Design and Construction of a Quad Rat Vitals Monitor

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Abstract

The design and construction of a rat vitals monitoring device is essential to easily monitor multiple anesthetized rats simultaneously. The design team's client currently runs positron emission tomography (PET) scans on four rats at the same time, and the scans can last up to two hours. During the two hour scans, the rats are under anesthesia and doses of the anesthesia medications must be adjusted based on the rats' vitals. The client desires to have an accurate, reliable, and easy to use rat vital monitoring device to aid in this process. The current design for this monitoring device includes force sensing resistors for monitoring breathing rate, thermistors to monitor rectal temperatures, and a pulse oximeter that can detect a rat's pulse. The design also includes an easy-to-use graphical user interface (GUI) that displays running averages of the four vitals, the histories of four vitals, and live traces of heart rate and breathing rate. All information will be presented on a single screen, and data from each trial will be stored for further analysis. Current areas of focus in the design and construction of a final prototype include fabricating additional pulse oximeter probes, integrating the new pulse oximeter circuit, constructing a unit to contain all of the circuit components, and developing the algorithms necessary to analyze the pulse oximeter signal.

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Introduction

Background

The design team's client currently runs positron emission tomography (PET) scans on rats to monitor the location of positron-emitting radionuclides (tracers) within the rats' brains. These scans can last up to two hours, and during the scans the rats are under anesthesia (Figure 1). The client and his assistant must monitor the vitals of the rats during these scans to ensure that they endure no harm while under anesthesia. Currently, the client monitors the rats qualitatively. The skin color of the rats is observed and recorded to ensure that the rats are receiving enough oxygen. The rats' breathing rates are monitored simply by observation, and body temperature is monitored by touch. Currently, heart rate and blood oxygen saturation are not monitored. The client would like to be able to obtain quantitative measurements of multiple vitals of each rat during the PET scans.

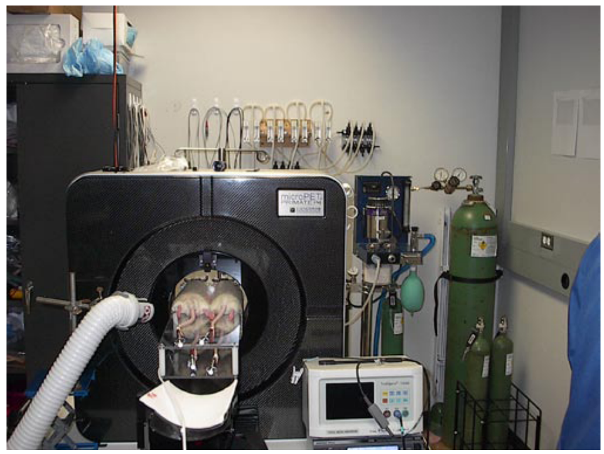

Figure 1: This picture shows four rats in the PET scanner at the client's laboratory. The rats are oriented in a two by two square [1].

Since the PET scanner is designed for monkeys instead of rats, it is large enough to simultaneously scan up to four rats at a time. The client always scans four rats at a time to keep costs down. The radiotracers used in the rats are expensive to produce and decay relatively quickly, so producing a single set of radiotracers for four rats is more cost effective than producing four separate sets for four rats. Due to these restrictions, the vital monitoring device must be able to monitor four rats simultaneously. While under anesthesia, the rats are wrapped in bubble wrap to keep them warm, because the PET scanner is located in a cold room.

Existing Devices

There is currently one device on the market that is capable of measuring the desired vitals of rats and mice (not including temperature). This is a pulse oximeter designed specifically for rats and mice, called MouseOx, produced by Starr Life Sciences (Figure 2). This device is not capable of monitoring four rats simultaneously, and is priced at $7000 for one device [2]. This is not what the client is looking for because of the high cost and the inability of the device to monitor multiple rats. A different pulse oximeter, produced by Nellcor (the Nellcor N-100), was tested for blood oxygen saturation (SaO_2) level accuracy when attached to a rat's tail. When SaO_2 levels were between 75% and 95%, this particular pulse oximeter was capable of measuring SaO_2 levels relatively accurately. When compared to the blood sample analysis, the N-100 measured SaO_2 levels with a standard deviation of ±5.7% [3].

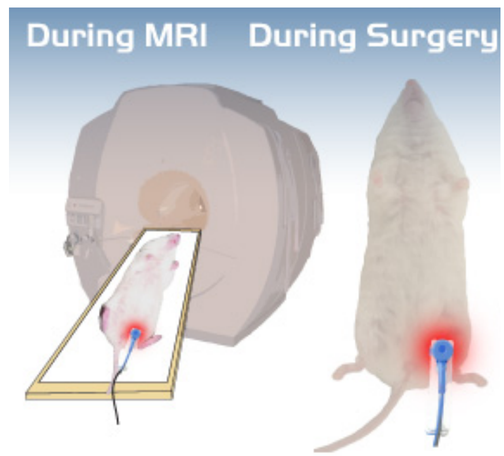

Figure 2: Pulse oximeter produced by Starr Life Sciences capable of measuring heart rate, breathing rate, and SaO2 levels [2].

The client occasionally uses a pulse oximeter designed for small animals, specifically monkeys and dogs, but is unable to consistently obtain accurate data. This is because of the high heart rate and low blood volume of rats. The heart rates of these rats can rise above 300 beats per minute, and this pulse oximeter was not designed with a high enough sampling frequency to measure these pulses or the corresponding oxygen saturation. Therefore, the monitoring device must be able to measure vitals outside the normal ranges of small animals or humans.

Client Requirements

The vitals monitor must be able to simultaneously monitor SaO_2 levels, heart rates, respiratory rates, and rectal temperatures of four rats simultaneously. SaO_2 levels must be monitored with an accuracy of ±2%. Heart rates of up to 500 beats per minute and respiratory rates of up to 30 breaths per minute must also be monitored. Rectal temperatures of 33 to 38 degrees Celsius (93 – 100 degrees Fahrenheit) are to be monitored as well. All four vitals of all four rats must be simultaneously displayed in a user-friendly graphical user interface (GUI) on one screen. All probes used to monitor rat vitals must be non-invasive and cause no harm to the rats. Finally, no component of the device can pass the cranial end of the sternum, because the PET scans are focused around the cranial region of the rats.

Motivation

Throughout the duration of the client's experiments, the rats are under heavy doses of anesthesia, which require manual adjustments by the laboratory assistants. The development of a system that readily displays the current values of each vital sign along with the option to view the history of each vital would be extremely beneficial. The laboratory assistants must be informed in a timely manner if any of the four vital signs enter critical ranges, in order that proper adjustments to the anesthesia can be made.

Currently there is no accurate, cost-effective method to monitor and display all four vital signs simultaneously. Since his research is based off of a four-rat setup, the existing devices previously mentioned will not suffice. It would be impractical for him to purchase four of the existing devices that are priced at or above $7000. The total budget of $4000 should therefore be considered throughout the design process and while planning to manufacture four final prototypes. Furthermore, the GUI that is to display the four vital traces must be specifically engineered according to the type of data it will be receiving from the circuit elements and corresponding probes designed to monitor each vital sign. The design team's goal is to design an inexpensive, easily operable prototype that incorporates circuit based monitoring systems along with a LabVIEW GUI to display the signals received from each monitoring system.

Previous Semester's Work [4]

The focus of the previous semester was to finalize the sensors for temperature and breathing rate along with developing algorithms that would accurately interpret the breathing rate and temperature signals. Ultimately, the team chose to utilize the inherent properties of force sensing resistors (FSRs) and thermistors (Figures 3 and 4) to determine breathing rate and rectal temperature, respectively. FSRs alter their internal resistance when pressure is applied, so as the rat breathes its chest will exert various amounts of pressure and the output voltage will then be proportional to the pressure applied. Thermistors also possess an internal resistance that responds to changes in temperature. Just as in FSRs, the changes in resistance within the thermistor correlate to changes in output voltage.

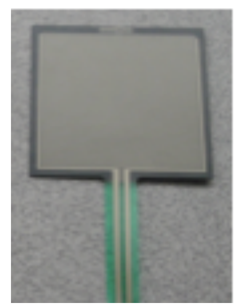

Figure 3: Force sensing resistor [4]

Figure 4: Thermistor [4]

LabVIEW was used to process all of the analog signals sent to the computer from the FSRs as well as the thermistors. Breathing rate was determined using a signal comparative algorithm. The average voltage received from a given FSR over a period of 10 seconds is compared to incoming raw data. When two sequential time points fall above and below the average value the time gets recorded and stored in an array. The breathing rate is calculated by determining the total time between the past 11 time points within the array, and dividing that value by 10 in order to determine the time between breaths. In order to process the temperature data, LabVIEW simply converts the incoming voltage into a live temperature based on the linear relationship between voltage and temperature within the thermistor.

Along with breathing rate and rectal temperature, steps were taken to develop a pulse oximeter circuit as well as individual pulse oximeter probes (Figure 5) with the help of a graduate student. The probe itself was made up of an assembly of excised components from an existing disposable Nellcor pulse oximeter probe. The harvested LEDs and photodiode were mounted onto a plastic clip opposite one another using a commercially available two-part epoxy. This configuration utilizes transmittance pulse oximetry as opposed to reflectance pulse oximetry. By utilizing transmittance, the output signal is stronger because it is not dependent on the amount of light reflected [5].

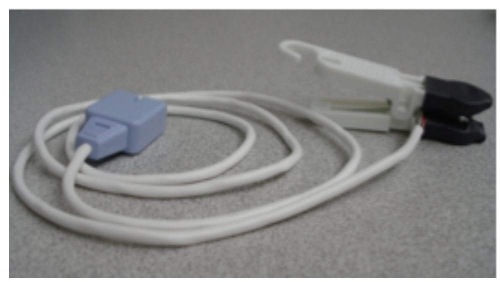

Figure 5: Pulse oximeter probe [4]

Finally, the team was able to program a graphical user interface (GUI). The GUI (Figure 6, next page) displays breathing rate and blood oxygen saturation (SaO_2) as live traces, as well as summary values and history graphs for all four vitals. Although the team was able to integrate the FSR and thermistor signals, work on integrating the pulse oximeter signal was not addressed.

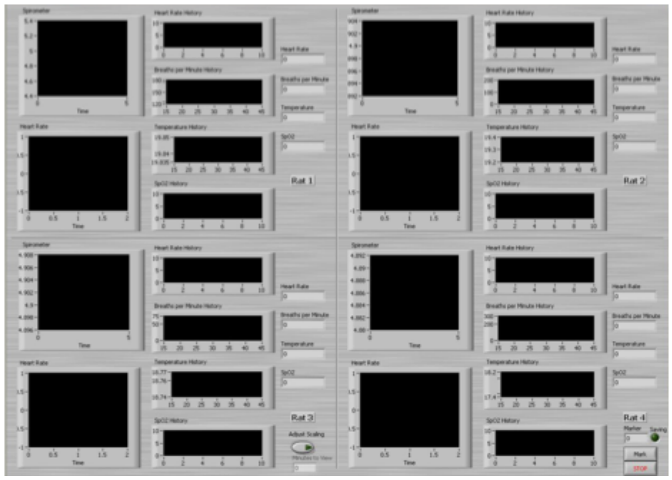

Figure 6: LabVIEW graphical user interface [4]

This Semester's Work

Up to this point in the semester, work has been done in a variety of areas. The team has spent a great deal of time developing the algorithms required to process the pulse oximeter data as well as calibration curves in order to generate more accurate SaO_2 values. Work has also been done to bring the current LabVIEW program up to date so it can receive the pulse oximeter data for processing as well as integration into the GUI.

With the prototype pulse oximeter circuit fully constructed the team has begun working on integrating the existing FSR and thermistor circuits with the ADC of the pulse oximeter. By coupling the thermistor and FSR circuits onto the pulse oximeter circuit board, the cost of circuit board printing will be greatly reduced.

Another aspect that has been taking into consideration is signal integration. The ultimate goal is to send an individual signal to the computer that contains the separate signals from each of the four circuit boards. Of the options available, the most promising option is the use of what is essentially a small computer, a Gumstix® processor. As mentioned this device works as a small processor and would be able to perform all data calculations before reaching the computer for display. This would prevent LabVIEW from becoming overwhelmed with data processing, resulting in a more streamlined display in real-time.

Communication

A major component of this project is to design and implement a method that allows the circuit boards to transmit data to the computer. The chosen method must allow data to be transmitted at a rate sufficiently fast enough so all data is acquired and included in the analysis. Additionally, it must be feasible for the team to complete any programming required. The team has researched and developed three methods that would allow for the communication of data between the circuit boards and the computer.

Universal Serial Bus (USB)

Universal serial bus, more commonly known as USB, is a wired connection directly between the pulse oximeter microcontroller and the computer. Such a connection would allow for data transmission of up to 480 Mbps (megabits per second) [6], well in excess of the requirements of one circuit board (each circuit board will have a data transmission rate of approximately 500 kbps). Because USB is commonly used in many aspects of computing today, using USB would not require users to learn how to interface the device with the computer. An implementation using USB would make the device plug-and-play. After connecting the USB cables to the computer, the computer would recognize the device and the user interface would be able to receive data from the pulse oximeter. Additionally, such cables are relatively inexpensive and would require no additional hardware for the computer or the microcontroller.

In order to make this device plug-and-play, some complex programming may be required. Most microcontrollers have USB libraries that allow for interfacing of USB with the microcontroller. It is unknown if the microcontroller in use on the pulse oximeter is USB compatible because the team is not working with the pulse oximeter hardware. If the microcontroller is not USB ready, additional work must be done to prepare the microcontroller for use with USB. With this method, each board would require one USB cable. As mentioned earlier, these cables are inexpensive ($16.99 for a 12 ft. cable [7]), but our client would require four of these cables at over 12 feet long each. The ideal setup of this device requires that the cables be taped to the floor to minimize tripping hazards.

A second option for using USB is to integrate the signals into an individual data stream using the Gumstix. This data could then be transmitted over a single USB cable. This single USB cable would help keep our client's laboratory cleaner and the overall cost a little less. However, it is unknown if each signal could individually be encoded on the Gumstix before being transmitted over USB. If that is possible, the computer could then separate the individual signals easily. Otherwise, some different method for identifying data must be developed.

Wireless Fidelity (Wi-Fi™)

Wireless fidelity (Wi-Fi™) is another commonly used computer protocol being considered for data transmission in this project. Wi-Fi is well known for allowing users to connect to a network or the Internet wirelessly. Another use of Wi-Fi is an *ad hoc* network. Such a network allows wireless devices to communicate directly with each other eliminating the need for other hardware such as a router [8]. Such a setup would be useful with this project as it would eliminate the cables required for the USB option and allow the users some flexibility with device setup in the laboratory. The Gumstix considered for use supports 802.11g wireless networking [9], which can achieve a theoretical speed of up to 54 Mbps. In practice, most 802.11g devices achieve a speed of 24 – 36 Mbps [10], more than sufficiently fast enough for this device. By setting up an *ad hoc* network between the Gumstix and computer, data can be transmitted between the two devices. Preliminary investigation into the capabilities of the Gumstix indicates that setting up this *ad hoc* network will be relatively easy.

However, this option is the most expensive. Depending on the Gumstix purchased, a separate Wi-Fi chip may need to be purchased. The estimated cost (including a Gumstix) can range anywhere from between $199 – $269 depending on the power of the Gumstix purchased. An Overo-series Gumstix contains a Wi-Fi chip already and is overall less expensive. The verdex pro-series Gumstix would require an expansion board with a separate Wi-Fi chip, but it may offer a little more flexibility with feeding the signal from the pulse oximeter microcontroller into the Gumstix. Some further research is needed in order to understand how to push data from the Gumstix through the Wi-Fi connection and how the computer will receive the data [9].

A final point to be considered with Wi-Fi is the potential for interference. Research indicates that the PET scanner should not interfere with the Wi-Fi signal. Additionally, wireless internet is present in the facility where the scanner is used and no problems have been reported.

Bluetooth®

Bluetooth® is another wireless option being considered. While similar to Wi-Fi in theory, it offers a shorter range, requires less power, and is less expensive overall [11]. One of the verdex pro-series Gumstix includes a Bluetooth chip which has an optimized data transmission rate of up to 3 Mbps, but it allows for individual tagging of signals to be transmitted at that rate [12]. However, it is a concern that the signal transmission speed will lower with multiple connections. Additionally, with lower power and a slightly lower speed, the range of Bluetooth is significantly less than that of Wi-Fi. Estimates of maximal range are between 10 and 33 feet [11]. Since this Bluetooth chip is built into the Gumstix, minimal interfacing should need to be done in order for it to transmit data from the pulse oximeter microcontroller.

The computer our client purchased for use with this project is currently not Bluetooth compatible; an adapter would need to be purchased and the computer configured to use it. Such adapters can be purchased for about $25 [13]. Additionally, some initial pairing of the device and computer will need to be performed and this may be difficult. Once paired, the devices should automatically detect and pair once they are within range of each other.

While this option is feasible, it still requires extensive research because not as much information is known about the Bluetooth protocol.

Communication Design Matrix

The Communication Design Matrix (Table 1) was used to evaluate the various design ideas. Programming feasibility was a major component of the evaluation criteria and USB scored the highest on this. Wi-Fi has a communication speed well in excess of the requirements, so it scored the highest in that category. Aesthetics was a measure of how clean the project would keep the client's laboratory and both Wi-Fi and Bluetooth scored the highest due to the fact they are both wireless. Operability was a measure of how easy it would be for the user to use the project; Bluetooth would require a little bit of setup and thus scored lowest in that category. With all criteria taken into account, the team will proceed with using Wi-Fi technology to stream data from the circuits to the computer.

Table 1 – Communication Design Matrix

Criteria (Weight)	USB	Wi-Fi™	Bluetooth®
Programming Feasibility (35)	29	28	31
Cost (15)	12	9	9
Operability (15)	12	10	8
Communication Speed (30)	25	30	20
Aesthetics (5)	1	5	5
Total (100)	**79**	**82**	**73**

Block Diagram

Figure 7 demonstrates the setup of this device. There will be four boards (one per rat) and each board will contain all the circuits components for the pulse oximeter, FSR, and thermistor. Each of these boards will feed into the Gumstix, which will act as the 'motherboard' to the entire system. Some signal processing may occur on the Gumstix. After signal processing, the data will be transmitted over the Wi-Fi connection where the computer will receive the data and display it in the GUI.

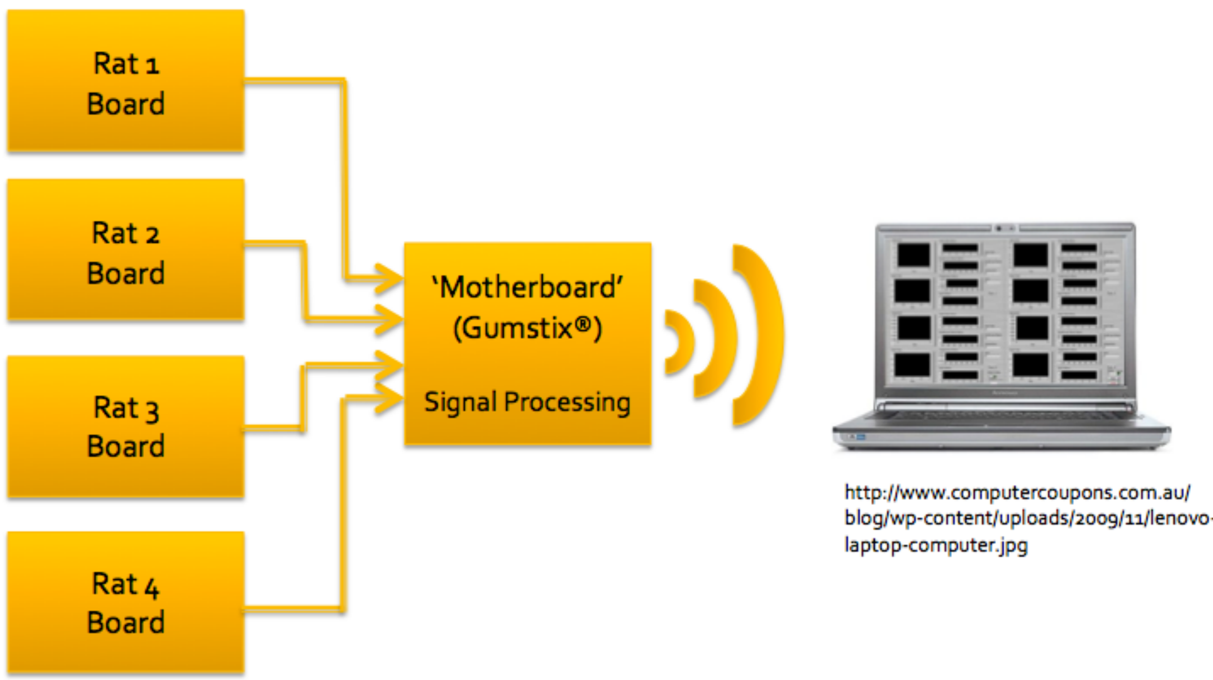

Figure 7: Block diagram of project

Circuit Board Housing

One of the main components of the device is the circuit board housing unit. The final design will consist of four identical circuit boards (one per rat) with the additional motherboard Gumstix piece. The housing unit must contain all of these circuit boards, as well as keeping them secure when the device is transported. The team considered three design options: the pegged 3 x 3 design, the toaster oven design, and the bunk bed design.

Pegged 3 x 3 Design

The pegged 3 x 3 design, as seen in Figure 8, is a two-piece rectangular prism. Each piece consists of three sides of the prism, and the two pieces slide vertically into each other. Pegs on the inside of the housing hold the circuit boards. The ports on the front of the housing allow the circuit boards to be connected to the probes. Each row of ports consists of one pulse-oximeter, one FSR, and one thermistor port. There is a fifth level of pegs inside to hold the motherboard.

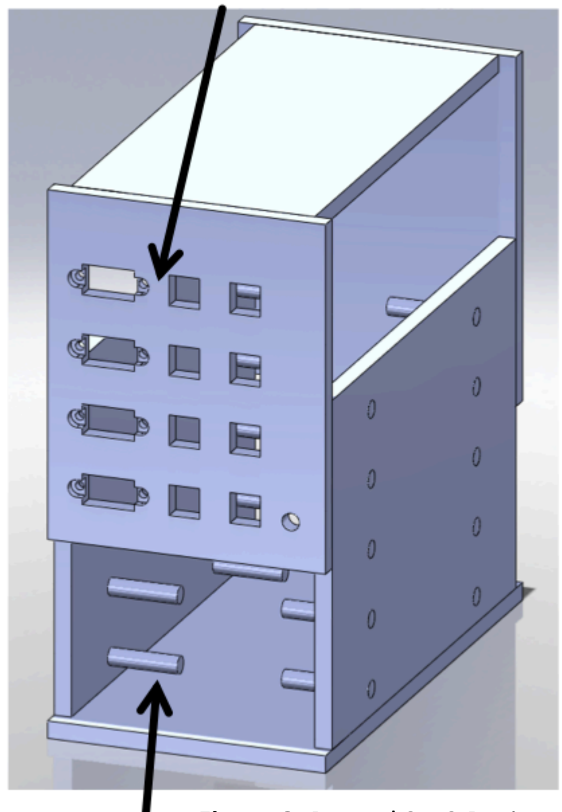

Figure 8: Pegged 3 x 3 Design

The advantages of this design include relatively simple construction as well as simple installation of the circuit boards. However, after the circuit boards are installed, they will be difficult to modify. In order to remove the top piece of the housing, all of the ports on the faceplate need to be removed. This design would also be slightly less stable than the other design alternatives, because each of the two pieces could flex inwards and outwards, possibly compromising the integrity of the joints. Also, the boards would require additional support to keep them from sliding around inside the housing after installation.

Toaster Oven Design

The second design option is the toaster oven design (Figure 9). This alternative is similar to the pegged 3 x 3 design in that it is a rectangular prism with roughly the same dimensions and the same faceplate. The difference between the two is how the circuit boards are supported on the interior, along with how the boards can be accessed. As seen in Figure 8, the toaster oven design has grooves in the interior walls that will support the circuit boards. These grooves allow the circuit boards to be slid in the back of the housing up against the faceplate, where the ports for the probes will be attached. Another difference with this design alternative is the hinged door. This design option allows for simple installation as well as easy modification of the circuit boards. Since the hinged door can be opened without removing any ports, individual boards can be removed without tampering with the rest of the boards. This design option is the most structurally sound because the four-sided piece is more rigid than the three-sided pieces in the pegged 3 x 3 design. Also, the circuit boards are more secure in this design because the grooves provide more of a fixed support than the pegs. However, this design option will be the

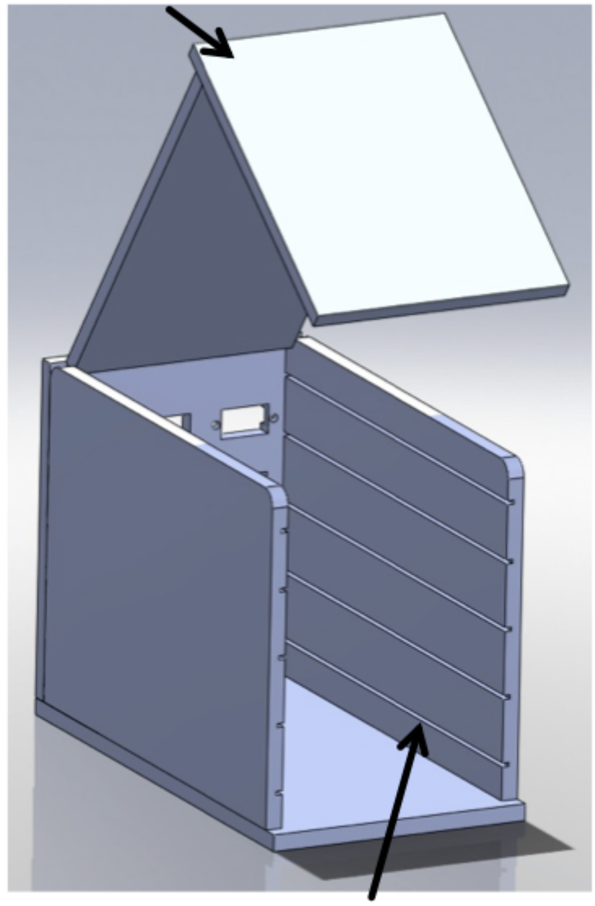

Figure 9: Toaster Oven Design

most difficult to construct because the grooves must be precisely aligned with the ports on the faceplate so there is no stress on the circuit boards or the probe receptacles.

Bunk Bed Design

The third design option is the bunk bed design. As seen in Figure 10, this design alternative consists of five 'bunks' supported by four rods. The bottom four bunks will hold the four identical circuit boards, and the top bunk will hold the Gumstix board. This design is aesthetically pleasing for the technologically savvy individuals working in the lab setting. It is also the easiest to manufacture. Any modifications to the circuit boards while testing the prototype would be extremely simple because of the open design. This open design, however, presents some problems. The circuit boards would be exposed with this design, which could result in damage if extreme care is not taken. Also, communication between the four identical boards and the motherboard would require additional wiring on the outsides of the bunks, increasing vulnerability to damage.

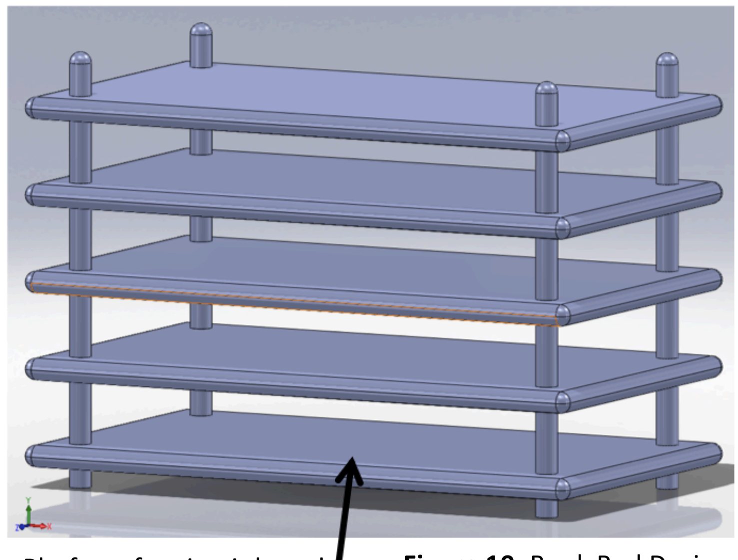

Figure 10: Bunk Bed Design

Circuit Board Housing Design Matrix

The circuit board housing design matrix (Table 2) was used to evaluate the three proposed design alternatives. Each option was rated using the following criteria: manufacturing feasibility, ergonomics, durability, and aesthetics. Ergonomics was weighted the highest because this will be the most important aspect of the design for the client. Even though the toaster oven scored lowest in manufacturing feasibility because of the extreme precision needed for the grooved sidewalls, this option scored highest in ergonomics and durability. The bunk bed design received a low score in ergonomics and durability because of the exposed circuitry and wiring. Because of its high durability and high grade in ergonomics, the design team decided to construct the toaster oven housing unit. Proposed dimensions for this design can be found on page 28.

Table 2 – Circuit Board Housing Design Matrix

Criteria (Weight)	Pegged 3 x 3	Toaster Oven	Bunk Bed
Manufacturing Feasibility (30)	26	22	26
Ergonomics (40)	30	35	25
Durability (20)	15	17	14
Aesthetics (10)	7	7	10
Total (100)	**78**	**81**	**75**

Future Work

The goals for the remaining part of the semester include extensive fabrication as well as development of signal processing algorithms. One of the more pressing matters on the agenda is the ordering of materials for construction of the compiled circuit boards along with the final housing after the boards themselves are printed.

Although a majority of the sensors that will be used by our client have already been constructed, there are still some that need to be put together. A majority of the sensor construction will be dedicated to the fabrication of the required pulse oximeter probes. Several replacement sensors will be created in case of sensor failure within the lifespan of the vitals monitor.

While working on the various circuit and probe fabrications, development of the algorithms required to process the individual pulse oximeter signals will ensue. Once completed, the last step will be to incorporate the pulse oximeter data into the GUI.

Ergonomics

When considering the various design options for the communication aspect and the housing portion of the project, human interaction with the vitals monitor was a major factor. The device must be, at a minimum, operable by someone with computer knowledge as their only experience with electronics. The LabVIEW GUI has already been designed to be exceptionally user-friendly, and all measurement probes require minimal setup with respect to each animal, and simply are plugged into the circuit housing unit. As seen in Figure 1 (pg. 4), there is already a significant amount of equipment present in the laboratory setting that our client and his research assistants work in. Therefore, the device should not add any clutter to the research environment. There will already be 12 external wires, one for each probe, and a cord for the power supply, so any additional external wiring should be avoided at all costs. This spatial constraint and the user-friendliness requirement are the main reasons why we selected the familiar Wi-Fi option for the method of data transfer (in addition to its high speed).

Unlike most central processing units of small animal pulse oximeters, our housing device is being designed while considering the feasibility of disassembly. This is because the user might be required to disassemble the housing in order to fix a malfunction in the future. The likelihood of a malfunction is minimal, but needs to be considered nonetheless. All three design options possess plug-ins for the 12 measurement probes that can be easily reached by hand and will not require any excessive force or maneuverability. The stacked layout of the circuit boards that rest in the horizontal grooves of the toaster oven design allows for a single circuit board to be installed and removed independent of the other four boards. Lastly, the housing will be constructed with lightweight acrylic to minimize its weight. If the housing unit needs to be transported to and from storage between uses, the lightweight feature will facilitate this process.

Ethical Considerations

Animal safety is the main ethical consideration in the design of a quad rat vitals monitor. The client has specified that all probes used in the final design should be non-invasive and cause no harm to the rats. All electrical components of the design have been designed to be isolated from the animals by being encased in an acrylic housing (See above section on housing design). While no testing has been conducted on animals up to this point in the current semester, several testing runs were conducted on a single anesthetized rat in previous semesters. During each test run, all governmental and university standards regarding proper animal care were carefully followed [14]. To finish, it is important to note that the design of a quad rat vitals monitor is to serve the sole purpose of a diagnostic tool, and should not replace any standard small animal laboratory procedures. The final design will be able to accurately notify the researcher when the vital sign of any rat enters a critical range; however, it is not designed to prevent any rat from entering into such a critical range.

Budget

Estimated costs can be seen below in Table 3 (next page). Probe plugs and receptacles, and a 5 V power supply will be purchased from digikey.com and are estimated to cost around $20 including shipping and handling. The acrylic that will be used for constructing the housing will be supplied by our client and will come at no additional cost to the project. Spare measurement probes (FSR and thermistors) are estimated to cost $20 total. The printed circuit boards will be purchased online from ExpressPCB.com. According to the website, four 4-layer printed boards should cost around $500 including shipping. The Gumstix processing board to be purchased from gumstix.com is priced at $269 (Gumstix board can be purchased with Wi-Fi chip already mounted). All of the circuit elements that need to be mounted on the printed circuit boards will be purchased from digikey.com and are calculated to cost $100.00 according to the pricing of elements used to build the prototype pulse oximeter circuit. Lastly, the design team's client purchased a high speed Lenovo laptop last semester for $660. This new laptop is needed in order to operate LabVIEW at an adequate speed.

Table 3 - Budget			
Item	Needed	Price per Unit ($)	Estimated Total Cost ($)
Plugs and receptacles	8	2.00	16.00
Power Supply	1	6.00	6.00
Acrylic	181 in^2	Free	Free
Spare FSR and Thermistor	2	10.00	20.00
Printed Circuit Boards	4	100.00	400.00
Gumstix Processor	1	269.00	269.00
Circuit Elements Set	4	25.00	100.00
Lenovo Laptop (Already purchased)	1	660.00	660.00
Estimated Total			**$1471.00**
Estimated Total Remaining			**$811.00**

Conclusion

This semester, the design team has worked to develop a pulse oximeter calibration curve and enable LabVIEW to receive data from the pulse oximeter. The team has worked closely with the graduate student working on the circuit and programming of the pulse oximeter microcontroller.

A method of transmitting data from the circuit boards to the computer has been selected. Wi-Fi will be used in conjunction with a Gumstix computer to do signal processing and transmit data to the project computer. Work will be done on pulse oximeter signal processing algorithms as well as enabling the Gumstix to transmit this data.

A blueprint for a circuit board housing unit device has been developed as well. The chosen toaster oven design allows for easy fabrication and installation of the circuit boards. Further modification of the circuit boards is easy because a single board can be removed from the housing unit independently from the other four.

The design team will continue to work closely with the graduate student building the pulse oximeter. In order to finalize the design, the pulse oximeter circuit boards need to printed and built and signal processing algorithms need to be developed to process the data from the pulse oximeter. This data will be integrated into the current LabVIEW GUI.

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Appendix

Product Design Specifications
Rat Quad Vitals Monitor
1/25/10

Team:

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Function: A device that is capable of recording and displaying SpO2 levels, heart rate, rectal temperature, and breathing rate of four rats simultaneously. The purpose of this is to help maintain appropriate anesthesia dosage on the four rats.

Client requirements: Accurately record and display SpO2 levels, heart rates, breathing rates, and body (rectal) temperatures of four rats under anesthesia simultaneously.

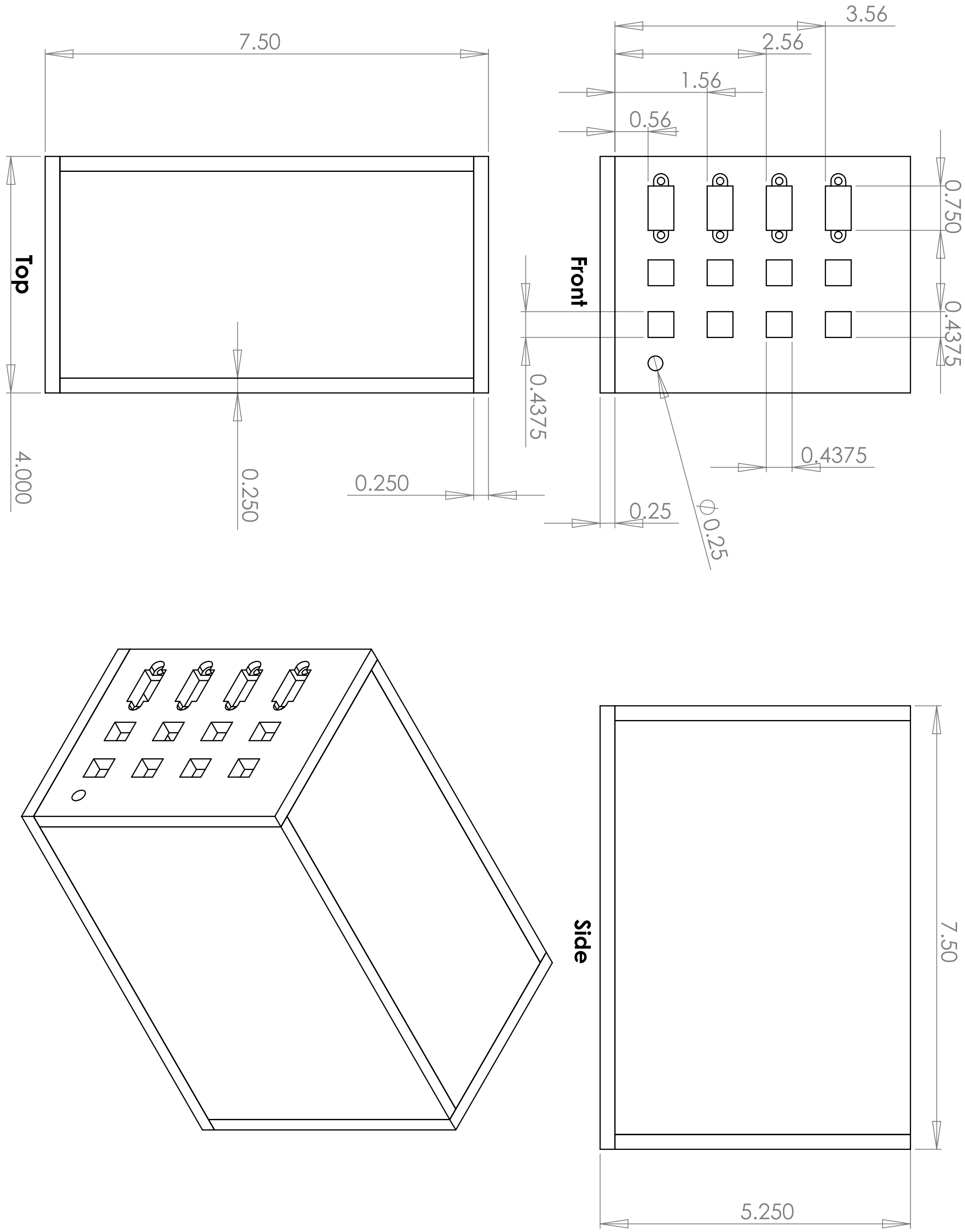
Design requirements: Build a device that measures and displays the vital readings of four rats under anesthesia. The device must be able to accurately detect heart rates of up to 500 bpm and blood oxygen saturation levels to an accuracy of ±2% so that the anesthesiologist is able to determine the adequate dosage of isoflurane to keep the rats anesthetized. Device will also be designed to monitor respiratory rate (around 20 breaths/min) and rectal temperature (93-100° F).

Physical and Operational Characteristics

1. *Performance requirements:* The device, at minimum, should be able to take the heart rates, breathing rates, and temperatures of four rats simultaneously and display them onscreen. It should also have running graphs showing the vitals of each rat for the duration of the experiment or for a user specified time. It should also display live traces of respiration and heart rate. The software should also record the average values of the vitals to hard disc every fifteen seconds.
2. *Safety:* The device should be safe for animal use and be consistent with the safety standards of the current rat platform.
3. *Accuracy and Reliability:* The device must be able to accurately detect heart rates of up to 500 bpm, blood oxygen saturations level accuracy of ±2%, respiratory rates of at least 30 breaths/min, and rectal temperatures of 93-100° F.
4. *Life in Service:* The device must be functional for at least 5 years, with calibration as needed. The device will be used twice a month to once a week.
5. *Shelf Life:* The device should be able to go without use for a semester and be put back into use with normal functionality.

6. *Operating Environment:* Will be used in a laboratory environment.
7. *Ergonomics:* The pulse oximeter probe should comfortably fit onto the hind paw of each rat. The probes should not be influenced by the inclusion of bubble wrap during tests. The graphical user interface must be optimized to minimize user interaction. All external probes must be user replaceable with minimal effort.
8. *Size:* Clips must be small enough so that it will not interfere with surrounding sensor and/or devices. No sensors should interfere with the PET imaging, keeping any large components inferior to the base of the heart.
9. *Weight:* The sensor system must not have a mass greater than 1 kilogram.
10. *Materials:* Derived oximeter sensors, converted human oral thermometers, and force sensing resistors. All other materials will not be in contact with the rats.
11. *Aesthetics, Appearance, and Finish:* There must be no exposed circuit components.

- **Production Characteristics**
    1. *Quantity:* One.
    2. *Target Product Cost:* under $4,000
- **Miscellaneous**
    1. *Standards and specifications:* N/A
    2. *Customer:* Research organizations working with rats.
    3. *Patient-related concerns:* Currently no patient-related concerns.
    4. *Competition:* MouseOx produced by Life Starr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0.250
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2.56
1.56
0.56
Front
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0.4375
0.4375
0.4375
0.25
ϕ0.25
Side
7.50
5.250