Rooster Band
The Wristband That Keeps You Awake

ECE 445 Design Document - Fall 2019

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1. **Introduction**

1.1 Objective:

Everyday life has become fast paced and with so much work to do and unexpected events, getting a good night's sleep can be hard to come by. Some people also have sleeping disorders which make them want to sleep at random times. People being drowsy can lead to sleeping in class, in meetings, behind the wheel, or on transportation. This will lead to them missing their stop, information, or even fatal accidents.

With the wristband we are creating, people will be kept awake within 5 minutes of entering the first stage of sleep. It will use an accelerometer and pulse sensor that will collaborate to accurately tell if the user has entered the first stage of sleep. Once the sensors send a positive single that the user is in stage 1 of sleep, then the wristband will use a small vibration motor to get the user back to being alert.

1.2 Background:

A large sleep census conducted by Sealy and the Loughborough University in 2016 showed that in the 5 countries where the census was conducted, an average of around 23% percent of people suffer from insomnia, and only 24% of people get the recommended 8+ hours of sleep. Clearly many people around the world have sleep problems and can't get enough sleep. The study further shows that around 47% of people take naps during the day which disrupts their work and school day.[1] People are clearly having trouble staying awake and our device should be a simple solution that requires minimum effort for the user to take advantage of.

At first this project may just seem to be as simple as adding a vibrating function to one of the popular smartwatches or wearable sleep monitors but there are clear differences. The aforementioned devices' main goal is to track a person's sleep, using an accelerometer to record the movements of the wearer and determine the wearer's sleep status by the stillness of his/her body.[2] The problem with this is twofold. Firstly, the movement of a body during sleep will only completely stop after stage 2 of NREM sleep, meaning that by the time the user has been detected sleeping, he/she has already been asleep for 10-20 minutes and the damage will have already been done. The second problem is that it won't be able to detect people falling asleep in other settings besides laying down on a bed making it useless for drivers and the like.

1.3 Visual Aid:

Fig 1.1: Visual of the device in use

1.4 High-Level Requirements List:

1. Assure accurate sensor reading within 10% of error while user is active in sedentary environment.
2. Once sleep is detected, alert the subject to wake within 1 minute.
3. Minimum of 30 mins of continuous runtime(long enough to chase off sleep) while activating all waking peripherals. 6 hours of continuous silent runtime.

2. Design

2.1 Physical Design:

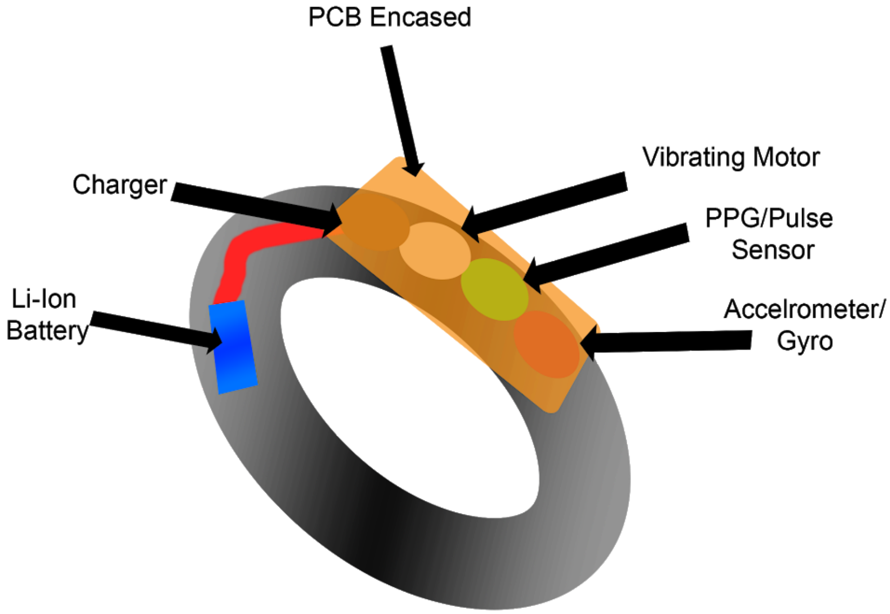

Fig 2.1: Basic physical diagram of the wristband

Our ideal form for this wearable device is that of a wristband. Wristbands are commonly used wearables that are convenient and compact. They are casual enough to wear in any situation making it very accessible. Figure 2 is a physical design prototype is similar to a watch where instead of a watch face, we will have a solid box that will hold the pcb and most of the internals including the pulse sensor and accelerometer. This box is represented by the orange rectangle in the diagram and the two dots underneath are the pulse sensor and accelerometer. The pulse sensor will be placed directly above the wrist in a way to effectively read the user's pulse. The battery could be placed in the band to save space in the box, or in the box itself if space is allowed. The material for the band is largely undecided.A possible option is a stretchable rubber or silicone ring so that the band will be tight enough for the sensors to have close contacts with the skin. Another option is a cloth wristband with stretchable fibers to make it more comfortable.The wristband need to be wide enough to house the PCB and its components on top of it.

2.2 Block Diagram

There are a total of 4 subsystems that we plan to implement for this project. Each one of these subsystems will fulfill or help fulfill one or more of our high-level requirements. The sleep detecting subsystem will be comprised of the 2 sensors we will be using to detect sleep within 3-5 minutes of stage 1 non-rem sleep. Every sensor will be able to send information to the control subsystem which will process everything through a programmable microcontroller. When it gets positive signals from the sleep detecting subsystem, it will send signals to the wake up subsystem which sends signals to the vibration motor to activate and wake up the user. The user can then press a button to stop the vibration and reset the device. The same button will also be power button to turn the device on and off. Everything will be powered by our power subsystem which will have a 3.3v lithium ion battery that goes through a voltage regulator to maintain a steady voltage that will power all of our individual parts. This battery will have a charger allowing the device the be rechargeable.

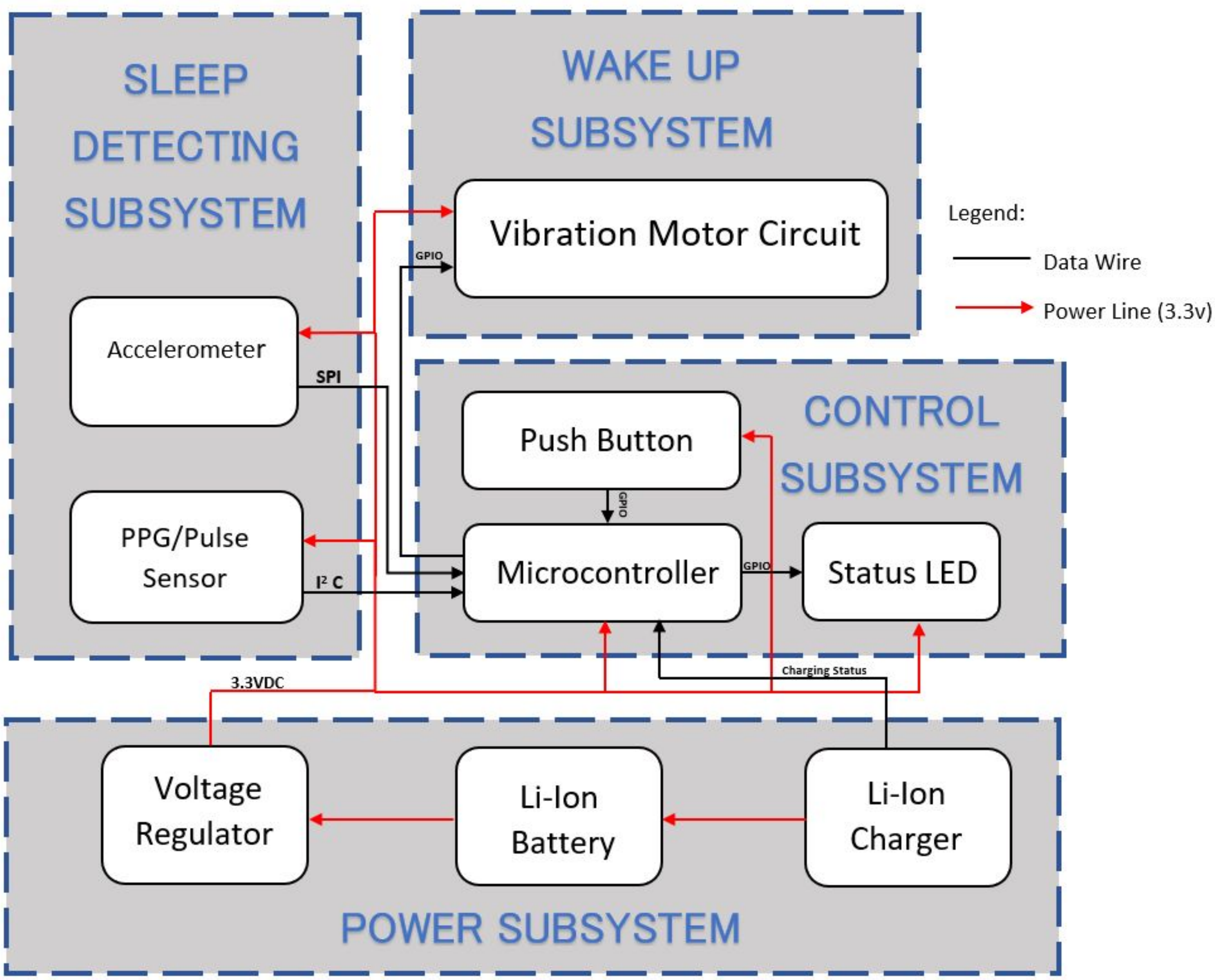

Fig 2.2: Block Diagram with 4 subsystems

2.3 Subsystems:

2.3.1 Sleep Detection system

This system takes in 3.3V as voltage input, each of the two sensors are connected in parallel, and communicates with the control system with different protocols. The accelerometer will use SPI and the pulse sensor will use I2C. The sensors will be continuously sending data through the data line.

- Accelerometer

  The accelerometer measures the movement in your wrist. The sensor should be able to catch the smallest movement in the wrist while typing driving or writing, the most frequent activity that people spend their time that causes sleepiness. Accelerometers generally supports both SPI and I2C but we decided to use SPI specifically because our microcontroller only has one I2C port and SPI is generally faster than I2C giving us better response times.

- Pulse Sensor

  A pulse(PPG) sensor measures the heart beat rate by shining 2 green LEDs onto the skin and using a photodiode to detect light that has been absorbed by blood vs. light that has been reflected by the skin.[3] The sensor should be setup so that any light activity does not disrupt too much on its operation.

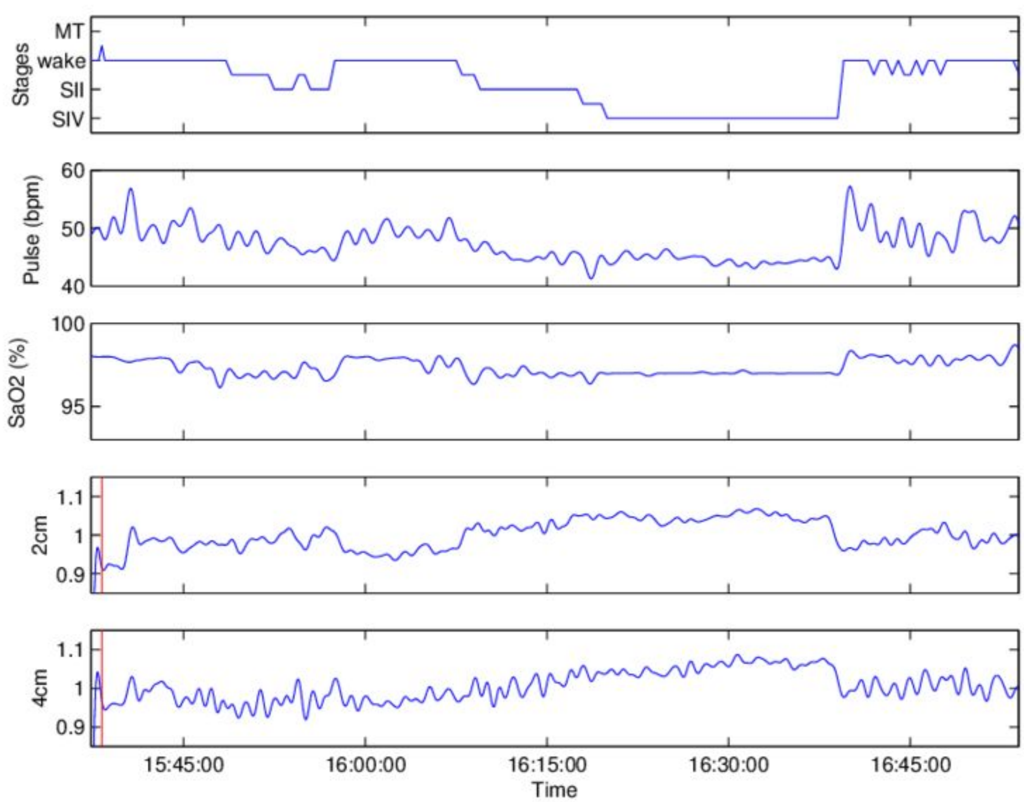

Fig 2.3 (Noponen, 2003) above image illustrates the pulse change with the corresponding sleep state.[4] If we can accurately measure and determine which sleep state the user is in, the accuracy of the device will increase. While other sensors sense the activity of the user, pulse sensor has the most direct way of detecting sleep.

2.3.2 Control Subsystem

Main control will be handled by the Atmega328P microcontroller, communicating with both of the sensors using the I2C protocol.[5] It will then use that information to determine whether or not the user is sleeping. If the user is detected sleeping then it will send signals to the wake up subsystem and activate the motor. The button in this subsystem will have 2 functions, the first will be a basic on/off button for the device. The second function will be a button to stop the vibrating motor after it is pressed. The Atmega supports The Atmega328P was chosen because of its' convenience during coding. We can test and code each subsystem separately with an Arduino UNO before integrating the parts into a PCB and when we have everything working, we can simply load the program into the microcontroller, remove it from the arduino and implement it into our PCB circuit. An LED is used to indicate whether or not the device is operating and is also used as a status indicator when charging.

2.3.3 Wake up Subsystem

Vibration motor will be embedded on the side of the wristband, the activation of the motor will be handled by sending a signal from a GPIO from the microcontroller to put power into the motor. The type of vibration motor that will be used is a coin type ERM(Eccentric Rotating Mass Vibration) motor. This was chosen over the pages type due to its smaller form factor and lack of moving parts which would potentially damage other parts of the circuit or the pcb itself.

2.3.4 Power

The main power comes from a 3.7V, 400mAh Lithium ion polymer battery, and the battery should be able to power the circuit with all sensors and motors active for at least 30 minutes and run silent for 6 hours straight. The battery will also be able to be recharged using a mini usb port. The battery is connected via voltage regulator to other subsystems to ensure constant 3.3V.

Requirement	Verification
Wrist band **1.** Ensure sensor readings are accurate while moving	**1.** (a)user puts on the wristband and fitbit (b)user runs at 3km/h for 3 minutes (c) ensure both readings match with error range of 10%

2. Elastic for sizes 6” to 9”	**2.** Make sure the diameter of the band while flat can extend from 3” to 4.5”
Wake detection **1.** Detect within 2 min whether the user is in sleep or not **2.** System does not incorrectly declare state as “sleeping” when sensor readings get unstable	**1.** (a)Track user with video while in a boring sedentary activity while wearing wristband. (preferably the user is already tired) (b) check if algorithm correctly marks state as sleep when the video shows the user is sleeping **2.** (a) User wears the wristband (b) Try rapid rotational motion of the wrist for 1 min, rotational motion of the whole arm in both directions for 1 min. (c) Ensure the system does not incorrectly categorize state as sleep.
Wake Up System **1.** User wakes up from sleep when vibration motor runs	**1.** (a) Put wristband on with vibration motor in, go to sleep (b) Set a random time during the sleep to run the motor (c) Ensure user wakes up when motor runs
Power Subsystem **1.** Run without charge in silent for 6 hrs. **2.** Run without charge with vibration motor on for 30 mins. **3.** Lithium battery recharges when 3.7V- 4.2V is constantly provided	**1.** (a) Calculate the power drain of circuit then construct a mock circuit with same power drain when the vibration motor is not active. (b) power the circuit with the battery and check if device still runs after 6 hrs. **2.** (a) Modify circuit to match power drain when vibration motor is running. (b) turn device on and check if device still runs after 30 mins. **3.** (a) Drain battery (b) Set up the recharging circuit (c) Test the battery using the mock circuit built above and can operate to standard.
Microcontrol **1.** Can communicate simultaneously with two	**1.** (a) connect Accelerometer to SPI, Pulse sensor to I2C, then connect GPIO output through a transistor to run the vibration

sensors and one vibration motor.	motor. (b) verify that Microcontroller can receive both data.

2.4 Tolerance Analysis:

Our project's main goal is to detect sleep and react quickly enough to activate the waking up mechanisms. This means that the most crucial point of our device is the sensitivity of the sensors and the response time for the sensors to send information to the microcontroller. The accelerometer has a sensitivity tolerance of 0.06 gs at a test condition of +/- 2gs, so around a 3% tolerance between the population of manufactured sensors.[6] We will define the minimum amount of movement an arm must have for a person to be considered awake as a change in position of at a velocity of 10 cm/s in any direction within a span of 1 second. This is minimal speed at which we can say for certain that the user is awake.[7] Setting the arm to start at rest,we find the acceleration for this movement to be:

$$a = \Delta v/t = 0.1/1 = 0.1\ m/s^2$$

The average mass of human forearm is 1.72% of his/her body weight and the average body weight of an adult human is 62kgs making the average mass of a human forearm 1.07kgs.[8,9] We can now find the force necessary for this movement with Newton's second law:

$$F = m * a = 1.07 \cdot 0.1 = 0.107\ kg \cdot m/s^2$$

3% of this is 0.00321 newtons, therefore we want to avoid having to measure the range between 0.10379 to 0.11021 newtons as the tolerance bias may skew our results and determine that the user is awake when he/she is actually closer to being asleep. We can mitigate this bias by using multiple readings over a short time frame rather than a single reading at an instantaneous time. The sensor can output data at a max rate of 400 Hz meaning we can have 400 readings within a second. We can then determine whether or not the majority of the readings is greater than the minimal .107 newtons of force to get a more accurate reading that will be affected less by the tolerance bias.

Our pulse/biometric sensor is a cornerstone of our design and needs to function appropriately with low bias and high sensitivity. Figure 2.4 shows the sensitivity ratio of the pulse sensor graphed over the wavelength of light used for the LED it drives.[10] There is a near 100% sensitivity ratio at around a wavelength of 540nm meaning that at that wavelength the measurement will be near 100% accurate. Therefore if we use a green LED with that wavelength, the tolerance for the pulse sensor should be around 0-1% which should pose little threat to the functionality of our device.

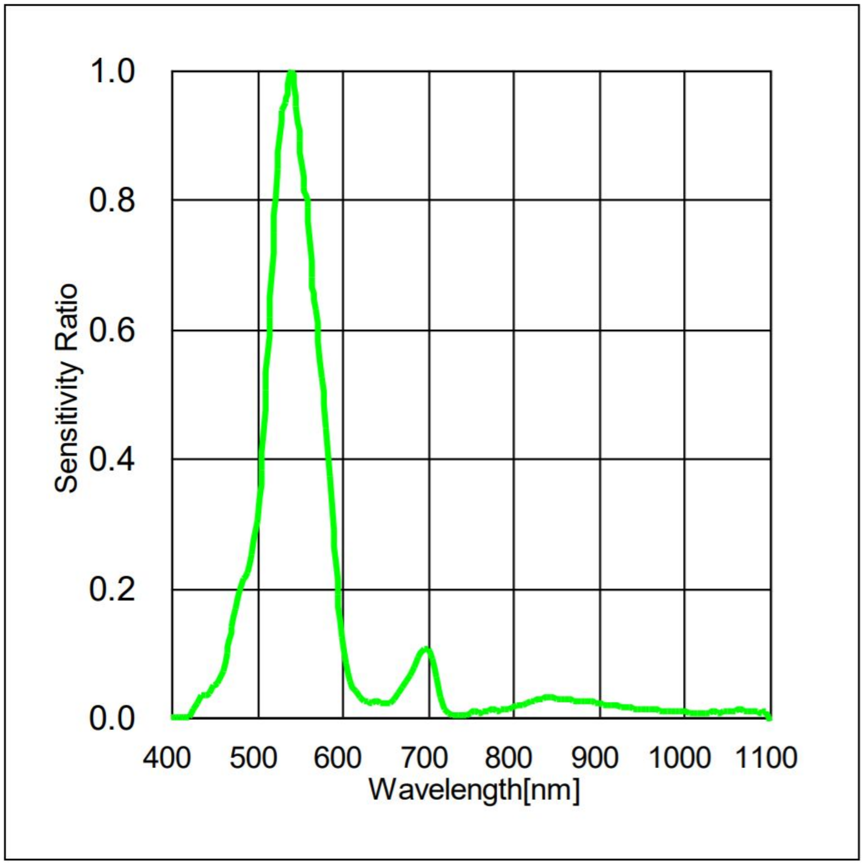

Fig 2.4 Sensitivity Ratio Vs. Wavelength for Pulse Sensor from the sensor's datasheet[10]

2.5 Cost

Microcontroller: ATmega328p : $6.99
Accelerometer: ADXL362BCCZ-RL $8.94
PPG ROHN Biometric sensor BH 1792GLC $10.03
Vibration motor C0834B011F $3.28 (digikey)
Battery: LIPO 801735 400mAh 3.7V $6.95

-Parts total: $36.19
-Labor total: $40/(h x people) x 10h/week x 16week x 3 people x 2.5 = $48,000

Total cost: $48,036.19

2.6 Schedule

Week	Junfei	Bum "Jun"	Jaime	Group
9/30/19				Order and Finalize components
10/7/19	Sensor and motor Subsystem	Controller Subsystem	Power Subsystem	PCB Design Schematic
10/14/19	Code for pulse sensor	Code for accelerometer	Build test circuits	Testing components with breakout board
10/21/19				Revised PCB
10/28/19	Sensors subsystem	Vibration motor and general controls	Power readings	Final PCB Revision Code for testing subsystems
11/4/19	Debugging Sensors	Debugging Controls	Debugging circuit	Testing code for Subsystems while PCB connected
11/11/19				Continue debugging Start working on Final presentation
11/18/19				Working Product for Final Demo
11/25/19 (Fall Break)				Work on Presentation for

				Final Demo (Monday/Tuesday/Wednesday)
12/2/19				Final Presentation due next week (monday/tuesday) Final Report due next week (wednesday)
12/9/19				Done with class

3. Safety and Ethics

The user should not have to take off the wristband when they go outdoors, so the wristband must be water resistant to keep the device safe from a potential shortage inside the wristband.

Using or charging the device in potentially explosive atmospheres, such as areas of high amount of flammable chemicals, vapors, or particles are in the air. In case of a device malfunction during use or while being charged, a spark of electricity can light an explosion.

The components will have to be stable and have strong connections so that they are not broken when the vibration motor turns on. If they do not then the wristband connections can break and can overload the capacitor causing it to explode or create a short in the wristband. Therefore we will follow code #6 of the IEEE code of ethics and promise “to maintain and improve out technical competence,”[11] and create a complete and safe device with no technical defects that may harm the user.

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