Ripple: Proposed Design of Anxiety Tracking Wearable

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Introduction

In 2021, over half of college students reported feeling “overwhelmingly anxious in the past year” [1]. Whether it is at a diagnosable level or not, feelings of anxiety are prevalent among college students and can manifest in feeling overwhelmed or panicked. Often, when feeling anxious, it is difficult to come up with a plan of action or coping strategy in the moment [2]. For this reason, I plan to create a wearable sensor and app that can help detect physical symptoms of anxiety and suggest pre-planned coping strategies. The specific behavior that will act as the trigger is leg shaking, which has shown to be correlated with anxiety [3][4][5]. Since this will require continual use of the sensor, it should be compact enough to be worn without discomfort and able to communicate with the user's phone wirelessly. Additionally, since the target customers are college students, it should be relatively inexpensive.

Background

In researching similar sensor products, I found heart rate variability(HRV) highlighted as the best indicator of stress and anxiety [6]. Many wearables exist which are capable of measuring HRV, primarily in the form of watches and chest straps. These wearables are often expensive, uncomfortable for daily wear long term, and/or targeted at fitness as opposed to mental health. Most devices recommended for measuring heart rate variability, such as the Fitbit Versa 3 and the Series 3($229) Apple Watch ($199), cost over a hundred dollars and have a multitude of features, primarily targeted at achieving fitness goals and connecting with your other devices [7][8]. Other devices are worn on chest straps, which are convenient for exercise and give more accurate results, but are inconvenient for everyday wear and can still be expensive [7]. The Lief Smart Patch is targeted exclusively at reducing anxiety, and has shown promising results in studies [9]. However, its $50 to $100 a month price tag puts it out of reach for those looking for an inexpensive aid in detecting and coping with anxiety. It is also meant to be paired with active coaching and lessons and requires the user to adhere it to their chest daily [10]. These facts combined present a barrier to entry for users with lower levels of anxiety or stress, or with less to spend, who might not see the associated cost, time commitment, and discomfort as justified.

The target customers for my device are college students, who are often stressed and anxious and might be looking for a more inexpensive device to assist them. In order to provide this, rather than monitoring HRV, the device will be worn on the leg and detect leg shaking, which has been shown to occur during periods of stress or anxiety [3][4][5]. This will distinguish it from the existing options by allowing it to use an IMU rather than the more complicated sensing systems required to measure HRV. It also has the added benefit of bringing attention to a physical sensation that users can observe themselves. This will help users start to notice and implement coping strategies even when not wearing the device and draw their attention to how anxiety shows up physically for them.

The device will be simple, inexpensive, and comfortable to wear. More specifically, it should meet the requirements below:

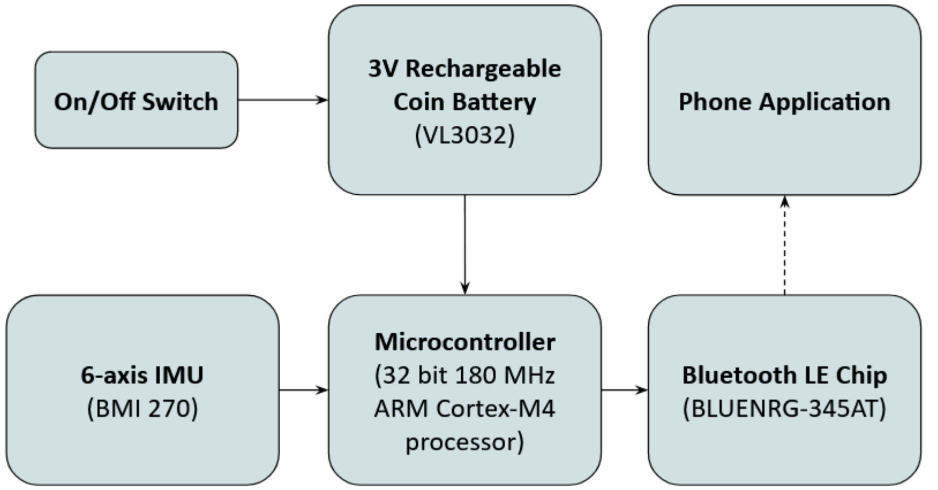
- The device is rechargeable with at least 8 hours of battery life.
- The user interface and function of the device and application are centered around detecting and coping with anxiety
- The device weighs 80 grams or less ,so it may be comfortably worn on the ankle.
- The cost of one unit is $35 or less. Initial prototypes may cost more, however eventual production using bulk quantities of the sensors as well as high volume production techniques (e.g. injection molding) will reduce eventual costs.
- The device should be capable of differentiating leg shaking from walking and sitting.

Concept

My approach to the design of this device has been informed by previous research “Detecting and Differentiating Leg Bouncing Behaviour fromEveryday Movements Using Tri-Axial Accelerometer Data” [11]. This paper suggests an approach for detecting leg shaking using two 3 axis accelerometers, one at the knee and one at the ankle. While this is practical for use in a research setting, it would be impractical for daily wear. In order to address this I plan to use a 6-axis IMU which will supplement readings from one 3-axis accelerometer with readings from a 3-axis gyroscope. The paper also outlines several types of leg shaking, I have chosen three of the most common types to test in my preliminary prototyping: up and down leg shaking with both legs on the ground, shaking of foot while propped on opposite knee, and up and down shaking of one leg while the other foot is propped on the knee.

Sensor Layout and Selection

The wearable sensor package will consist of a 6-axis IMU and a Bluetooth Low Energy(LE) chip connected to a microcontroller. This is powered by a 3V rechargeable coin battery, with an on/off switch to allow the user to save battery when not using the sensor. The microcontroller uses the Bluetooth LE chip to transmit the accelerometer and gyroscope data to the user’s phone, where it is filtered and analyzed for possible leg shaking events.



In order to develop accurate estimates of the system requirements, I prototyped the system using my phone's built in accelerometer and gyroscope, attaching my phone to my leg with athletic wrap. From this I determined that leg shaking has a typical frequency between 5.5Hz and 6.5Hz. In order to get accurate results, at least 15 data points per leg shake are required, giving a minimum sampling rate of 97.5Hz. The operating temperature of the sensors should allow the device to operate in a wide range of conditions from 0℃ to 40℃, to account for the fact that the device may be worn in different climates. The threshold for acceleration magnitude to detect leg shaking from my prototype was 0.05 m/s^2, so a sensitivity of at least 0.005m/s^2 / LSB or 0.51mg / LSB is desirable. Similarly, for a 10 Hz bandwidth, the noise should be less than 0.01 m/s^2 or 0.102 mg. The gyroscope readings for walking and leg shaking differ greatly in magnitude, and a high threshold of 5 rad/s or 286dps can be used for the gyroscope data in detecting leg shaking, so the sensitivity and noise of the IMU gyroscope is unlikely to be a limiting factor. All components should be as small and light as possible, while remaining inexpensive enough to keep the total cost under $35. In order to achieve the required 8hr battery life, the battery must have capacity greater than or equal to the total current requirement for all components multiplied by 8 hrs. My final consideration was compatibility of the components in terms of required voltage, current, and data rates. The selected components and relevant specifications are listed below (data sheets are linked in the references):

<u>IMU:</u> BMI270 6-axis, smart, low power Inertial Measurement Unit for high-performance applications [12]
Sampling Rate/ Output Data Rate(ODR): 12.5 Hz to 1600Hz - The preferred configuration would be an ODR of 200Hz which gives a maximum bandwidth of 89Hz, which is more than acceptable for the application.
Operating Temperature: -40℃ to +85℃

Sensitivity: 16384 LSB/g for ±2g range - This results in a value of 0.061mg/LSB, which is nearly a factor of ten better than the minimum requirement.
Noise: 0.16 mg/√Hz - This noise density gives a value of 0.51mg for a 10Hz bandwidth, which meets the requirements outlined above.
Supply Voltage: 1.71V to 3.6V
Current consumption: 970µA for accelerometer and gyroscope in performance mode (maximum possible value)
Dimensions: 2.5mmx3mmx0.8mm
Weight: 0.57g
Cost: $12

Bluetooth LE Chip: Programmable Bluetooth® Low Energy wireless SoC [13]
Output Data Rate: 2 Mbps (maximum) - This provides the necessary data output rate to accommodate all the accelerometer and gyroscope data (16bits x 6-axis x 200Hz = 0.019Mbps).
Operating Temperature: -40℃ to 105℃
Supply Voltage: 1.7V to 3.6V
Current Consumption: 4.3 mA (transmitting)
Dimensions: 2.5mmx3mmx0.8mm
Weight: 0.07g
Cost: $5.35

Microcontroller: LPC54S016JET180E 32-bit ARM Cortex-M4 microcontroller [14]
Operating Temperature: -40℃ to 105℃
Supply Voltage: 1.71V to 3.6V
Current Consumption: 3.0 mA (CCLK = 12MHz)
Dimensions: 28 x 28 x 1.4 mm
Weight: 0.04g
Cost: $8.02

Battery: VL3032 Coin Battery Panasonic [15]
Operating Temperature: -20℃ to 60℃
Nominal Voltage: 3V
Cutoff Voltage: 2.5V
Capacity: 100mAh - The total current consumption from the other components is approximately 8.27mA, this gives a battery life of approximately 12 hours which gives a comfortable margin for the 8 hour requirement.
Dimensions: 30mmx3.2mm
Weight: 6.3g

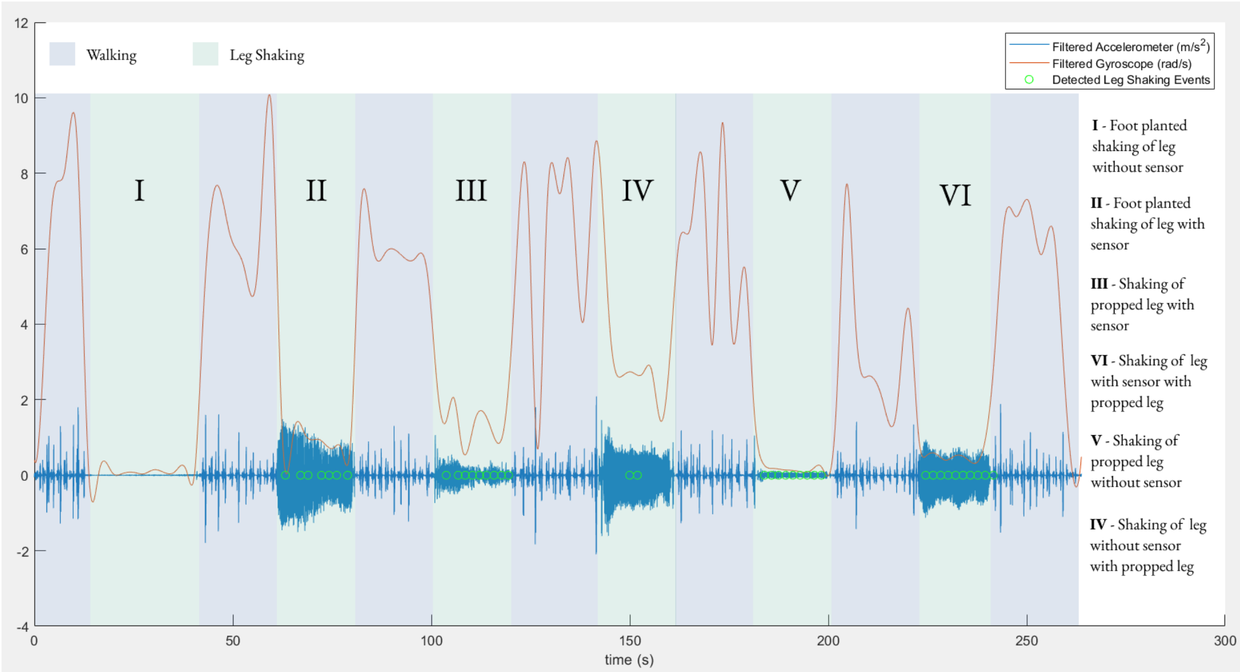
Cost: $8.35

The total weight of the components is 6.98g, which leaves a generous 73g for the housing, band, and miscellaneous additional components (PCB etc.). The total cost is $33.72, which comes close to the target of $35; however, as previously stated, this could be reduced by producing the units in large quantities.

Data Processing

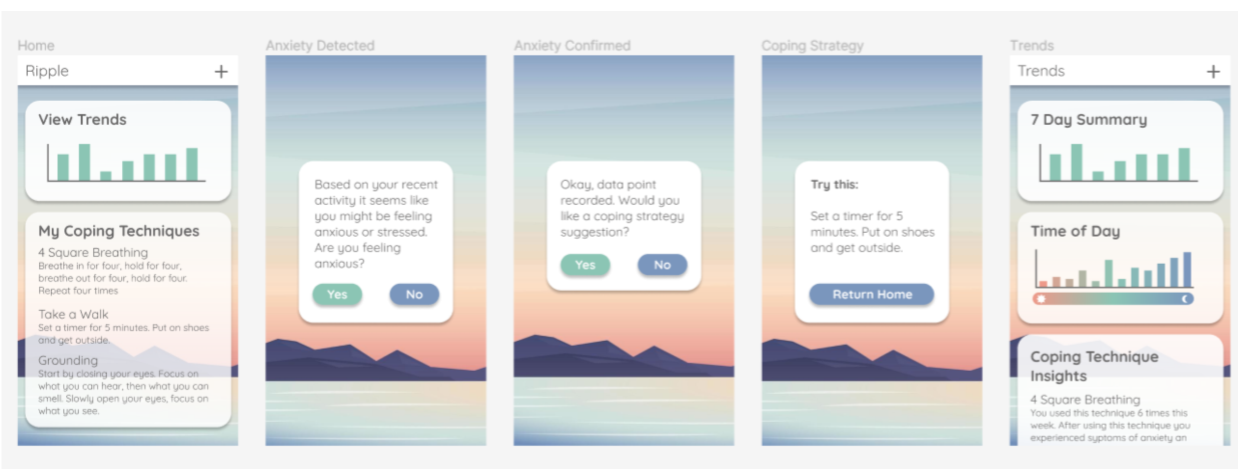
Once the IMU data is transmitted to the application, it will be processed to detect leg shaking events. Leg shaking events are defined as 1.5 second long periods of constant leg shaking. To detect these events, the magnitude of the acceleration and gyroscope data is calculated and then filtered. A bandpass filter with cutoff frequencies of 5.5Hz and 6.5Hz is applied to the accelerometer data. The gyroscope data is used mainly to distinguish between walking and leg shaking by the magnitude of the peaks, so the upper envelope based on peaks is used to smooth the data over 200 sample windows.

The recognition algorithm works by detecting when the magnitude of acceleration crosses over a threshold value (set to 0.05 m/s^2 in the phone based prototype) while the gyroscope peak magnitude is under a threshold value (set to 5 rad/s in the prototype). Once a threshold cross is detected, a short timer (0.17s) is set, and if another threshold is not reached before the timer expires, all values reset. If repeated threshold crosses are detected without the timer expiring for 1.5 seconds or more, a leg shaking event is noted. Shown below are filtered acceleration data, filtered gyroscope data, and detected leg shakes for the phone based prototype. As can be seen, this algorithm results in good detection of leg shaking (except foot planted shaking of the leg without the sensor). The results may be expected to further improve with a more refined prototype.



App Interface

Once the app detects a possible leg shaking event, it alerts the user and asks them to confirm whether they are feeling anxious or stressed. It then asks if they would like a suggestion for a coping technique. Coping techniques are entered by the user when setting up the app and can be added or removed at any point. This allows the user to customize the suggested coping techniques to only those that work for them and adjust as they find new techniques. The app also stores confirmed anxiety/stress points with their timestamp and the coping technique used so that users can look at long term trends. A mockup of the application is shown below.



Packaging

The sensor, microcontroller, transmitter, and battery will be housed in a circular injection molded case approximately 35mm in diameter. The case will attach to the user's ankle with a removable elastic, fabric strap. In the phone based prototype three attachment locations (ankle, knee, and calf) were tested and attaching at the ankle resulted in the best leg shaking detection. This is also a convenient and comfortable location for a wearable. The priorities with the housing design will be user comfort, rigid attachment to the user's ankle, and vibrational isolation of the sensors. It will also be important to allow access to easily charge the battery.

Summary

Ripple is a proposed design for a wearable sensor and app focused on tracking and coping with anxiety and stress. It is based on the correlation between leg shaking and anxiety, and uses a six-axis IMU to detect shaking. The cost to build a prototype would be approximately $50. This accounts for differences from the proposed final design, including a 3D printed housing and a TeensyLC microcontroller for easy prototyping. The prototype would require an estimated 3 hours of CAD design, 2 hours of miscellaneous component (eg. protoboard) selection and ordering, 5 hours of assembly, and 5 hours of coding, including debugging, for a total of 15 hours. Future improvements would include improving battery life through algorithm detection of when bluetooth transmission is required as well as improvements to the detection algorithm described in this paper. Overall, Ripple is intended to provide a low cost wearable to help college students notice and reduce stress and anxiety.

References

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