We will ensure that athletes are getting the closest experience to a true training setting. This follows the ACM Code of Ethics standards of honesty and trustworthiness.

Any assumptions or uncertainties in our design and testing processes will be explicitly stated in our reports to avoid any misconceptions about the technology's performance.

Safety Concerns

Clear Usage Guidelines and Supervision

Beginners should attempt techniques on our prototype only under supervision of experienced Taekwondo athletes. Both Liam and Alex have 10+ years of experience with Taekwondo and are thus well suited to handle this project safely.

Comprehensive user manuals and safety protocols will be developed, outlining proper usage, and maintenance.

Hardware and Electrical Safety

Use components that meet safety standards to prevent electric hazards. I will use appropriate tools to aid our project such as static wrist bands and anti–static surfaces.

Physical Safety

Ensure that not too much is loaded onto the paddles, and no components are within striking range to avoid injuring the athlete.

The design will undergo repeated impact and durability testing to assess structural integrity under real-world training conditions.

Feedback from athletes during pilot testing will be incorporated into design iterations to ensure that the form factor remains ergonomic and minimizes risk during use.

References

IEEE Corporate Governance
IEEE. "IEEE Corporate Governance – p7-8." *IEEE*, n.d., https://www.ieee.org/about/corporate/governance/p7-8.html. Accessed 3 Mar. 2025.

ACM Code of Ethics
Association for Computing Machinery. "ACM Code of Ethics and Professional Conduct." *ACM*, n.d., https://www.acm.org/code-of-ethics. Accessed 3 Mar. 2025.

STMicroelectronics (STM32H7R7I8T6)
STMicroelectronics. "STM32H7R7I8T6." *STMicroelectronics*, n.d., https://www.st.com/en/microcontrollers-microprocessors/stm32h7r7i8.html. Accessed 3 Mar. 2025.

Monolithic Power (MP1584)
Monolithic Power. "MP1584." *Monolithic Power*, n.d., https://www.monolithicpower.com/en/mp1584.html?srsltid=AfmBOoqg9ycbG2jjCZhzu9VrFmhruAD5Cu0stIlrv6IsgJWpHSUe8sJE. Accessed 3 Mar. 2025.

Digi-Key (AP2112K-3.3TRG1)
Diodes Incorporated. "AP2112K-3.3TRG1." *Digi-Key*, n.d., https://www.digikey.com/en/products/detail/diodes-incorporated/AP2112K-3-3TRG1/4470746. Accessed 3 Mar. 2025.

Corcoran, Daniel et al. "Impact Force and Velocities for Kicking Strikes in Combat Sports: A Literature Review." *Sports (Basel, Switzerland)* vol. 12,3 74. 6 Mar. 2024, doi:10.3390/sports12030074

Flexiforce
Flexiforce. "Flexiforce." *Flexiforce*, n.d., https://www.flexiforce.com/us/en. Accessed 3 Mar. 2025.

Phidgets
Phidgets. "Phidgets." *Phidgets*, n.d., https://www.phidgets.com/?srsltid=AfmBOooUV2uXknFXI8Lnb31N7vQz6U9lfzbdyDyhKi-aqAbMDTLjV9Le. Accessed 3 Mar. 2025.