# Low Cost Sleep Quality Tracking Using Arduino

Rachel Bai, The Webb Schools


## Abstract

Sleep trackers that use actigraphy are a lower cost alternative to traditional overnight PSG (Polysomnography) sleep labs, and offer more mobility and access to people who might not have access to a sleep lab. However, many commercial sleep trackers can still cost more than one hundred dollars.
Using Arduino in conjunction with a 3D printed case and easily accessible materials, we were able to make a cheap wrist-mounted sleep tracker that can accurately track several AASM standards of sleep, including sleep efficiency, sleep onset latency, and WASO events. After the data was collected, it was processed using Python and then R studio. A positive correlation was found between the self-reported sleeping quality measures and the device collected standards, indicating the feasibility of much lower-cost sleep trackers with Arduino. The next phase of this project would focus Bluetooth connectivity, automated data processing using machine learning, and improved comfort for the user of the device.


## Introduction

Sleep is a massively overlooked aspect of general health and cognitive function. In a poll by the National Sleep Foundation, the daily effectivity of U.S. Adults increased directly with the perceived quality of sleep[4]. For many, poor sleep quality can also be an indicator of sleeping disorders or other underlying health issues. The standard for measuring objective sleep quality is the American Academy of Sleep Medication (AASM) recommended reporting parameters, which uses total recording time (TRT), total sleep time (TST), sleep efficiency, sleep onset latency, and wake after sleep onset (WASO) events[1]. In order to measure these parameters, researchers typically use a polysomnography machine (PSG), which can often be expensive, bulky, and intrusive. The development of fitness trackers such as the Fitbit and other smart watches that use actigraphy to track sleep has introduced a lower cost option for long-term sleep quality tracking [3]. Purely actigraphy-based sleep trackers are frequently more than 80% effective in determining the start and end times of periods of sleep [5].


## Objective

The objective of this project was to create a low cost, wrist-mounted data collection device using Arduino that collects actigraphy data in order to track overnight sleep quality.

## Methodology

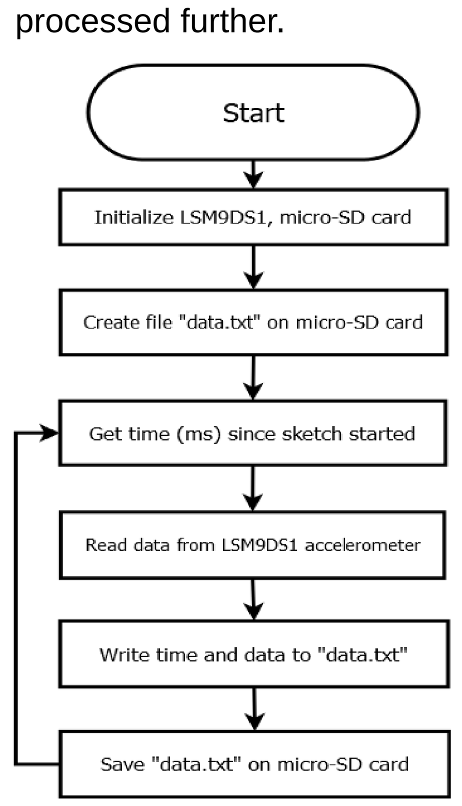
**Electrical Components**
Arduino Nano 33 BLE Sense
Micro-SD module
Micro-SD card
Adafruit PowerBoost 500
3.7v 1000 mAh Lipo battery
Mini slide switch
22 AWG stranded wire

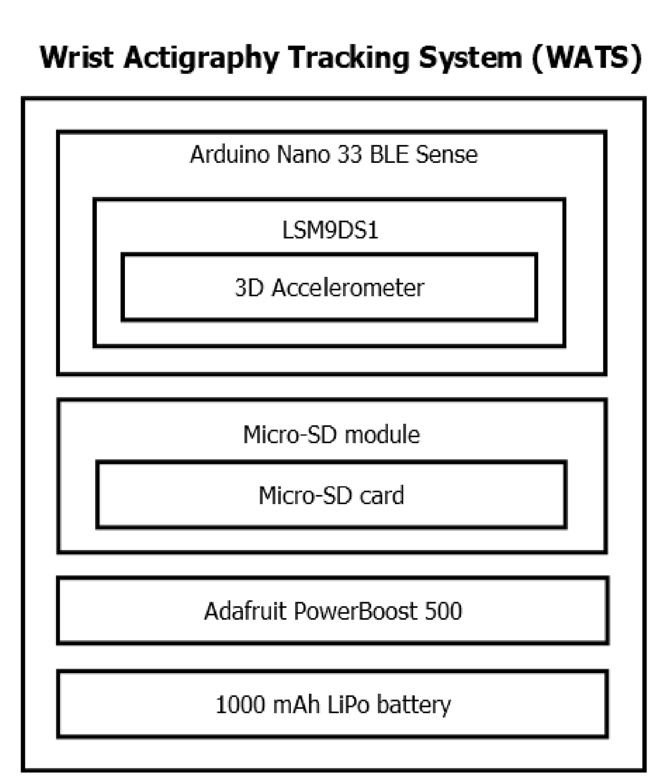
**Hardware Components**
Nylon watch straps with buckles
Medical felt padding
MakerBot PLA
3/8 inch screws

**Software**
Arduino, Python, R Studio, GitHub

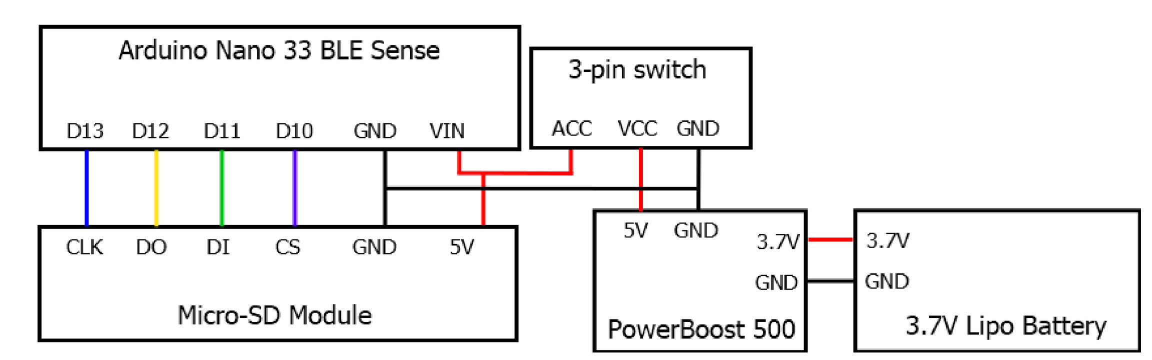
**Tools**
Soldering Iron
3D printer
Visual Studio Code
Autodesk Inventor

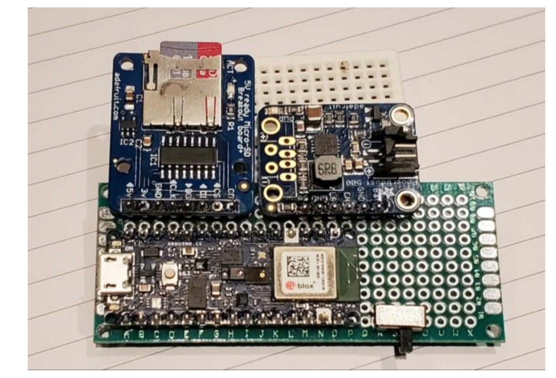
Arduino was chosen as the platform for the Wrist Actigraphy Tracking System (WATS) for the ease in programming and prototyping, as well as the built-in sensors and low power consumption of the Arduino Nano 33 BLE Sense board. The built-in 9-axis IMU of the Arduino BLE Sense was used as an accelerometer to measure movement. A micro-SD module, connected to the Arduino using SPI was used as external storage for the recorded data. Because of the size and weight constraints, a lightweight LiPo battery was chosen as a power source. However, commercially available LiPo batteries have a nominal voltage of 3.7 volts, so the Adafruit PowerBoost 500 was used to maintain 5.2 volts to power the Arduino board. After measuring the power consumption of the device to be 55.6 mA, a 1000 mAh LiPo battery was chosen to provide ~20 hours of continuous power. A schematic was drawn with all connections between components. When the electrical connections were finalized, the components were arranged and soldered onto a double sided perf board, and connections were made with 22 AWG stranded wire according to the schematic. A 3D printable case was designed for the device using Inventor with cutouts for the micro-SD card, switch, and micro-USB port on the Arduino.
Self selected participants(n=7) wore the WATS device on their wrist during overnight trials. Each participant also filled out a sleep quality questionnaire with questions asking about sleep onset latency, total sleep time, and WASO events after they woke up. The data was collected from the WATS device and processed further.

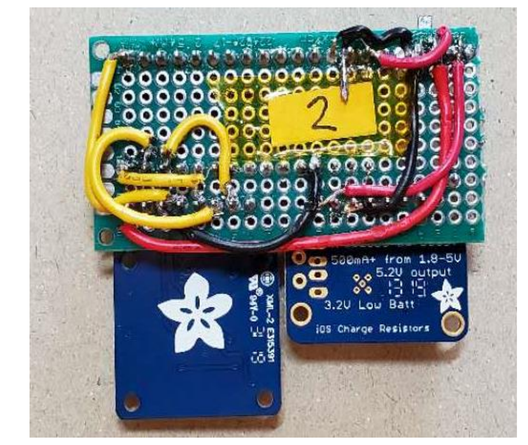


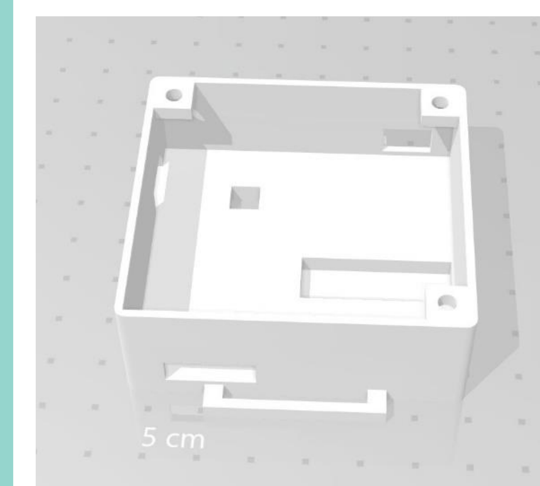




## Final Device



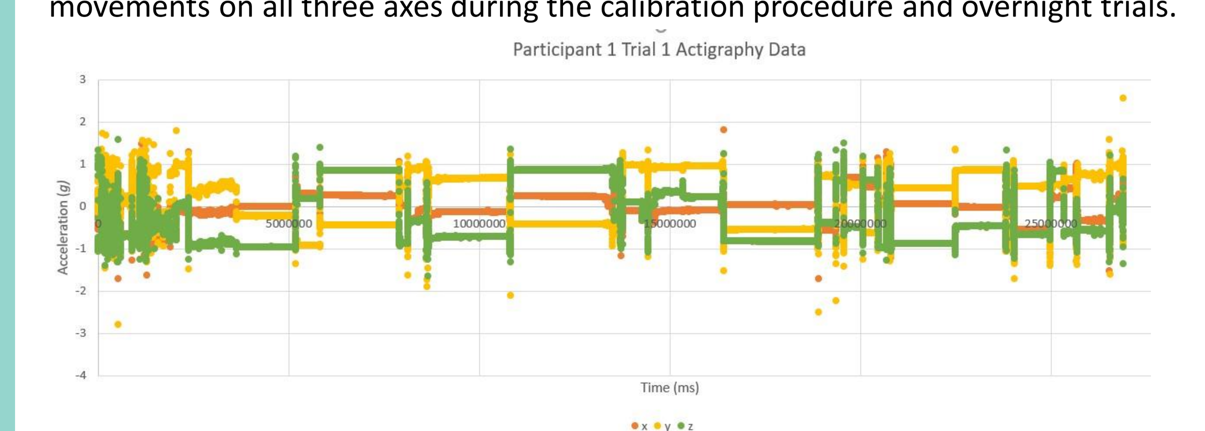








## Results

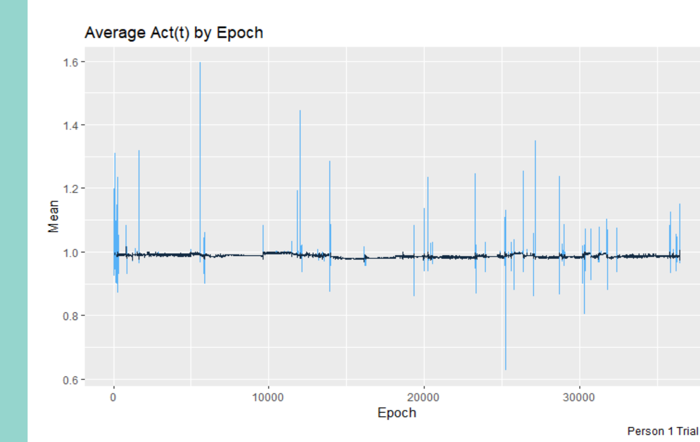
The LSM9DS1 accelerometer which was used to measure movement during sleep had an accuracy of ±90 m$g$ on the ±4$g$ default setting. It was able to capture noticeable movements on all three axes during the calibration procedure and overnight trials.

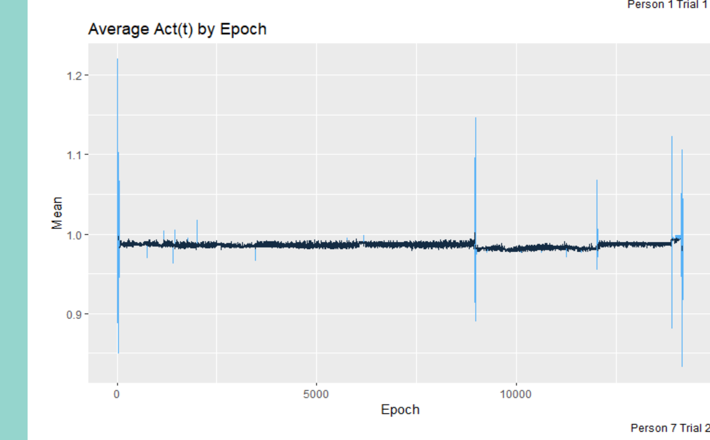



After the accelerometer data was collected from the micro-SD card, the raw data x(t), y(t), and z(t) was composed into the magnitude Act(t) [5] using Python.

$$act(t) = \sqrt{x(t)^2 + y(t)^2 + z(t)^2}$$

The Python script separated the data into 3-min epochs with the mean, median, max, and 95th percentile of each epoch. The average activity of each epoch was used to split epochs into the active or inactive categories. Using this classification, sleep latency, total sleep time, and sleep efficiency could be calculated.




| Measure | Correlation | P-Value |
|---|---|---|
| Sleep Latency | -0.397 | 0.2 |
| Total Sleep Time | 0.863 | 7e-05 |

## Conclusion

This low cost sleep tracker can be used to track sleep, offering a lower cost alternative to commercial sleep trackers like the Fitbit. Based on our results, the device is able to track movement and periods of inactivity and activity during sleep when compared to the self-reported metrics of sleep quality, as well as track total sleep time and WASO events.

## Future Direction

Currently the data has to be processed manually by taking out the micro-SD card from the device and using Python and R, but the process can be streamlined by using the built-in Bluetooth capabilities of the Arduino Nano 33 BLE Sense. In the future, we plan on improving the accuracy of the sleep tracking by adding secondary sensory data, such as an EEG to track heart rate or a humidity/temperature sensor. The electronic components were the limiting factor in size and cost, so a custom-made PCB board would be not only cheaper to mass-produce, but also allows for a smaller form factor for the comfort of the wearer. The analysis of the data can also be improved by applying machine learning to personalize the quality analysis.

## Acknowledgements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