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Project IdealB

By

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SUMMARY:

Injuries in exercise or sports-related settings can occur for a variety of reasons. A study analyzing the causes of injury among aerobic athletes found that 41.67% of injuries were due to excessive fatigue (Wang). While the medical technology sector offers various injury prevention methods, there are currently no real-time systems specifically designed to detect when an individual is nearing their physical limits. Although adjusting training routines or using specialized athletic gear can help reduce the risk of injury, a system that provides real-time warnings as users approach their physical limits would enable them to push their boundaries more safely.

To address this gap, the IdealB system uses electromyogram (EMG) signals to predict whether a user has exceeded their maximum fatigue level. Since accurately determining this limit is challenging without verifying with invasive technology, the first iteration of the IdealB system is based on perceived fatigue. The system predicts, in real time, whether a user has surpassed their self-perceived maximum level of fatigue.

Building on previous research (Liu), instead of using more processing power by analyzing the raw EMG signal, the IdealB system analyzes the filtered envelope EMG signal to quickly predict fatigue. The system, encapsulated in a 3D-printed box, uses Bluetooth to send EMG signals data to a laptop for off-boarding processing. On the laptop, a pre-trained ML algorithm predicts whether the user is beyond their maximum fatigue level, then sends back the results to the system which is connected to a mini-vibration motor to warn the user. The algorithm was trained on a small dataset of controlled exercise trials, collected by the IdealB team, with varying movement patterns: maximum voluntary contraction (MVC) and relative voluntary contraction (RVC). The training methodology of the algorithm is based on time-to-event analysis commonly used in biology-related research where researchers aim to predict time of an event like death (Gong). The entire system was designed to be light-weight, wireless, and battery powered while satisfying our environmental, socio-cultural, and FDA compliance constraints.

PROBLEM STATEMENT:

People are unaware of their physical limits which cause unforeseen injuries and fatigue.

Our approach involves a portable device leveraging physiological signals to identify the exercise inconsistencies of users which can be attributed to their fatigue level and inadvertently lead to injury. Our device enables people to exercise freely, with a reduced risk of overdoing and injuring themselves.

DESIGN REQUIREMENTS:

The design requirements were selected after conducting research on features found in existing sensing wearable devices available on the market, such as the Apple Watch and the Shimmer3 EMG Unit. Product reviews were also used as references to inform design decisions, with benchmarking comparisons made between devices. The following design requirements were adopted:

Design Requirement		
Date:	10/2/2024	
Project Name/Title:	IdealB	
Team Advisor	Dr. Charles Kim	
Project's Goal/Scope	Prevent injury	
Team Members	Michael, Brady, Anu	
1-sentence problem statement	People are often unaware of their physical limits, leading to unforeseen injuries and fatigue, so our approach uses a portable device that leverages physiological signals to notify users when they are nearing their limit, allowing them to exercise freely with a reduced risk of overexertion and injury.	
Requirements	Items	Quantity
1. Product Specification	Size:	Smaller than 8x5x1 inches
	Weight:	No Heavier than 61.3 g — (I propose a range of 62-250g max)—Brady
	Heat emission:	Recommend 3 hours battery life
	Power Consumption:	Recommend 3 hours battery life
	Wireless	Use Bluetooth, so that device wirelessly communicates to phone within 10 feet?
	Visually representative	Black or White
	Continuous Monitoring and Predictive	Utilize a sampling rate of no less than 15Hz to measure heart rate and body

		temperature (indicators of fatigue) over time so that we can feed data to create a quality predictive mod
	Battery powered	Use less than 5 AA 3v batteries or is rechargeable
	Sense fatigue	Gives estimate of user's limits every 1 minute
2. Constraints	Environmental Constraints	Prioritize modularity and quality wearable materials to maximize the product's predicted lifespan
	Socio-Cultural Constraints	Some cultures don't prioritize exercising thus should still be sensitive enough sensors for everyday physical tasks
	Compliance (Rules, Regulations, and Standards)	Subject to FDA General Controls Regulation, as a FDA Class 1 Medical Device under the General Physical Medicine subcategory. Also mandated to comply with IEC 60601 to ensure safety of electrical equipment in medical devices

SOLUTION DESIGN:

Solution Design Description for the Top Design: Compression Sleeve

Overview

The Compression Sleeve is a wearable device developed to monitor and analyze physiological signals during physical activity. Its purpose is to reduce the risk of injury by notifying users when they are nearing their physical limits. The system integrates compact hardware with advanced software to provide real-time feedback via a mobile application. The design emphasizes functionality, reliability, and user comfort, adhering to the project's design requirements and safety standards.

Functional Description

The compression sleeve continuously monitors fatigue levels by utilizing data from EMG (electromyography) and flex sensors. It processes this data in real-time to deliver notifications, helping users avoid overexertion.

- Sensors and Microcontroller:
    - EMG Sensor: Detects muscle activity and identifies fatigue by analyzing signal amplitude.
    - Flex Sensor: Measures movement and form changes, complementing the data from EMG sensors.
    - Arduino Nano: Microcontroller: Manages data processing and runs fatigue detection algorithms.
- Power Supply: The device operates using a rechargeable lithium-polymer battery, ensuring portability and meeting power efficiency requirements.
- Data Transmission: The Arduino Nano microcontroller transmits processed data to a mobile application via Bluetooth for visualization and user interaction.
- User Notification: The system sends alerts and summary data to the app, enabling users to monitor their condition and respond appropriately.

Aesthetic Description

The compression sleeve is designed for ergonomic and practical use during various physical activities. It features a lightweight, slim profile that minimizes restriction of movement while maintaining durability and comfort. The outer layer conceals internal components, providing a clean and professional appearance.

-5 Deficiency of patent-style description

Solution Design Figure and Description

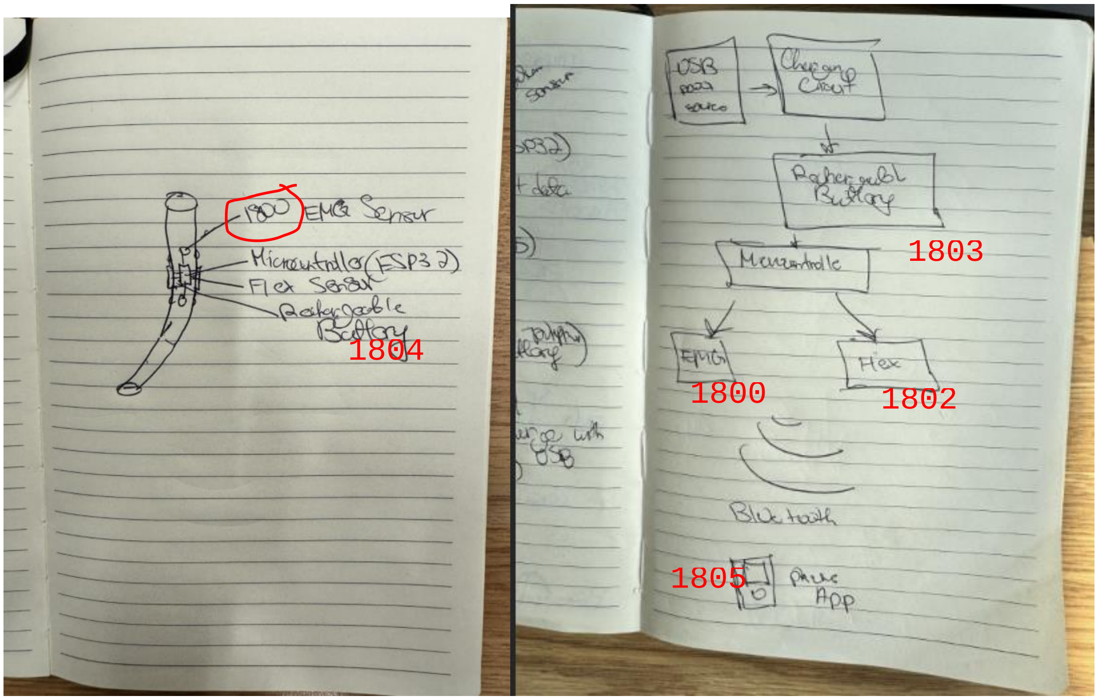

Figure 1: Diagram of Compression Sleeve

Function Description:

The compression sleeve collects physiological data using an EMG sensor (1800) to detect muscle activity and a flex sensor (1802) to track movement. This data is processed by a microcontroller (1803), which runs fatigue detection algorithms. A rechargeable lithium-polymer battery (1804) powers the system, and a Bluetooth module (1805) transmits the processed data to a display (1806), where users receive alerts and summaries in real time. These components are integrated into the sleeve design to ensure functionality, portability, and user comfort.

The diagram includes:

1. Outer Sleeve: Covers all internal hardware for protection and comfort.
2. Sensor Placement: EMG sensors are positioned near key muscle groups, while the flex sensor is integrated into the sleeve fabric.
3. Microcontroller Module: Strategically placed to minimize heat emission and allow easy access.
4. Battery Pack: Compact and rechargeable, securely integrated into the design.
5. Bluetooth Module: Ensures reliable wireless communication with the mobile application.

Advantages of the Compression Sleeve

1. Feasibility: The device utilizes readily available and cost-effective components, including the ARDUINO microcontroller, EMG sensors, and flex sensors.
2. Customization: Algorithms allow the system to tailor alerts based on individual user history and preferences.
3. Ergonomic Design: The sleeve's lightweight and slim construction ensures comfort and ease of movement.
4. Real-Time Monitoring: Continuous data analysis enhances the accuracy of fatigue detection and notifications.

Limitations and Considerations

- Heat Emission: The Arduino microcontroller may generate heat, requiring insulation to ensure user comfort.
- Environmental Constraints: The sleeve does not fully meet the desired temperature range for all operating conditions. A solution is to use a lower input Voltage

AGILE WORKFLOW AND WEEKLY PLAN:

The Agile workflow outlines the planned steps for ensuring the successful completion of the project. An incremental approach was adopted to support goal achievement and reduce the learning curve associated with unfamiliar systems and tools.

IdealB	
Trackigue	
Increment (or intermediate working component)	Weekly development tasks

Visually assess your sensor information in a way that is accurate and repeatable	Visualize the raw signals while normalizing the noise
	Setting up software timers/interrupts to frame ADC sampling data, record that data, store the data, and plot it
	Test signal while varying dependent variables to ensure the signal is clean enough for feature extraction. Choose at least one exercise to focus on
Integrate signal processing to notify users about fatigue levels	Learn on to use ML and signal processing on MCU
	Determine best features for each exercise and gather data samples, essentially "training data" for feature extraction
	Develop signal processing algorithms to notify fatigue levels based on defined thresholds/benchmarks
	Test combinations of MCU and sensors to determine selections for the final product
Assemble wearable product using each individual component	Test different methods of encapsulation to optimize for user comfort, while developing app
	Finish app and decide on final encapsulation of electrical components in our product
	Create user manual and final presentation slides

PROJECT IMPLEMENTATION PROCESS:

Final Component Choice:

After comparing multiple options, we decided to go with the following components for our most viable product.

Microcontroller: Arduino UNO R3	EMG Sensor: Myoware 2.0 Sensor	Electrode: Wet	Vibration: Arduino Vibration Motor	Communication: Arduino BLE Module

				
Enclosure: 3D Printed Box with Velcro-Wrap 	Power: 9V Battery with Arduino Connector 			

1) Zero the Signal:

To ensure accurate capture of physiological signals, several precautionary steps were taken to reduce external sources of noise. After multiple iterations, it became clear that the primary sources of noise were the testing room itself and the power cables used in the system. To address this, a 60 Hz notch filter was added to eliminate interference from electrical power sources. Additionally, the original cable electrodes were replaced with snap electrodes, which provided a more stable and noise-resistant connection.

The problem with noise:

The expected output range is from 0 mV to 1100 mV (1.1 V) when using a 4093-bit resolution of an Arduino analog output pin. The typical output from the envelope pin of the EMG sensor based on the manufacturer's provided data sheet, voltage range from 50 µV to 30 mV, which falls well within this output range. The signal frequency typically lies between 20 Hz and 500 Hz. To reduce interference from electrical power sources, a 60 Hz notch filter was used to eliminate noise from the signal.

The “resolution process”

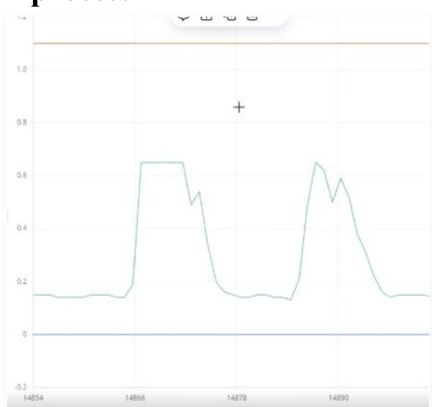

Figure 2: Demonstration of Flat Peaks

2) Collecting and Processing the signal

The IdealB team collected data of controlled exercise trials of two types of movements: Maximum Voluntary Contraction (MVC) and Relative Voluntary Contraction (RVC). For simplicity we focused on measuring EMG signals from only the biceps muscle group in both types of movements. During the MVC movement, participants contracted maximally for as long as they could. While contracting, participants told recorders when they perceived themselves using more than just their physical strength and overall extra effort to continue contracting. During the RVC movement, participants did bicep curls with four weights for three sets: 5 pounds, 10 pounds, 15 pounds, and 30 pounds. Although the participants told the recorder when they perceived tiredness, the participants were instructed to beyond that point to extract data after perceived tiredness as seen in Figure 3.

In relation to the ML training methodology, we extracted features based on identified peaks in the signal from the envelope EMG signals. To classify a signal in real-time as before or beyond the maximum level of fatigue, we extracted features such as average slope, voltage peaks, and peak intervals at a 2000 ms sampling rate where each sample was associated with a number called commonly referred to as time-to-event or in our case time-to-fatigue. Although our ML algorithm is classifying into 2 discrete classes, the training process is weighted by the time-to-fatigue, meaning the classifier is more inclined to correctly classify samples closer to the decision boundary than those further away. After training and testing multiple algorithms such as Random Forest, Support Vector Machine, and Logistic Regression for classification, the algorithms which generalized best to unseen individuals were used with the final device.

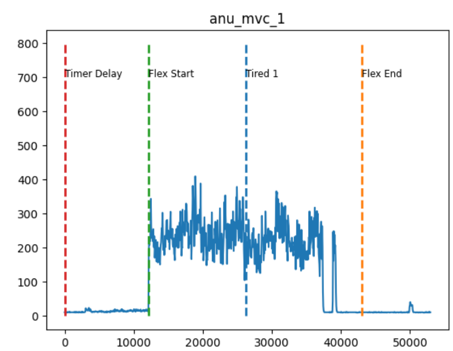

Figure 3: Anu's MVC Trial 1 with timestamps

3) Assemble the Product:

The finalized device, enclosed within a custom-designed, 3D-printed enclosure as illustrated in Figure 4, integrates a user-centric graphical user interface (GUI) depicted in Figure 5. This GUI facilitates real-time visualization of the algorithmic state, providing intuitive feedback to the user. The system is designed with adaptability in mind, offering users the ability to select from multiple fatigue detection algorithms based on their specific movement patterns. Recognizing that conventional gym-based exercises may not be universally practiced or culturally embraced, the interface allows users to tailor their experience by choosing the type of physical activity they are engaged in. This selection dynamically adjusts the algorithm to optimize fatigue detection performance based on their chosen activity.

Figure 4: CAD File of 3D-Printed Box

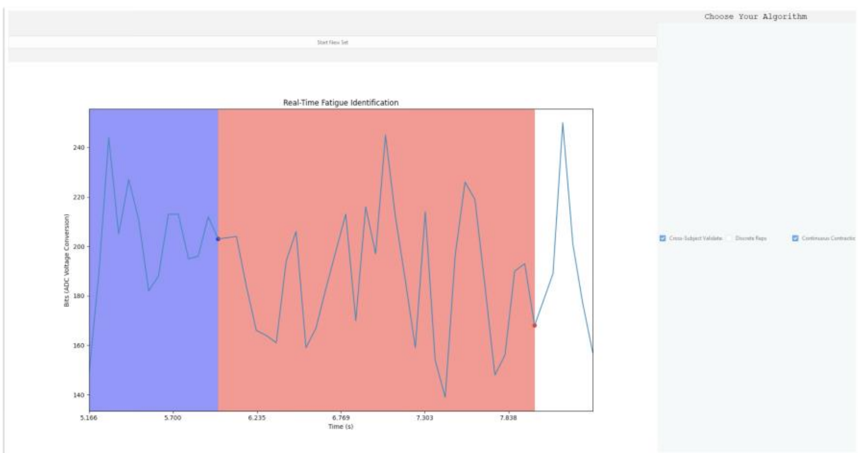

Figure 5: GUI for Final IdealB Device

CONCLUSION:

The product was successfully used to identify when an individual approached their physical limit by utilizing EMG signals obtained from non-invasive electrodes to distinguish between pre-tired and post-tired data, which served as the fatigue indicator. Machine learning algorithms were leveraged to analyze a group dataset consisting of EMG data collected during exercise from multiple individuals. For future work, several enhancements were proposed to improve system functionality and user experience. These included the development of a faster communication protocol to increase data transmission speed and responsiveness, and the design of a custom PCB to reduce excess wiring, thereby creating a more reliable and streamlined hardware setup. Additionally, improvements to the ergonomic design were planned to enhance comfort during prolonged use, and the training dataset was intended to be expanded to improve the accuracy and adaptability of the models under a wider range of conditions.

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