Low Cost Sleep Quality Tracking Using Arduino

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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, and cloud-based data storage.

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 about 60% effective in finding the different stages of sleep compared to overnight sleep studies, but are frequently more than 80% effective in determining the start and end times of periods of sleep [5].

Research Question:

Is it possible to create a wrist-mounted sleep tracker that provides a low-cost and accessible platform for long-term sleep quality tracking?

Hypothesis:

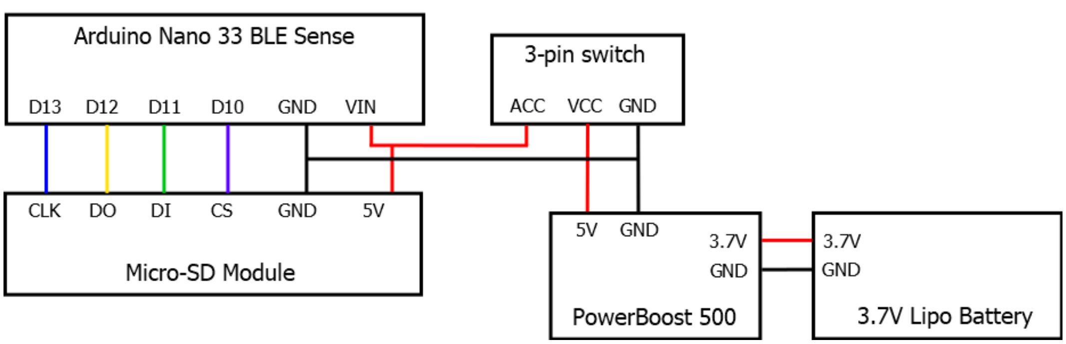
Using a low-cost data collection system built using Arduino that collects actigraphy data, several AASM sleep quality standards, including sleep efficiency, sleep onset latency, and WASO events can be tracked.

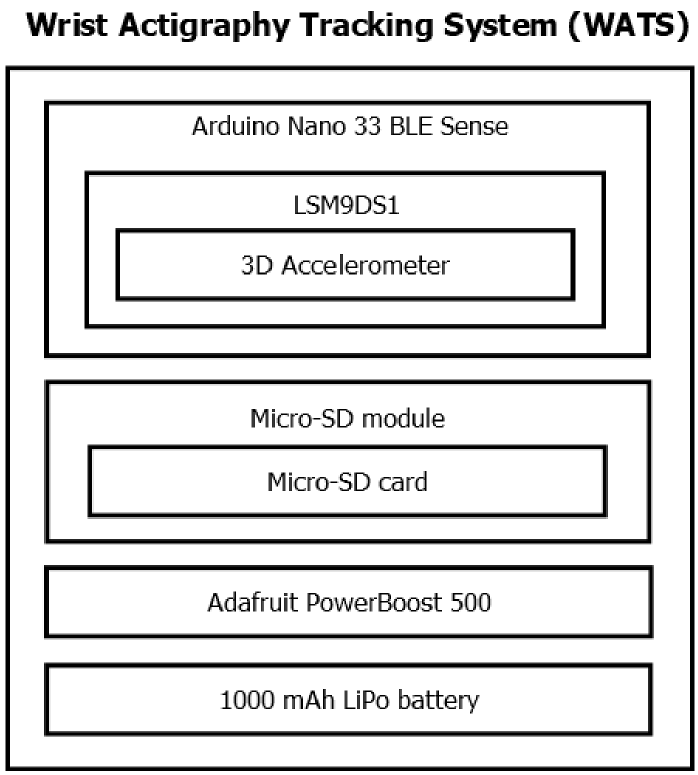
Methodology:

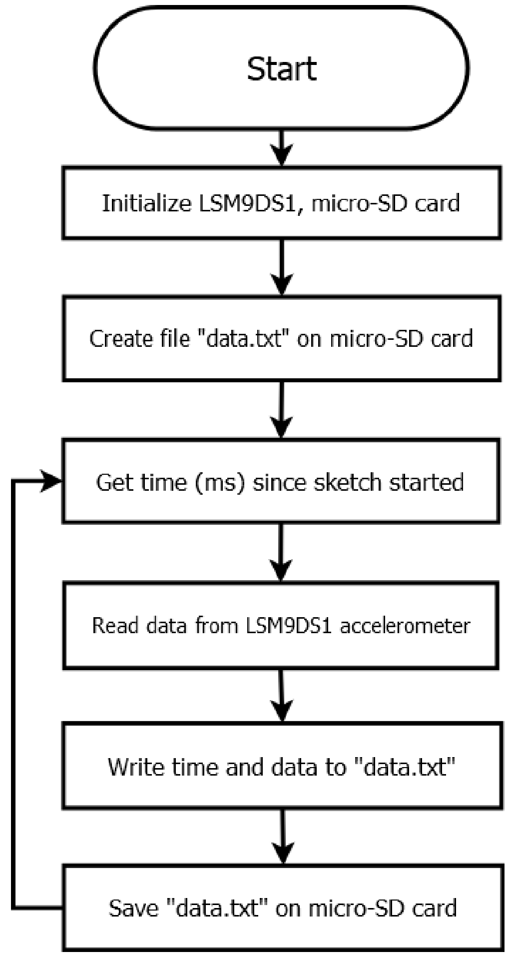
Materials:

Name	Seller	Description	Price	URL
Arduino 33 BLE Sense	Arduino	small mcu with built-in sensors and BLE	$31.50	link
Micro SD Storage Board	Amazon	micro sd module for arduino	$11.89	link
Micro SD card	Amazon	8 gb micro sd card	$5.45	link
Micro Lipo w/MicroUSB Jack v1	Adafruit	micro lipo charger	$10.16	link
Adafruit PowerBoost 500	Adafruit	3.7v to 5v booster	$11.52	link
Lithium Ion Polymer Battery - 3.7v 1000mAh	Amazon	lipo battery	$9.99	link
Nylon watch straps	Amazon	nylon black watch straps with buckles	$11.99	link
Medical felt padding	Amazon	1/8 inch felt adhesive for medical use	$18.45	link
3-pin switch	Polulu	3 pin mini slide switch	$1.50	link
Stranded wire kit	Amazon	22 awg stranded core wire	$18.99	link
Tacklife Digital Multimeter	Amazon	digital multimeter	$26.97	link
Soldering Station	Amazon	Weller 40 watt soldering station	$38.97	link
Solder Wire	Amazon	60/40 solder wire, 0.8mm	$7.99	link
3/8 inch screws	Ace Hardware	3/8 inch pan head screws	$0.30	link

Hardware:







Software:

Software: Arduino IDE, Python, R Studio, Github

Tools: VSCode, Autodesk Inventor, Soldering Iron, 3D printer

Planning:

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.

Building Process:

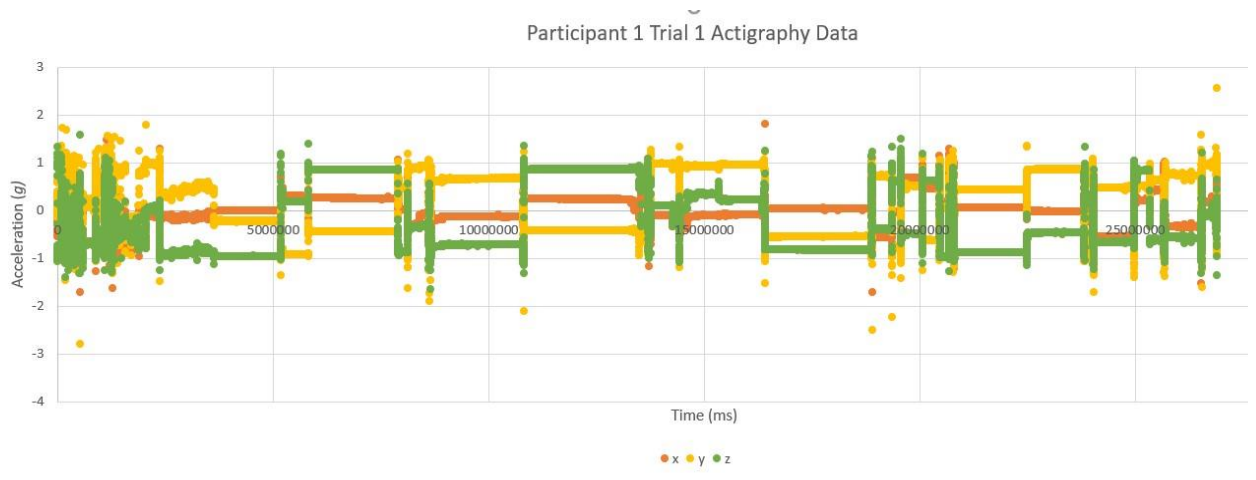
Before soldering, the electrical components were connected on a breadboard using jumper cables. Once the layout was finalized, each component was soldered onto a protoboard and connections were made by soldering 22 gauge wires to each soldered pin. The Arduino Nano 33 BLE Sense, Adafruit micro-SD module, Adafruit PowerBoost 500 module, and a 3-pin switch were soldered onto protoboards. To conserve power and prevent distracting lights during overnight sleep trials, each non-essential LED was de-soldered from the boards. To design the 3D case, the finished electrical components were measured to get the necessary dimensions for the box. A lid was designed to be held to the box body using screws. After the first prototypes of the 3D box had some small issues, the overhangs were changed and the box was made slimmer. A nylon watch strap and plastic buckle was then attached to each device's case.

Programming:

Using C++ with the Arduino environment, a program was written that used the built in LSM9DS1 and SD card module libraries to read from the built-in IMU on the Arduino board and wrote the data to an inserted micro-SD card. A zero-delay timer was used instead of the built-in delay() function in order to maintain a faster sampling rate. Based on research into sampling rates and movement speeds, a sampling rate of 5 Hz was chosen.

Results

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 and written into an Excel file.



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

In order to validate that the actigraphy data collected by the sleep tracking device could be used to identify AASM standards of sleep quality, the actigraphy data was processed using Python to convert the raw data into the mean, median, maximum, and 95th percentile of each 3-min epoch.

Using R-Studio, each epoch was classified as either wake or sleep, which allowed the

To classify each epoch as active or inactive, we used the mean of each epoch to decide if it was an outlier or not. The formula we used was mean < (25th percentile – 1.5 * IQR) or mean > (75th percentile +1.5 * IQR).

In order to find the total sleep time, we counted the total number of inactive epochs in the trial.

To find the sleep efficiency, we divided the total time spent asleep by the total number of recorded epochs.

To find the sleep latency, we found the first four epochs, which is 12 minutes, with continued inactivity, and defined the start of sleep as the start of those four epochs [6]. Sleep latency was calculated by finding the number of epochs up to the start of sleep epoch.

Using the questions from the questionnaire, the measured standards were compared to the self-reported questions.

Correlation Metrics:

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

Discussion:

Based on our results, the device is able to accurately track movement and periods of inactivity and activity during sleep when compared to the self-reported metrics of sleep quality. However, it is not very accurate at matching the participant’s self reported sleep onset latency measures.

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.

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.

References:

1. Atkinson, J. (n.d.). Polysomnography Reports –Interpreting the Data. Retrieved from https://www.aastweb.org/hubfs/International Congress Presentations/4 Atkinson Polysomnography Reports.pdf
2. Blackwell, T., Redline, S., Ancoli-Israel, S., Schneider, J. L., Surovec, S., Johnson, N. L., … Study of Osteoporotic Fractures Research Group (2008). Comparison of sleep parameters from actigraphy and polysomnography in older women: the SOF study. *Sleep*, *31*(2), 283–291. doi:10.1093/sleep/31.2.283
3. Martin, J. L., & Hakim, A. D. (2011). Wrist actigraphy. *Chest*, *139*(6), 1514–1527. doi:10.1378/chest.10-1872
4. National Sleep Foundation's 2018 Sleep in America® Poll Shows Americans Failing to Prioritize Sleep. (n.d.). Retrieved from https://www.sleepfoundation.org/press-release/national-sleep-foundations-2018-sleep-americar-poll-shows-americans-failing
5. Yuda, Emi, et al. “Sleep Stage Classification by a Combination of Actigraphic and Heart Rate Signals.” *Journal of Low Power Electronics and Applications*, vol. 7, no. 4, 2017, p. 28., doi:10.3390/jlpea7040028.
6. Maglione, Jeanne E et al. “Actigraphy for the assessment of sleep measures in Parkinson's disease.” *Sleep* vol. 36,8 1209-17. 1 Aug. 2013, doi:10.5665/sleep.2888