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. Future areas of focus in the design and construction of a final prototype include fabricating additional pulse oximeter probes, integrating the new pulse oximeter circuit, and constructing a unit to contain all of the circuit components.

Table of Contents

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.

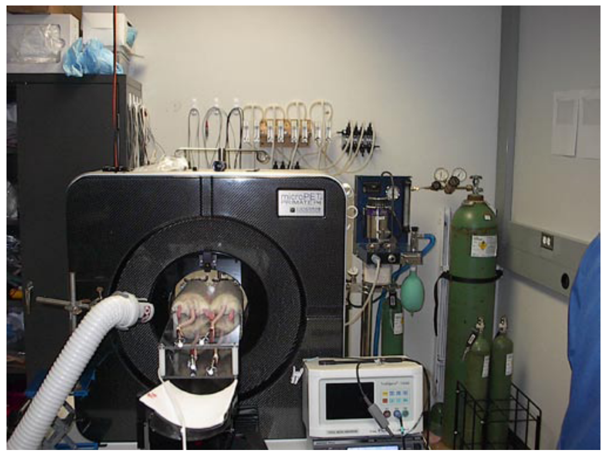

Figure 1: This picture shows four rats in the PET scanner at the client's laboratory. The rats are orientated in a two by two square [1].

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 (SpO_2) level accuracy when attached to a rat's tail. When SpO_2 levels were between 75% and 95%, this particular pulse oximeter was capable of measuring SpO_2 levels relatively accurately. When compared to the blood sample analysis, the N-100 measured SpO_2 levels with a standard deviation of ±5.7% [3].

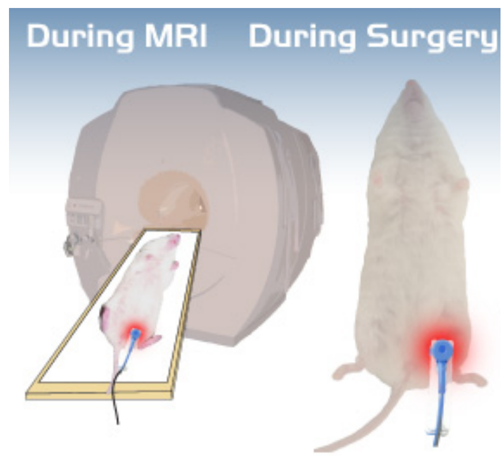

Figure 2: Pulse oximeter produce by Starr Life Sciences capable of measuring heart rate, breathing rate, and SpO_2 levels [2].

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 SpO_2 levels, heart rates, respiratory rates, and rectal temperatures of four rats simultaneously. SpO_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 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 our 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 our client's research is based off of a four-rat setup, the existing devices previously mentioned will not suffice. It would be impractical for our client to purchase four of the existing devices that are priced at or above $7000. Our client's 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. It is our goal 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

The BME 402 design team that began work on this project during the 2008-2009 school year was able to engineer methods for calculating breathing rate and rectal temperature. The method for calculating breathing rate is dependent on a force plate, shown in Figure 3, which contains a force sensing resistor (FSR) that is placed underneath the rat just below the sternum. As the rat breathes, pressure is exerted on the plate, causing the variable resistance of the resistor to change. Applying a five volt voltage dividing circuit across the FSR allows this

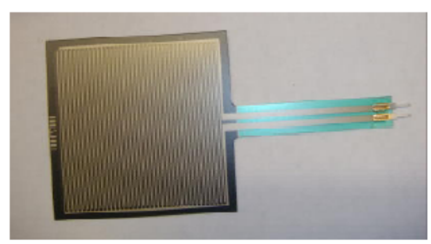

Figure 3: Force plate containing force sensing resistor [1].

fluctuation in resistance to be converted to a voltage, which can then be sent to LabVIEW where the digital voltage readings are displayed graphically as a breathing rate (breaths/min).

The method for calculating rectal temperature uses the circuit layout shown in Figure 4. Digital human thermometers purchased from Walgreen's each possess an internal resistance that changes along with temperature and thus causes the voltage across the thermistor to change, much like the FSR described above changes with pressure. The thermometer is connected to the positive input of a non-inverting amplifier to amplify the voltage signal, which is then sent to LabVIEW where the digital voltage readings can be displayed graphically.

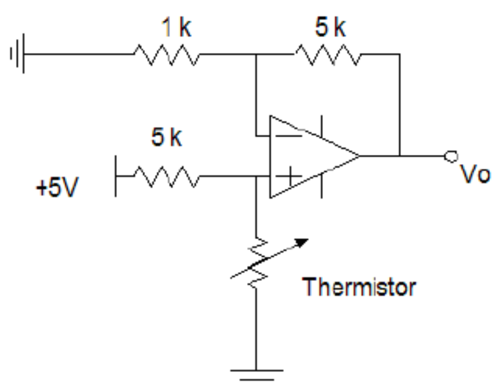

Figure 4: Circuit diagram for temperature sensing thermistors. Circuit contains a voltage divider connected to a non-inverting amplifier [1].

After the circuit elements for detecting breathing rate and sensing rectal temperature had been designed, the design group wrote a LabVIEW program for receiving the digital signals from each circuit via an analog to digital converter. LabVIEW calculates the average voltage received from the FSR circuit for the most recent 10 seconds of data, and then compares the incoming raw data to that average value. When two sequential time points fall above and below the average value for the past 10 seconds, the time is recorded and stored in an array. From there, breathing rate is calculated by finding the total time between the past 11 time points stored in the array, and dividing by 10 to give the time between breaths. Lastly, the time calculated between breaths is converted from milliseconds to minutes in order to give a value in breaths per minute to be displayed to the user.

For the temperature sensing circuit, the previous design group ran voltage calibration tests and concluded with an R^2 value of over 0.993 that the voltage versus temperature relationship for the store bought thermistors behaves linearly in the temperature range required by our client. Results can be seen above in Figure 5. This linear relationship is programmed into the LabVIEW GUI to convert the incoming voltage data into a live temperature displayed to the user.

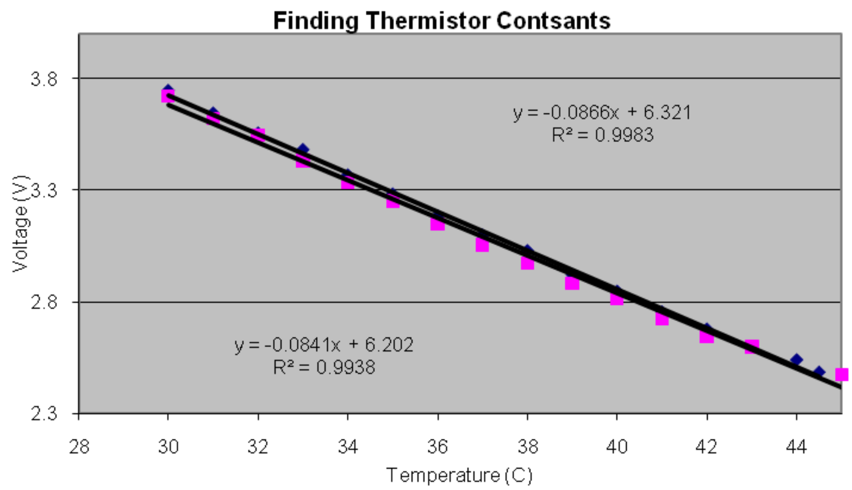

Figure 5: Test data showing the linear relationship between voltage and temperature [1].

A simple LabVIEW GUI was designed by the previous team to receive the signals from the FSR and thermistors circuits. This GUI, which can be seen in Figure 6 (next page), is far from the final interface designed this semester. Nonetheless, the previous GUI was able to receive the FSR and temperature signals and display a live trace of voltage from the FSR circuit, which was used to determine when a breath had taken place, and also displayed temperature readings from the thermistors. This GUI layout did not have the capabilities of receiving data from a pulse oximeter circuit nor could it integrate that data to display live traces of blood SpO_2 and heart rate. Expanding this GUI was a priority for this semester, and three design options for doing so are highlighted in the following section.

Figure 6: Final graphical user interface from last semester.

Mid-Semester Design Options

Pulse Oximeter Probe

One of the fundamental physical properties that allows a pulse oximeter to measure oxygen saturation of hemoglobin is that blood undergoes a color change as hemoglobin absorbs varying amounts of light depending on its oxygen saturation. Highly saturated hemoglobin (oxyhemoglobin) does not absorb much red light (a wavelength of about 660nm), but as oxygen saturation falls, blood becomes darker and an increase in red light absorption results. The opposite relationship is true for infrared light (a wavelength of about 940nm); oxyhemoglobin absorbs more infrared light than blood with reduced hemoglobin. Beer's Law, the underlying principle used in pulse oximetry, relates the concentration of oxygen bound to hemoglobin to the amount of light that is absorbed by the hemoglobin for specified wavelengths [4].

The difference in absorption relations for the red and infrared light generate relative concentrations of the reduced and oxygenated hemoglobin. Upon comparison, a ratio of oxygenated to deoxygenated hemoglobin is produced. The ratio can then be used in conjunction with a calibration table to determine a specific SpO_2 value.

Following several probe design requirements, such as reusability and the ability to adjust to various size rats, the first major component of this design project was initiated.

Foot Clip

The foot clip probe (Figure 7) is loosely based off of existing human pulse oximeter probes. Essentially it works like a clothespin, where the hind paw of the rat is placed between the top and bottom halves of the clip. On the inside surfaces of the two halves are mounted LEDs and a photodiode. The LEDs and photodiodes are positioned across from one another, so that only light passing through the tissue is registered by the photodiode. This design is similar to current devices used by the client, so implementing it into their laboratory would be easy. Although the ability to reposition the probe contributes to its attractiveness, the opportunity for undesired displacement is also possible. Another shortcoming of this design is the potential for the clip to apply too much pressure to the hind paw of the rat, altering arterial blood flow. Any disruption in arterial blood flow will result in inaccurate SpO_2 data.

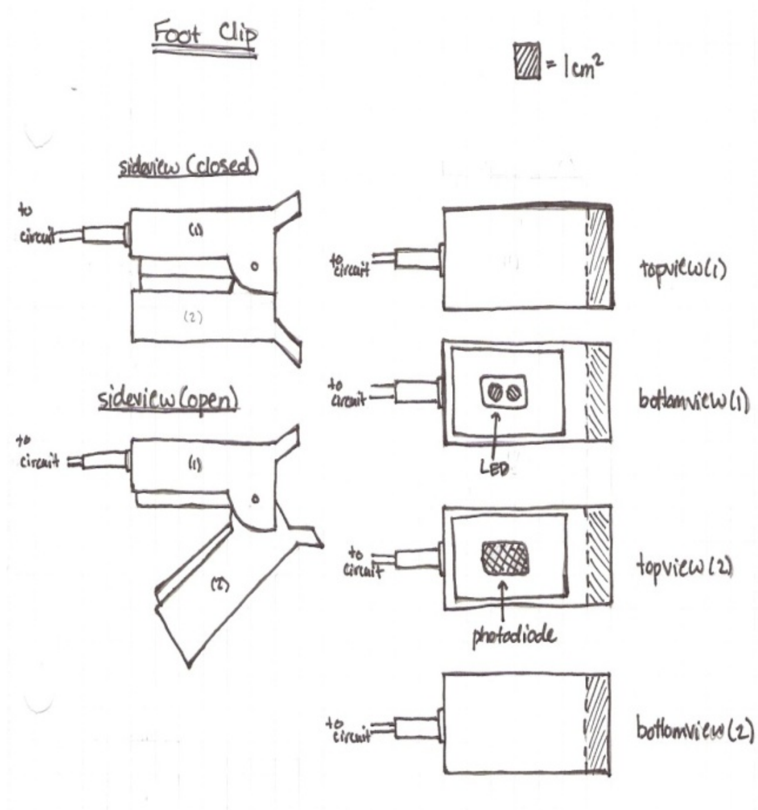

Figure 7: Design of *Foot Clip*

Foot Wrap

The second probe design (Figure 8) is a system of symmetrical hinged plates held in position by a Velcro™ strap. As before, the LEDs and the photodiode are mounted on opposite plates. The rat's hind paw is placed between the two plates and then held in position once the probe is attached. One of the main benefits of this design would be the immobility of the probe after attachment. Once fixed in place, there is little opportunity for the probe to become misaligned. Although successful in eliminating alignment concerns, this design does not allow for easy readjustment. If any problems arise with probe placement throughout testing, adjustability of the probe is vital to maintain accurate data acquisition.

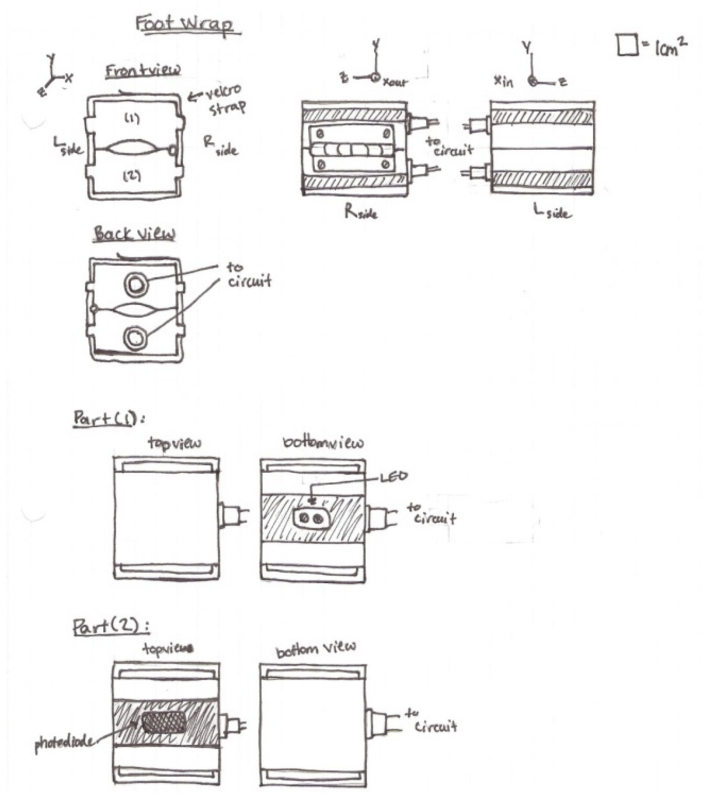

Figure 8: Design of *Foot Wrap*

Tail Clip

The final probe design, shown in Figure 9 (next page), is very similar to that of the foot clip. It again behaves as a clothespin would, trapping the tail between the two halves of the clip. For this design, the rat's tail is positioned so that it rests within the groove machined into the opposing halves of the tail clip. The LEDs are again mounted opposite to the photodiode.

Similarly to the foot clip, the tail clip is easy to attach as well as adjust. Along with the dangers of applying excessive pressure on the arteries within the tail, this probe design also has the potential to interfere with or damage the catheter located below the tail during the course of the experiment. Blood flow is not as prominent in the tail when compared to the foot, so the signals received by the photodiode would most likely be less intense and contain more noise.

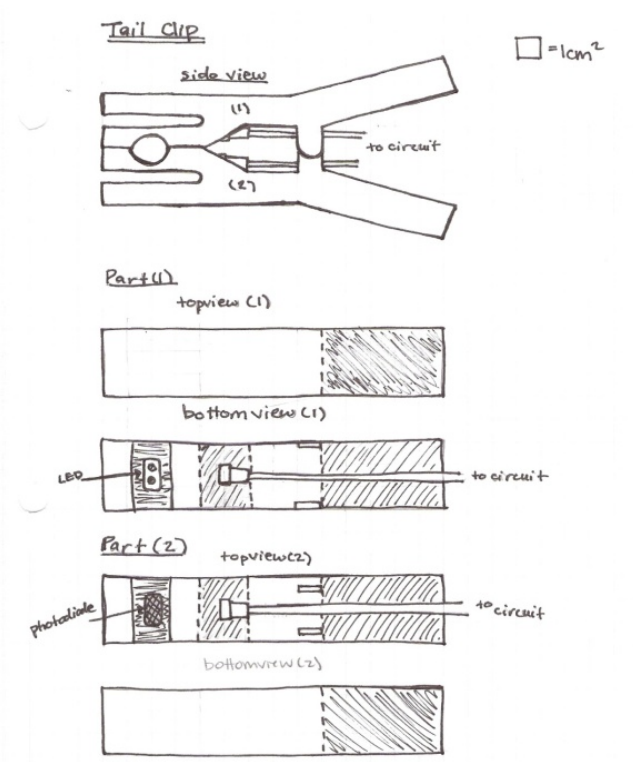

Figure 9: Design of *Tail Clip*

Pulse Oximeter Probe Design Matrix

The pulse oximeter probe design matrix (Table 1) was used to evaluate the various probe designs and to determine which design best fits the client's needs. For ergonomics, the foot clip scored the highest because of its ease of use and adjustability. The cost for each probe was relatively the same for each case, and therefore did not heavily influence the final probe decision. The accuracy of the tail clip was rated significantly lower than the other two designs due to the denser skin properties of the tail, as well as the location of the catheter in close proximity to the tail. The flow of blood through the tail is also less than that of the foot, so the tail clip may have difficulty collecting data. As for safety, all three designs were rated relatively

Table 1 - Design Matrix: Pulse Oximeter Probe

Criteria (Weight)	Foot Clip	Foot Wrap	Tail Clip
Ergonomics (20)	18	12	14
Cost (5)	4	5	4
Accuracy (50)	46	46	35
Safety (10)	8	9	8
Durability (10)	9	6	9
Feasibility (5)	4	5	4
Total (100)	**89**	**83**	**74**

the same; none of the probe designs put the long term health of the rats in danger. Although it was mentioned that the foot and tail clips may exert excessive pressure on their relative body parts, with proper manufacturing, this can be avoided. The durability of the foot wrap was rated low because of the potential for the Velcro strap to wear out over time. For the amount of times these probes will be used, durability is vital for extended use. Just as in cost and safety, feasibility is relatively the same for each probe. After considering all of the aforementioned criteria, the design team decided to construct the foot clip model.

Graphical User Interface

The second major component of this design project was to display the collected data to the user in an easy-to-use fashion. The decision was made last semester to utilize National Instrument's LabVIEW software package not only for data acquisition, but to generate a GUI. This semester's team went forward with that decision. LabVIEW, in contrast to normal programming languages, is a graphical-based programming language that allows the programmer to wire connections between functions provided by LabVIEW. These functions include, but are not limited to, math functions, tools to acquire signals from devices, and displaying data on graphs.

Four Corners with Buttons

The first design idea divides the user's screen into four sections; each rat is designated a section, as seen in Figure 10 (next page). Within each section, the user is presented with a live trace of breathing and heart rate. Below the live traces, the numerical values of the vitals can be found. Buttons are available for the user to view a graph of the history of a vital over the course of the experiment or a user-specified amount of time. The history graphs allow the user to view the trend of the vital. This design allows the user to quickly glance at the screen to view the current status of a rat and compare it to the other rats. It is attractive and would work well on many different sized screens. However, because the user must click a button to view the history graph, it may become cumbersome for the user to view the history of a vital and compare it to others because of the extra clicking involved. Additionally, because of the clicking involved, this may detract from the researcher's experiment because it is another task they must be concerned about. Additionally, this option requires much more programming in order to code the individual buttons for their functionality, but it is not beyond this team's abilities. Overall, this design idea would result in a clean, easy-to-use interface.

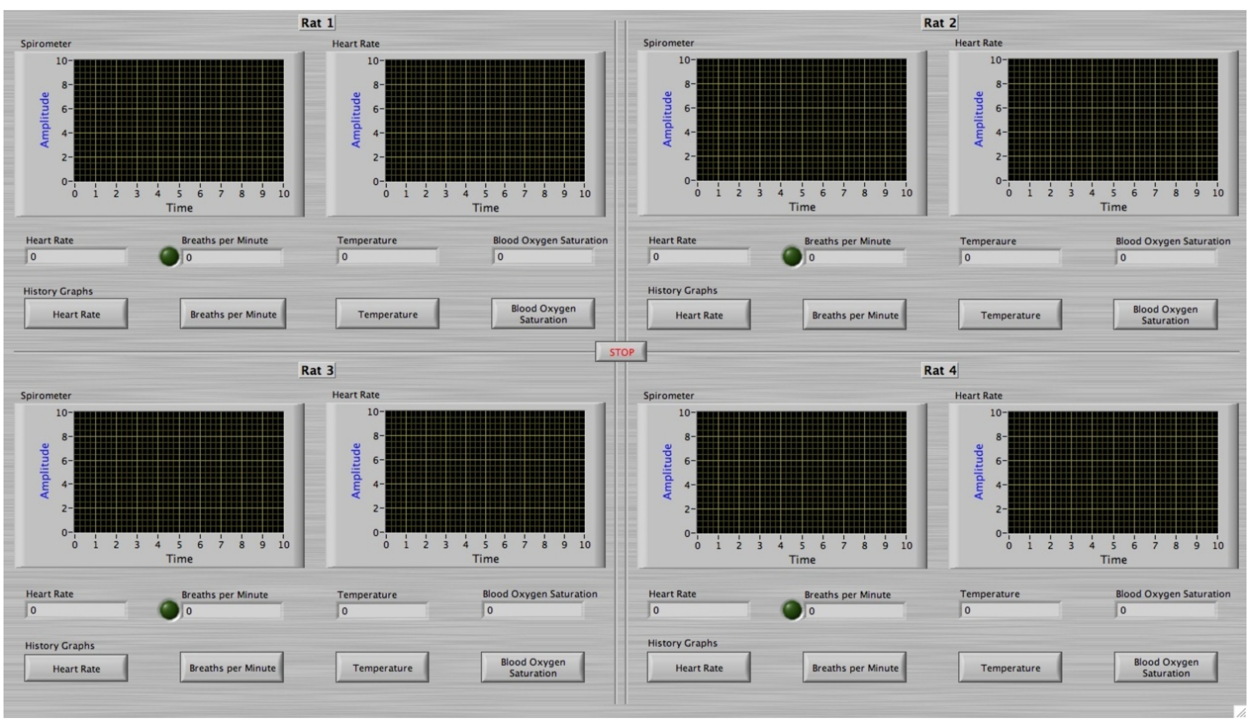

Figure 10: Design of *Four Corners with Buttons* interface

Tabbed

The second design idea is a departure from the first. Each rat is designated a tab, and within each rat tab, two more tabs are present: one for live data and one for histories. This tabbed organization is visible in Figure 11. The live data tab displays the same two live traces as the first: breathing rate and heart rate. The values of the vitals being gathered are displayed underneath the live traces. The history tab displays the four history graphs over the course of the entire experiment or over a user-specified amount of time. This interface is even cleaner and with a few clicks, the user can quickly navigate to the data they wish to view. Because of the nature of this design, the user cannot compare the available data, live or history, between any of the rats simultaneously. Additionally, similar to the first design idea, this would require extra clicking on the user's part. However, using the tools LabVIEW provides, the tabs are very easy to program. This design is an acceptable contender, but its positives must be completely evaluated against its deficits.

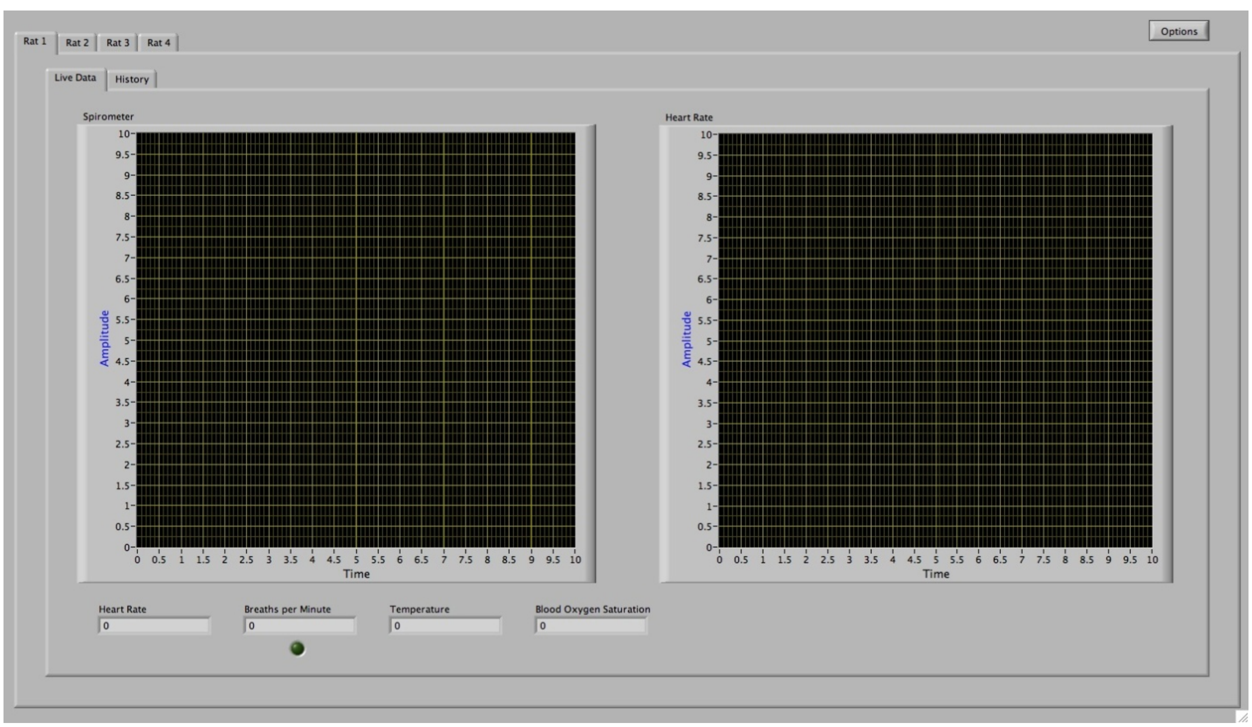

Figure 11: Design of *Tabbed* interface

Four Corners with Histories

The third proposed design is similar to the first in that it divides the screen into four sections. This design can be seen in Figure 12. Within each section, all the data that is available for rat is displayed. There are two live traces of breathing and heart rate and the values of the vitals are displayed. But in departure from either of the first or second design ideas, the four history graphs are also displayed. By displaying the history graphs on the same screen as the other data, the screen appears cluttered, but this is an acceptable tradeoff for the least amount of user interaction required. As matter of fact, the only user interaction required with this design is to start the data collection, adjust options as necessary (such as the time interval of history graphs) and to stop the data collection.

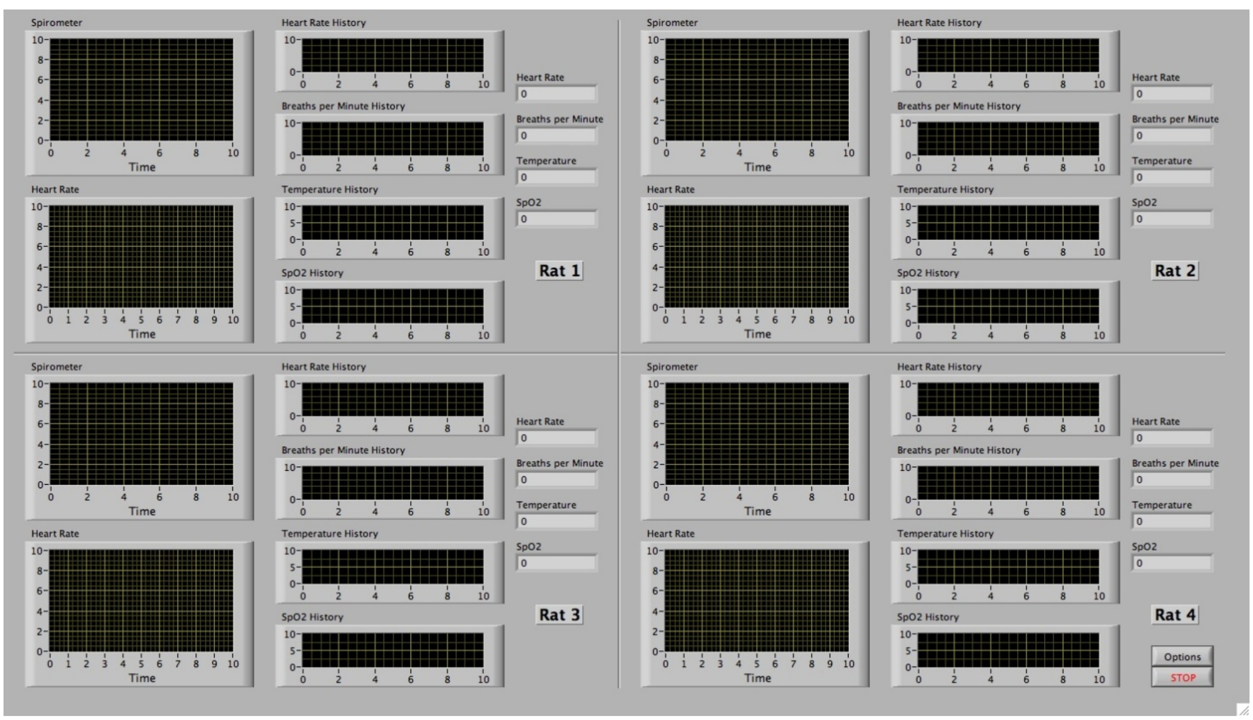

Figure 12: Design of *Four Corners with Histories* interface

A glance at the screen by the user is all that is necessary to check the status of a rat. Because the history graphs are all on the same time interval, it is easy for the user to correlate trends not only among one rat, but also among all the rats. This option is doable well within the programming expertise of the group. However, because of the large amount of data on the screen, this display may become small and hard to read on smaller screens. It is also unknown how the performance of this design will keep up with a massive amount of data due to LabVIEW's need to process all the data before it can be displayed every time the history graphs update. This design has many positive points and meets all of the client's requirements, but some further investigation is required.

GUI Design Matrix

The graphical user interface design matrix (Table 2, next page) was used to evaluate the three design ideas on the basis of ergonomics (weighted 45/100), programming feasibility (35/100), and aesthetics (20/100). For the purposes of this matrix, ergonomics refers to the ease of use for the user and is weighed the highest because of the client's need for an easy-to-use and view interface. The four corners with histories option scored the highest on ergonomics because of the least amount of user interaction required to view the data. However, because of the cluttered interface, this option also scored the lowest in aesthetics. This option did not score as well in programming feasibility as the tabbed interface due to the amount of precise measurements and resizing of elements required to make the interface appear uniform and have even spacing. However, this was a minor tradeoff for a gain in ergonomics. After considering all of the aforementioned criteria, the design team decided to program the *Four Corners with Histories* option.

Table 2 - Design Matrix: Graphical User Interface			
Criteria (Weight)	Four Corners with Buttons	Tabs	Four Corners with Histories
Ergonomics (45)	38	25	44
Programming Feasibility (35)	26	32	30
Aesthetics (20)	15	18	14
Total (100)	**79**	**75**	**88**

Final Design

The final design consists of five integrated components – the breathing rate monitoring devices, the thermistors, the pulse oximeter, the LabVIEW GUI, and the power supply.

Force Sensing Resistors

Breathing rate will be monitored using the same force sensing resistors that the previous team used (Figure 13, next page). After initially receiving negative test results, the team decided to improve on multiple aspects of this part of the prototype. The team rewired the force sensing resistors with solid core wire to improve connections to the breadboard. A respiration belt was constructed in an effort to reduce noise in the data (Figure 13, left). The respiration belt consists of an acrylonitrile butadiene styrene (ABS) plate connected to a strap. The strap contains an elastic component and an inelastic component. The inelastic component is an adjustable Velcro™ strap, which allows the belt to fit a wide range of rat sizes. The research assistant utilizes the respiration belt by strapping it around the circumference of the rat's thoracic cavity so that the strap stretches when the rat inhales. The force sensing resistor is placed between the rat and the ABS component of the belt. The respiration belt helps direct the force of the expansion of the rat's lungs into the force sensing resistor. Since measuring breathing rate worked equally well either using the respiration belt or by simply placing the force sensing resistor underneath the rat's lungs (see testing section), it will be the client's decision whether or not to use the respiration belt.

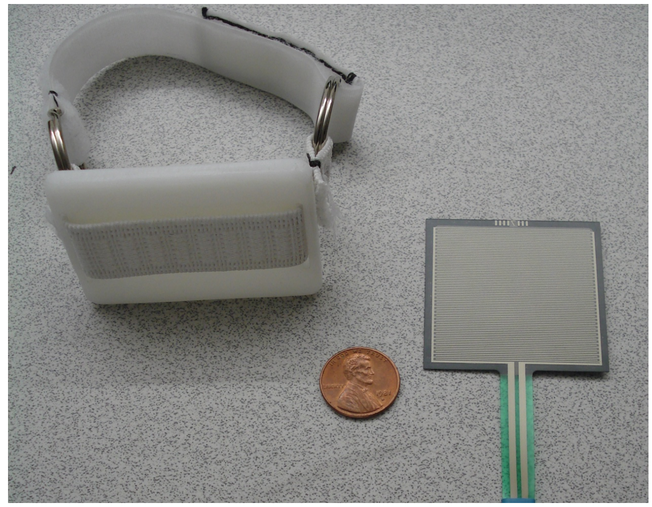

Figure 13: Breathing monitoring devices. The upper left shows the respiration strap and left show the force plate.

It is possible to use a pulse oximeter to measure breathing rate, but the client stated that he would rather measure breathing rate using the FSR. A signal from a pulse oximeter contains a low frequency waveform that corresponds to inhalation and exhalation, and this wave could be used to indirectly measure breathing rate. Since this wave has very low amplitude, the pulse oximeter would need to be extremely accurate to detect and process this signal. The client did not want to risk not being able to detect breathing rate with the pulse oximeter, so the team decided to continue using FSRs to easily quantify breathing rate.

Thermistors

Temperature is monitored almost exactly how it was using the previous design. This is done by using modified digital thermometers purchased from a local pharmacy (Figure 14). These function as thermistors that have resistances that vary linearly with temperature. The wiring and circuitry for this component of the final design were improved this semester, as well as individual temperature calibrations. The previous team used the same conversion factor for all of the thermistors, but this semester the team noticed during thermistor tests that each thermistor had a slightly different resistance versus temperature relationship. Calibrating each thermistor individually increases the accuracy of the temperature readouts the client will be using.

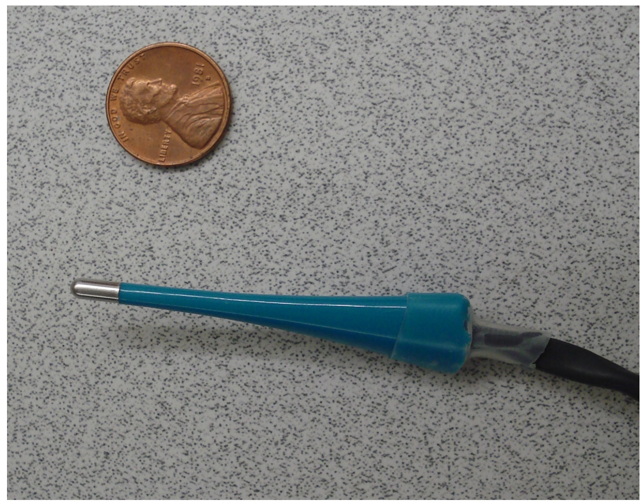

Figure 14: Thermistor used for monitoring temperature.

Pulse Oximeter

The third component of the final design is the pulse oximeter. The previous design team's attempt at reverse engineering a pulse oximeter fell short of their expectations because the data they were able to collect was too noisy to discern an accurate signal. The goal this semester was to create a pulse oximeter probe that would later integrate with a pulse oximeter circuit being constructed by graduate students assisting the design team throughout the semester. The final design for the pulse oximeter probe consisted of excised components, namely the red and infrared LEDs and photodiode, from an existing disposable Nellcor pulse oximeter probe. The LEDs and photodiode were mounted onto a plastic clip opposing one another, using a commercially available two-part epoxy. Black heat shrink was then used to encase the components, ensuring that the elements would be properly contained as well as reducing the amount of ambient light let through the white plastic clip (Figure 15). The pin connection for the pulse oximeter probe remained unaltered from the original Nellcor pulse oximeter probe. This ensures that the probe will be able to integrate with the pulse oximeter circuit under construction (the graduate students use Nellcor pulse oximeter probes to test their circuit). Although the pulse oximeter circuit is a work in progress, all of the independent elements (i.e. LED and photodiode) function properly, as evident by our test data (see testing section).

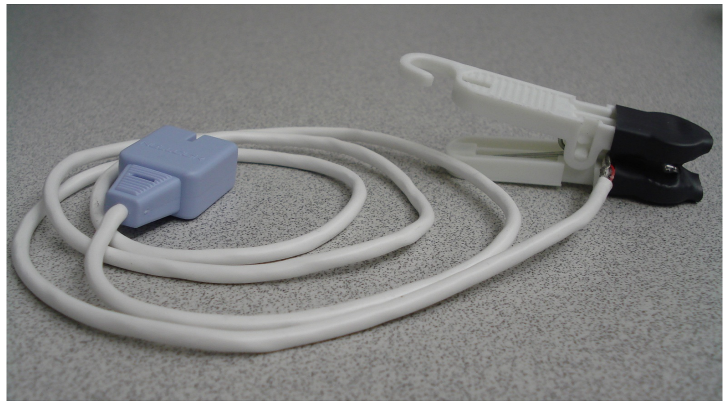

Figure 15: Pulse oximeter probe.

Graphical User Interface

The GUI allows the user to view all the data collected by the device. National Instrument's LabVIEW was used to help accomplish this. The interface was completely redesigned this semester and it is pictured in Figure 16. Each rat is designated a corner of the screen. A live trace of breathing is displayed, and when the pulse oximeter is added, the pulse

Figure 16: Graphical user interface designed by the design team this semester.

plethysmograh will be incorporated. The history graphs for the vitals are displayed in the smaller graphs to the right. These graphs default to viewing the history for the entire experiment, but it is user-adjustable with the toggle button and text box located underneath the Rat 3 label. Finally, the current values of the vitals are displayed to the right of the history graphs.

Two other features were added: autosaving and a data marker. Before data collection starts, the program prompts the user to create a folder to save all the data; all files that the data will be saved to are created in this folder. During the course of program execution, the data is saved every 15 seconds into a comma separated value. Each individual vital is saved to a separate file to allow the user to quickly find what they are looking for. This is visibly evident by the lighting of the saving indicator in the lower right corner of the screen and the refreshing of the history graphs. Secondly, the data marker was added by client request. A way was needed to correlate events during the course of the experiment and see if they affected the rats in any way. Pressing the Mark button added a mark to the data files that the researchers could view later.

Performance on the project computer was of concern this semester. Large amounts of data processing and parsing is needed in order to accomplish everything the client wished. The team encouraged the client to purchase a faster computer that would aid in data collection and processing. This computer will be configured and incorporated in the future.

Power Supply

A new power supply was incorporated into the final prototype for this semester. The previous power supply was extremely cumbersome and contained exposed wires that were dangerous to the user, so a smaller and safer power supply was desired. The design team decided to use a 5.14V wall unit that was originally used to charge a cell phone. This new power supply provides a steady 5.14V up to a maximum current of 850mA, depending on the load. Since the new voltage source output a slightly higher voltage than the previous 5V voltage source, the thermistors needed to be recalibrated, as explained in the testing section.

Testing

All testing this semester was conducted on a single anesthetized rat at the Wisconsin Institute for Medical Research (WIMR) with the assistance of Elizabeth Ahlers. This testing allowed for verification of the device function and feedback from our client and research assistant about the ease of use of the prototype.

Initial testing to verify the function of last semester's prototype was not favorable. Only three of the four FSRs produced a voltage signal and none of the thermistors were producing reasonable data. Each FSR was producing an extremely noisy signal and data from last semester was unable to be replicated, even with adjustments on the placement of the FSR.

Force Sensing Resistors

After the circuit was cleaned up and all FSRs were working, verification was needed to ensure that the voltage signal being received from the circuit was being observed correctly within the GUI. This was easily accomplished by having the research assistant say 'breath' every time the rat breathed. A peak was observed within the GUI and corresponded to when 'breath' was narrated.

Since the design team decided to use the previous algorithm for calculating breaths per minute using peak detection on the voltage data from the force sensing resistor, only basic verification was needed. A force was applied to the force plate at constant intervals and the output from the algorithm was observed. If a force was applied every second, the expected output was 60 breaths per minute. This was observed. Verifying proper breaths per minute calculation during testing with a live rat was more difficult. A peak detection indicator was added to the GUI that would light up every time a peak was observed. After an initial period of computing a stable baseline that usually lasted a few seconds, the peak indicator was very accurate. The baseline is used for a comparison of voltage. If the present voltage was below the baseline voltage, the rat was inhaling. Since the algorithm uses the peak voltages to calculate each breath, dividing the number of peaks over a set time interval would yield a value for breaths per minute. After an initial period of approximately twenty seconds, the algorithm was able to accurately measure breathing rate.

Thermistors

Last semester, it was proven that temperature varied linearly with voltage with an R^2 value of over 0.993. This was verified in the beginning of the semester with an R^2 value of 0.9981 (see figure X). After incorporating the new 5.14V power supply into the final prototype, the thermistors were recalibrated using the same methods the previous design team had used.

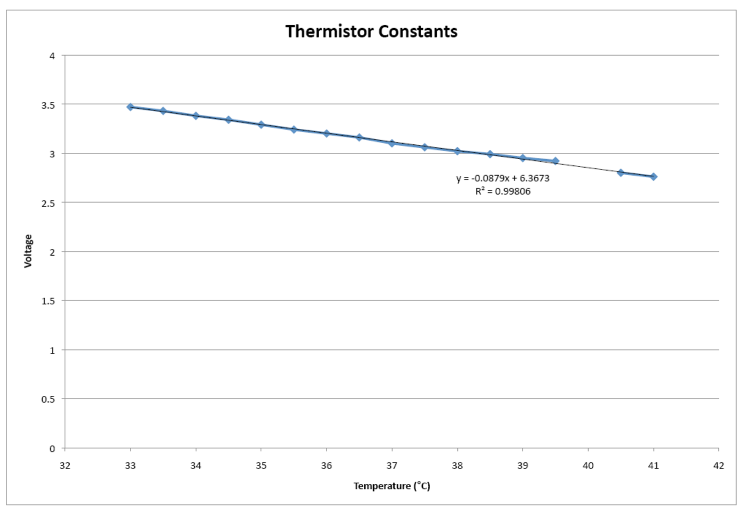

Figure 17: Temperature versus voltage relationship of the thermistors determined by the team this semester.

Once recalibrated, the thermistors were tested on an anesthized rat. The temperature observed was constant and discussions with our client indicated that the thermistors were functioning correctly and accurately.

Pulse Oximeter Clip

A test circuit was constructed in order to ensure that the fabricated pulse oximeter probe could detect a rat's pulse. Because the final pulse oximeter circuit is under construction, a simple photoplethysmograph was observed to determine if the probe was sensitive enough to detect the pulse of an anesthetized rat. In traditional photoplethysmography, a florescent light is used in conjunction with a photoresistor, analogous to a photodiode, to detect heart rate by shining light through the earlobe and evaluating the change in absorption (i.e. change in output voltage) [4]. To create the simple photoplethysmograph, only one of the LEDs needed to be lit at a time. The LED was biased using the 5.14V source and a 330Ω resistor so that a 15mA current was used to power it. Both the red and the infrared LEDs can be powered by the 15mA current; a simple inversion of the signal switches which LED is lit at a given time. For the majority of the tests, the design team chose to use the red LED so that there was visual confirmation that the LEDs were in working order (the infrared LED is not visible to the naked eye when lit). In order to power the photodiode, a simple transimpedance amplifier was constructed in conjunction with a voltage amplifier. The transimpedance amplifier consisted of an op-amp, 4.7MΩ resistor, and a 390pF capacitor. The resistor helped to amplify the signal, and the capacitor aided in stabilization and the elimination of noise. Along with the LEDs and photodiode, grounded shielding was used around the photodiode to eradicate extraneous radio waves and ambient frequencies emanating from any given environment.

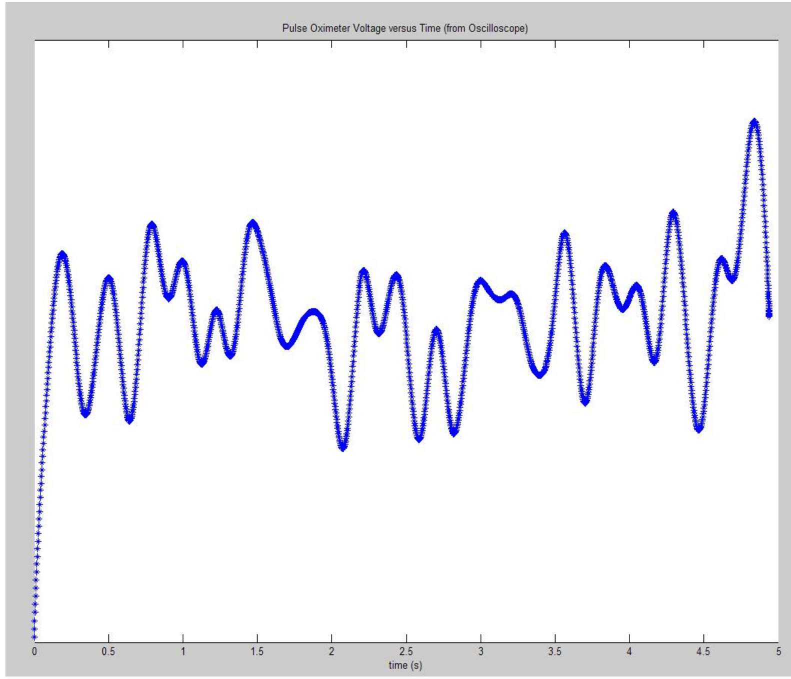

Figure 18: Filtered heart rate plethysmograph detected from a rat's hind paw.

Initial testing was conducted on design team members and then on a rat during a testing session. Although the signal from the rat contained more noise and was less definitive than the signal from individual team members, a distinct pattern was discernable when compared to ambient conditions. Figure 18 is a graph of some filtered data collected during the testing session. After some simple calculations, it was determined that the heart rate result of 220 beats per minute is within a range for anesthetized rats.

Graphical User Interface

The primary concern with the GUI was the ability of LabVIEW to sample data at a high enough rate so the peaks for breaths per minute calculation would be properly observed. An oscilloscope was used to observe the voltage signal from an FSR (Figure 19, next page). Figure 20 (next page) demonstrates a sample of data being collected with LabVIEW. The baseline is significantly less noisy as compared to the oscilloscope, but this has no bearing on the peak

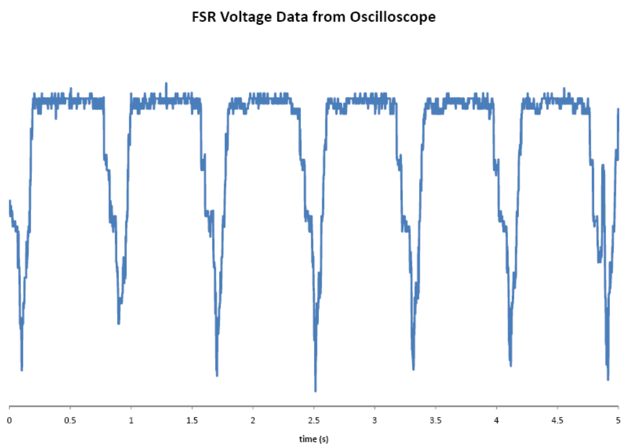

Figure 19: Voltage data from FSR on oscilloscope.

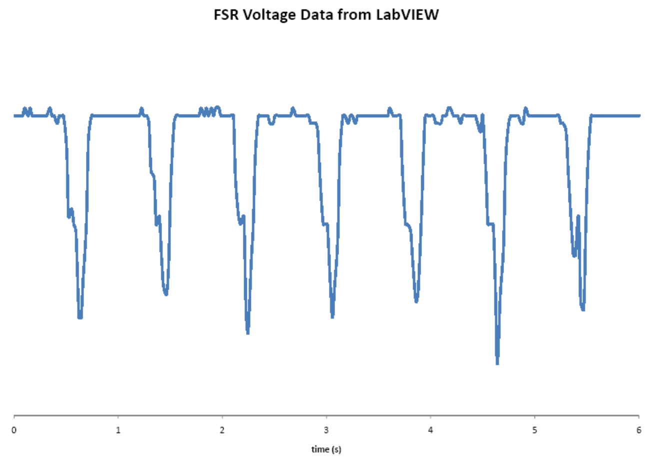

Figure 20: Voltage data from FSR on LabVIEW.

detection. The peaks are still there with most of the detail and further analysis indicates peak detection still works as expected.

Finally, the interface was extensively tested for any bugs. Error reporting was implemented in core areas, but it should never have to be used if the device and computer are properly configured. The only potential downfall is how LabVIEW handles the end of a program. There is a default button, provided by LabVIEW, which immediately aborts an executing virtual instrument. The interface programmatically includes a stop button that is designed to close all files and end all connections to the device. If the abort button is used instead of the provided stop button, there is a possibility that the data files may become corrupted, especially if they are in the process of saving data. This will require the user to consciously remember to use the correct button or possibly lose data from the experiment. With this exception, no other unexpected bugs were found and the interface is robust for use.

Future Work

The primary goal for next semester is to integrate the pulse oximeter circuit being designed by graduate with four copies of the current pulse oximeter probe seen in Figure 15 (page 24). This entitles manufacturing three additional pulse oximeter probes and printing four circuit boards. The standard 9-pin male plug of the pulse oximeter probe will easily interface with a female 9-pin plug on the pulse oximeter circuit. Second, a new laptop purchased by our client must be prepared to run the finalized LabVIEW GUI by cleaning out all unnecessary programs in order to free-up the maximum amount of memory space and to increase the processing speed. A faster processing laptop should produce cleaner live traces for breathing rate and heart rate than the current laptop is capable of producing. The third goal for next semester is to fabricate a housing apparatus that will function to hold all circuitry and wiring. This box-like unit will contain external plug-ins for the four thermistors, four FSRs, and the four pulse oximeter probes. A plug-in for the USB cord that facilitates communication between the DAQ inputs and the laptop should also be incorporated onto the exterior of the housing. The fourth and final goal for next semester is to test the finalized prototype throughout the duration of an actual PET scan in our client's research environment.

The cost requirements for next semester's work will likely significantly increase from this semester's cost requirements. Printing one circuit board for the thermistor and FSR circuits and four circuit boards for the pulse oximeter circuits are estimated at $175 total. Materials needed to fabricate the housing apparatus are estimated to be $119.18 plus shipping from www.mcmaster.com. The new laptop purchased by our client cost $659.68. The total estimated cost for next semester's work is totaled at $953.86. For comparison, the amount of money spent this semester was less than $15 as most of the materials were simple household items, circuit components provided by the University of Wisconsin-Madison and free materials obtained from the student COE shop.

Ethical Considerations

First and foremost, the goal of this device is to help the experimenter monitor the status of each rat during the course of the experiment. This device, however accurate, cannot prevent the rats' vitals from entering dangerous levels; rather, it will supply the data and the experimenter must utilize the data in order to decide on the proper course of action. This device is not intended to replace any standard laboratory procedures and is only to be used as a diagnostic tool. All government and university regulations regarding animal research are still expected to be observed.

Proper animal care and use considerations had to be properly met during all testing trials on live rats. Prior to each round of testing, all equipment associated with our prototype was approved by our client Dr. Converse, and one of his research assistants. The rats were always transported from their housing location to the WIMR testing location by a research assistant, who followed necessary precautions to ensure the safety of the rat throughout transport. Proper attire (i.e. latex gloves, cotton smock, etc.) were worn at all times by any certified personnel handling the rat, and no member of the design team was allowed to touch the rat or apply the prototype to the rat during testing.

Conclusion

This semester, the design team has greatly improved the GUI for the LabVIEW program. The interface is able to simultaneously display running averages of the four vitals, the histories of four vitals, and live traces of heart rate and breathing rate. All of this is be displayed on one screen in an easy-to-read format.

A template pulse oximeter probe has been fabricated. This design is easy to attach to the rats' hind paw and also easy to reposition. Accuracy is extremely important for the pulse oximeter, so the probe has been designed to block out ambient light to ensure precise readings. Currently, two graduate students are working on producing a pulse oximeter circuit so that SpO_2 levels and heart rate can be obtained using the pulse oximeter probe.

The method for detecting breathing rate and temperature remained largely unaltered from last semester's form. The design team augmented accuracy of the force sensing resistors by fabricating a respiration belt. Using a respiration belt has been deemed optional as demonstrated by testing data.

In the future, the design team hopes to incorporate a pulse oximeter circuit and develop an apparatus to house and organize the prototype. Following the design and construction of this device, the team hopes to conduct several rounds of testing on multiple rats during the client's PET scans.

References

[1] Ho, Jack et al. *Quad Rat Vitals Monitor*. Department of Biomedical Engineering, University of Wisconsin – Madison 2009.

[2] Starr Life Sciences™ Corp. ©2009.

[3] Decker MJ et al. *Noninvasive oximetry in the rat*. Biomed Instrum Technol. 1989 May Jun;23(3):222-8.

[4] Webster, J. G., Design of Pulse Oximeters. IOP Publishing Ltd 1997.

[5] Covidien Respiratory & Monitoring Solutions. *Nellcor Patient Monitoring Systems*.

Product Design Specifications

Rat Quad Vitals Monitor

9/24/09

Team:

Robert Bjerregaard	Team Leader	rbjerregaard@wisc.edu
Derek Klavas	Communicator	klavas@wisc.edu
Caitlyn Collins	BSAC	cjcollins2@wisc.edu
Matthew Bollom	BWIG	mbollom@wisc.edu

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 takes 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 saturations level accuracy of ±2% so that the anesthesiologist is able to determine the adequate dosage of isoflourine to keep the rats anesthetized. Device will also be designed to monitor respiratory rate (around 20 breaths/min) and rectal temperature (93-100° F).

Goals for this semester:

- Modify previous semester's LabVIEW graphical user interface according to client's requests.
- Construct a pulse oximeter clip prototype
- Finish construction of prototypes to measure breathing rates and rectal temperatures. Tests these devices and display data in LabVIEW.

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 a 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.

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. If necessary, the breathing rate monitor could include a body wrap, but should not interfere with the rat's breathing. The probes should not be influenced by the inclusion of bubble wrap during tests. The graphical user interface must display real-time graphs for each of the four measurements for all four rats simultaneously.
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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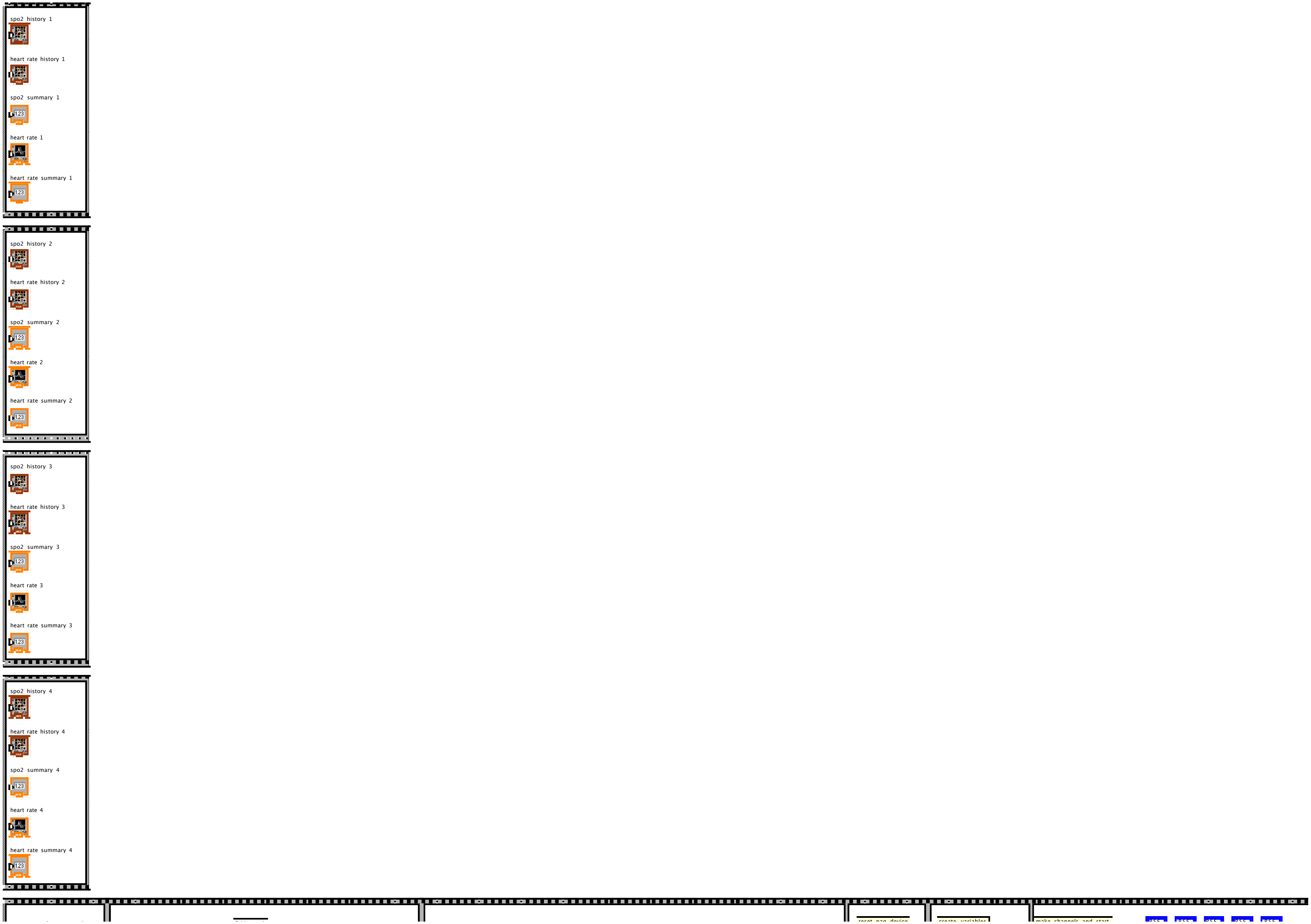

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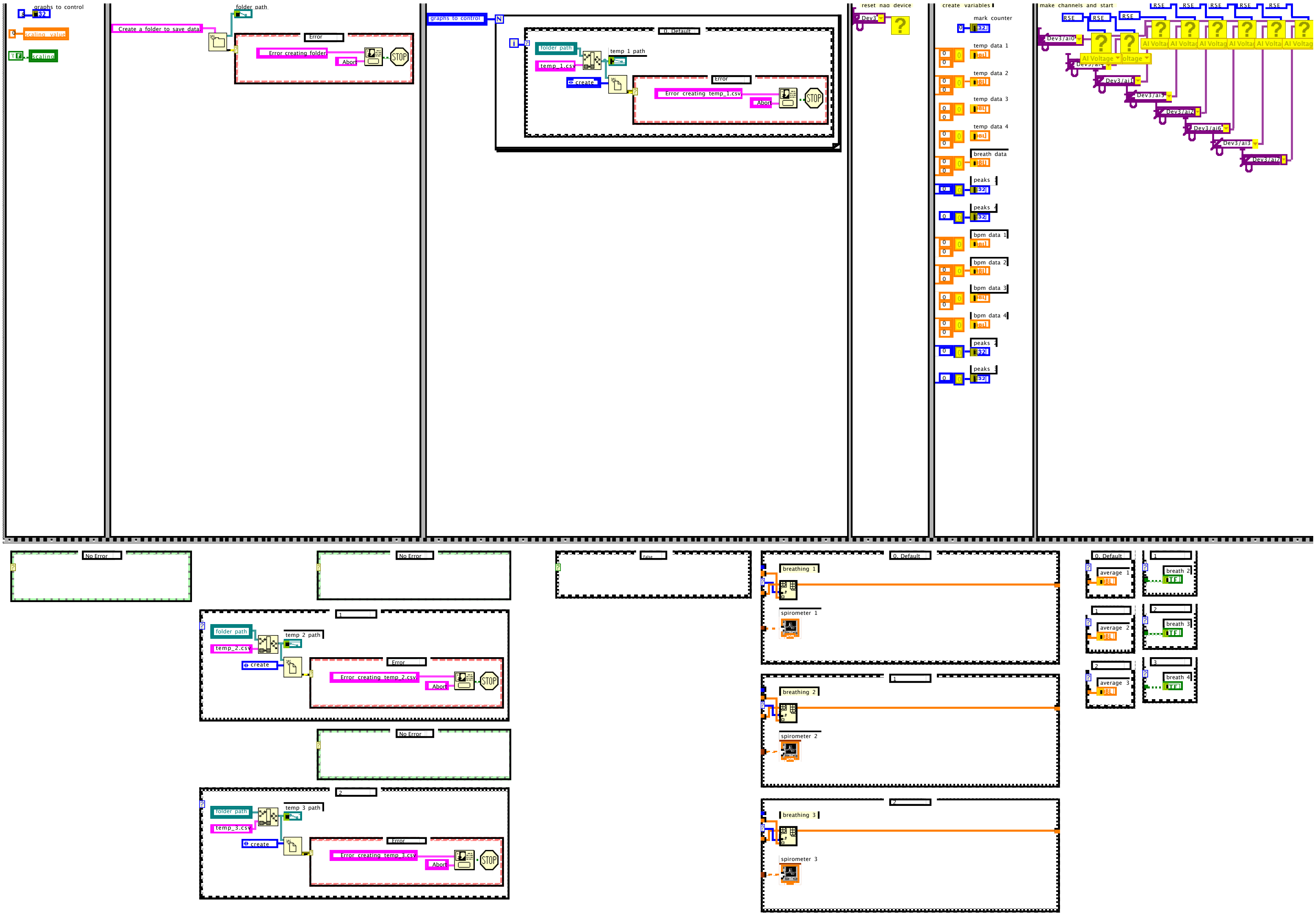

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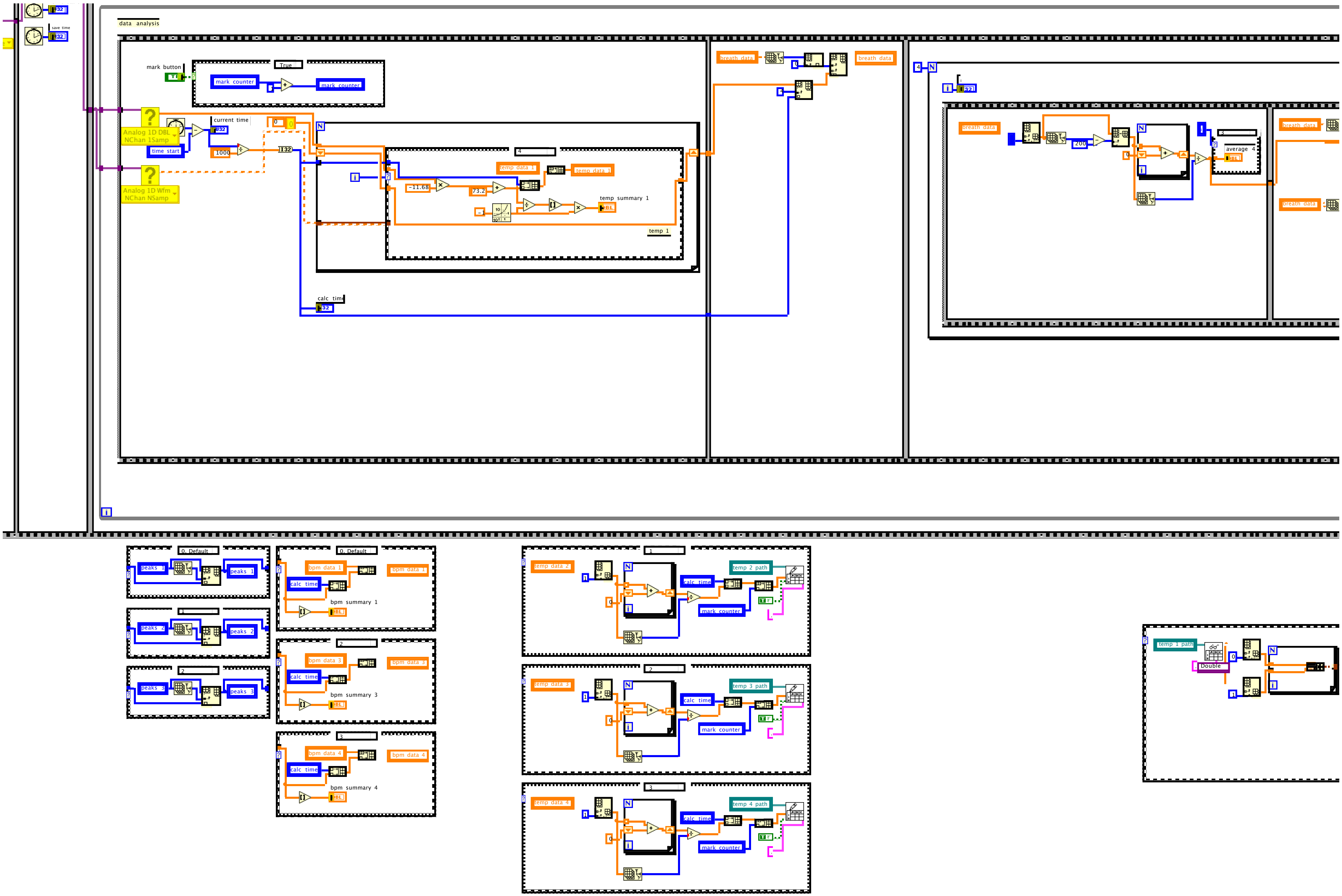

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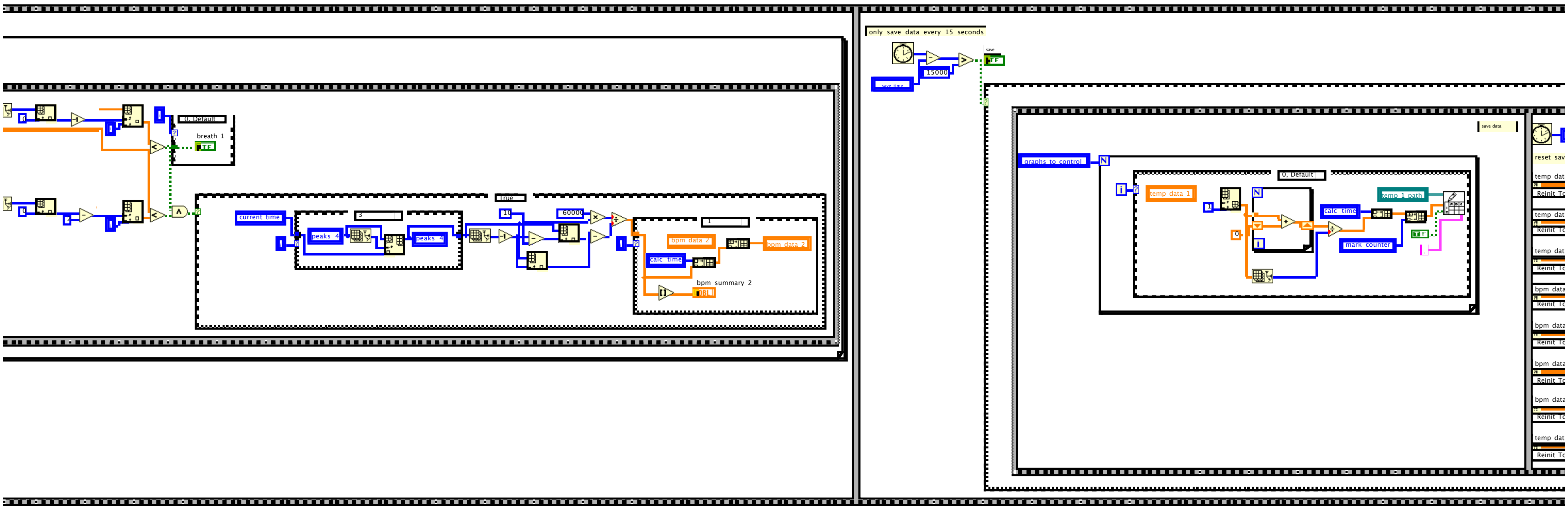

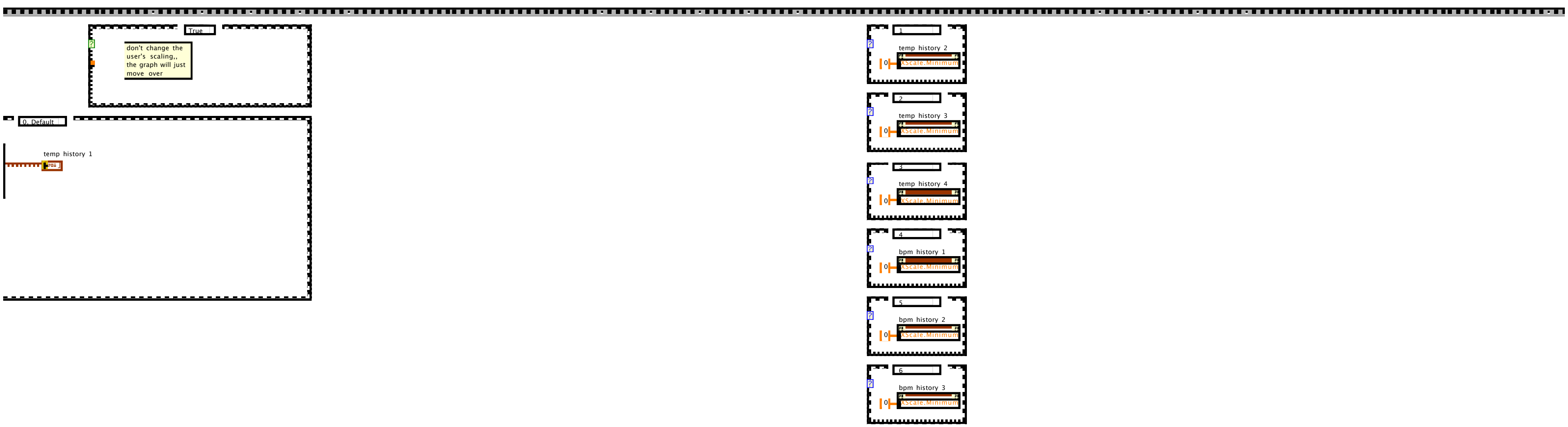

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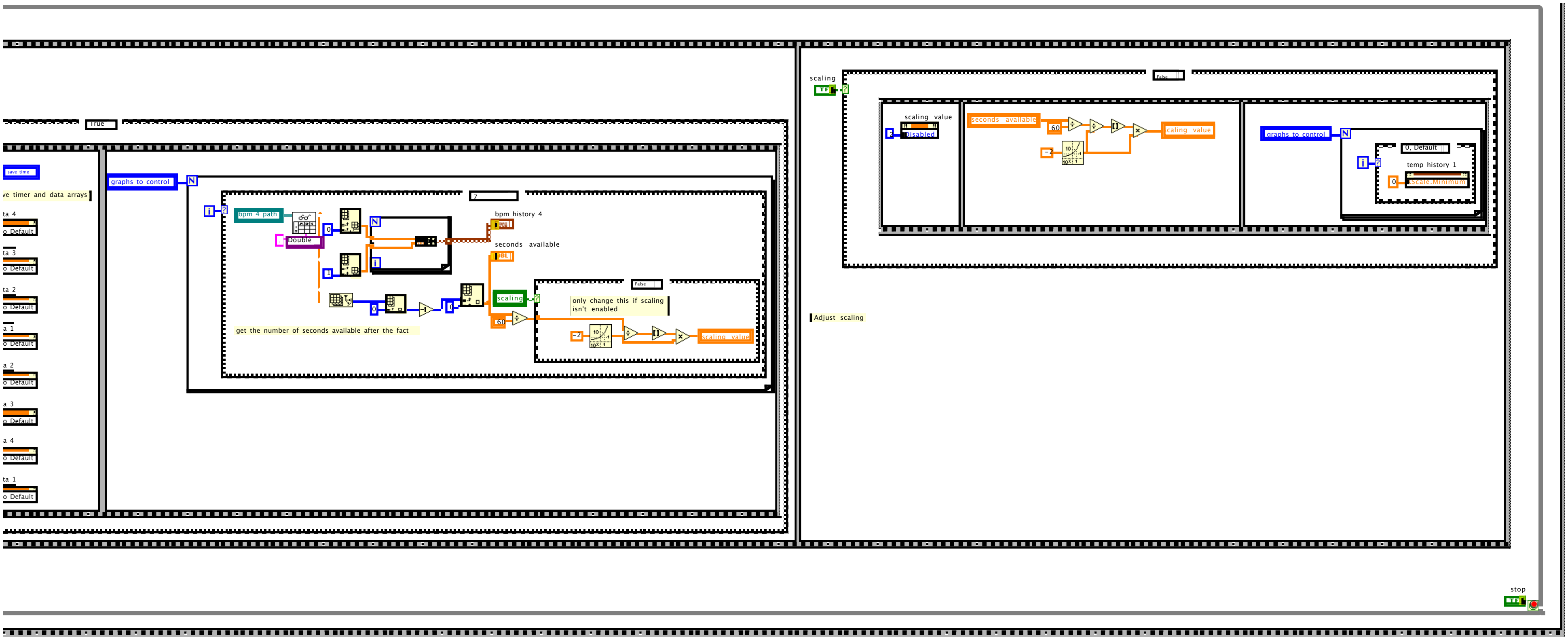

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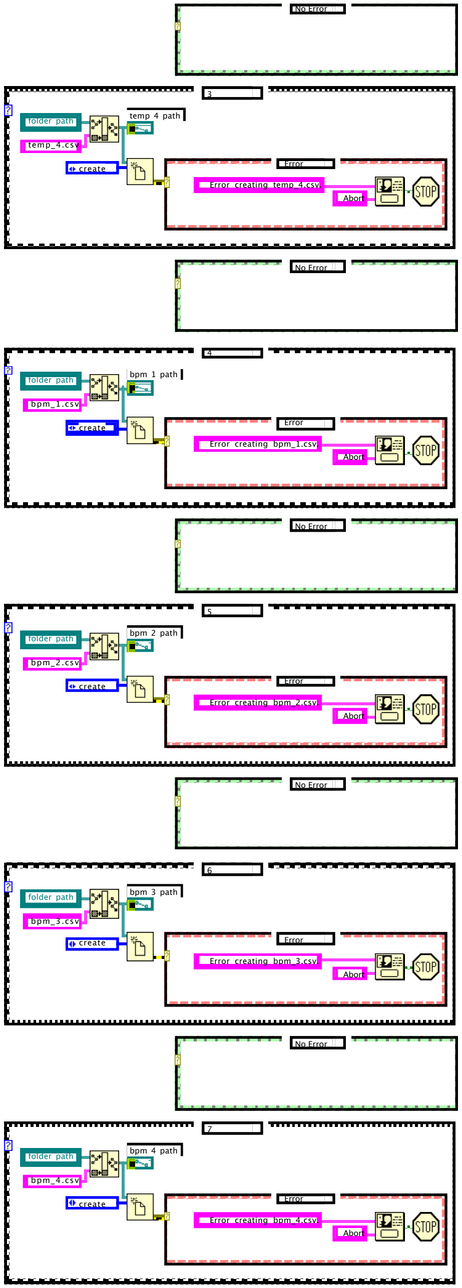

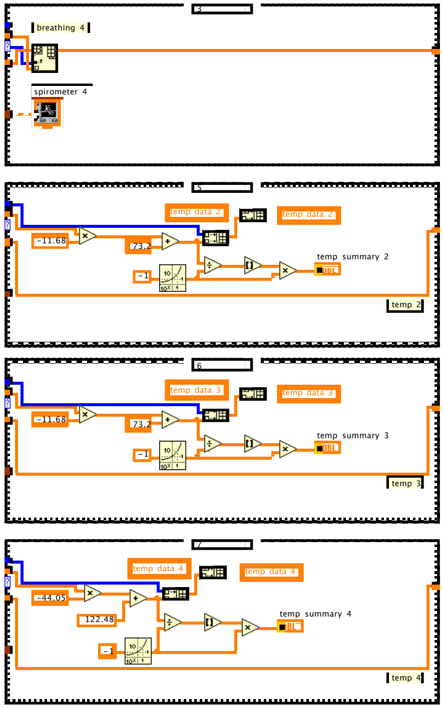

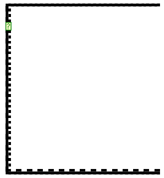

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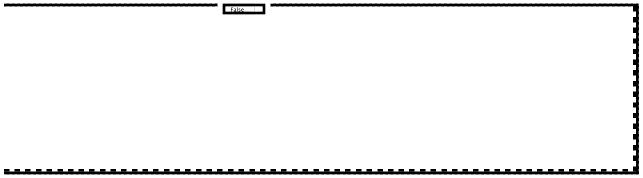

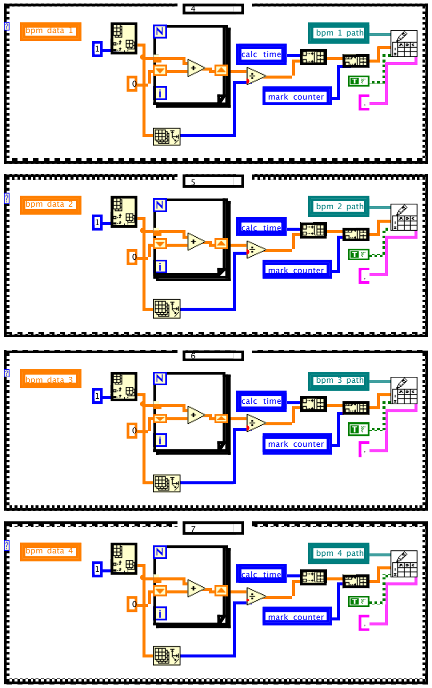

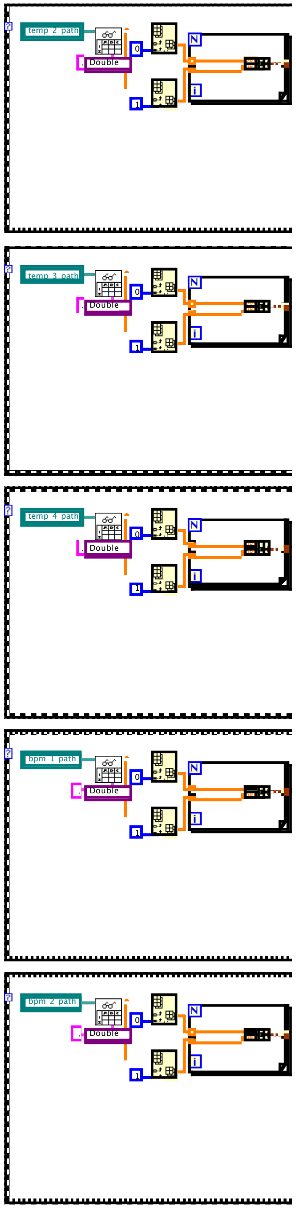

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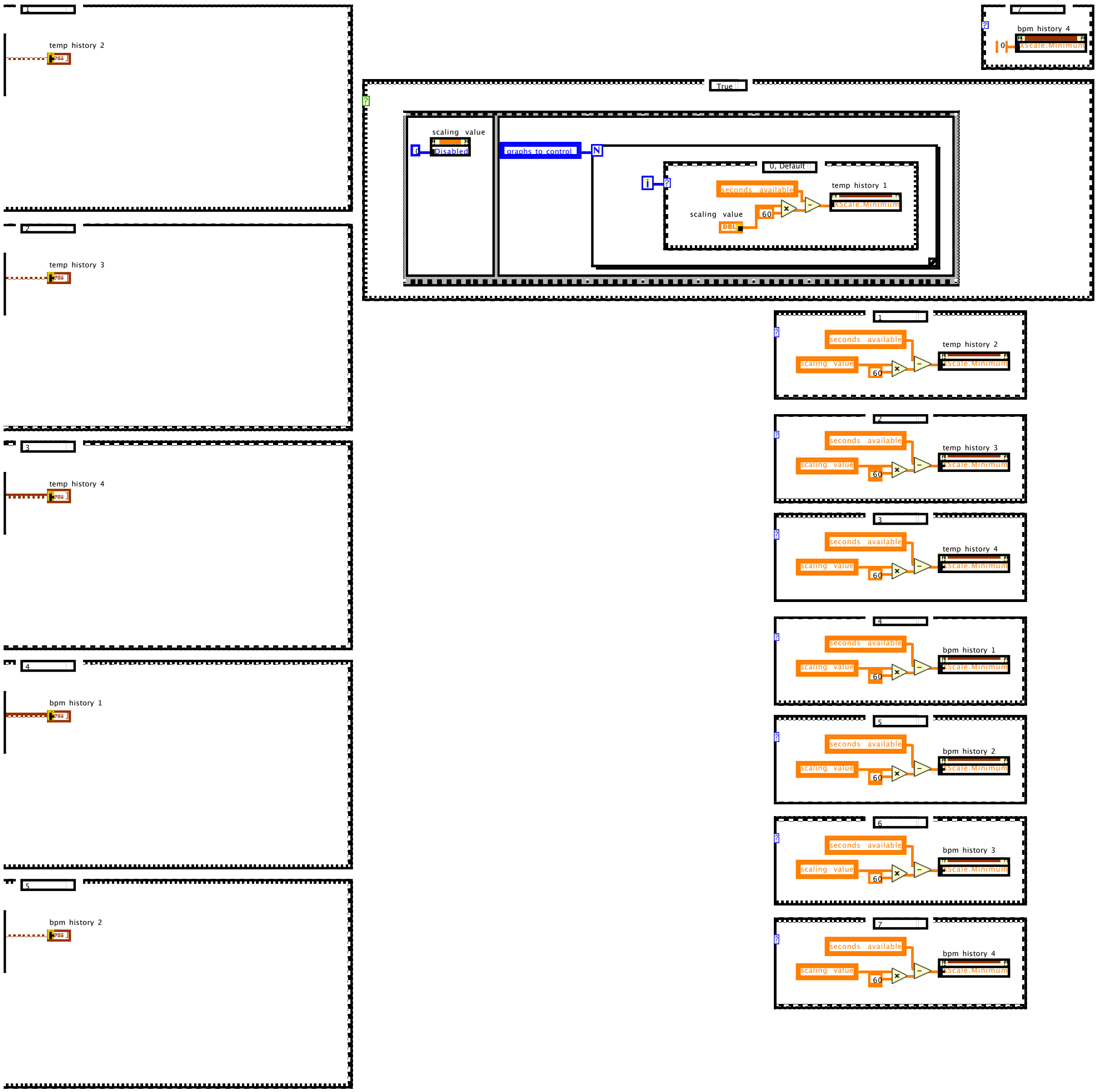

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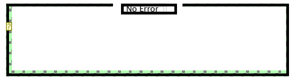

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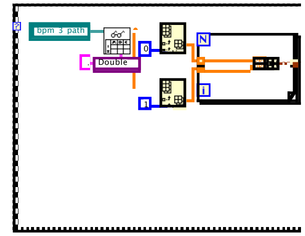

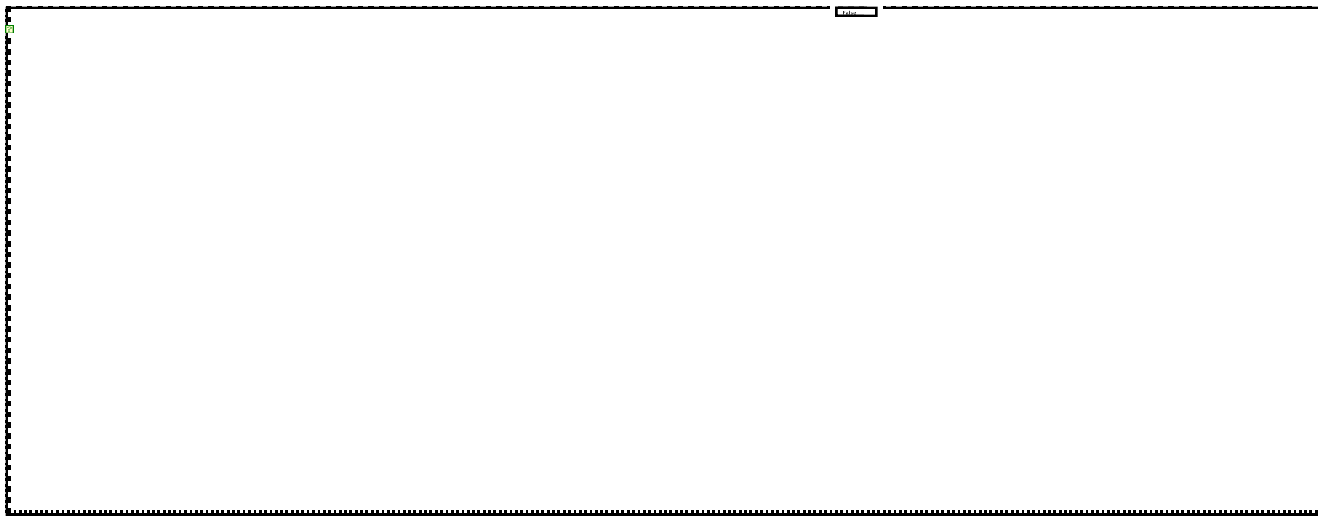

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