Wireless Pulse Oximetry

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Abstract

Pulse oximeters measure a patient's blood oxygen saturation level and pulse and are used to diagnose and treat medical problems. Most oximeters today are wired, which limits the range of motion and the patient can remove the probe with the wire. The proposed system will use Bluetooth technology and will interface with existing oximeter hardware. This will help eliminate several of the noted problems while optimizing a system with minimal power requirements, minimal hardware costs, and minimal size of the transmitter and receiver.

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Introduction

Throughout the medical world, a crucial tool used in many various applications is the pulse oximeter. A pulse oximeter utilizes the different absorptions of oxygenated and deoxygenated blood to calculate a person's oxygen saturation levels in their blood. Dr. Chris Green, a practicing pediatrician at the UW Hospital, has noted some issues with wired pulse oximeters. His child and infant patients tend to remove the probe from their finger or foot via the cord. Dr. Green is interested in the possibility of designing a system that would convert his wired oximeters into wireless without the expense of buying new oximeters.

So far, the group has narrowed down the hardware that will be used, the basic design, and the general path the software will take. The idea is to have a probe attached to a wrist strap which houses the wireless transceiver, probe battery, and a microcontroller. Using Bluetooth technology, the probe and table top system will communicate wirelessly the same information that would otherwise be sent through the cord between them. The table-top system that houses all the necessary software to control the probe and process the signal is the pre-existing one that Dr. Green uses. An adapter will be attached to this system to wirelessly transmit any signals to the probe; the probe will gather the necessary information and send it back to the table system for processing.

The next step will be to start programming a microcontroller that can be used with our Bluetooth system to transmit the signals. When this is done, a satisfactory battery will be picked and the specific design will be prototyped. This system will then be extensively tested.

Pulse Oximetry

A pulse oximeter is a medical device that can measure a patient's arterial oxygen saturation (SpO_2) level and determine pulse rate without the need to draw arterial blood. Pulse oximetry uses the different light absorption characteristics of oxygenated and deoxygenated hemoglobin in order to calculate SpO_2. Oxygenated hemoglobin absorbs more infrared light (850 – 1000 nm) while deoxygenated hemoglobin absorbs more red light (600 – 700 nm).

Two methods of gathering information from the measuring site exist, transmission and reflectance. For transmission, the two LEDs (red and infrared) are placed adjacent to each other, as seen in Figure 1.

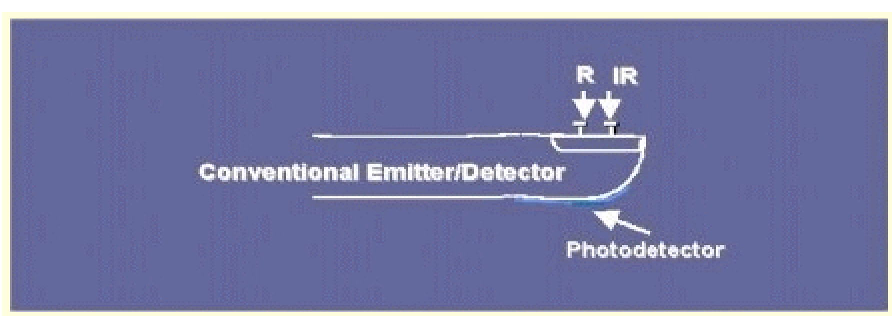

Figure 1: Transmission pulse oximetry (Barker)

The photodetector opposite to the two LEDs measures the light that passes through the measuring site and sends the information to the oximeter unit. For reflectance, the less commonly used of the two methods, both emitters and the photodetector are placed above the measuring site. Light reflects from the LEDs off of the measuring site and back to the detector. The information is then received by the oximeter which calculates the red to infrared light absorbance ratio of the patient. This ratio is compared to a “look-up” table that converts it to a SpO_2 value. Each manufacturer has their own “look-up” table which they create by testing their oximeters against arterial blood samples.

By comparing light transmittance during the systolic and diastolic periods, oximeters account for the constant light absorbers always present in the measuring site (i.e. skin, tissue, venous blood, and arterial blood). As shown in Figure 2, the oximeter measures the SpO_2 level of blood in arterial blood only.

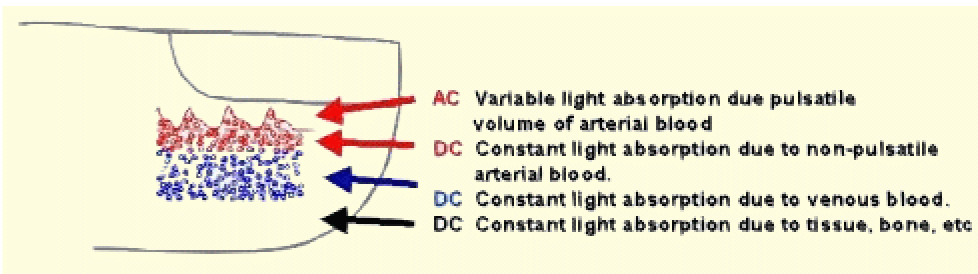

Figure 2: Light absorption due to bodily components (Barker)

Applications

Due to recent advances in pulse oximeter technology, pulse oximeters are being more widely used throughout the medical world. Common uses for oximeters vary from patient monitoring while under the effects of anesthesia, in intensive care units, during transport, and even in diagnostic labs. These recent advances in pulse oximeter technology have made them more dependable to base medical decisions on. Oximeters have also seen an increase in personal use for sports use due to new low cost oximeters being manufactured.

Motivation

Children and infants have the tendency to remove the oximeter probe via the wire during monitoring. Creating a modular wireless system would help deter some of those false readings that would occur if the child were to accidentally remove the probe via the wire and would reduce the risk of entanglement with the wire itself. Additionally, a wireless system would allow a wider range of motion for the limb that the probe is attached to. This way the user would have a much greater range of movement compared to using a wired system. In addition, this system aims to be less expensive than purchasing a brand new system and thus would create a financial incentive as well. Finally, because the project is designed to operate for the children and babies, its use on adults would be unchanged and would be able to operate to its full extent on individuals of all ages.

Requirements

The goal of this project is to build a wireless transmitter and receiver for existing oximeter hardware while minimizing the cost, size, and weight of the device. Based on expected device function, the target prototype cost is under $500. A benchmark of five hours of continuous operation was implemented. This is tentative to change depending on the needs of the oximeters' users and the power consumption of the device itself. Due to the fragile nature of the device's primary audience, size and weight is another concern that should be taken into account. The device should not be so cumbersome to restrict limb movement and thus a 70 gram maximum weight restriction was implemented. Data wise, the aim is a lossless analog to digital conversion and vise-versa so that the original output can be recorded without any loss in fidelity. Finally, due to the nature of the project, an inherent requirement was that it must interface with the existing Masimo oximeters present at the hospital.

ContecMed

ContecMed is an Asian-based company that produces a wide range of oximeter solutions some of which have wireless capabilities. The devices they produce are relatively inexpensive (~$100). In addition, their devices have the probe and the oximeter combined in a large rectangular block that is placed onto the finger. For an adult, this is acceptable, but for a child or infant, the device would not only be tiring to keep in an operational position but would have difficulty staying on the finger itself.

Nonin

Nonin is another medical supplies company that produces pulse oximeters. Currently, they have two brands that have wireless capabilities, the Onyx II 9650 and the Avant Digital 4. The Onyx II 9650 is the benchmark the project is competing against cost-wise (~500) as it is a very competent system that has the capability to display readings on a variety of Bluetooth capable devices including laptops, PDAs, cell phones etc. The Avant Digital 4000 is another device of interest as it appears to be very similar to the projected prototype as seen in Figure 3. It contains a small probe, which would be placed on the finger. The data there would be sent to the wrist attachment which houses the wireless receiving and transmission hardware. The wrist attachment would interact with the oximeter itself via Bluetooth to display the readings.

Figure 3: Nonin Avant Digital 4000 wireless pulse oximeter (Nonin)

Power

In designing a wireless pulse oximeter, there are two different power sources to consider. The first is the source to power the table-top unit that displays the information and governs the probe's actions. The second is the power needed for the wireless probe. The table-top unit has pre-existing plug for a standard 120V wall outlet. The wireless probe will need the use of an external power source.

What the most effective power source to use is dependent on the requirements of the probe. The necessary functions of the probe will be to receive and process information from the table unit, to power the LEDs, and to transmit the photodiode information. The amount of voltage required from the power source is reliant on what the necessary voltages are for the microcontroller, transceiver, and LEDs. Any battery used must provide enough voltage and will also need to have a sufficient capacity to allow for a minimum of a few hours of continuous running time. With this in mind, the most important aspects to look for in a power supply are total voltage capacity and price. The probe is wireless and meant to be very portable, so with any battery used, a careful evaluation of size and weight is necessary as well.

Two power sources are seen throughout the current market of wireless probes. The first source is a standard AAA alkaline battery. These are common in some of the larger probe systems. The benefit to using a AAA battery is that they are relatively small compared to a 9-V alkaline battery or a AA. They also can carry large amounts of energy for their size. Some specific values can be seen in Table 1. The standard voltage for an alkaline battery is 1.5 V. There will inevitably be 2 in series because at least 3 volts is necessary to run either the microcontroller or transceiver, and sometimes up to 5V will be needed. The requirement for having at least two in series begins to push limits on the size and weight restriction and having more than two would be unreasonable. These batteries are cheap and disposable; in the short run this is beneficial but over the long run it can be both costly and wasteful.

Battery	Voltage (V)	Weight (oz)	Capacity (mA-h)	Price ($)
AAA	1.5	0.4	1200	0.50
AA	1.5	0.8	2700	0.50
9-V (alkaline)	9	1.7	560	3.00-5.00
9-V (Lithium)	7.4	1.2	1200	8.00
Li "button" rechargeable	3.6	0.18	120	1.40
Li rechargeable	3.0	0.6	450	2.50

Table 1: Comparison of power sources

Lithium ion batteries are commonly used in cell phones, laptop computers and many other applications. They can be recharged without any memory effect. A memory effect occurs when a rechargeable battery is recharged before the battery has run out of charge. From that point on it can only be discharged to the point where it was recharged from, so it "remembers" how much energy was used. Lithium ion batteries are smaller and lighter weight than alkaline batteries. Weights can be seen in Table 1. The standard voltage of Li-ion batteries is also anywhere from 3.0-4.0V, considerably more than that of an alkaline. Because the provided voltages are higher, a probe would require less in series to achieve the required voltages. Also, Li-ion batteries can be recharged many times. This allows for only a few batteries to be used over and over, decreasing the long run costs of use. The downside is that they hold less charge than traditional alkaline batteries. As seen in Table 1, the standard capacity is many times smaller than AA or AAA batteries. This means the user would need to recharge their Li-ion batteries more often than replacing their alkaline ones. Finally, the upfront cost for Li-ion batteries is substantially higher than that of alkaline but because they do not need to be replaced as often, they offer a more financially friendly solution in the long run.

Wireless Modalities

The wireless modality is the centerpiece for the design project. Specifications for the wireless modality include deciding which transfer protocol and which hardware to use. The design of the pulse oximeter being augmented necessitates bi-directional communication using this modality. Categories considered for the modality include bit rate, power consumption, programming feasibility, range, size, and cost. After this, specific chips will be chosen to execute the data transmission. Specifically, two transmitter chips and two receiver chips must be implemented. However, using two transceiver chips is desired to reduce the amount of time learning new hardware. The chips must be compatible with UART specifications, as this is the desired output of the microcontroller that will be used.

Wi-Fi™

The first of the four wireless transfer modalities is Wi-Fi. Wi-Fi is commonly used for wireless networking applications. Being designed for this purpose, Wi-Fi has a high bit rate and high range. Wi-Fi effectively transmits data as high as 50 megabits/second. Depending on the subset of Wi-Fi used, it can transmit data to a network of a 100 meter radius. However, this causes the modality to be excessively power hungry.

The hardware associated with Wi-Fi is different than the other modalities. Because it was designed for computer networking purposes, the only way to transfer a Wi-Fi signal into serial output is to first process it in a computer. This gives rise to the added costs of a laptop, router, and any processing software needed. To convert the serial (UART) signal into Wi-Fi, a LS-UART-Wi-Fi (Appendix 2) module will be used. This chip is priced at $32.00. For the receiver, a laptop/router system can be avoided by using the WF2SL module (Appendix 2). This unit, which looks exactly like a regular router, can process the Wi-Fi signal internally, giving the serial output needed to communicate with the pulse oximeter.

Bluetooth®

A second wireless modality choice is the Bluetooth protocol. Bluetooth specializes in pairing wireless devices in an ad-hoc, or decentralized, manner. Examples of this include wireless headsets, speakers, etc. Bluetooth exhibits a 10 meter range and 1 Megabit/second transfer rate. While these numbers are lower than Wi-Fi, Bluetooth is significantly less power hungry. Additionally, Bluetooth chips automatically exhibit 'channel hopping' behavior. This causes the signal to bounce around a narrow frequency range whenever it detects other networks are in range. This helps avoid interference from other signals (Bluetooth).

The CSR BC417143 (Appendix 2) module was chosen for Bluetooth hardware. Priced at $18.95, this chip acts as both transmitter and receiver. This simplifies the fabrication process, as only one chip must be dealt with for both functions. The chip, depending on configuration, can operate at 1.8 volts. Additionally, the chip is small and will easily fit inside the proposed plastic casing of the probe unit.

Zigbee®

Zigbee is a relatively new technology. It was designed not to compete with Wi-Fi and Bluetooth, but to fill a different niche (i.e. wireless light switches). It is specifically designed towards lightweight, low power applications. It has the same range as Bluetooth, roughly 10 meters. The transfer rate is low at 250 kilobits/second. Also, because the Zigbee protocol is very new, hardware and documentation will be hard find.

The Zigbee modality offers no pre-bundled serial-wireless hardware modules. Therefore, to use Zigbee, the signal conversion must be done on a chip fabricated solely for this project. This fabrication will be costly in both terms of time and money; such an effort would be detrimental to project success as a whole and will not be pursued.

Infrared

Transmitting the data by infrared light, instead of radio waves, was initially considered as a possibility. However, research indicates that direct line of sight between receiver and transmitter is mandatory to achieve wireless transfer. Doing this in the case of the wireless pulse oximeter is severely detrimental to the client's design specifications and will not be pursued.

Design Matrix

The design matrix, shown in Table 2, includes the four modalities listed above. In addition, these modalities and their respective hardware are rated in terms of power consumption, size, programming feasibility, bit rate, and cost. Programming feasibility is weighted highest with 35 points. Interfacing the microcontroller with the wireless chip will be the most challenging aspect of fabrication. If the hardware is too hard to deal with, the project fails as a whole. The second highest category is power consumption with a score of 25 points. Using less power means the device can cam be used for longer periods of time without being recharged. This is a prominent design specification given by the client. Cost is the third highest category at 20 points. While there is a large budget from the client for the prototype, the cost of the modality hardware becomes important if large scale manufacturing is to be performed. The fourth highest category is size. While any chips could easily fit inside the proposed casings (both probe casing and oximeter side casing), the hardware is too large when dealing with the Wi-Fi receiver module. The lowest category is bit rate. The bit rate category receives a low value because any of the considered technologies have sufficient bit rate and bandwidth to transfer the minimal data that will be transmitted between the probe and table unit.

	Bluetooth	WiFi	Zigbee	Infrared
Power Consumption (25)	20	10	25	20
Size (15)	15	5	15	10
Programming Feasibility (35)	30	35	25	25
Bit Rate (5)	4	5	3	3
Cost (20)	20	10	10	5
Total (100)	**89**	**65**	**78**	**63**

Table 2: Wireless modality design matrix

Hardware

The hardware design for this project plays an important role. Good hardware design has to complement the software so the two will work well together. To further understand the hardware goals of this project, the reader should have an understanding of Figure 4, which depicts the general communication scheme between the oximeter base unit and the probe.

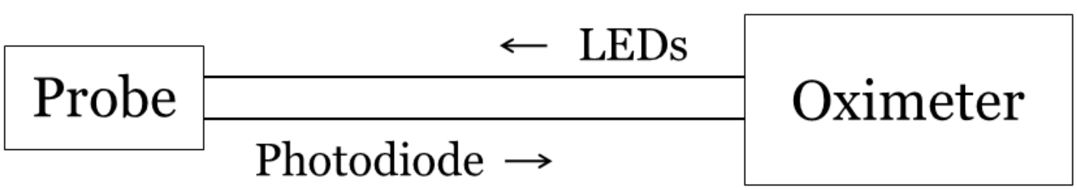

Figure 4: General communication scheme between oximeter and probe

In a standard, wired oximeter, voltage travels from the oximeter to probe. Note that current, not voltage, powers the LEDs, but for the sake of brevity and consistency, voltage will be used. The red LED is on when the voltage is one polarity, and the infrared (IR) LED is on when the polarity is reversed. This aspect facilitates the development of a prototype. For the photodiode, the signal travels from the probe to the oximeter, where it is processed and analyzed. A photodiode converts light to voltage, so the more light present, the greater the voltage.

In both cases, the signals are analog signals, meaning they are continuous. This poses a problem for making such a system wireless. In order to broadcast data wirelessly, the signal must be a digital stream. By definition, a digital signal is discrete, meaning it is distinct, and it has 2 states – high and low. Therefore, the conversion of analog to digital (and vice-versa on the other end) must be done at a high enough resolution such that no data will be lost on either end. It also must be done at such a rate that will ensure all essential data is broadcast and received.

Analog-to-digital converters (ADC) and digital-to-analog converters (DAC) will play an important role in the data conversion in this project. However, because digital signals are discrete, they have a limited range and resolution they are capable of displaying. The resolution of an ADC or DAC is dependent on how many bits it has; more bits yields more resolution. This follows from Equation 1 (Webster)

$$Resolution = \frac{1}{2^n} V_{ref} \qquad [1]$$

Where *n* is the bit size of the converter and V_{ref} is the reference voltage of the circuit to be sampled. Bit size can be chosen after the range of precision and values have been determined from the Masimo oximeter testing.

Probe

Figure 5 shows a generalized block diagram of the wireless probe. The existing probe will be interfaced with the microcontroller using a standard 9-pin d-subminiature (d-sub) connector. Pin outs of the probe are discussed later. The microcontroller will contain standard a standard ADC and DAC. As dictated by the communication scheme discussed above, the photodiode will connect to the ADC since the data will be transmitted digitally back to the oximeter, and the LEDs will connect to the DAC because the probe is receiving a digital signal as to which LED to power.

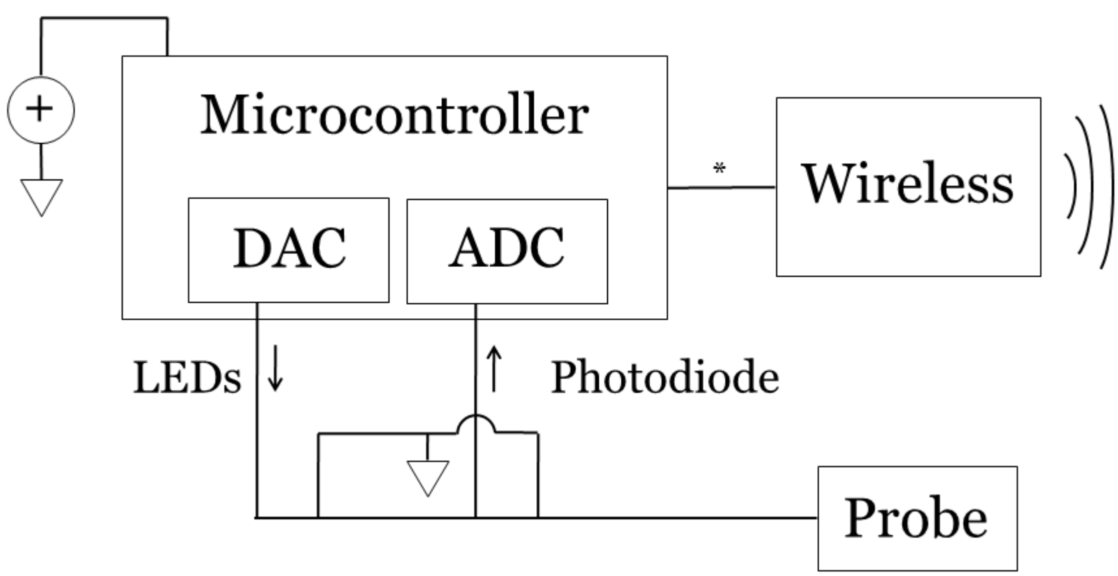

Figure 5: Block diagram of probe

The microcontroller will also interface with the wireless chip. The interfacing method is dependent on the chip purchased. Various options exist, but the team believes that universal asynchronous receiver/transmitter (UART) protocol, more commonly known as serial, will be easiest. It is easy to program and since it is well established, there is excellent help and resources available if the team were to run into trouble.

UART allows a receiver and transmitter to transmit data without having to use a clock to time the signals. Rather, the receiver and transmitter agree on the clock parameters in advance and each component uses its own clock to keep track of time. As a check for the transmitter and receiver, certain bits, known as the start and stop bits, are added to the start and end of transmission respectively. When a transmission has been finished, the next transmission may start immediately with the start bit. In this way, a continuous stream of data is transmitted (Durda). The UART protocol will always take care of adding and removing the start and stop bits. As long as the receiver and transmitter are configured correctly, these bits will never be observed.

The microcontroller will also power the probe such that the LEDs will work correctly. Since the microcontroller requires power, the team anticipates a voltage output through the DAC will be sufficient to power the LEDs. If not, other avenues can be explored, such as providing a constant power to the probe, and then using the DAC as input to an inverter which will causes the polarity shifts needed for the red and IR LEDs. The first method is desirable because there may be states in the LEDs cycling where neither LED is lit; this would require a cascade of inverters and some additional power requirements to power those inverters. Additionally, although small, the inverters will increase the size of the device.

Oximeter

Figure 6 shows a generalized block diagram of the oximeter. Note that this block diagram is almost identical to the probe, with the LED and photodiode leads reversed because the roles of these leads are opposite to that at the probe. This is a simple hardware modification, along with some minor software changes. The wireless chip will interface with the microcontroller in a similar means as the probe.

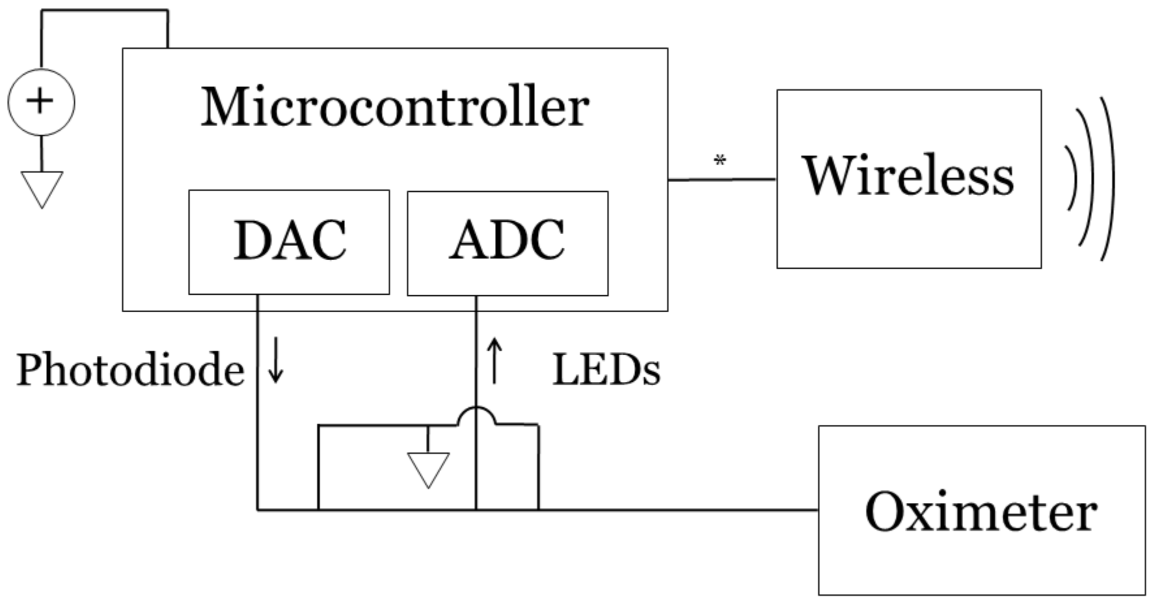

Figure 6: Block diagram of oximeter

Similar designs of the probe and oximeter simplify the hardware design. This will correlate to lower costs as components could be purchased in larger quantities and manufacturing is easier. Because most of the changes are in software, an extendable software programming system will be created. This system will allow for the code to be based on the same framework, but each component would have its application specific needs. This will also reduce the amount of time and effort needed for additional programming.

It is currently unknown how this portion will be powered. The team hopes that this portion may be powered by the oximeter. However, the LED voltage signal would have to be used and it is not sure as to whether that would be enough voltage for the microcontroller. Additionally, it is an alternating signal and the microcontroller requires a direct current. A chip could most likely be bought that would allow for the power to become direct voltage. If not, an external power source such as batteries or direct outlet connection would be needed.

Additional topics of discussion follow similar to the probe, so refer above for more information.

Considerations

The team has compiled a list of considerations that must be kept in mind when the final hardware is designed. As discussed above, microcontroller selection will be influenced by the resolution of the ADC and DAC. This will be directly correlated to the precision and range of values needed. In order to determine these values, testing on the Masimo oximeter will need to be done; the beginning phases of this testing are described below. Once the signal has been observed on a variety of subjects, the team can make an informed decision on a microcontroller.

Also directly related to the microcontroller is the capability of In-Circuit Serial Programming (ICSP). ICSP allows for the microcontroller to be placed in position on the device and still allows it to be programmed via a programming header. Without ICSP, the microcontroller must be removed from the device every time it needs to be reprogrammed. Although adding this feature will add some components to the device, the team feels that this tradeoff is worth it and will help minimize the possibility of damage to the device.

In direct conjunction with Figure 4, it is apparent that bidirectional communication is necessary. If the signal is only able to be sent in one direction, there is a large risk of losing proper oximeter functioning because of the delayed transmission of signals. In Figure 4, the individual signals are carried by individual wires. The correlation to wireless is individual streams of data. Therefore, the wireless modality must be bidirectional capable, like Bluetooth.

Another aspect to consider about wireless is data security. The Health Insurance Portability and Accountability Act of 1996 (HIPAA) was a law passed by the United States Government in an effort to protect the privacy of individually identifiable health information(US Department of Health and Human Services). HIPAA was designed to help secure healthcare data transmitted not only by wireless, but by any means; however, this law refers to information included in an individual's medical record, billing information, and more. If transmitting this information in some manner, including wireless, there are certain precautions and safeguards that must be observed. This law does not apply to this project because the information is not individually identifiable. If an unauthorized third party was able to intercept the oximeter data over Bluetooth, they would need to have an understanding of how to decipher the data from the probe and how to process that data. Without a deep understanding of pulse oximetry and knowledge of the system, this is unlikely. Additionally, the data being streamed over Bluetooth does not identify the patient; it only has diagnostic information that will only provide useful information to the healthcare provider.

A final point of note for wireless is the pairing of the system. Al l Bluetooth devices must be paired before they will communicate with each other. With common devices such as computers or cell phones, there is an interface present in order to enter the passcode for the paired device. There will be no such interface here, so the devices must be paired programmatically and testing must be done to ensure that devices communicate only with each other.

Testing

Contec Bluetooth Oximeter

A ContecMed COMS-50EW was purchased and tested to verify the accuracy of Bluetooth transmission for recording. The device required a Bluetooth receiver in order for it to be recognized. A BlueSoleil BS003 USB dongle was used to receive the Bluetooth information from the oximeter. The software included allowed programming of the device to recognize drops in pulse or SpO_2 or 'events'. This way, these events could be tracked if patient undergoes rapid change in his/her condition. It also recorded minimum and average SpO_2 levels along with minimum and average heart rate. These values were recorded and graphed in real time as seen in Figure 7. There was little variation in SpO_2 over time but that was expected. A series of jumping and high energy movements were done during the recording which resulted in changes in the pulse rate as can be viewed in both Figures 7 and 8. Figure 8 displays the key data from the entire recording along with a graph of spO_2 and pulse rate over time. It can be seen that Bluetooth is clearly a viable method of pulse oximetry data recording.

Figure 7: SpO2 software that came with the device. Data is recorded and plotted in real time

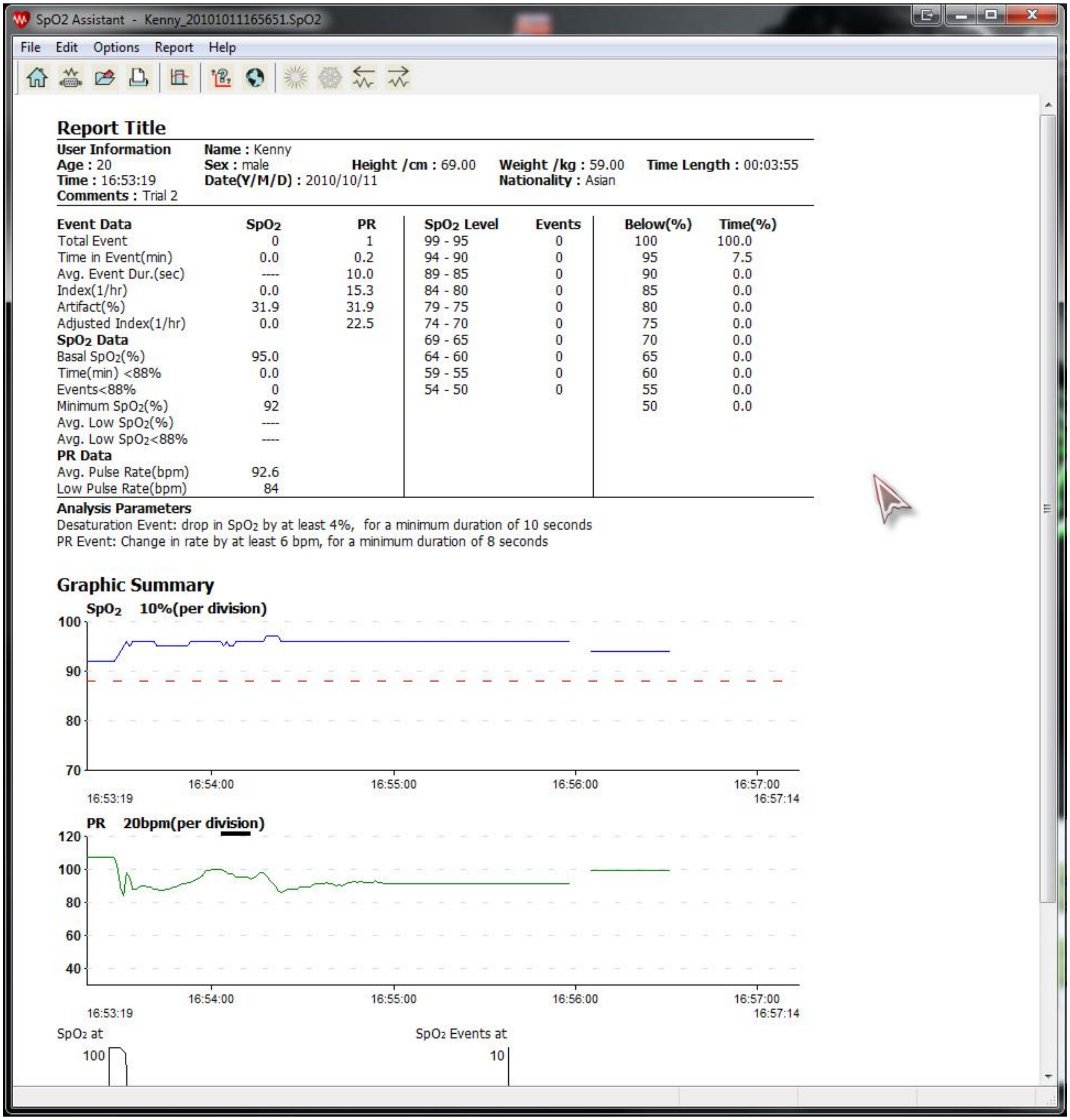

Figure 8: Results of a 3 minute 55 second test. There is a small break at the end due to removing the probe before ending the recording

Masimo Pulse Oximeter

The team is currently conducting testing on the Masimo pulse oximeter that will be used for the project. In order to further design the hardware, the team has been focusing on understanding the pins of the probe as well as expected behavior and voltage ranges for these pins. At the time of this report, 5 of the 9 pins had been identified – the 2 LED pins, 2 photodiode pins, and a ground pin. The other 4 pins may also be ground references, but the team needs to verify that before concluding that. The voltage ranges for the LED pins are also well understood.

The Masimo pulse oximeter has the capability of detecting when no probe is attached to the oximeter. It does this with an electrical connection and the mechanism is not well understood. It appears as if the photodiode pins also serve as this detector and measurement of the voltage ranges on those pins are causing the oximeter to declare there is no sensor attached. The team will continue to work on this problem.

Future Work

After the rest of the pins on the Masimo oximeter as well as their voltage ranges have been determined, the team will design a circuit that will work with those parameters. This includes microcontroller selection and design. The microcontroller must be selected so that it is compatible with these voltage ranges. The Bluetooth chips have already been ordered and preliminary testing must be performed so it can be determined how to pair them to interface them with the microcontroller. When this has been concluded, the team will need to prototype the system and perform extensive testing to ensure it functions as expected and the output from the oximeter can still be considered reliable. Figure 9 depicts the design of the probe system.

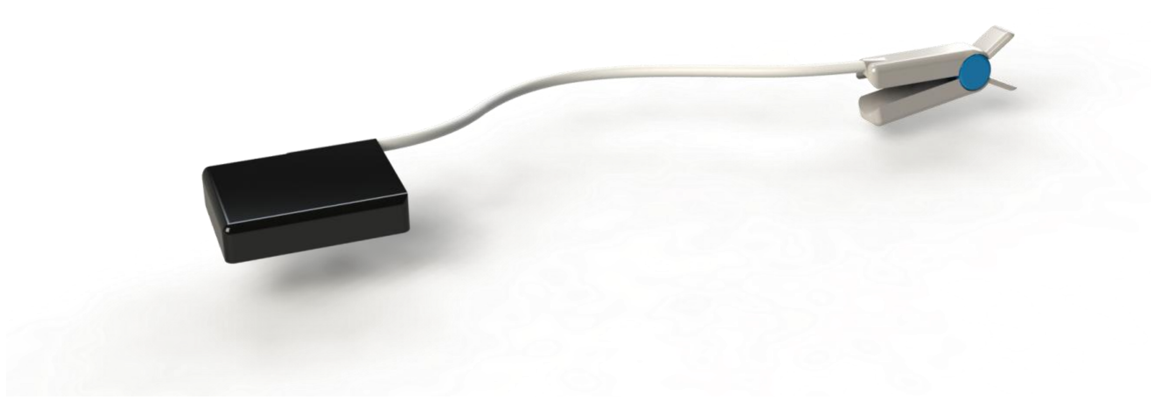

Figure 9: Probe system

Conclusion

The team is working towards building a wireless extension of existing oximeter hardware. The goal is to minimize power consumption, hardware costs, and overall size of the wireless transmitter and receiver. After considering various options, the team has decided to move forward with using Bluetooth technology. Research has been conducted on power sources, but a final decision cannot be made until testing is complete on the oximeter this project will complement. After the power source has been selected, the team will supplement the current hardware design and focus on prototyping the system.

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Appendix

Product Design Specifications

Function:

Design a wireless transmitter and received for existing pulse oximeter hardware mostly intended for pediatric use. This device should be compatible with existing hardware.

Client Requirements:

- Patient should be unable to remove via wire
- Patient should retain full range of motion
- Minimal power consumption
- Minimal final product weight

Design Requirements:

1) Physical and Operational Characteristics

a) *Performance requirements* – Less than 5 second delay between data transmissions

b) *Safety* – Device must be enclosed in electrical---safe material with no loose, swallowable, parts

c) *Accuracy and Reliability* – Minimal transformation of data between conversions of analog to digital

d) *Life in Service* – Should be functional for 5 hours with native power supply and device must be functional for 5 years

e) *Shelf Life* – Should be able to be stored indefinitely with discharged power supply and in a clean, dry environment

f) *Operating Environment* – Transmitter must be able to withstand large motion artifact. Prototype should function well in a normal hospital environment with consideration for higher than normal operating temperatures and possible residual fluid contact

g) *Ergonomics* – Should be comfortable for long periods of time on the patient.

Receiver should not require excessive force to remove from pulse oximeter.

h) *Size* – Should be small enough to be used with babies and small children

i) *Mass* – Should be less than a few ounces

j) *Materials* – Cannot irritate skin and should not have sharp edges

k) *Aesthetics, Appearance, and Finish* – All parts should be fully enclosed

2) Production Characteristics

a) *Quantity* – One, but should be designed with the intent of mass production

b) *Target Product Cost* – Under $100.00

c) *Target Prototype Cost* – Under $1,000.00

3) Miscellaneous

a) *Standards and Specifications* – None aware

b) *Customer* – Physicians working with babies and small children

c) *Patient--related Concerns* – Should not contain easily accessible parts. Device not intended for patient repair.

d) *Competition* –

i. *CMS--50E (Wi-Fi)*--$389.00

ii. *Nonin 4100 (Bluetooth)*---$495.00

Bill of Materials – Wireless Modalities

Chip Name	Cost ($)	Description	Website
CSR BlueCore-04	59.00	Bluetooth to UART (receiver)	http://microcontrollershop.com/product_info.php?currency=USD&products_id=2265
CSR BC417143	18.95	UART to Bluetooth (transmitter)	http://www.sparkfun.com/commerce/product_info.php?products_id=9913
LS-UART-WiFi	32.00	UART to WiFi	http://www.cutedigi.com/product_info.php?products_id=4340
WF2SL	117.35	WiFi to UART	http://www.smarthome.com/81182/Global-Cache-WF2SL-iTach-Wi-Fi-to-Serial/p.aspx