SMART PILLOW

ECE 445 Design Document

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1 Introduction

1.1 Problem

As technology advances, more people tend to use devices such as their phones or laptops right before going to bed. Studies have shown that sleep is affected drastically due to the use of technology in the hour before going to bed. This is mainly due to the blue light that is produced by the screens of these smart devices. The blue light produced has been known to interfere with the production of melatonin (the sleep hormone) in the body. This can result in less satisfactory sleep which causes people to be sleepier and more fatigued during the day. Some studies have also shown that bright screens can have an impact on alertness which can lead to users having disrupted sleep more often. Repeated dissatisfactory and disrupted sleep can lead to conditions such as sleep apnea. This is a growing concern due to the increase in the use of technology and can be dangerous.

The signs that a person is not having satisfactory sleep can be loud snoring and frequent changes in sleeping positions. One way that can improve sleep is by listening to relaxing music or some peaceful podcasts. However, you cannot be sure when you would be having disrupted sleep. Smartwatches do a good job of detecting your sleep cycle but they must be charged very often and they are not able to help you improve your sleep.

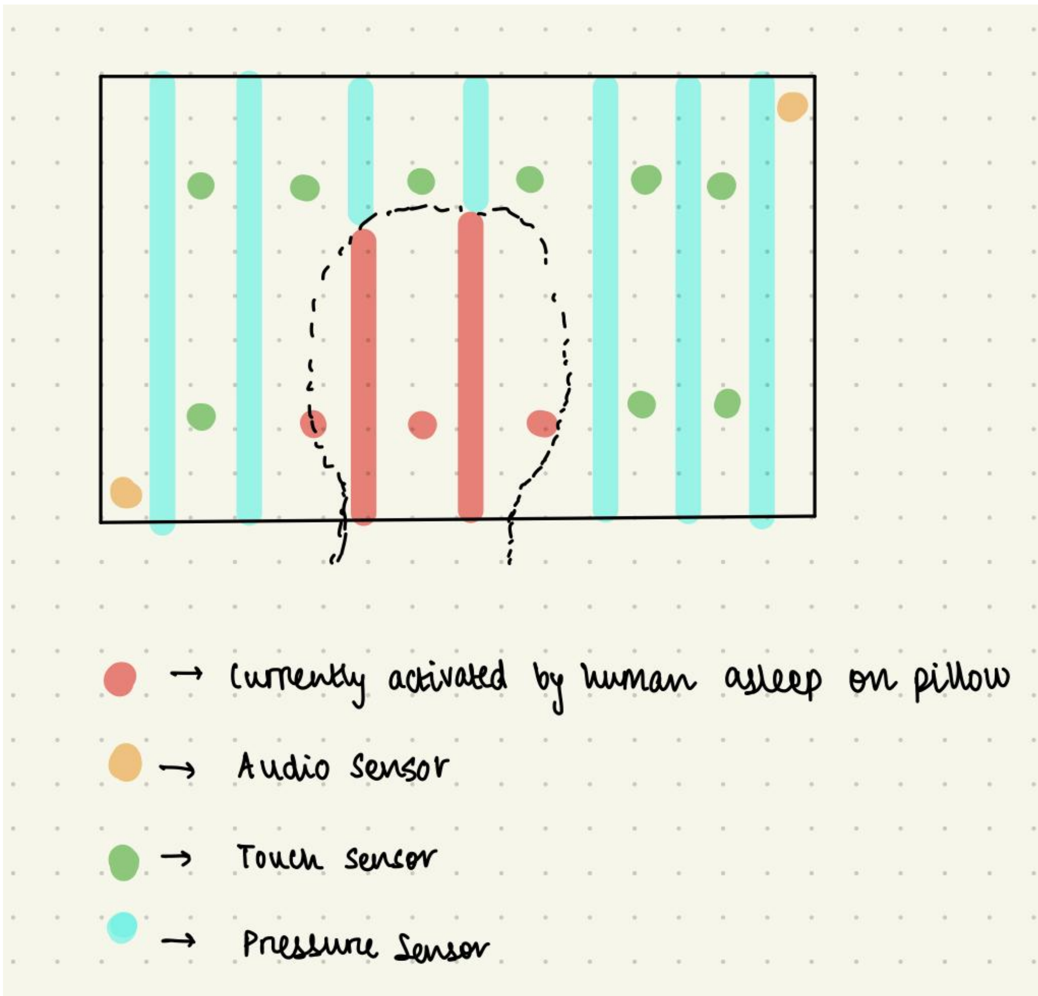
1.2 Solution

To fix the above-stated problems, we propose the implementation of a smart pillow. Through this smart pillow, we aim to not just track sleeping habits, but also improve them. We will track the sleeping habits of the user through the following sensors: touch sensor, audio sensor, and pressure sensor. In addition to these sensors, we will also use a Bluetooth speaker that can play white noise or any other sounds/music that the user feels comfortable with to aid sleep.
The audio sensor will be used to detect snoring which will provide us with insight on the quality of sleep of the user and potentially also detect sleeping disorders like sleep apnea. The touch sensor will be used together with the pressure sensor to determine the various sleeping positions of the user. This will then help us determine the quality of sleep of the user at each sleeping position.

We believe that our idea stands out from what is already available today through the usage of the Bluetooth speaker system and the fact that this is more cost-effective. Most devices that are currently available include mattresses and smartwatches. We believe that this is the feature that sets us apart from the other technology that is currently available in the market such as smartwatches and mattresses.

We will be using a power system to regulate the power of each sensor subsystem. Hence we will have to use a PCB since it will contain all the logic related to the sensors and the power modules. We believe that our product is a cost-effective and more versatile alternative to the current products available on the market.

1.3 Visual Aid



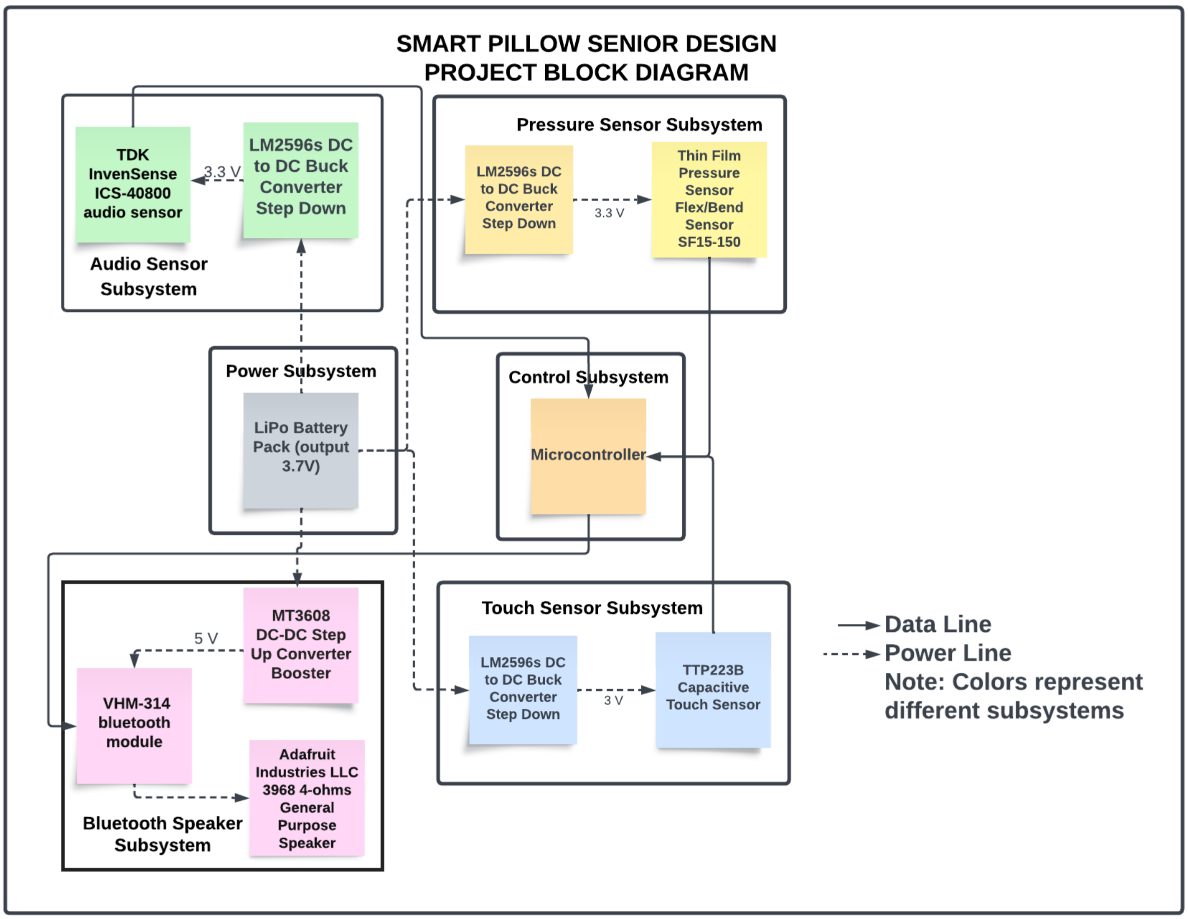
1.4 High-Level Requirements

1. The pillow should be able to detect motion when the person is in contact with the surface of the pillow.
2. There should be no interference in the data collected by the sensors from other components of the pillow (for example the Bluetooth speaker should not interfere with the working of the audio sensor).
3. The pillow should be comfortable, which means that the user should not be able to feel the sensors when they touch their head to the top of the pillow

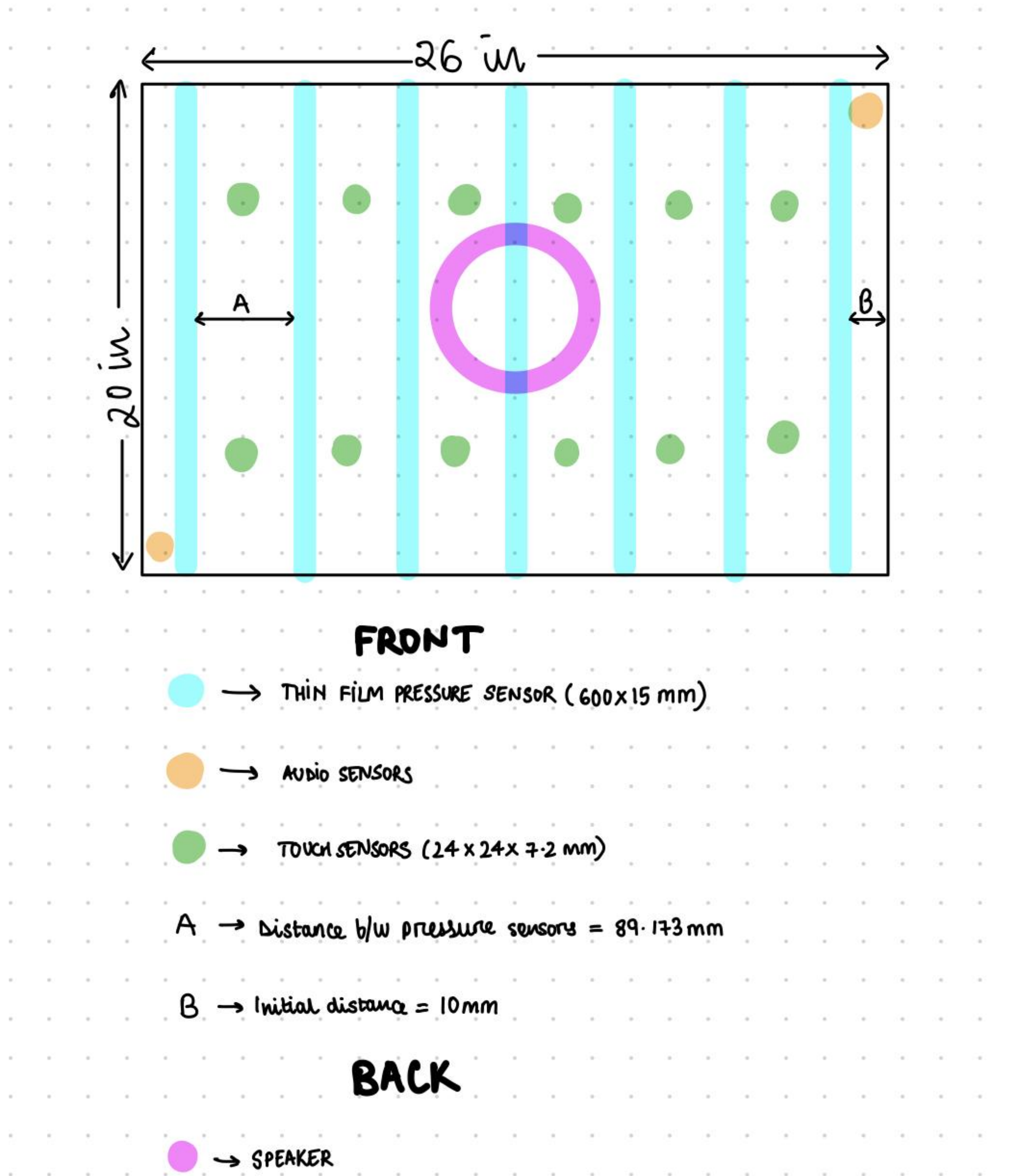
4. The front and back of the pillow should be clearly differentiated so the data from the pillow is actually usable.

2. Design

2.1 Block Diagram



2.2 Physical Design



The design is created keeping sleeping positions in mind. To accommodate for side and front sleepers there is an even positioning of the touch and pressure sensors. This ensures that regardless of the location of the head resting on the pillow, there will be a combination of at least one touch and pressure sensor in contact with the head. Hence there will be enough data points to make an interpretation of the subjects sleep quality. Additionally, the positioning of the audio sensors on two opposite ends provides the design with a far larger range to detect snoring and any other sounds. Finally, positioning the speaker at the back has several advantages. For one, it helps the user recognize which side to sleep on easier. Additionally, it opens up more space for the sensors on the front. Finally, it reduces the rigidity of the structure in the front, allowing the pillow to feel more plushy and comfortable.

2.3 Subsystem Overview

2.3.1 Power Subsystem

For the power subsystem, we will consider 4 parts that may require different power sources. These parts are (but are not limited to):

1. The pressure sensor subsystem
2. Touch sensor subsystem
3. The speaker (power here will be provided to the Bluetooth module and through that to the stereo amplifier unit and speakers)
4. The audio sensor subsystem

To ensure that the pillow remains light and comfortable we have decided to consider using Lithium Batteries. These are usually lightweight and are used in a variety of medical devices ensuring that they will be safe for use. Additionally, they have good capacity, and sufficient voltage for the sensors we plan on using (thin film pressure sensors and audio sensors). Doing some further research into flexible batteries we noted that most of the reported flexible batteries are based on flammable organic or corrosive electrolytes, which suffer from safety hazards and poor biocompatibility for devices (Stapleton)[1]. Hence, we have gone for the more rigid lithium-ion batteries as alternative sodium-powered batteries are too expensive for a project of this scale. To ensure that we can make the system as modular as possible we plan on using Lithium Polymer batteries.

Table 1: Power Subsystem Requirement + Verification

Requirement	Verification
The DC power supply must provide a constant 3.7 V within a 5% margin of error.	Measure the output voltage of the DC power supply using an oscilloscope to ensure that the voltage of the DC power supply is between 3.51 and 3.88 V.
Should be small and compact to ensure comfort while sleeping. The battery pack should be within the following dimensions: 35x100x15 mm and should weigh less than 80g.	Comfort of the pillow is extremely important for this project as individuals must be able to sleep on the pillow with ease. To ensure that this is the case, we will be using a Lithium Polymer battery pack which has the following dimensions: 33.5x96x10.3 mm and weighs 74g.

2.3.2 Control Subsystem

This subsystem will mainly be used to collect and transmit data between our different sensor subsystems. This subsystem will be responsible for collecting data from all our sensors such as audio, pressure, and touch, and will be able to signal the Bluetooth speaker to play music to improve the user's sleep. It will consist of the ATmega328P microprocessor which will be responsible for collecting data regarding head positions, head pressure, and snoring. Here, the data will be processed to determine if the person is having bad sleep or not. If the person is, then data is transmitted back to the microcontroller which will signal the Bluetooth speaker subsystem to play music.

Table 2: Control Subsystem Requirement + Verification

Requirement	Verification
The control subsystem must be able to determine if the person sleeping on the pillow is snoring	This will be done by ensuring that data can be collected from the audio subsystem. If the decibel level detected by the audio subsystem is above 40dB, then the person is determined to be snoring.
The control subsystem must be able to determine if the person sleeping on the pillow is changing positions every 30 seconds	This will be done by ensuring that data can be collected from the touch subsystem. If the control subsystem receives data from various touch sensors, the person is determined to be changing positions.
The control subsystem must be able to determine if the person is applying high pressure on the pillow while sleeping	This will be done by ensuring that data can be collected from the pressure subsystem. If the pressure detected by the sensors is above 330mmHg, the person is determined to be applying high pressure on the pillow.

2.3.3 Pressure Sensor Subsystem

This subsystem will mainly detect changes in pressure when a person is sleeping on the pillow. Usually, the pressure due to one's head can be used to determine the quality of sleep. People that tend to have poor sleep tend to put higher pressure on the pillow. Along with this, changing head positions very often can be a sign of bad sleep. Thin Film Force or Thin Film Pressure sensors SF15-150 Resistance will be used to detect changes in pressure and changes in head positions. One Thin Film Pressure sensor is 3.9 inches long, 0.4 inches wide, and 0.25 mm thick. Given the length and width of each sensor, we would be using 5-6 such sensors and placing them vertically across the pillow as shown in the visual aid. Each sensor would require around 3.3V to run. Since our power supply is 3.7V, we would be using LM2596s DC to DC Buck Converter Step Down Converter to get the desired voltage for the pressure sensor.

The use of multiple sensors will help us detect the different head positions of the person (which will be calibrated beforehand). The multiple sensors will also ensure the accurate detection of pressure applied to the pillow while sleeping.

Table 3: Pressure Sensor Subsystem Requirement + Verification

Requirement	Verification
Each sensor should be at a cost lower than $12.	The way we ensure that the sensors are cost-effective is by determining the length of the pillow and purchasing only the required amount of pressure sensor strips to cover the pillow. Along with this, we looked at many different vendors and compared the prices of the sensor in each to make sure we are buying the cheapest one available.
The thickness of the sensor should not exceed more than 7.62mm to ensure comfort while sleeping	To achieve this, Thin Film Pressure sensors were chosen to use in the pillow design. These sensors have a thickness that is significantly thinner than other types of pressure sensors available. To ensure this, we compared the thickness of different types of pressure sensors available and decided to go with the thin film pressure sensors since they have the lowest thickness.
The distance between each pressure sensor should be 89.173 mm to ensure accurate reading of the head position	The placement of the sensors is critical to get accurate and reliable data, as the spacing between sensors will impact the sensitivity of the measurements. If the sensors are placed too far apart, it can result in gaps in the data. Hence, to ensure this distance is maintained, the distance will be measured accurately beforehand.

Must be used to detect the amount of head pressure while sleeping	The way the pressure sensors will be tested is by checking the voltage across the sensors by connecting a multimeter to it. The voltage will be checked once pressure is applied to the sensor which should be the same as the voltage mentioned on the datasheet of the sensor.
Must only receive 3.3V instead of 3.7V from the battery	The way the voltage will be stepped down is by using an LM2596s DC to DC Buck Converter Step Down Converter. The way the sensor is receiving the required voltage will be tested is by using a multimeter and checking the voltage across the sensor.

2.3.4 Touch Sensor Subsystem

This subsystem will work in conjunction with the pressure sensors. Since the pressure sensors are strips, they would not cover the entire pillow. We will be using multiple small touch sensors that would be placed between two pressure sensors. The main aim of using the touch sensor is to detect the location of the head on the pillow because as mentioned earlier, head positions can help determine if a person is having bad sleep. Along with this, our goal is to try to use the touch sensors as a way to activate and deactivate other sensors to save power for our entire device. The dimensions of the touch sensor that we would like to use would be 24x24x7.2 mm. Each sensor would require around 3 volts to run. Since our power supply is 3.7V, we would be using LM2596s DC to DC Buck Converter Step Down Converter to get the desired voltage for the touch sensor

Table 4: Touch Sensor Subsystem Requirement + Verification

Requirement	Verification
The dimensions of the sensors should not exceed more than 24x24 mm, and the thickness should not be more than 7.2mm to ensure the comfort of the pillow	Comfort of the pillow is extremely important for this project as individuals must be able to sleep on the pillow with ease. To ensure the size of the sensors, we compared the thickness and dimensions of different types of touch sensors available and decided to go with the touch sensors that match our requirements.

Each touch sensor must be placed exactly in the middle of 2 pressure sensors, which means the distance between a touch sensor and a pressure sensor on either side must be around 44.58 mm.	To make sure that this is achieved, the distance on either side of the touch sensor to a pressure sensor will be measured and will only be placed once the distance of either side is the same.
Able to detect head positions when a person is sleeping on the pillow	Since the touch sensors will be placed all around the pillow, between pressure sensors, by mapping the positions of the sensors, the position of the head will be determined. At first, the sensors will be calibrated with different possible head positions. Later, when a person places their head on the pillow, due to the previously calibrated sensors, the head position can be determined easily.
Can be used to activate or deactivate other sensors which can help save power for the whole device	This is the secondary use of the touch sensors. Essentially, if the touch sensors are in use, it means that the pillow is in use by someone, which means the other sensors should be on. However, if the touch sensors are off, it means that the pillow is not in use, meaning that the sensors can be turned off to save power. This can be achieved by connecting the sensors to the battery which can be controlled by the touch sensors. The power supply will be cut off from the system when the touch sensors are not in use and will be connected back to the power supply once the touch sensors are in use.

2.3.5 Audio Sensor Subsystem

This subsystem will be used to detect sounds such as snoring. Snoring is the most common sign of disturbed sleep and sleeping disorders such as sleep apnea. For the use case of this project, we will be making use of two audio sensors so that we are able to detect any sounds produced by the user. We will be utilizing the TDK InvenSense ICS-40800 audio sensor for our device. It has a sensitivity of -38dBV and Signal to Noise ratio of 70dBA. We believe that these specifications will be adequate enough to detect sounds such as snoring which typically range from 45-60dB. The dimensions of each sensor are 4x3x0.97mm and require 155uA to run. Since our power supply is 3.7V, we would be using LM2596s DC to DC Buck Converter Step Down Converter to get the desired voltage for the audio sensor. (“ICS-40800 TDK InvenSense | Mouser”)

Table 5: Audio Subsystem Requirement + Verification

Requirement	Verification
Small in size to ensure the comfort of the pillow. This dimensions of each sensor should be within the following: 5x5x2mm.	Comfort of the pillow is extremely important for this project as individuals must be able to sleep on the pillow with ease. To ensure that the subsystem meets these requirements, we will be using twoTDK InvenSense ICS-40800 audio sensors which have the following dimensions 4x3x0.97mm. These dimensions are ideal since they are unlikely to disrupt the shape and comfort of the pillow.
Need to ensure that the audio sensors and the bluetooth speaker do not interfere with each other.	This will be done by implementing PCB logic such that both subsystems will not be receiving power at the same time. While the speaker is still on, the sensors will not be activated. However, once the sensors are activated, the user will not be able to use the speaker unless they manually switch it back on.
Must be able to detect sounds as soft as 40dB	We will be using two TDK InvenSense ICS-40800 audio sensors which will be placed at opposite corners of the pillow. This will ensure that we are able to detect any sound made by the user such as snoring. We will calibrate the sensor by using various sounds in the range of most snores (45-60dB).
Must only receive 3.3V instead of 3.7V from the battery	The way the voltage will be stepped down is by using an LM2596s DC to DC Buck Converter Step Down Converter. The way the sensor is receiving the required voltage will be tested is by using a multimeter and checking the voltage across the sensor.

2.3.6 Bluetooth Speaker Subsystem

This subsystem can be broken up into 3 main parts: The connection from the power subsystem, the Bluetooth module, and the speakers. To ensure that the speakers get the right amount of power to function at a higher level, a voltage booster will be required. Hence we plan on using a step-up converter to convert the incoming 3.7V from the power source (the LiPo batteries) to the 5V that the system can utilize. To accomplish this, an MT3608 DC-DC Step Up Converter Booster (Electronic Co, Ltd.) will be used. The potentiometer on the booster will allow us to adjust the output voltage to 5V. The next step is to find and use the correct Bluetooth module. This means one that combines a Bluetooth receiver with a stereo amplifier and decoder, enabling us to both receive and play the song using only one chip. The choice for this is the VHM-314. This Bluetooth board offers Bluetooth 5.0 connectivity and comes in at a small size of 3cmx3cm which is something that we can easily fit into our design. The board will receive power from the PCB connection and will only be powered when the audio sensor is not in function. Finally, this Bluetooth board will be connected to a single speaker. The Adafruit Industries LLC 3968 4-ohms General Purpose Speaker is an ideal choice because it has a lower power rating of 3W and an ideal size (40mm diameter). To summarize, the main components of the design will be in the middle of the pillow with the speaker being at the back for comfortable hearing.

Table 6: Bluetooth Speaker Subsystem Requirement + Verification

Requirement	**Verification**
Small in size to maximize space for more important sensors. Limited to the sum of size dimensions 45x45x40mm	To achieve this and make sensors work well, the components for the speaker are small. The MT3608 is just 36x17x14mm, the VHM-314 is 3x3cm and the speakers have a diameter of only 40mm.
Ability to work with the audio sensor, switching it off within 1 minute of the audio sensors being used	Implement logic to ensure that power is not being supplied to both simultaneously by running a check every minute through the code to see if there is data collected from the audio sensor and if there is power to the speakers at the same time.
Cross device connectivity enabled by Bluetooth 5.0	Our choice of the VHM-314 offers Bluetooth 5.0 connectivity and connects across all platforms.
Acceptable sound quality with speakers over 3-ohm impedance, ability to decipher what is being played	The Adafruit Industries LLC 3968 General Purpose Speaker has an ideal impedance of 4-ohms which will work well with the amplifier present in the VHM-314, giving greater output but not at the expense of too much power (3W)

2.4 Tolerance Analysis

The batteries we have chosen have a voltage of 3.7V and a power rating of 150mAh. This would work perfectly as a battery pack would allow us to power all the sensors. The calculations to prove this can be shown by using the specifications of an audio sensor:

- A typical audio sensor has voltages ranging from 3.3V to 5V.
- The operating current is usually 4mA to 5mA (Jadhav).
- Taking the upper limits, we get the power as 25mW. Running for 10 hours, the maximum power is 250mW.
- Run at 5V for the entire period of time (using a voltage converter) the maximum value comes to 50mAh which is well below the rating of a single lithium polymer battery.
- The voltage ratings for the thin film pressure sensor (3.3V), the Bluetooth module and speaker (5V), and the touch sensor (3V) all lead to similar calculations, telling us that a pack of batteries will be more than capable of providing power to run the 3 subsystems.
- Additionally, as the speaker and audio sensor subsystems cannot run at the same time, the power converted there will be enough to account for longer battery life in case the user forgets to switch the system off the previous night or has any other such problems.

3 Cost and Schedule

3.1 Cost Analysis

According to research, an ECE graduate receives an average of $45/hr. Given that the expected number of hours spent on this project would be 80 hours, each member should receive an expected salary of 45*80 = $3600. So, the total expected salary for the whole team would be 3600*3 = $10,800.

Table 7: Cost of components

Component	Price Per Unit	No. of Units	Total Price
TDK InvenSense ICS-40800	$4.03	2	$8.06
Thin Film Pressure sensors	$10.70	7	$74.9
Touch Sensors (pack of 10)	$8.49	2	$16.98
LM2596s DC to DC Buck Converter Step Down Converter (pack of 2)	$9.99	1	$9.99
MT3608n DC-DC Step Up Converter Booster	$0.16	1	$0.16
VHM-314	$0.99	1	$0.99

Adafruit Industries LLC 3968 4-ohms General Purpose Speaker	$4.95	1	$4.95
Adafruit Micro-Lipo Charger for LiPo/LiIon Batt w/MicroUSB Jack - v1	$6.95	1	$6.95
EEMB Lithium Polymer Battery 3.7V 3700mAh 103395 Lipo Rechargeable Battery Pack	18.99	1	$18.99
TOTAL COST OF COMPONENTS			$141.97

If we are to make a rough estimate on the total cost of the components and labor, as seen from the values above, this comes up to **$10,942**.

3.2 Schedule

Table 8: Schedule for the project

Week	Tasks	Person
Feb 19 - Feb 25	1. Complete the Design document and team contract	Everyone
Feb 19 - Feb 25	2. Start working on the schematic of the PCB	Aniketh and Karan
Feb 19 - Feb 25	3. Order sensors and pillow needed for the project	Trusha
Feb 26 - March 4	1. Work on modifying PCB design	Aniketh and Karan
Feb 26 - March 4	2. Review PCB design at the Design meeting with the professor and TA	Everyone
Feb 26 - March 4	3. Work on Design Document review suggestion	Karan
March 5 - March 11	1. Work on finalizing PCB design	Everyone

March 12 - March 18	Spring break	
March 19 - March 25	1. Design Document Review completion	Trusha and Aniketh
March 19 - March 25	2. PCB ordering after passing the audit	Everyone
March 26 - April 1	1. Finish soldering and testing of sensors 2. Make revisions to the PCB once testing of sensors is complete	Aniketh and Karan
March 26 - April 1	3. Start calibrating head positions 4. Order revised PCB (if needed)	Trusha
April 1 - April 8	1. Finish soldering new PCB	Karan
April 1 - April 8	2. Start testing sensors on revised PCB	Trusha
April 9 - April 15	1. Finalize the project by testing all sensors and components again	Aniketh
April 9 - April 15	2. Create the pillow with all the sensors attached 3. Begin testing of the entire pillow	Everyone
April 16 - April 22	1. Work on mock demo	Aniketh and Trusha
April 16 - April 22	2. Work on final presentation	Karan
April 16 - April 22	3. Complete mock demo	Everyone
April 23 - April 29	1. Make final changes to the projects after feedback from mock demo	Everyone
April 23 - April 29	2. Work on final demo	Aniketh and Karan
April 23 - April 29	3. Work on Final presentation	Trusha
April 23 - April 29	4. Complete final demo	Everyone
April 30 - May 6	1. Work on and complete final presentation 2. Complete final paper + lab notebook	Everyone

3. Ethics and Safety + Risk Analysis

Ethics and Safety

This project does not breach any ethical guidelines. This product is designed for those interested in improving their sleep quality. Throughout the development of this product, we plan to strictly adhere to the IEEE and ACM Code of Ethics. Safety will be the top priority of everyone involved in this project. Since our project is utilized in close proximity to the user's face and neck area, we will be using low-voltage components to ensure safety. In addition to this, during testing, we will not be collecting or storing any personal information of those involved. As engineers, we also have a commitment to sustainability. Through the development of this product, we will attempt to optimize the part list as best as possible. This will be accomplished by comparing different components and seeing which will give us the superior performance and the longest life span.

Risk Analysis

This project seems low risk in comparison to other projects. The reason for this is twofold. The first is that the components building this project are small and not rigid enough to cause physical damage to a person. They are not particularly dangerous and there is almost no large hard object used in the build. The second reason is that the voltages being used are very low, with the highest voltage being 5V and the lowest going to 3.3V. Hence I think that the project is not classified as a high-risk project.

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