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CPAP Monitoring

With Pressure Sensor and Bluetooth

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1 Introduction

1A Objective

Obstructive Sleep Apnea is a very prevalent disease among adults in the United States, which is caused by the obstructions of the upper airway (from nose / mouth to throat) [1]. Leading to repetitive episodes of shallow or paused breathing (which is called “apneas” here) during sleep, despite the effort to breathe, this syndrome may lead to a reduction in blood oxygen saturation. Due to the paused breathing during night sleep, the patient may suffer from daytime sleepiness and fatigue, together with significant sleep disturbance that last for decades without identification due to the hardship to identify obvious daytime syndrome [1]. The key to alleviate the impact of Obstructive Sleep Apnea on patients, is to continuously open their airway to ensure they may have a good breathing during the whole night. It is usually done by a ventilation device that keep “pushing” air into the patient, which is called CPAP, the abbreviation for continuous positive airway pressure [2]. Usually, this system use ventilation to maintain a positive pressure of around 2 centimeters of water (which is around 200 Pa) to 20 centimeters of water (which is around 2000 Pa). Under this pressure, the patient will be able to breath normally without obstacles.

However, the major inconvenience of CPAP system is that it lacks an accurate monitoring system to keep an eye on its performance. This inconvenience may lead to inconsistent air pressure in the patient’s airway, which is usually associated to uncomfortable sleeping experience. This inconvenience leads to our plan, which is aimed to provide a continuous monitoring and recording tool for the pressure in the CPAP system. By continuously monitoring and recording the air pressure data inside the air tube, we can provide a detailed analysis for its user to monitor how their CPAP system is performing, and an immediate warning if they need to fix their CPAP system due to the malfunctional or inconsistencies.

1B Background

One of the common solution before is what called “Auto CPAP”. It is an integrated solution that provide a continuous monitoring over the air pressure, and provide instant adjustment based on that monitoring. However, it is not an economical (a typical CPAP cost you around $350, while an automatic one cost you $700) [3]. Also, the need for an “auto CPAP” is not permanent: people can manually change their CPAP settings once several weeks, leave no reason to adopt such an “automatic” device to work. Another disadvantage of such design is that it increased the failure rate of the whole system, with the reduction of reliability. The failure of “auto” module could severely impact the ability to provide a continuous airway pressure. Another uncomfortable thing is the time and labor. Usually, the patient has to bring the CPAP machine back to their physicians to diagnose and fix it [4]. For patient living far away from the clinic, the time cost is so high that many people choose to tolerate rather than fix.

Thus, here we should provide a simple, accurate and reliable solution that can keep record of airway pressure for further analysis. The system should have the capacity of continuously recording of airway pressure for at least eight to ten hours; The data should be easy to access for computers for further analyses; Also, the installation and usage should be simple and our device should be compatible to almost all CPAPs available in the market.

1C High-Level Requirements

The theoretical ground of our plan is the continuous monitoring of air pressure: according to reference, a good CPAP device should keep the pressure in a range about four to twelve centimeters of water, which is about 39 to 118 Pascal. Thus, the precise measurement of air pressure is the key to implement our plan. Also, since we must monitor the pressure for at least eight hours (which covers the whole night), our plan should also have the ability of continuous recording. The last requirement for our plan is the ability to export data into Personal Computers or Cellphones for convenient display.

Based on these key requirement, we have proposed three main key technological requirements for our plan.

1) Accuracy: the measurement of air pressure provided by our plan should be with a range from 0cm to 20cm of water, with a minimum resolution of 1 mm of water;
2) Durability: our plan we used should ensure at least ten hours of continuous pressure sensing and storing, without the usage of external power supply;
3) Permanent Storage Ability: our plan should provide functionalities to store and export the measurement for further retrieval and analysis.

2 Design

The overall design is based on a branch on the CPAP hose that connected to the mask and the machine. We designed five major independent parts:

1) a power supply chip, which converts various power source into regulated voltage for chips and equipment;
2) a sensor unit, which records the pressure information;
3) a control unit, which converts the raw sensor data into human-readable format;
4) a storage unit, which temporarily store the data for later retrieval; and
5) an output unit, which provides output onto PCs or cellphones via serial port.

In our plan's general physical design, immediately on the branch there will be a pressure sensor that monitor the continuous change in the main hose; the signal will be passed to control unit for the conversion, and then temporarily stored in the storage unit. Once retrieved an appropriate signal from computer or phone, the stored data will be transmitted via the output unit.

2A Diagrams

2A1 Block Diagram

We consider the system components with the principle of modular design, and arrange components into four independent portions, that may be independently implemented and organized:

a) Power supply, in charge of provide stable power;
b) Sensor, provide raw, analogous signal to the system;
c) Convertor, convert nonlinear signal into linear signal;
d) Computer, write input signal into the memory provided and transmit it to clients.

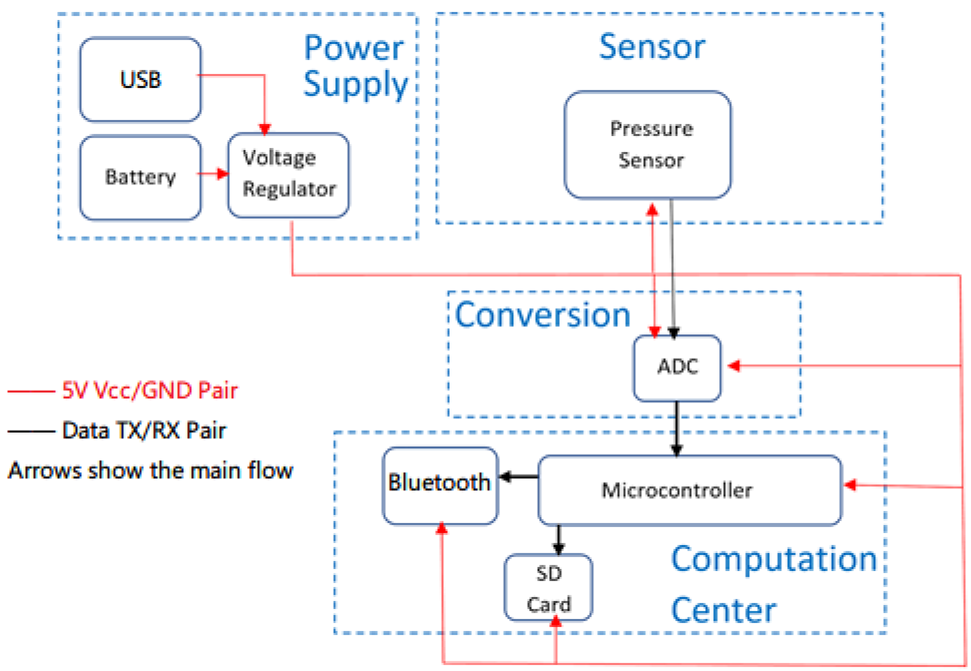

Figure 1 The block Diagram

2A2 Physical Diagram

Our physical design includes two key components: one is the main chip, the other is the sensor chip. Two chips will be connected by wires to make sure that the sensor is flexible to installed according to different places.

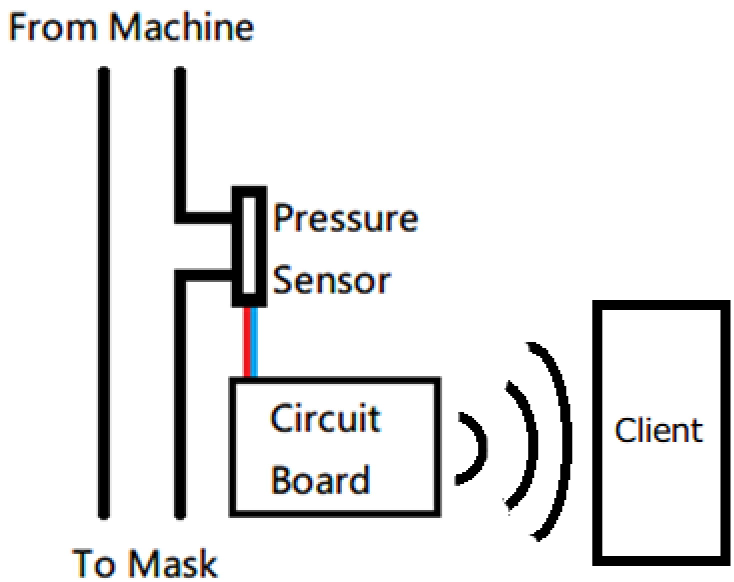

Figure 2 The Physical Design of Program

2B Circuits Design

In the description, we will discuss the pressure sensor (hereinafter referred to as "sensor circuit") and microprocessor (hereinafter referred to as "main circuit"). Sensor circuit will include the circuit of pressure sensor and an ADC, while main circuit will include a microprocessor and its peripheral, and power supply.

2B1 Main Circuit

2B1A Power Supply

We here design a power supply chip that accepts multiple different power sources (Batteries, USB, etc.). To accepts different voltages, we need a power regulator chip that regulates the input voltage to voltage around 5V, and provide it to main microprocessors and sensors.

To allow direct power supply from USB, one of the most common low-voltage direct current power supply, we set the working voltage to 5V, with an allowance of $\pm 5\%$. This means that the output voltage at power source is around 4.75V to 5.25V.

However, we cannot ignore the factor of the cable resistance. According to the American Wire Gauge, we can calculate the resistance of some common copper cable: [1]

Table 1 The AWG indicates diameter (and resistance) of different standard cables.

	AWG20	22	24	26	28

Diameter (millimeter)	0.812	0.644	0.511	0.405	0.321
Resistance (mΩ per meter)	33.31	52.96	84.22	133.9	212.9

Here we can generate a table at a given output current of 1A (which is the maximum current that we may use, under a very rare circumstance), based on the formula of resistance and Ohm Law.

Table 2 The possible voltage drops on the wire due to cable resistance

	20	22	24	26	28
15cm	0.13V	0.14V	0.15V	0.16V	0.18V
50cm	0.15V	0.19V	0.20V	0.25V	0.33V
100cm	0.19V	0.23V	0.29V	0.39V	0.55V

Now we can see that a reasonable estimation will be about 0.3V to 0.4V (the only circumstance beyond this range is 100cm of AWG28, which is rarely used in USB power cable). So we estimated it to 0.35V.

The range of voltage on the chip is now among 4.4V (4.75V – 0.35V) to 5.25V. This allows users to use a qualified USB charger or power bank to charge directly.

However, USB charging is dependent on cables, limiting the mobility. Thus, there should be other possible supplies, like battery supplies considered. for the power supply unit, we have researched some different power supplies, like AA batteries (provide about 1.2V to 1.5V each cell). Here we utilized four cells to provide a voltage around 4.8V to 6V.

We may implement the power supply circuit on our own (with usage of transistors and diodes), or choose a pre-manufactured chip. No matter what specification we have chosen, our design should consider this variety of voltage, and provide a uniform output of 5V with 5% allowance.

Requirement	Verification
1. Input Voltage: The power supply chip should work without fault under input voltage from 4V to 6V;	1. We test the supply chip with these configurations: a) USB supply b) 4 Alkaline AA batteries, each with 1.5V; c) 4 Ni-MH AA batteries, each with 1.2V.
2. Output Voltage: When the input voltage is within the range, the circuit should provide an output voltage falls in 5V with 5% allowance.	2. We will use a multimeter to monitor the output voltage, then draw the relationship between input and output on graph to make sure that it falls in the allowed range.
3. Temperature: Under the “normal load” mentioned before, the surface temperature should not be more than 35℃.	3. Temperature: We will use a digital thermometer to measure the temperature at surface.

In other words, the power supply will be like:

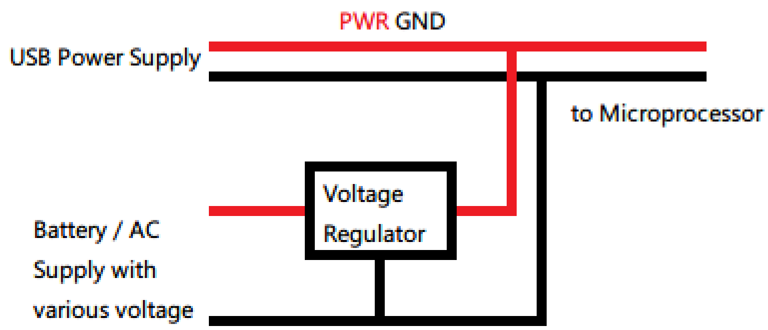

Figure 3 How Power Supply is working

One of our preliminary choice is the LM7805 chip: It accepts 7 to 25V as input voltage, and provides a stable 5V output voltage by using a BJT transistor; The other choice is a pre-defined PCB by SparkFun, which implement the same functionality, with some possible peripheral circuits like the jacks.

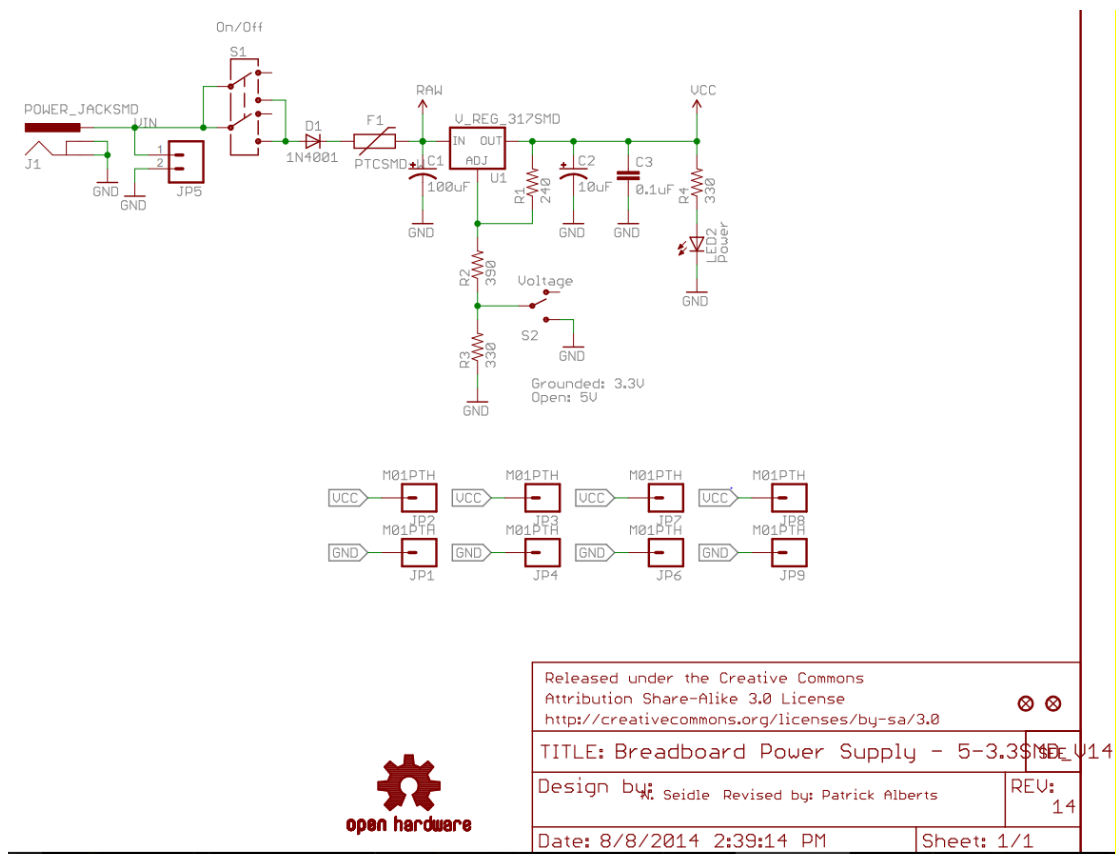

Figure 4 The schematic of power supply module

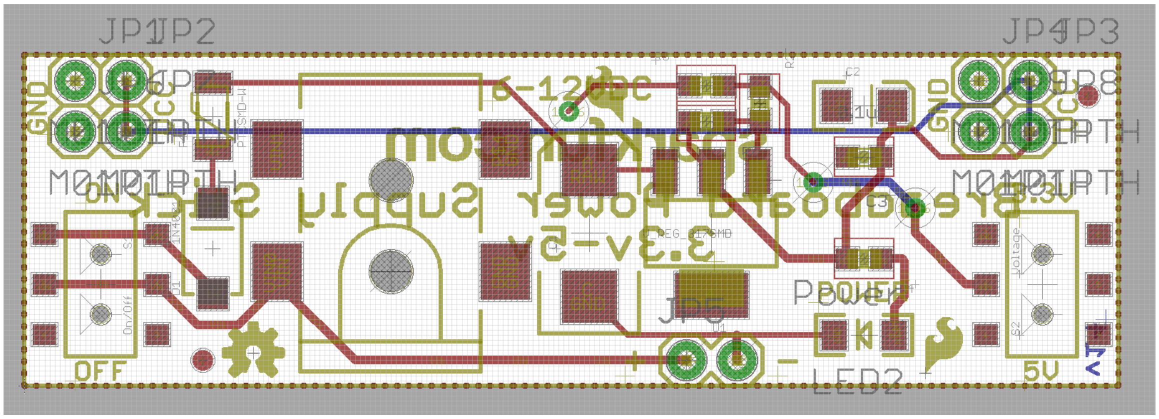

Figure 5 The board designed by SparkFun to provide Power Regulation [5]

The advantage of a single chip is that it is cheaper when developing; however, it still requires extra components and developing time when integrating into PCB board. On the contrary, the pre-designed circuit by SparkFun provides a schematic and PCB design which simplified the procedure of integration and testing. Thus, we here decided to utilize the pre-defined PCB from SparkFun, for the simplicity of integration into our final PCB design.

2B1B Main Microprocessor

The main microprocessor is the component that takes both software and hardware computational tasks. It keeps sampling the input signal from Sensor Circuit, stores it in the storage with a given filename, and sent the stored data to clients via Bluetooth Serial. In order to simplify the design, we set the processor to start recording automatically once it is powered on. We use the starting time as the filename, so that multiple records are allowed.

We have defined the main software routine of main processor like this:

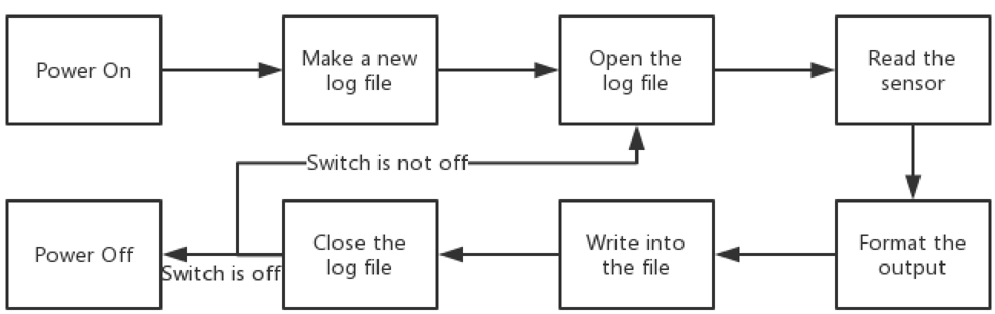

Figure 6 The routine map of designed microprocessor

The major input device our program will handle is the Sensor Circuit (which will be introduced in 2B2), and the major output device will be a micro SD card (communicated in SPI interface) and a Bluetooth dongle (communicated in Serial interface). Thus, we design the circuit to be:

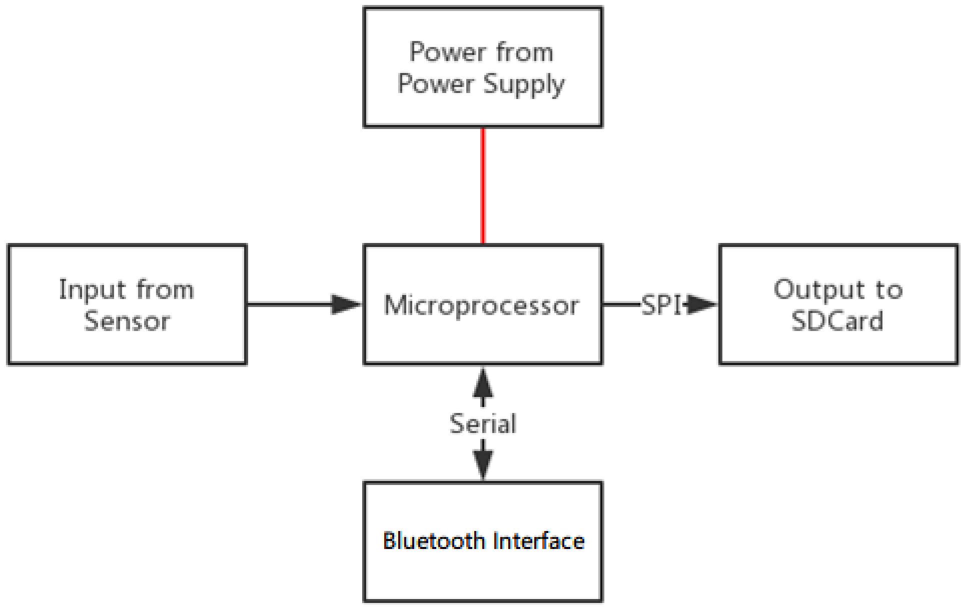

Figure 7 The power and data flow in microprocessor.

The key of our microprocessor design is the communication with sensor. We consider multiple available approach, and summarized their advantage and disadvantage here:

	A/D Circuit	FSM Circuit	Interface Width	Implementation Difficulty
Analog	Not Required	Not Required	1 analog input	Simple: read analog voltage
Digital Parallel	Required	Not Required	10 digital input	Intermediate: encode analog voltage into digital signals
Digital Serial	Required	Required	2 digital input 1 digital output	Advanced: implement a FSM to determine sequence

Here we decided to implement a serial digital input because it takes a balance between the usage of ports (3 ports) and precision (using digital signals than analog), and fully displayed the need of hardware circuit design.

In order to design a serial input, we have set up two finite state machines, one in the microprocessor, and the other in the sensor circuit. The finite state machines in the microprocessor is listed here:

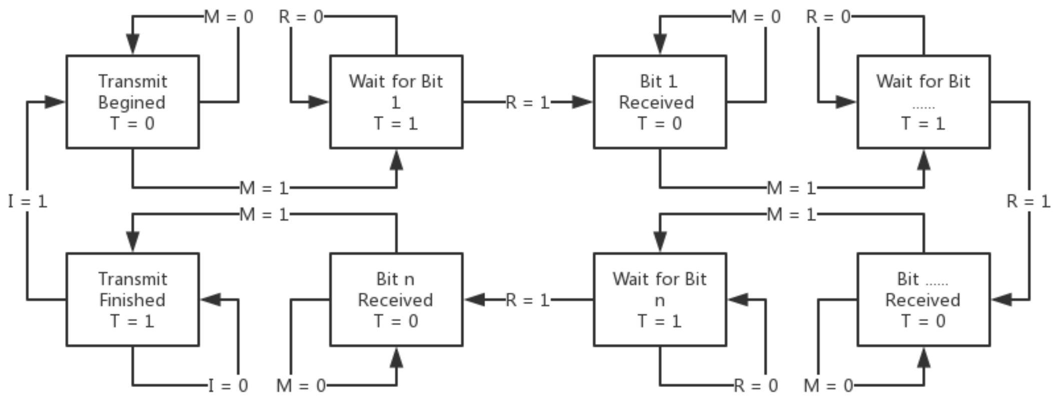

Figure 8 The proposed state machine used to transmit code

Here we have three inputs:

1. I: I indicates the Initial Bit, meaning that the sensor is about to transmit a new sequence that indicates a new data. Once an initial bit is received, the microprocessor opens the record file and prepare for recording.
2. M: M indicates the Memory Bit, meaning that the corresponding memory operation is finished (for example. Once a memory bit is received, the microprocessor will allow the sensor for data transmission;
3. R: R indicates the Receive Bit, meaning a bit has been transmitted from the sensor circuit. Once a receive bit is received, the microprocessor will receive the data from sensor, and start writing the data into buffer.

And one outputs:

1. T: T indicates the Transmit Bit, meaning a bit may be transferred from sensor to microprocessor. Once the microprocessor is able to handle it, it sets T to 1 so that sensor may start transmitting data.

Under this design, we need $2x + 2$ states for x bits of data. In order to make sure that we have at least 10 samples every second, with the precision of 256 statuses, we need at least 250 states handled, thus a frequency at 250Hz is required.

Here we state the main requirements and verifications:

Requirement	Verification
1. Input Voltage: The microprocessor should work without fault under input voltage from 4.4V to 5.25V;	1. We change the voltage continuously from 4.4 V to 5.25 V on microprocessor, and observe if the program is working properly.
2. Performance: the processor should be able to handle at least 10 samples per second, each sample with 10 bits of precision.	2. We will use a timer to track the time it uses to process these samples. We test it with a 250Hz clock (which will have both up and down signal) and verify if the output sequence is exactly the same as the input sequence.

3. Temperature: When executing our program, the surface temperature should not be more than 35℃.	3. We will use a digital thermometer to measure the temperature at surface during the testing of (2)

Our preliminary choice of Microcontroller will be atmega328p, the chip currently using on the Arduino microboard, for its common software package support and a 16MHz clock which should be capable for the design. It also provides multiple different package for the needs of PCB manufacturing.

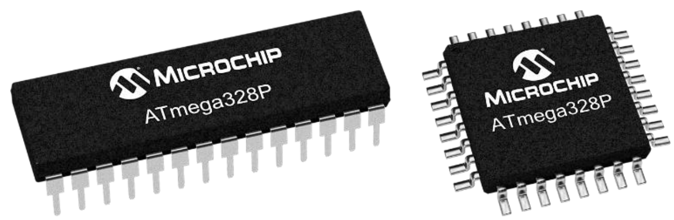

Figure 9 The variable design of 328p for different stage of project design.

2B1C SD Card reading / writing chip

The reading and writing of SD Card is utilized by SPI format. It utilizes four digital pins (one in, one out, one ground and one selection) for the transmitting and receiving of data from/to user-provided SD Card. In order for the log file to computer-readable, we decided to format the SD Card into FAT format.

Now we have to determine the relationship between time and storage capacity. In 328p, the microcontroller we chosen, there is an internal clock that can measure the time passed by after the system is powered on. We use this system to generate our x-axis (the time axis), and gather the corresponding y-axis from sensor.

In order to monitor 12 hours of cpap data, we need $12\mathrm{h} * 3600\frac{\mathrm{s}}{\mathrm{h}} * 250 * \frac{1}{s} = 10800000$ entries; each one is with eight characters used for time, and five characters for pressure (we start from 0cm to 20cm with precision of 1mm, so the format will be xxx mm or xx.x cm). So, it will use about 14 characters (bytes), and the total number we will have will be 10800000×14=151200000 bytes = 144MB. If we are going to store it longer, we need larger SD Card.

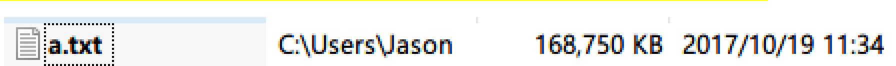

Figure 10 The actual size occupied by the file.

To be compatible with most of SD Cards (which is provided by our users), we set these requirements for the reading / writing chip:

Requirement	Verification
1. Compatibility: The R/W chip should work with Cards with different make,	1. We will use cards with ● variable make: SanDisk, Samsung, Kingston

size, and file system;	● size: 2GB, 4GB, 8GB, 16GB, 32GB ● filesystem: FAT16, FAT32 to test if the controller is able to: ● open a new file for writing ● open and close an existing file ● write ascii chars into the file buffer
2. Performance: the processor should be able to handle at least 1MB per second.	2. We will use a timer to track the time it uses to process these samples. The time of writing a 1MB text file should be within 1 second.
3. Temperature: When executing our program, the surface temperature should not be more than 35℃.	3. We will use a digital thermometer to measure the temperature at surface.

The design for SD/MMC is simply a breakout from SD Card to our controller because all necessary chip is integrated in SD Card. We here utilized a breakout developed by SparkFun:

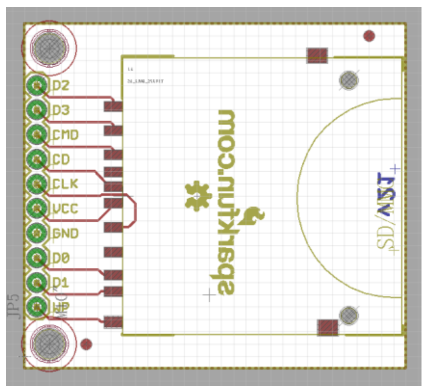

Figure 11 The SD/MMC Module by SparkFun [6]

2B1D Bluetooth Serial Output Chip

The transmission between our microcontroller and clients (cellphones) is based on serial interface. The implementation of serial interface includes RS232, USB and Bluetooth, and using Bluetooth serial interface is the most suitable choice for usage with wireless phones. We will use the serial interface to transfer measurement data to cellphone for visualization. We set these requirements for the reading / writing chip:

Requirement	Verification
1. Compatibility: The Bluetooth device should be compatible with most mobile and desktop system.	1. We will use device with ● variable system: Android, iOS, Windows, Linux ● form: Phone / Tablet, Desktop / Laptop to test if the controller is able to: ● detect and pair with microcontroller ● receive Bluetooth serial messages

	● transmit Bluetooth serial messages
2. Performance: the processor should be able to handle at least 1MB per second.	2. We will use a timer to track the time for the Bluetooth chip to finish the transmission of a text file to personal computer.
3. Temperature: When executing our program, the surface temperature should not be more than 35℃.	3. We will use a digital thermometer to measure the temperature at surface.

Our choice for Bluetooth is the HC-06 Board that accept Serial TX/RX signal and convert it wirelessly on Bluetooth network.

Figure 12 HC06 Board that perform Bluetooth functionality.

2B2 Sensor Circuit

2B2A Pressure Sensor

The Pressure Sensor is probably the most important part in our design. According to some research we make online, we have found that the most pressure sensor available to us are force sensor: they detected the force on the surface, not the pressure. So, we need some calculation to build a link between pressure and force. The pressure on a surface could be calculated by the force over area.The area is a fixed value (it is dependent on our sensor selection), so we can apply some force on the sensor surface to provide pressure, by multiplying a given coefficient.

Our calibration of pressure sensor is based on a U-shaped tube. We can use the difference of liquid level as a standard of air pressure to calibrate our pressure sensor. When we are verifying the pressure sensor, the easiest way to provide force continuously is using water and a long pipe. By changing the height of water above sensor, we can easily change the force we set on the sensor. And if we marked it clearly, we can measure the pressure directly using the definition of cmH2O (height of water).

The pressure on a surface could be calculated by the force over area: $\mathrm{p} = \frac{1}{\mathrm{S}}\mathrm{F}$

The area is a fixed value (it is dependent on our sensor selection), so we can apply some force on the sensor surface to provide pressure. The best way to provide pressure is using gravity: $\mathrm{p} = \frac{\mathrm{g}}{\mathrm{S}}\mathrm{m}$

Using fluids, like water, allow us to add and remove according to our needs (just like in a chemistry lab), so we rewrite the mass with volume and density: $\mathrm{p} = \frac{\mathrm{g}\rho}{\mathrm{S}}\mathrm{V}$

If we replace volume with area and height, and eliminate the height, it will be the definition of liquid pressure: $\mathrm{p} = \frac{\mathrm{g}\rho}{\mathrm{S}}\mathrm{hS} = \rho\mathrm{gh}$

So, by changing the height of water on the sensor surface, we can change the pressure we set on the sensor to the accurate value we need for measurement.

The output of our pressure sensor is a variable value of resistance. Thus, it will change from infinity (when there is no pressure) to 0 (when the pressure is at maximum). Thus, we can use either the operation amplifier ($\mathrm{V_t} = \frac{R_f V_s}{R_s}$) or voltage ($\mathrm{V_t} = \frac{V_s R_f}{R_f + R_s}$), of which Rs is thesensor, Vs is our source voltage, and Rf is the reference resistance.

Requirement	Verification
1. Measurement Precision and Range: the sensor should measure within our pre-defined range (from no water to 20 centimeters of water, with a millimeter difference) with linear map. The range of our output value may depend on the type of our conversion circuit. 2. The sensor circuit should generate an output signal that is precise enough (the minimum requirement is a millimeter of water). 3. The sensor should not need any calibration when the environment (temperature, humidity) is relatively	1. Set up a long pipe with even marking that allow us to measure water depth accurately; 2. Then, we put our pressure sensor on the bottom of our long pipe; 3. Apply some constant pressure to the measure port through water, then record the output signal corresponding to each pressure. 4. Make multiple measurements to check if the output signal varies too much for the same pressure. 5. As we keep pouring water, we will measure the reaction on the output signal, to see if the reaction is linear.

stable. If this requirement is hard to be reached, we need to find a way to easily calibrate it for the user.	

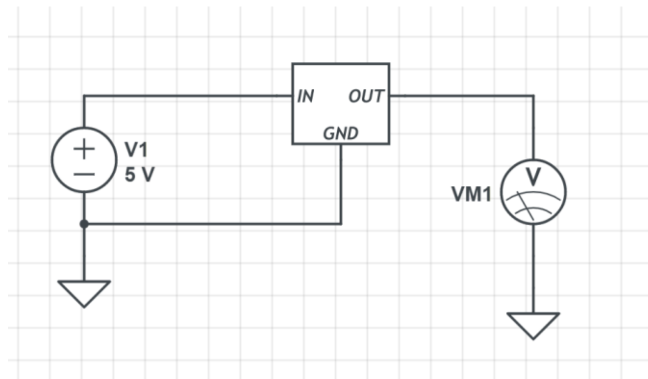

Figure 13 The test circuit we designed to measure output signal

2B2B Conversion Circuit

2B2B1 the conversion from resistance to voltage

One of the common characteristics of pressure sensor on the market is that they use resistance as output signal. However, it is hard to measure resistance with utilized variable resistance corresponding to various pressure values (usually, more pressure lead to less resistance). Since the resistance is hard to measure directly, we utilized a measure circuit that converts resistance into voltage.

Our measurement circuit is an operator amplifier. We have a calculation that allow the output voltage to be calculated with formula $V_O = -\frac{V_T R_F}{R_S}$.

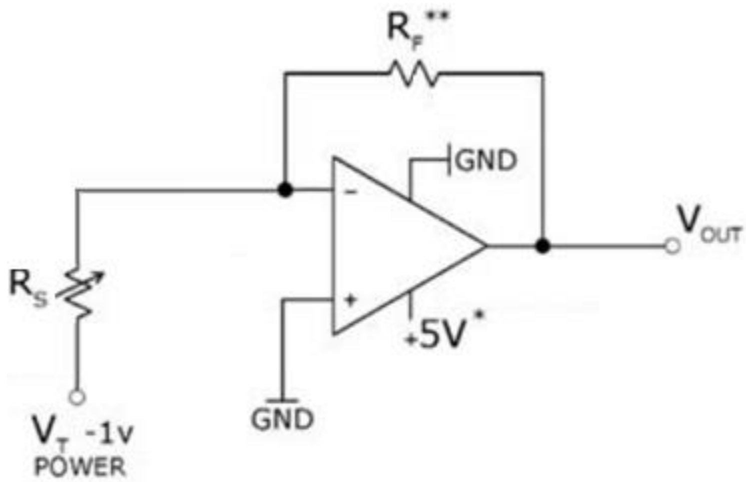

Figure 14 The principal schematic for our op-amp

$V_T R_F$ here is a fixed value (which determines the range and sensitivity of our sensor, the larger it is, the more sensitivity our sensor will have), so the output analog voltage will be inversely proportional to the resistance, thus directly proportional to pressure.

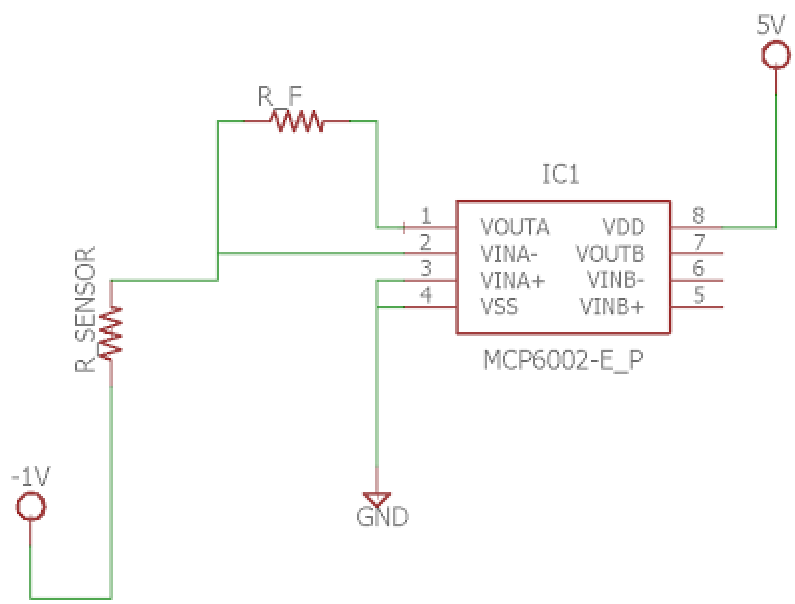

Figure 15 The component schematic of our design

Now, the major problem of our previously mentioned sensor is the output format: the input signal is analog, but we need digital signal in order to process in the microcontroller. Thus, the conversion circuit converts the analog input signal into a formatted digital input, that includes an analog-digital conversion and a parallel-serial converter with a FSM. This FSM may be implemented inside the Microcontroller, or implemented as an independent circuit.

We here set up several requirements on the conversion unit, in order for it to work correctly during the set up:

Requirement	Verification
For circuit that map resistance to voltages, the circuit should keep enough precision and range, and maintain a linear map from pressure to voltage.	1. We use the same fundamental structure and routine from 2B2A (which use continuously pouring water as input and measure the continuously changing signal output)
For real-time changing voltage, the circuit should be fast enough to provide its digital representation, and finish the serial transmission to the processor. In our design, the circuit should be able to handle at least ten voltages each second.	1. We Build a simple circuit that can give the sensor and converter a power supply. The reason why we are not using function generator is that an actual test in the production environment, which may include signal noise, is necessary for the testing. 2. We use an alternative voltage as input signal, and turn on the clock so that the circuit may start sampling. 3. We use a multimeter to measure the input voltage, and check the reference from DAC. They have to be almost the same. 4. When an alternative voltage is set, the output signal should alternate at least ten hertz 5. For every signal in the shift-register, the circuit shall transmit it to the microcontroller without loss

2C Peripheral LED and Switches

In order to indicates current running and allow operation, we need some LEDs and Switches. Here we state the requirements for them:

Requirement	Verification
For LEDs, it should be running under an appropriate voltage. For switches, it should switch the circuit precisely when handle moved.	We build a simple circuit that made of a battery, a switch, wires, and a LED. The LED should change its light when we change the switch connected to it.

The place, quantity, and usage of LED and Switches is still under discussion and may change due to the actual need. A final version of the LED assignment shall be placed during final report.

2D Tolerance Analysis

The most important value is the sensor pressure we monitored. There is three portion that may lead to serious imprecision:

1. The pressure sensor when converting sensor to resistance;
2. The Operation Amplifier when converting resistance into analog voltage;

3. The ADC when converting analog voltage to digital voltage.

In our requirements, we want the final value to be as precise as 5 mm. This means that when the measured value is 20 cm, the actual value should be around 19.75cm to 20.25cm.

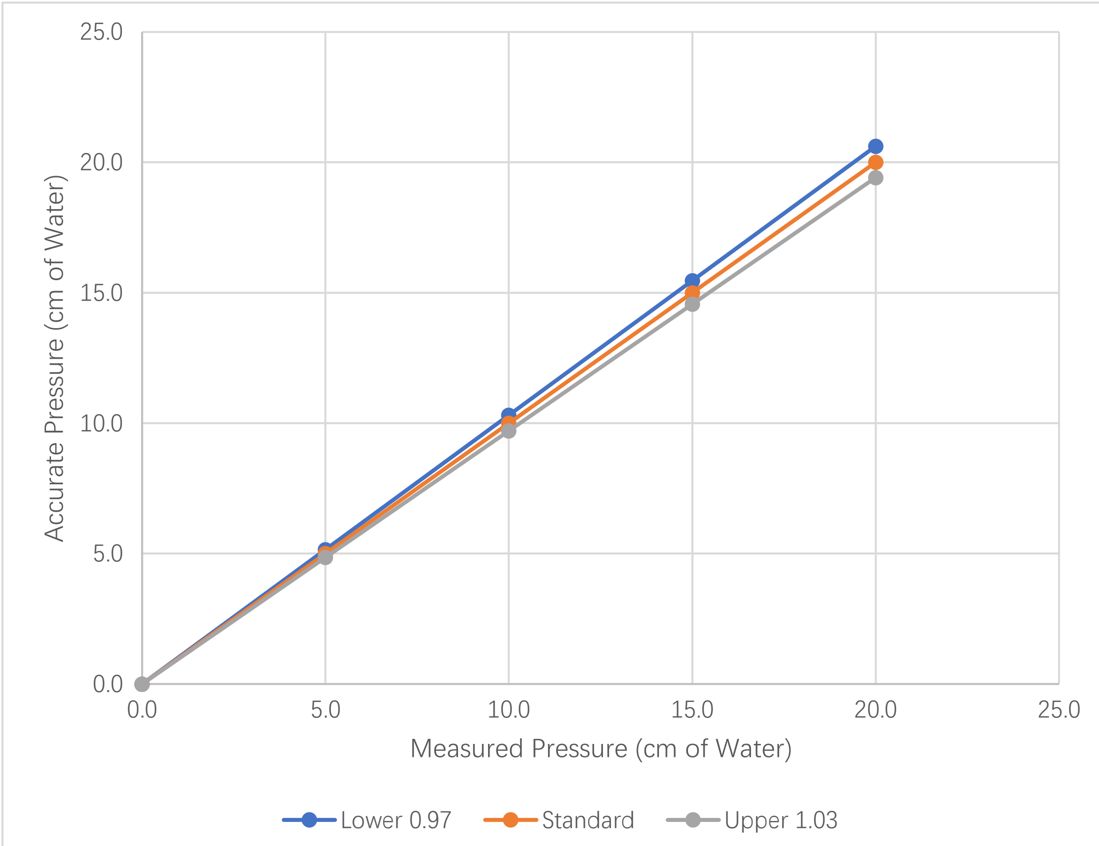

Figure 16 The error analysis when there is a possible error of three percent

This accuracy means that the minimum precision requirement for this equipment are $\frac{0.5}{20} = 2.5\%$. However, since most of our value will be in the range from 4 to 12 cm (this is the range when most CPAP device will use), our precision requirement could be loosened to 4.2%. In the Figure 7, we have provided a graph that shows the influence of a possible error of 3%.

Now, we analyze the error of components:

1. For the sensor, the error is due to structural reasons. According to our estimation, most sensor can have about 1% to 3% error if configured properly. Here we take the worst case of 3%.
2. For the operation amplifier, we estimate there should be no extra error because the signal is not losing accuracy when being converted from resistance to voltage: both are continuous.
3. For the ADC, the possible error is due to the digitization. When we are representing the level from 0 to 5V (which is mapped to 0cm to 20cm by sensor and amplifier) with sensitivity of 0.1 cm (0.025V), the maximum possible error is half of the sensitivity 0.05

cm. Which means that we need at least 200 statuses, or eight bits to digitize our signal in order not to have extra loss of precision.

3 Cost / Time Analysis

Table 3 Schedule

Task	Done by	From to
Design Review Writing	Hanming	Oct 1 to Oct 5
Sensor Circuit: Sensor and ADC Design	Yijun	Oct 1 to Oct 21
Sensor Verification		Oct 8 to Oct 14
Analog to Digital Circuit Design		Oct 8 to Oct 14
Parallel to Serial FSM Design	Yan	Oct 15 to Oct 21
Power Supply Chip Design	Hanming	Oct 15 to Oct 21
Power Supply Chip PCB Design	Hanming	Oct 15 to Oct 21
Microprocessor: Bluetooth Communication	Yijun	Oct 16 to Oct 29
Design and Breadboard testing		Oct 16 to Oct 22
PCB design		Oct 23 to Oct 29
Microprocessor: SPI SD Card Writing	Hanming	Oct 16 to Oct 29
Software design and Breadboard testing		Oct 16 to Oct 22
PCB design		Oct 23 to Oct 29
Microprocessor: FSM Serial Reading	Yan	Oct 16 to Oct 29
Software design and Breadboard testing		Oct 16 to Oct 22
PCB design		Oct 23 to Oct 29
Production: final confirmation of PCB Design	Hanming	Oct 30 to Nov 5
Production: Wait for manufacture		Nov 6 to Nov 12
Writing Reports and Preparing demos	All	Nov 6 to Nov 12
Production: Soldering and Test	Hanming	Nov 13 to Nov 19
Final Demo and Report According to class calendar		

Cost analysis is based on two portions: the material, and the labor. On the material portion, we majorly dependent on our current components and free samples, so during the development there should be no major material cost. However, the production cost analysis is here:

Table 4 Cost Analysis

		Development	Production
ATmega328P Microcontroller	Microchip	Free Samples	Around $1 to $2 per chip
HC-06 Bluetooth	HC Information	$10	Around $3 to $4 per

Controller			board
SD / MMC Breakout	SparkFun	$5	Around $1 per jack
Power Breakout	SparkFun	$5	Around $2 per jack
SD Card	Various production	$10	Around $10
Peripheral circuits	Various Production	$5	Around $10
Labor	Around 100 Hours	$15 (TA Salary) * 100 Hours = $1500	$30 (Full Time Salary) * 100 Hours = $3000

4 Ethics and Safety

We have examined some possible safe, ethical and environmental risk that may occur in our plan.

4A Safe

According to IEEE Code of Ethics, #1 [7] and #9 [7], our work should "make decisions consistent with the safety, health, and welfare of the public", and "avoid injuring others, their property, reputation, or employment by false or malicious action". When designing and manufacturing our work, the most important factor to consider is the safety and health of our user.

There are two possible safe risk on the design of our plan: one is the direct safety risk, lead to fire hazard by the battery that we installed in the plan; The other is the indirect safety risk that may lead to respiratory infection by the tube we installed in the plan.

The direct safety hazard is the risk of a firing battery due to the over discharging, which is the situation when the battery is discharging with a large current. The large current may cause overheat in the cell component of battery, leading to possible fire or even explosion. One of the possible solution is to use an external power supply like USB power, while the other solution is to enhance its heatsink so that the heat accumulation on the chip will be controlled. One of the good news is that this product will be used in door when sleeping, which means that the temperature in its surrounding environment will be relatively controllable within a reasonable range of room temperature.

Another safety hazard, though not acute, is the possibility of bacteria accumulation in the device. The system, which directly connected to the patient's airway, may lead to severe infection if contaminated by bacterium. If there is any colony propagating on the device, the positive airway pressure will keep the air flowing in the tube, transporting bacteria into the airway of our patient. Sometimes there will be no serious impact: there may be just a common cold, or some squeezes; however, if the patient is already sick with respiratory infection, these new bacteria could be dangerous for their weakened immune system. In order to deal with this possible failure, we may have to pay specific attention to the selection of tube materials, and use some appropriate measurements, like the cleaning of internal tube, the dehumidification of air to prevent bacteria from propagating, et cetera.

When developing this solution, there is another immediate safety concerns regarding the lab safety. In order to minimize the risk of using high-temperature device, we will use breadboard and sockets to reduce the necessity of using soldering irons and hot air in order to replace components.

4B Ethic

The other possible risk is the user's privacy. The monitor data of CPAP may lead to speculation on the patient's physical health situation, which may lead to concerns over the privacy. In order to protect patient's privacy, we have to ensure that there will be no unintended or unauthorized access to the CPAP data.

According to IEEE Code of Ethics, #2 [7], we should avoid real or perceived conflicts of interest whenever possible, and disclose them to affected parties when they do exist;

One of the important measurement is to limit the functionality to offline access. In our plan there will be no need of internet service, so that the privacy data will be kept in user's own devices. Also, we have removed USB and Bluetooth remote access from our design, so the only way to access the CPAP data is the physical access of SD Card, which limited the access to peoples in the immediate surrounding.

4C Environment

According to IEEE Code of Ethics, #1 [7], our work should "make decisions consistent with the safety, health, and welfare of the public", by protecting the environment and carefully our usage of public resources to enhance the public welfare. When designing and manufacturing our work, we have to take the environmental impact into consideration.

One of the serious environmental impact is the usage of battery. The battery we used in our daily life may lead to serious contamination of metals and other chemicals. In order to reduce the usage of battery, we have to reduce our power consumption to the lowest available one, so that a battery can last for the longest time. One of the other solution is to accept NiMH batteries in our design, which requires either the design of power supply circuit to accept 4.8 V as input voltage ($4 * 1.2$ V = 4.8 V). We have designed the power supply module so that it accepts the usage of rechargeable batteries as power source. The last solution is to encourage the usage of external power supply like USB Power, which can use the alternative power instead of massive number of batteries during its lifecycle.

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