Shiver-Ring

John Murray, CompE, Adam Maciaszek, CompE, Michael Burton, CompE, and Connor Loughman, CompE

***Abstract*—When a patient's blood sugar drops to dangerous levels the patient is said to be in a hypoglycemic state. In severe cases of hypoglycemia the patient will develop Hypothermia and start to shiver. This is extremely dangerous and can result in death if not treated quickly. Our proposed solution is a wrist mounted device that detects shivering in patients. The wrist mounted device is wirelessly connected to a smartphone using a bluetooth low energy module. This module will notify the smartphone of an emergency when shivering is detected, and then the smartphone sends specified individuals emergency alerts via SMS messaging.**

I. Introduction

A. *Significance*

When blood glucose levels fall below 70 mg/dl at night while sleeping, the person experiences a condition called nocturnal hypoglycemia. Studies show that almost half of all episodes of low blood glucose occur at night during sleep while over half of all severe cases do. This is bad at night since there are no warning signs of low blood sugar levels like you have while you are awake and your body will not wake you up. Hand tremors have been shown to occur for all patients with diabetes.[3] Since hand tremors are consistent and early signs of hypoglycemia our product aims to detect these shivering hand tremors and first play a loud alarm to wake up the user or anyone within earshot and adjust the glucose levels through a snack or the hospital if it is severe. If this alarm is not deactivated within twenty-four seconds it will then send an SMS message to a predetermined number via a custom android application connected via Bluetooth.

B. Context and Competing Solutions in Marketplace

Currently, there exist two major ways to detect hypoglycemic episodes through temperature and sweat or by directly testing the blood using an implanted device. An example of a competing solution is the diabetes sentry which uses temperature and sweat detection, a problem with this is that it is less effective in very warm humid environments or people who are naturally disposed to be more sweaty. The other solution is through an implant that tracks blood sugar content, which is not only invasive but also more expensive and needs to be replaced every three months.

C. *Societal Impacts*

The target demographic is anyone who has diabetes but especially those who are living on their own. Shiver-Ring is useful for anyone who has diabetes as even without the added functionality of being able to contact someone via SMS it also can wake you up in order to adjust it yourself if it is not severe. For the user, it is important that the device is comfortable and adjustable for all body types. To accomplish this a flexible PCB is used to bend to the user's dimensions forearm below the wrist, which is encased in an elastic fabric so it is not loose on the skin rendering it unable to detect the shivering.

D.*System Requirements and Specifications*

Our system had a handful of important requirements. The most important specification was that the system was accurate. This means that the system can properly detect movement in the 8-12 Hz range. Additionally, our system had to be wearable. This requires that the system be compact, lightweight, and flexible to increase the comfort of the device. Lastly, the device must be Bluetooth compatible while maintaining approximately a 12-hour battery life in order for the device to monitor continuously throughout the night.

Wearable	Flexible
	Lightweight
	compact
Accurate	8-12 Hz
Bluetooth compatible	functions with android app
Battery life	~12 hours

Table 1: Requirements and Specifications

II. DESIGN

A. *Overview*

We solved the problems posed by creating a system consisting of an accelerometer, processing unit, and an alert system. There were many other possible solutions researched but all of the similar solutions involved invasive medical procedures or were cost prohibitive to general adoption. Additionally, we consider the use of an EMG. However, this design was changed as the EMG was not capable of producing accurate results and the sensors were often one time use.

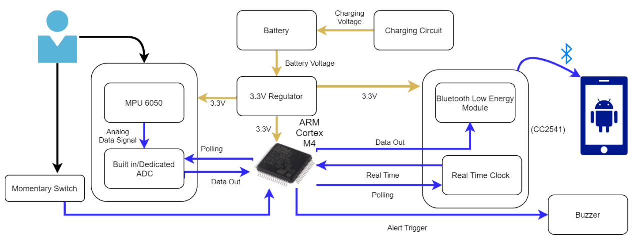


Figure 1: System Block Diagram

B. *Accelerometer*

The purpose of this block is to collect data from the user using a MPU 6050 accelerometer and, using the integrated ADC, convert the signal to a signal that can be effectively processed by the processor block.

C. *Battery and voltage regulation*

The purpose of this block is to provide power to the system via a 2100 mAh lithium polymer battery which is regulated by a 3.3V regulator. Additionally this block includes a battery charging controller which allows for safe and reliable battery charging.

D. *Processor*

The purpose of this block is to handle all of the data and inputs into the system. Some of the inputs include the data from the accelerometer block as well as the system control button which is used to disable the alarm buzzer.

E. *BLE Module*

The purpose of this block is to communicate via bluetooth low energy with the android app installed on the user's phone.

III. DATA COLLECTION & ANALYSIS

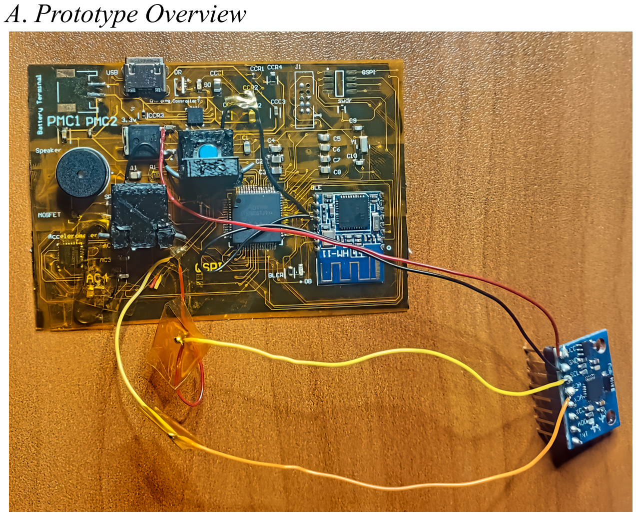
1024 points of positional data are collected from each of the x, y, and z directions totaling 3072 points over 4096 milliseconds giving a sampling frequency of 250 Hz. This frequency was chosen since it is well over the Nyquist frequency of our range of detection going up to 12 Hz and with such a large amount of points this will counterbalance any outliers or bad points of data collected. For each axis, a discrete-time Fourier transformation is performed. Then on that DTFT of each, a spectrogram was taken. Then the peak frequency is reported back for each of the three-axis and then recorded.

After 3 blocks of data are collected in approximately 12 seconds there are 9 frequencies reported back 3 in each direction. If out of the 9 frequencies there are 5 or more frequencies in the range of eight to twelves hertz the alarm is reached

If the alarm is reached then the speaker will go off and then if the button is not pressed to turn off the speaker then the Bluetooth sends a signal to the app that an emergency state is reached and then sends an SMS.

IV. THE REFINED PROTOTYPE (FINAL)

A. Prototype Overview



B. List of Hardware and Software

- HM-11 BLE Module
- M4 ATSAMD51J19A
- FreeRTOS
- FFT Code
- Bluetooth Code
- Android App Code

C. Custom Hardware

The circuit board that we designed was intended for use on a flexible circuit board. When planning for this use case it was vital that component placement allows for the board to articulate with the curvature of the user's wrist. In order to maintain this design we designated a small portion of the board to large, rigid components that are not able to provide flexibility and it is planned that this region is backed potentially with the battery for extra support.

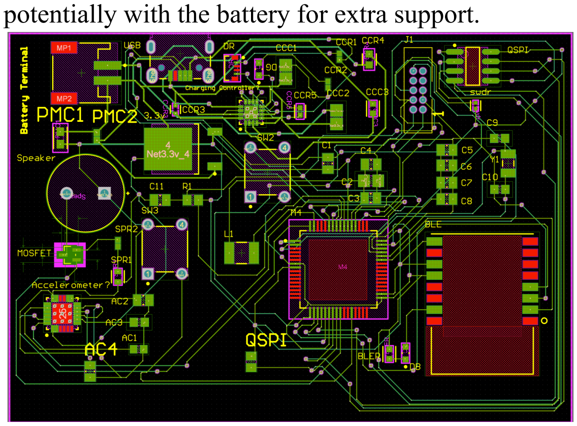


Figure 2: PCB Layout

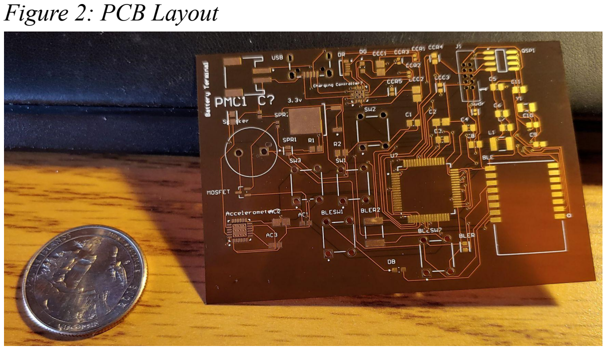


Figure 3: Unpopulated flexible PCB v1

In order to get a good design, it was vital that the circuit schematics remain neat and organized. As such the schematics were sectioned off by their corresponding subsystems and connected together on one final sheet as seen in Fig. 4. This technique resulted in a larger number of schematic files however they are much easier to understand. Additionally, the use of multiple schematic diagrams made solving design problems significantly easier.

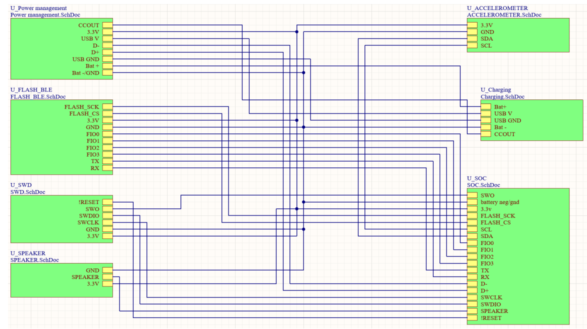


Figure 4: Schematic diagram linking all subsystems

D. Prototype Functionality

All elements of the prototype are functional. The full integrated system runs without fail. The accelerometer collects the data and calibrates correctly. The FFT and spectrogram output meaningful data reliably as expected. The bluetooth module connects and send the data to the application and the application sends sms correctly

E. Prototype Performance

All of the requirements set forth were met. Some specifications were modified such as data collection taking only 4 seconds rather than 5 and the number of points collected was quadrupled after the switch to C++ which greatly decreased the processing time for the data.

IV. CONCLUSION

As of 5/4/2021, we completed our project by satisfying all of our system specifications except for the wrist band and battery. We had a CDR prototype to use as reference for testing our PCBA design. Our PCBA went through several revisions after CDR. When testing the PCB, there were several issues with the trace widths and connections that necessitated another revision. Since it was discovered within close proximity of FPR, we designed a traditional PCBA that we could receive faster. At the same time, we also ordered a flexible PCB of the same design that we had ready by demo day. Our software design is complete, and no changes to the core logic are necessary. We calibrated the accelerometer for the PCB, and had a wearable to demonstrate by the demo days. We collected data for overnight testing to confirm that the alarm does not go off. We also tested various other sources, and found that fast keyboard typing can also trigger the alarm.

ACKNOWLEDGMENT

We would like to acknowledge Professor Noh who encouraged us to attempt a device of this type,

provided insight into possible solutions, and assisted us with testing and assembling hardware. Without his assistance, we wouldn't have been able to properly test the potential of using an EMG device. It is also likely that we would not have dared to attempt using a flexible circuit board.

REFERENCES

[1] C. Tran et al., "Hypothermia is a frequent sign of severe hypoglycaemia in patients with diabetes," Diabetes & Metabolism, vol. 38, no. 4, pp. 370–372, Oct. 2012, doi: 10.1016/j.diabet.2012.03.005.

[2] Charles PD, Esper GJ, Davis TL, Maciunas RJ, Robertson D. Classification of tremor and update on treatment. Am Fam Physician. 1999 Mar 15;59(6):1565-72. PMID: 10193597.

[3]K. Zahed, F. Sasangohar, R. Mehta, M. Erraguntla, M. Lawley, and K. Qaraqe, "Investigating the Efficacy of Using Hand Tremors for Early Detection of Hypoglycemic Events: A Scoping Literature Review," Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 62, no. 1, pp. 1211–1215, Sep. 2018, doi: 10.1177/1541931218621278.

APPENDIX

A. Design Alternatives

The primary design alternative early on was the choice of sensor for our events. We were measuring muscle movements, so two sensors came to mind, namely the EMG and accelerometer. Ultimately, the EMG required for our level of detection would have no longer been classified as a wearable (a rather large and expensive device far beyond the SDP budget). So, we decided to go with the accelerometer in our design. The accelerometer in our design was chosen due to the ubiquity of it in common electronics kits, which was a major factor, since there was plenty of documentation for the device. Since we encountered no problems with the precision of the device affecting our results, we remained with the accelerometer in the design.

Another important design alternative was the choice of alarm reset device. Ultimately, we chose a button with a cover, but we were also considering a switch with a cover. However, we realized that that a switch would not make sense, because a user could toggle the switch to prevent the alarm from ever going off, which would defeat the purpose of the system.

B. Technical Standards

Will add BLE standard docs on app development and implementation later

C. Testing Methods

The main test is for frequency accuracy where the accelerometer was adhered to the diaphragm, a subwoofer that is rated for fidelity down to five hertz and was tested using a reference microphone. Tones were played from five to twenty hertz during tests.

Another important test was for actual human shivering where both the raw data values and the predicted frequency were recorded. The raw data was processed off the microcontroller to see if the calculations were correct from the data. The predicted frequencies were then compared to see if they fell within the eight to twelve hertz range which they did.

The final test was for battery life. To test this the prototype and final design were powered via a usb peripheral which logged the voltage and current draw for the device over time. The switch to C++ proved to be optimal for this and the power draw was not only less but also more consistent with the cortex M4 chip.

D. Project Expenditures

For the initial prototype no expenditures were necessary other than to test the emg which was not part of the final design. All other supplies were acquired through the M5 maker space. For the final design, enough parts to build five copies in the end were bought. This was because our team is separated by distance and only one member is on campus.

E. Project Management

Our team consists of 4 computer engineers with varying degrees of experience with hardware and software. Michael's primary responsibility during the course of the project was to implement FreeRTOS into our software codebase, as well as act as the Project Co-manager. Adam's primary responsibility was to develop the sensing, collection, and processing of our shivering data portion of our software codebase, as well as handle project expenditures and shipping. Connor's primary responsibility was designing the PCB as our Altium lead. John's primary responsibilities were bluetooth connectivity and app development.

Overall, we have performed well as a team that is mostly remote, most recently completing all of our major tasks that we set for CDR. We meet often each week in small groups of two or three for varying reasons such as a software integration meeting

(Michael, Adam, John) or PCB related meetings (Connor, Adam, John). In addition, we meet as a team before our advising meetings to touch base and make adjustments to our work schedules as need be. If a team member is struggling with something, we always try to get it resolved by helping each other out. We primarily communicate through Messenger, Zoom, and Slack every day for scheduled meetings as well as updates on time sensitive things (such as PCB/parts coming in, or updates on work done).

Early in the Spring 2021 semester, Michael was working on compilation issues with the FreeRTOS + sensing codebase, and John went through each and every relevant file to try to find solutions. During a software development meeting with John, Adam, and Michael, Michael pointed out that the easiest way to check if the bucket that was reported after the FFT processing was valid (not just a result of noise) was to set a threshold so that any number larger than reasonable (has to be tuned per system) would be safely ignored. This threshold is part of the equation of balancing false negatives (setting the threshold too low) and false positives (threshold too high). During a meeting with Michael and Adam, Adam spent the meeting helping to debug the code. For code meetings, having one person code and share their screen while others comment was a common strategy to debug code much faster than individual work.

F. Beyond the Classroom

Each member should describe the skills they have needed to develop and the knowledge they have needed to learn as a result of this project so far. What resources have been useful to you? Do you see any connections between this and your life as a professional?

John has learned about the development and integration of bluetooth low energy into both embedded and android application systems. This includes GATT server management and notification based communication over BLE, and threaded implementation of UART streams to a separate bluetooth embedded module. John also learned more about the Altium circuit design software working with Connor to review the circuit board before ordering. John has also gained experience soldering micro components by hand on a flexible circuit board.

Adam developed a better understanding of digital signal processing as this project is centered around the ability to process the periodicity of signals being collected. In addition to that Adam gained useful experience in memory management. For both systems in C++ and Python Adam had programmed on my desktop which ran the programs very fast only to be met with long wait times and memory overflows on the microcontroller. Adam learned better to save calculated values to be used again and optimize equations to do as little operations as possible. Adam also learned skills in memory management such as not using dynamically linked lists when all sizes will be the same and is completely unnecessary. Arrays that are not used again are to be immediately deleted to not bog down the memory with anything unneeded.

Michael has developed team-leading and organizational skills. In terms of technical skills, Michael has learned general memory management skills, as well as working with real-time operating systems in environments with strict memory and processing constraints. Namely, working with C++ without the standard library was particularly challenging but ultimately rewarding. As a professional, Michael thinks that this troubleshooting process will be useful.

Connor was focused on developing a strong skill set with Altium and circuit design. Prior to this project Connor had used Altium for personal projects, however the understanding of the software was limited. Within Altium and circuit design Connor made extensive use of the Altium support page in order to learn how to make use of multiple schematic sheets which can then be transferred onto a circuit board. Additionally, Connor had to research the use of MOSFETs as switches so that our speaker device could be capable of drawing enough current to operate. Lastly, Connor had to learn how to use Android studio as well as the programming language Kotlin to assist John with the calendar integration into the android application. All of these Skills will be useful in Connor's professional career by improving workflow and broadening the possible design choices available.