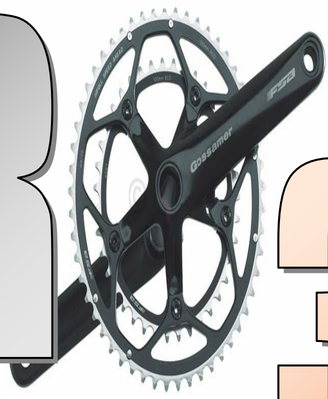
IPRO 324



Power Measurements for Road Bikes

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IPRO It takes a team!
INTERPROFESSIONAL PROJECTS PROGRAM

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Abstract

We have worked this semester to develop a system that measures the applied torque at a bicycle crankset. In contrast to current solutions, we are attempting to be able to retrofit our system to existing cranksets, obviating the need to abandon parts that the bicyclist already owns. In principle, according to preliminary tests performed at the MMAE department, this can be done using sets of quite inexpensive strain gauges. However, being able to get accurate torque measurements is requiring some advanced processing of signals from the strain gauges. These signals can then be transmitted wirelessly to a bicycle computer like the Edge 705 that the global positioning system corporation Garmin released this spring. There is a defined wireless protocol, called ANT+Sport, which has been developed specifically for the purpose of transmitting exercise data, such as power output or heart rate, to small computers. The electrical team purchased the chipsets and development kits for this protocol and learned their operation, designing a circuit to process the strain gauge signals. The task of the mechanical team was be to find an optimal configuration of strain gauges that will be attached to the crankset, and to develop an algorithm to process the strain gauge data in order to isolate a signal that is proportional to the applied torque. This signal will then be transmitted to the bicycle computer for display and storage.

We anticipate being able to assemble a power measurement system, based on the work outlined above, that should cost a small fraction of the price at which currently available systems retail. In addition, we expect that our system can easily be used with any existing bicycle, without the need to replace parts. Ultimately, after another semester of this project as an IPRO, if this development is successful we may be able to explore the market potential of a commercial product in a follow-up ENPRO project.

Background

The problem that this IPRO is trying to solve is how to develop an inexpensive, but accurate way of measuring the power output of a bicycle rider. Issues with systems currently available are: compatibility so new parts need to be purchased, along with the cost of the product itself, and other systems whose accuracy is not sufficient.

There are four main ways in which current systems measure the power output of a rider. They include crankset, free hub, chain, and opposing force systems. The crankset system uses strain gages to measure the strain in the crankset which can be related to torque from which the power is calculated. The free hub system works in much the same way except the strain gages are attached to the rear wheel of the bicycle. Chain systems detect the vibration and the speed in the chain and convert that to a power reading. Opposing force systems calculate opposing forces to the rider and bicycle including: gravity, drag, acceleration of the bicycle, and wind speed. The system takes all this information and calculates the power using Newton's Third Law.

The bicycle pedals are directly attached to the crankset. The crankset includes the spider, which is attached to the crank arm, and the chainrings, which drive the chain. The free hub is used to connect the chain to the rear wheel.

Comparison of Existing Power Meters (SRM, Power Tap, & Polar)

An article from the New York Times explains the basics of power measurement in the SRM crank and Tune's Power Tap. Austen first describes strain gauges and their approximate locations of application. The strain gauges in his definition are basically "pieces of extremely fine wire formed into a series of tightly spaced U shapes." These wires come bonded to a piece of flexible plastic with two contacts for soldering lead wires. The strain gauges are glued on either side of the crank arm in SRM's design and inside of the rear hub in the Power Tap. In either position, the metal is slightly deformed as the cyclist pedals. This distortion reduces the voltage through the gauge, and that reduction of voltage should be proportional to the torque being applied to the bicycle. Both of these models use a small computer on the handlebars to calculate the power from the voltage signals *(Austen)*.

The president of SRM claimed that "his tests had found that the crank was the only accurate place for measurements because it was not distorted by power loss caused by inefficiencies from the bicycle's chain and sprockets." The marketing director for Tune's Power Tap "acknowledged that, by using a hub for its system, up to 4 percent of a rider's actual output may be missing from its readings. But he said that that distortion was offset by the fact that the hub made it convenient for a cyclist to remove Tune's system when they don't need power measurement" *(Austen)*. According to this article, once the racing season begins, the power measuring devices disappear from the bicycles because of weight (about 200 grams) and probably also drag *(Austen)*. SRM has an amateur model that retails for $1530 and a more accurate model for $2300 (in 2000). Both models "can store power readings, heart rate, pedal speed, time and road speed for downloading later to a PC." The president of SRM also mentioned that the SRM crank power meter was much more popular for the amateur Italians that Americans (Austen).

Tune has a Power Tap model with no memory for $499 and one that can store seven hours of data for $769. Customers buying either version of the Power Tap must also "spend additional money to have the hub built into a wheel" *(Austen)*.

A second source was a very in depth analysis and comparison of the SRM, Power Tap, and Polar meters. The conclusions of this analysis is summarized his table below *(Willet)*.

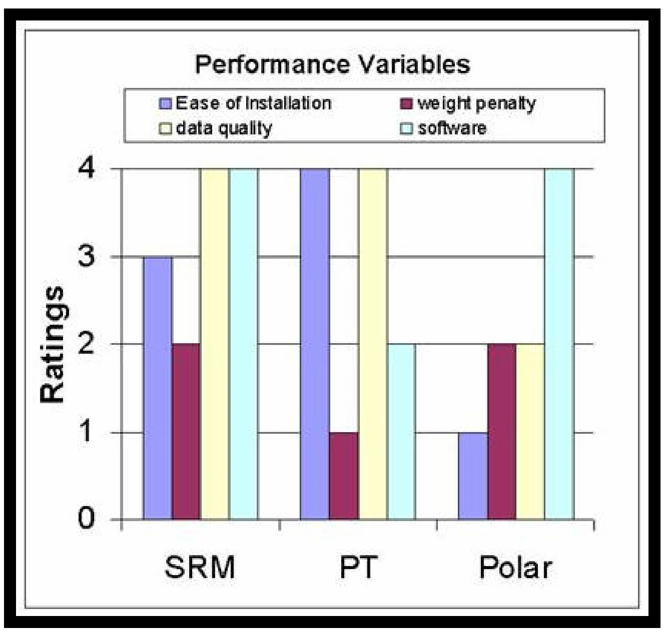


Table 1: Performance Comparison of Power Meters (Willet)

The author rated the SRM Pro best for performance, but also highest in price with little difference in data quality from the other models. The installation is fairly easy (much easier than the Polar and a little more difficult than the Power Tap. There are three types of the SRM: Amateur, Pro, and Science. The Amateur version costs $1500 and has 2 strain gauges at ± 5% accuracy. The Pro version (used for this analysis) costs $2300 and has 4 strain gauges at ± 2% accuracy. The Science version costs $4600 and has 8 strain gauges at ± 0.5% accuracy *(Willet)*.

The author rated Tune's Power Tap best in performance value. It is lower priced and has the easiest installation, but it has less software. There are issues with durability because of rotating seals and the wiring harness design. There are also issues with "aero wheels" during competitions. There are two types of this meter: Standard and Power Tap Pro. The Standard Power Tap costs $699 and has ± 1.5% accuracy, while the Power Tap Pro costs $899 and has hard wired cadence with faster downloads and more memory *(Willet)*.

Finally, Willet rated the Polar power meter best in terms of value. This meter is the least expensive at $680 and has ±5% accuracy, but has potential data quality issues (especially in capturing max wattage). It has the most difficult installation, but it has a good software package with lots of additional features such as an altimeter and pedal balance *(Willet)*.

Quarq CinQo

A biker generates force that is transmitted into the bicycle's crank arm and moves from there to the spider. The spider connects to the bicycle's chain rings and in the case of the Quarq CinQo, doubles as a power sensor. Quarq's sensor uses strain gages at each of its five arms to measure the strain and, by inference, the torque, which is proportional to the strain. While the unit's microcontroller computes torque, the spider employs Reed switches to count revolutions as the wheel passes a magnet mounted on the bike's frame. Using the torque and velocity data, an onboard microcontroller calculates the power generated by the rider *(Murray)*.

CinQo, which consists of an aluminum part in a molded plastic case, accomplishes that by employing its onboard Nordic Semiconductor nRF24AP1 transceiver and microcontroller. After the MCU calculates the power numbers, the unit's 2.4-GHz transceiver uses the built-in ANT communications protocol to send the data to the handlebar computer, a Garmin Edge 705. A separate transceiver in the computer gathers the wireless data for the display" *(Murray)*.

Summary

Each of these methods has downsides. The crankset systems can be very complicated systems and therefore are very expensive. Not only are the systems themselves expensive, but the system requires a new spider, causing the replacement of an expensive part of the bicycle. The Quarq CinQo has an accuracy of ± 2%, but costs $1159. The freehub systems have similar problems to the crankset systems plus the accuracy is can be diminished because the power output of the rider is not directly measured. Inaccuracy is a bigger problem with the chain systems because of power loss from the crank to the chain as in the freehub systems as well as vibration in the chain caused by other factors including terrain. While cost is not as much a factor in the opposing force systems as in the crankset systems the accuracy can be far less. The inaccuracy can be caused by drag being affected by rider position, weight fluctuation of the rider, as well as surface of riding surface. The iBike Pro claims to have accuracies comparable to those of high end models, like the crankshaft and freehub systems, but says becomes more inaccurate in sharp turns or long stretches of rough terrain. The cost of the iBike system is $399.99.

The other side of the project is the interaction with the rider. This is done through the bicycle computer. The computer processes the information from the power measurement systems displays it so the rider can see. Problems faced with the computers involve finding a way to relay the information wirelessly. The Garmin Edge 705 bicycle computer will be used to communicate the information to the rider. The ANT+Sport system will be used for communication between the computer and the rest of the system.

Objectives

Develop a configuration of strain gauges

- Accurately measure the output of the strain gauges under various load conditions
- Crank angle
- Direction of applied force
- Point of force application
    - Left pedal
    - Right pedal
    - Both left and right pedal

Develop an electronic processing unit for post-processing the strain gauge signals

- Implement an algorithm to calculate the applied torque at the bicycle crank
- Transmit the data wirelessly to the Garmin Edge 705 using the ANT+ protocol
- Must be power efficient

Package the system

- Must work under realistic conditions
- Needs to conform to the space requirements associated with a bicycle

Methodology

Mechanical

The research done for the Mechanical side of the project was done primarily online for different methods of power measurement in bicycles. The primary focus from the beginning was on the crankset method where strain is measured in the spider. Much of the research was done on systems that used this method including the Quarq. Some direct investigation was done on the Quarq which was available to the group. However, this did not provide much insight to the Mechanical team, but some of the minor details of the system should turn out helpful to future groups.

http://www.wipo.int/pctdb/en/wo.jsp?WO=2008058164 *(address to Quarq patent)*

Changes made to proposed time line:

- Testing of strain gauges started October 15 due to application of gauges taking over a week instead of a day, however data acquisition ended as planned.
- Analysis of strain data did not run concurrently with data acquisition, but occurred after data acquisition so the process continued through the week of November 9th.
- There was no reverse engineering of the commercial product due to limited abilities.
- RPM measurement design was omitted due to need to solve other objectives.
- Hardware programming and product testing with both omitted due to time restraints.

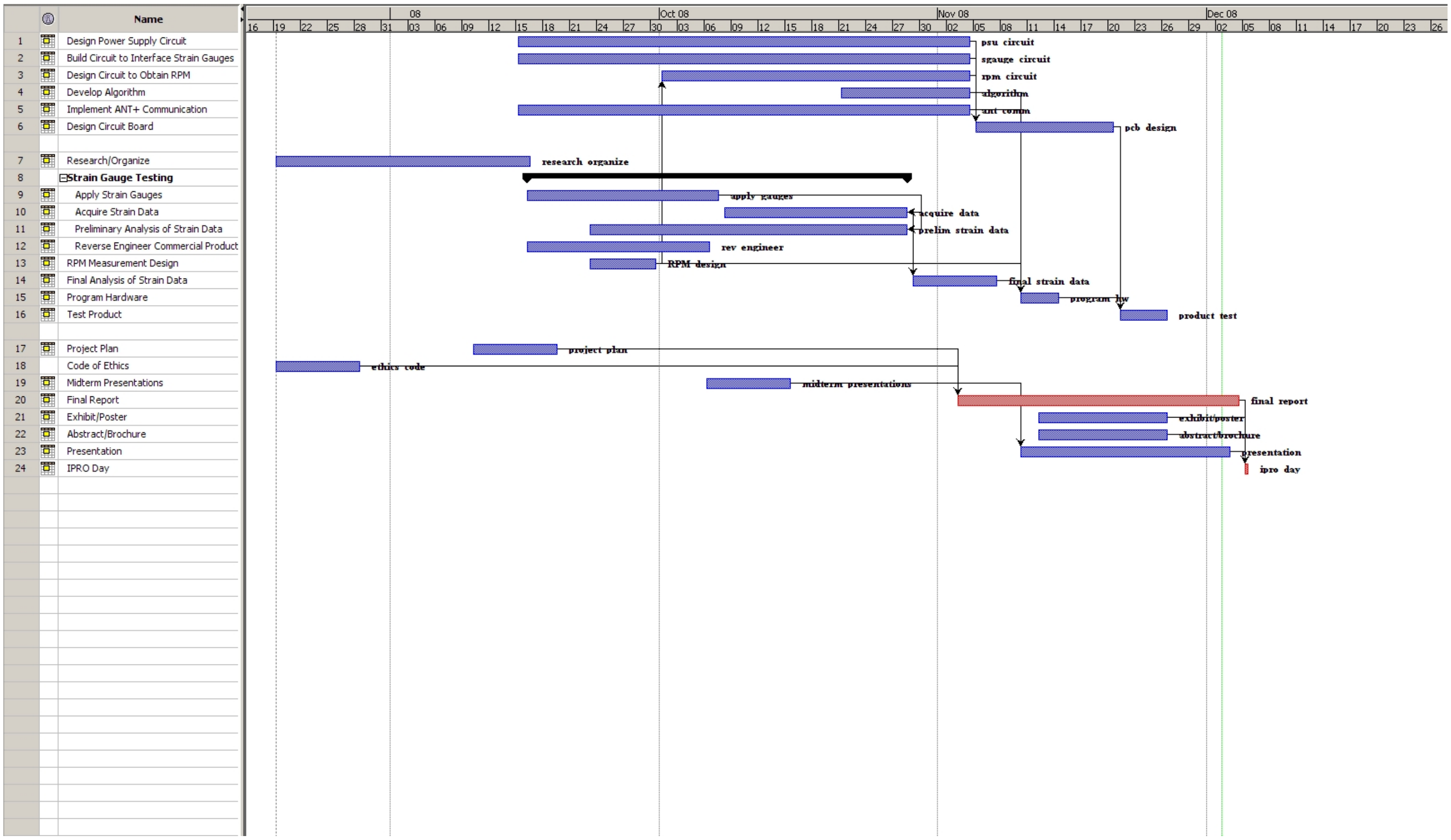
Electrical

The Electrical side of the project consisted in the beginning of doing online research in the ANT+ Sport wireless technology protocol, since this was the communication solution decided on at the start of the project. Research was also done on the Garmin Edge 705 and the CinQo Power Sensor from Quarq which utilize ANT+ Sport communication. As the project moved on focus was also placed in the circuitry that would receive signals provided by the Mechanical side of the project and had to properly encode it in order for the ANT+ to transmit it to a receiver. For this, research was done on various amplifiers, power supplies, switching, bridging, and processing circuits. The team decided on switching every single strain gauge, to read one at a time, after knowing the characteristics of and how many strain gauges there would be. The process implemented by the Electrical team was to assemble, and debug, each part individually and to put it together once all the parts were working properly.

Changes from the proposed Project Plan

- Working on the circuitry and ANT+ Sport communication took two more weeks than anticipated due to various problems that came up along the way.
- The CinQo Power Sensor was not reverse engineered due to limited tools and abilities.
- Due to time restraints an RPM sensor unit was dropped in order to focus in main objectives, and the implementation of circuitry into a board was dropped altogether.

GANTT Chart


Name
Design Power Supply Circuit
Build Circuit to Interface Strain Gauges
Design Circuit to Obtain RPM
Develop Algorithm
Implement ANT+ Communication
Design Circuit Board
Research/Organize
Strain Gauge Testing
Apply Strain Gauges
Acquire Strain Data
Preliminary Analysis of Strain Data
Reverse Engineer Commercial Product
RPM Measurement Design
Final Analysis of Strain Data
Program Hardware
Test Product
Project Plan
Code of Ethics
Midterm Presentations
Final Report
Exhibit/Poster
Abstract/Brochure
Presentation
IPRO Day
08
Oct 08
Nov 08
Dec 08
psu circuit
sgauge circuit
rpm circuit
algorithm
ant comm
pcb design
research organize
apply gauges
acquire data
prelim strain data
rev engineer
RPM design
final strain data
program hw
product test
project plan
ethics code
midterm presentations
final report
exhibit/poster
abstract/brochure
presentation
ipro day

Team Structure and Assignments

Name	Major / Year	Skills and Strengths	Experience and Academic Interest	Subteam	IPRO Assignments
Sergio Aguilar	Computer Engineering 4th Year	Experience in hardware and software design for microprocessors, fluent with multiple programming languages	Intern at Rush Oak Park Hospital - IT Dept.	Electrical	Familiarize with Garmin computer / Interface with ANT or Design power supply circuit (using a coin cell like CR2032)
Patrick Becker	Electrical Engineering 4th Year	C++, Assembler, Ladder Logic programming	Associate Process Control Engineer at the Metropolitan Water Reclamation District of Greater Chicago. Maintain Distributed Control Systems.	Electrical	MCU Programming, circuit design and testing
Daniel Gonzalez	Electrical Engineering 4th Year	Experience in MATLAB, C++, Java, Assembly Language, building and debugging circuits, good writing skills, bilingual (Spanish-English)	Electrical engineering and MATLAB code writing. Work in IPRO 302 last semester	Electrical	Member of the electrical team. Design power supply for the circuit. Implement Algorithm for Gauge processing / Misc Coding
Bryan Kaminski	Electrical Engineering 3rd Year	Various computer languages, EagleCAD, MPLAB	Familiarity with programming microcontrollers, soldering	Electrical	Sub team lead Implement ANT+ Communication
Nathan Knopp	Aerospace Engineering and Mechanical Engineering 4th Year	Experience in Pro/E, MATLAB, multiple computer programming languages. Practical experience with instrumentation.	Mechanical engineering work in IPRO 310 in Spring 06. Propulsion systems engineering co-op with NASA Kennedy Space Center.	Mechanical	Mechanical sub team lead. Apply/test strain gauges on bike spider. Organize and analyze results. Design product packing and perform FEA.
Crystal Jankhot	Aerospace Engineering 4th Year	MATLAB, LABVIEW, Pro/Engineer, interested in project management.	Laboratory experience (setting up experiments, data acquisition, processing, fluid dynamics [esp. flow visualization])	Mechanical	IPRO leader. Apply/test strain gauges and process/isolate signals. Organize results.
Brandon Marcellis	Aerospace Engineering 3rd Year	MATLAB, AUTOCAD, Some electronic instrumentation experience	Interest in using equipment and solving problems.	Mechanical	Apply/test strain gauges on bike spider and analyze results.
David Poli	Electrical Engineering and Engineering Physics 4th Year	MATLAB, circuit simulation, Printed Circuit Board (PCB) design, instrumentation interfacing, practical instrumentation	Optics and Detectors Internship at Ball Aerospace & Technologies, Technical Co-op at Argonne National Laboratory Electrochemical Analysis and Diagnostics Laboratory	Electrical	Electrical sub team scribe. Develop circuitry and ANT+ communications. Final presentation compiler
Ryan Ruidera	Mechanical Engineering 4th Year	Experience in Pro/E, Solid Works, MATLAB, multiple computer programming languages. Practical experience with instrumentation.	Mechanical engineering work in IPRO 349 in Spring 08. SAE build team for last year's 3rd place Formula Hybrid Competition	Mechanical	Apply/test strain gauges on bike spider and analyze results.
Henrietta Tsosie	Mechanical Engineering 4th Year	Experience in SolidWorks, MATLAB, Maple, C++, and Adobe Illustrator. Microsoft pack (WORD, Excel, etc). Instrumentation in Lab-- soldering, recording data, etc.	Internship at Argonne National Lab (research in enhanced heat transfer). Academic interest in hybrid vehicles, heat transfer applications, engine efficiency, and alternative energy.	Mechanical	Apply/test strain gauges on spider crank set and data analysis. Scriber. Ethics and team charter deliverables.
Jaewon Yoo	Electrical Engineering 4th Year	MATLAB, Dreamweaver, Orcad for electrical design automation.	Rockwell Automation Korea during summer 08. Interested in designing power circuits.	Electrical	Abstract/Brochure. Develop circuitry and ANT+ communications.
Arkadiusz Ziomek	ECE 3rd Year	SolidWorks, AutoCAD, MATLAB, Simulink, C, Assembler of AVRAtmega16/32	Experience in design and construction of four legged walking machine. Interested in mechatronics, robotics, electronics, and control systems.	Electrical	Testing of an interface between strain gauges and microcontroller.

Team Leader

- Crystal Jankhot

Mechanical Sub-team

- Nathan Knopp (Sub-team Lead)
- Crystal Jankhot
- Brandon Marcellis
- Ryan Ruidera
- Henrietta Tsosie

Electrical Sub-team

- Bryan Kaminski (Sub-team Lead)
- Sergio Aguilar
- Patrick Becker
- Daniel Gonzalez
- David Poli
- Jaewon Yoo
- Arkadiusz Ziomek

Changes to Team Structure and Responsibilities

There were no changes to the team structure, and only minor changes to team responsibilities to better utilize all team members and adjust to realities of the project.

Sub-team Responsibilities

Mechanical

- Determine ideal locations for strain gauges on spider
- Apply strain gauges to spider and solder wires
- Test spider under various loads and angles
- Analyze results of strain gauge testing
- Reverse engineer commercial device

Electrical

- Develop microcontroller and circuitry for strain gauges and RPM measurements
- Interface standard bike computer with measurement circuitry
- Reverse engineer commercial device

Budget

ITEM	UNIT PRICE	QTY	PRICE	PURPOSE
IPRO Budgeted Items				
Pizza and Refreshments	$87.00	1	$87.00	Team building Activities
Strain Gauges CEA-13-062UW-350	$442.50	1	$442.50	Sensor to determine torque
Garmin Edge 705 bike computer	$470.29	1	$470.29	Displays power data
	IPRO Budget Subtotal:		**$999.79**	
Items from Outside Sources				
NRF24AP1	$6.00	2	$12.00	ANT Chipset, used for communication with GARMIN Edge 705 using ANT+ protocol
NRF24AP1-EVKIT	$699.00	1	$699.00	ANT Developers KIT
ANT Alliance membership (5yr)	$500.00	1	$500.00	Needed for Profiles and Network Key
Quarq Crankshaft	$1,525.00	1	$1,525.00	Reverse Engineering
Other electronic components	$100.00	1	$100.00	MCUs, resistors, capacitors, amplifiers, switches, wire, etc…
	Outside Source Subtotal:		**$2,836.00**	
	Total:		**$4,748.58**	

Results

Electrical Results

Purpose

The Electrical team was tasked with processing the strain gauge signals and transmitting an instantaneous power measurement to a bicycle computer like the Garmin Edge 705 using the wireless protocol, ANT +Sport.

Procedure

To develop an electrical processing unit for post-processing the strain gauge signals, our team needed to develop both software and hardware. Program code for a PIC18F2320 microcontroller was written using the MPLAB IDE's MCC18 C programming editor and compiler. The program is responsible for reading the strain gauge signal at A/D ports, computing the power from the strain signals and a future RPM signal and sending the power to the ANT nRF24AP1 module using the ANT+Sport message protocol. The ANT module would need to be configured by configuration messages sent from the microcontroller using the same protocol. When configured as a power sensor device as specified by the ANT+Sport protocol, the ANT module would broadcast the power data in a format recognizable to an ANT+Sport receiver such as the Garmin Edge.

Hardware design involved a power supply circuit, strain gauge bridges, strain gain switching and the MCU and ANT module connections.

1) Implement ANT+ communication.

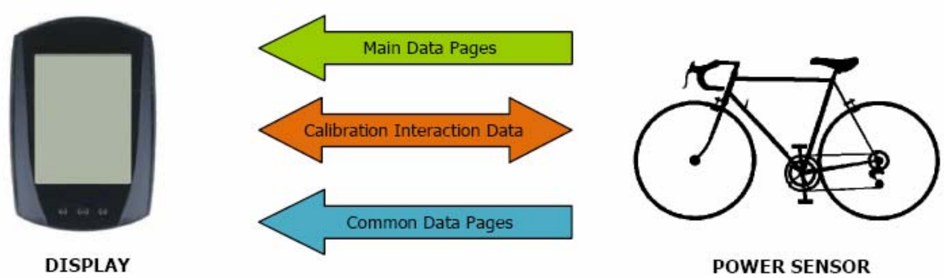


Figure 1: Standard Use Case of an ANT+ Bike Power sensor

ANT's dynamic wireless network enables power consumption management. It can construct simple and complex practical wireless networks and is engineered for low power, ease of use, scalability, and interoperability that enables sensors to operate for up to three years on a coin cell battery.

ANT features:

- operates on world-wide licensed-free 2.4GHz ISM band
- Small size ANT protocol embedded radio chip.
- 16 bit CRC data validity detection
- Message rate 0.5Hz to 200Hz with 8 byte data load per message

ANT (nRF24AP1) to MCU (PIC18F2320) Interface

The interface between ANT and the Host MCU has been designed with the utmost simplicity. ANT allows a low-cost 4-bit or 8-bit microcontroller to establish and maintain complex wireless networks.

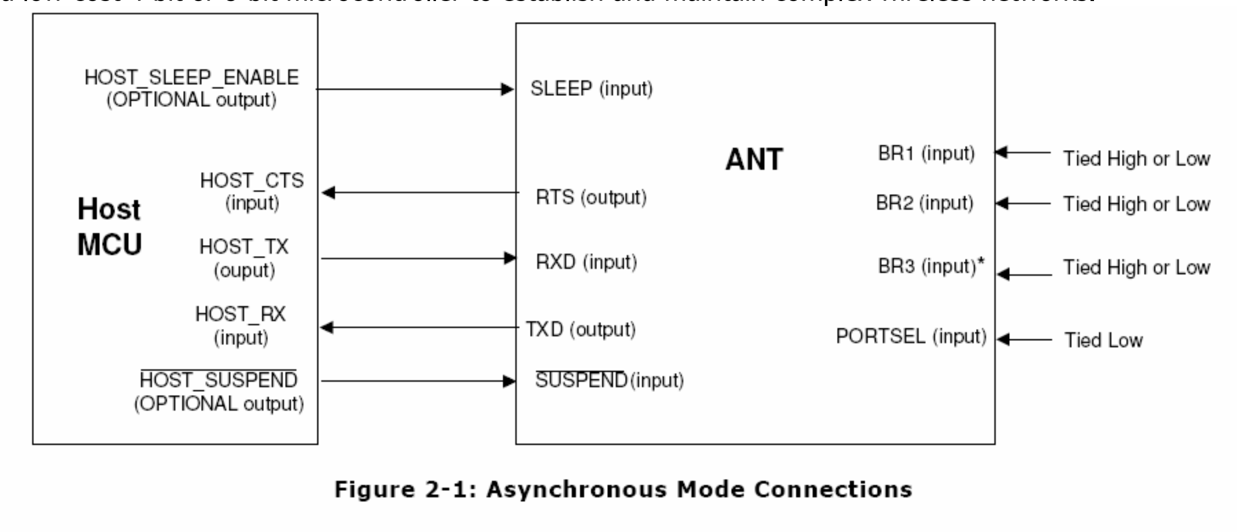
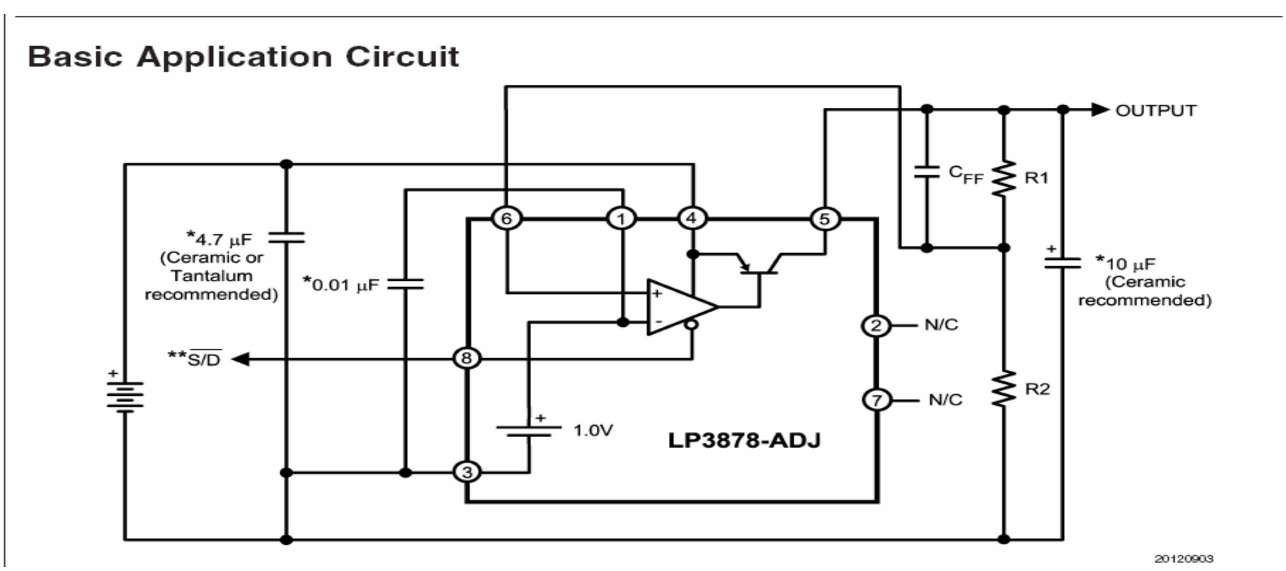


Figure 2-1: Asynchronous Mode Connections

The MCU and ANT may communicate using the asynchronous mode of the serial interface. The connection diagram is shown above in Figure 2-1. Synchronous mode is selected by setting the PORTSEL input high. For Asynchronous mode, PORTSEL set low. The ANT+Sport protocol dictated that we us Synchronous mode.

2) Power supply circuit

We needed two voltages levels, 1V and 3V, and used voltage regulator to keep constant voltage. To meet the voltage level that each chip requires, we designed circuit shown on the schematic below. The regulator keeps the output at a constant 1V, which is then used to drive the strain gauges. Because this voltage well regulated, errors are minimized in reading the corresponding strain value.



3) Strain Gauge interface

To build a switching interface for the strain gauges, we decided to use analog switches and a decoder connected to the microcontroller. The purpose of the switching circuit is to allow us to read the individual strain values from each gauge and process the data in software, rather than rely on a full bridge (which combines gauges to give one output value) and physical positioning of the gauges. Currently, the bridge in our circuit needs to be balanced by use of manual potentiometer. In the future, this could be controlled automatically by a digital potentiometer or other such device.

4) RPM circuit

In order to calculate the power generated by the rider, the torque must be multiplied by the RPM. We decided to leave the RPM circuit for last, as it is fairly simple to implement. Due to focusing on other aspects of the project, we were unable to finish the RPM circuit. In the future, this could easily be implemented by a simple Reed switch and magnet combination. We have researched this type of RPM circuit and it would not take long to include in the final circuit.

Schematic

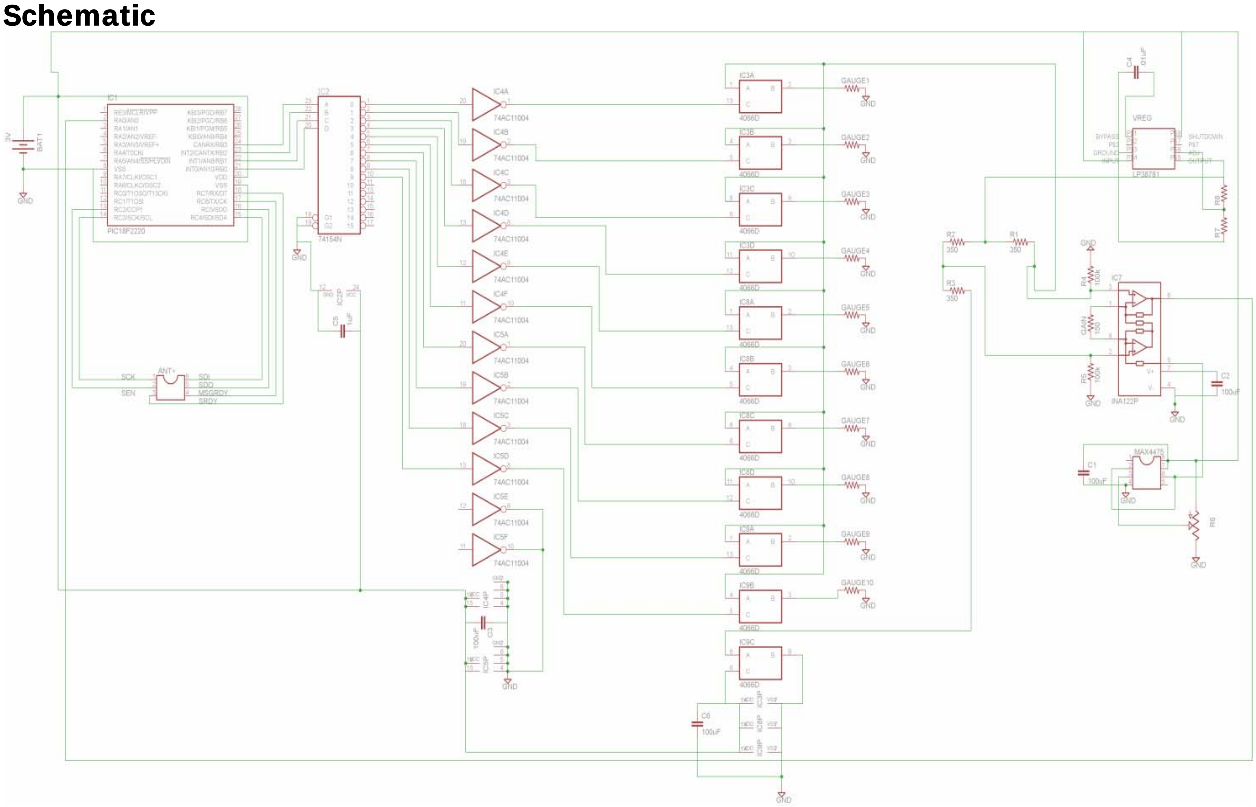


Figure E1 Circuit Schematic

This schematic is made up of microcontroller, filter, differential OPAMP, switch, multiplexer, strain gauge and inverter.

Testing

To test the operation of ANT+ software routines, we used a logic analyzer to verify the correct signals. When we encountered problems, the code was modified and tested again. This procedure was repeated until basic ANT+ communication was successful.

A majority of our tests were to verify, with a voltmeter, that the proper voltages were present at various nodes. For example, we used the voltmeter to verify that the voltage regulator was correctly outputting a regulated 1V to the strain gauge bridge. Also, we used the same procedure to verify the reference voltage going to the instrumentation amplifier.

We tested the strain gauge bridge in a similar manner. Before hooking up the switching circuit, we connected only one strain gauge to the bridge, and verified that the output voltage was correct. Due to our reference voltage being 1.5V, the strain gauge output should have a baseline of 1.5V, swing to 3V when the gauge is fully tensioned, and drop to 0 when the gauge is fully compressed. With only one gauge in our bridge, this operation was correctly verified.

To test the switching circuit without the gauges installed, we used 10 LEDs (Light Emitting Diodes) to indicate which switch was currently active. In our microcontroller, we sequentially went through each switch, using a time delay between each switching operation. This allowed us to visualize the operation of the circuit on the LEDs, which would turn on and off in the same pattern as indicated in our code.

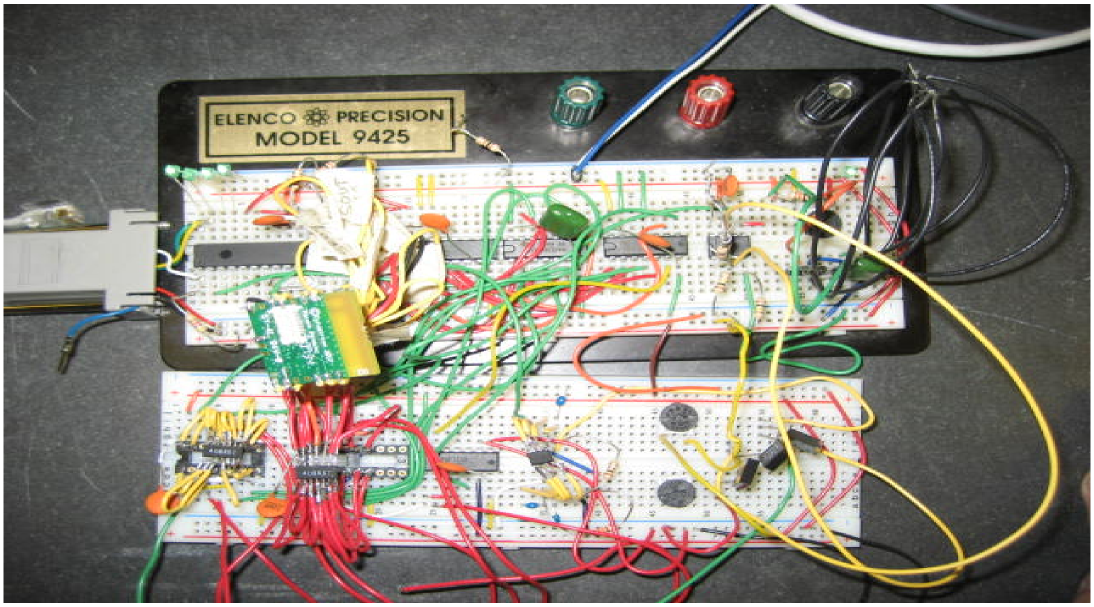


Figure E2 Circuit

Data

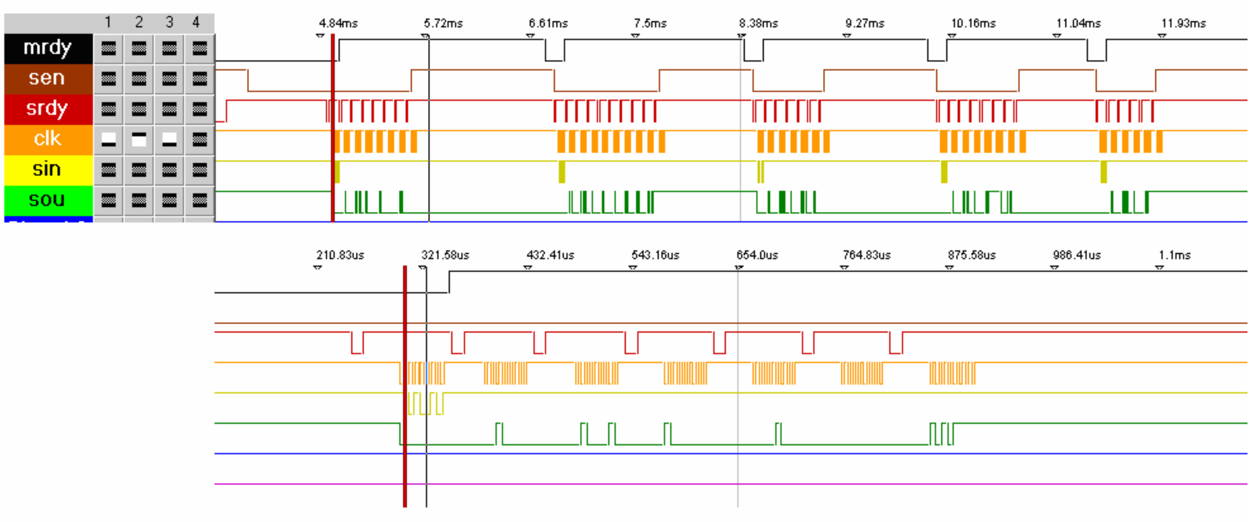


Figure E3 Logic Analyzer capture of MCU <-> ANT communications

Figure E3 shows the byte by byte transmission of messages from the MCU to the ANT module captured with a logic analyzer. Our transmission sequence matches the sequence shown in the ANT examples below.

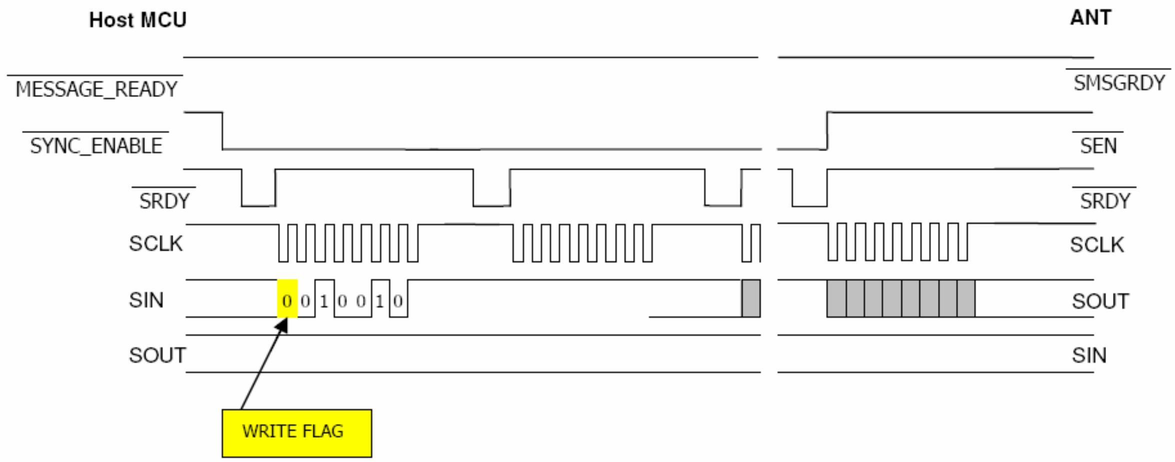


Figure 3-2: ANT -> Host Transaction (Hardware $\overline{\text{SRDY}}$)

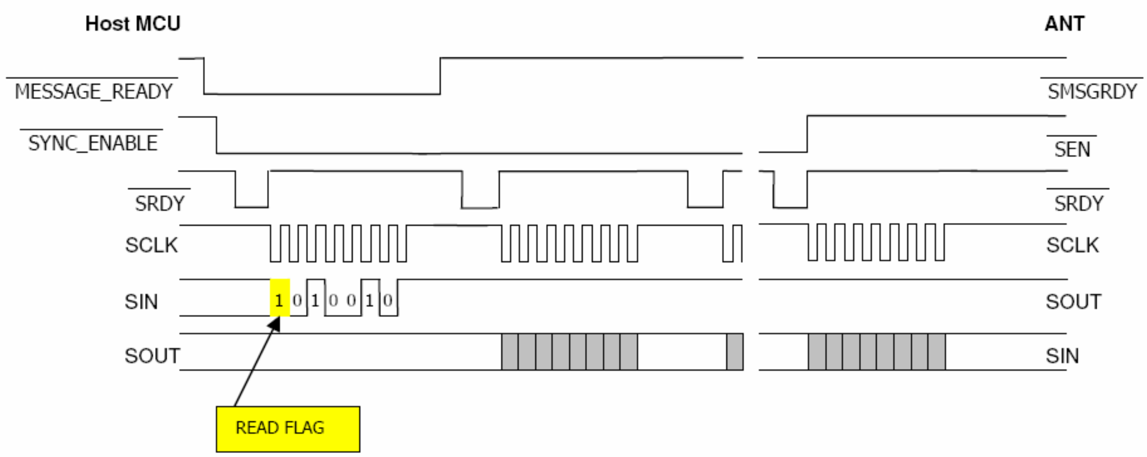


Figure 3-3: Host -> ANT Transaction (Hardware $\overline{\text{SRDY}}$)

The above Figure 3-2 and 3-3 are examples of transactions between the MCU and ANT in byte synchronous mode from the ANT protocol documentation. Note that both ANT -> Host transactions and Host -> ANT transactions both begin with the Host reading a byte from ANT.

For the Host to send data, the MESSAGE READY signal is set low, followed by ANT setting SYNC ENABLE low. The Host then pulses SRDY low to initiate the clock from ANT. The MCU then reads the first byte and verifies that it is 0xA5. This byte value indicates that the ANT module is ready to receive our message. In our application, the Host will send configuration messages to the ANT module to establish the correct ANT+Sport radio settings and to send power data messages to the module for broadcast.

For ANT to Host Messages, the process begins with ANT setting SYNC_ENABLE low. The Host responds by pulsing SRDY low and reading the byte per the ANT generated clock signal. If the first byte is 0xA4, the Host is to read the rest of the message by continuing to pulse SRDY low and reading the next byte. In our application, the ANT module will only send messages to the Host in response to the receipt of a configuration message. To comply with the ANT+Sport protocol, the Host must also be able to process calibration request messages from ANT. We did not include the calibration routine in our implementation due to time constraints.

Experimental Results

We initially had problems communicating with the ANT module. One problem we ran into was that the first byte we sent from the Host to the ANT module was 0xA5. This was due to confusion with ANT's documentation. We also learned that the Host sends data Most significant bit (Msb) first. After asking for help form ANT+ developers, we learned that the Host does not send the 0xA5 byte. The Host will read a 0xA5 byte from ANT and then send the first byte of the message, message length. We created a function to swap the bits in each byte of our message so that the Host would transmit the least significant bit first.

In order to talk to the Garmin Edge 705 correctly, we need to spend more time re-working the software. This will require more robust error handling, hardware interrupt capability and the ability to handle calibration requests.

To read the strain gauge signal, we were presented with two options: create full bridges gauges composed of 4 strain gauges or create a switching circuit to obtain each gauge's value individually. We chose to take the option of the switching circuit. Prof. Mostovoy had warned us that if we use switches, the resistance through each switch will unbalance the bridge and also make it hard to manually balance. Understanding this, we found analog switches with a very low ON resistance (0.4-0.8 ohm), but they only came in very small SMT packages. We were unable to hand-solder these small packages, and had to abandon the use of them in our circuit. In order to meet our deadline, we tried used an analog switch that we could buy at our local electronics shop (CD4066). The resistance of these switches was too high, and we were unable to reliably balance the bridge. Due to this, we were unable to obtain any numerical data from our circuit. What we have built so far though, can be easily modified so that we can attempt again to use the originally intended switches and hopefully return a result.

We researched the costs of electrical components needed for a final design to determine if it is feasible to produce a final product which costs substantially less than other power measurement systems mentioned in the Background section. The cost of electrical components should not pose an obstacle to that goal.

Part	Quantity	Cost Each	Total
Microchip 18F2320	1	$8.65	$8.65
74HC154 Decoder	1	$0.96	$0.96
INA122 Amplifier	1	$5.56	$5.56
ADG811 Analog Switch	3	$3.40	$10.20
LP3878 Voltage Regulator	1	$2.50	$2.50
Precision 350 Ohm Resistor	3	$11.52	$34.56
MAX4475 Op-Amp	2	$0.72	$1.44
nRF2401A (ANT+ Chip)	1	$4.75	$4.75
Supporting Components -			
Resistors/Capacitors		$5.00	$5.00
Total Estimated Cost			$73.62

Resources

- MPLAB IDE v8.00

Mechanical Results

Application of Strain Gauges

The mechanical team learned how to correctly apply strain gauges to material as done in industry. Below, is the step-by-step process that was employed in attaching the strain gauges to the bicycle spider:

1. **Surface Preparation**
    1.1. sand the surface then add mild acid (red top on bottle) and sand a little more
    1.2. put the acid on a Q-tip and wipe until the qtip is clean
    1.3. put neutralizer (base in blue top bottle) on a piece of gauze and wipe from the center out to one side, then turn the cloth and wipe from the center out to the other side [repeat this step for the top of the plastic case for soldering tabs]
2. **Gauge Preparation**
    2.1. cut soldering tabs apart with some sharp pliers and place on top of the box
    2.2. take the gauge out with tweezers (touching near soldering points) and place on the top of the box as well
3. **Gluing**
    3.1. Use Mylar tape, stick the end to the box
    3.2. make sure gauge is in place (and tabs if necessary to be close)
    3.3. slide your thumb firmly and quickly along the tape over the gauge (be sure to do this quickly to avoid static electricity)
    3.4. Peel tape slowly at a very low angle until just past the parts
    3.5. Apply a very thin layer (strike about 10? times) of catalyst to the surface, let dry 1 minute
    3.6. put 1 drop of super glue on the surface and run your thumb firmly over the tape and gauge, press and hold for ~ 1 minute *for a real product there is a better glue that does not decay over time
    3.7. This time, peel the tape back at a very high angle ~180 degrees onto itself and off of the surface
    3.8. cover with another smaller piece of tape (and stick edges to the table to stabilize it for soldering) *Epoxy
4. **Soldering**
    4.1. Hint: don't forget to keep the needle clean with a wet sponge
    4.2. buff soldering tabs with an eraser
    4.3. burn the coating off of a copper wire and leave a dot of solder on it [hold the soldering iron behind the wire and the solder in front]
    4.4. put a tiny dot of solder on each soldering point
    4.5. solder down the end you have prepared
    4.6. bend the wire a little (between gauge and soldering tabs) for flexing so that it isn't too tight
    4.7. cut the wire just past where you need to secure it
    4.8. again burn off the coating, leaving a dot, solder down
    4.9. [repeat for the other wire]
5. **Attaching the lead wires**
    5.1. strip wires and clip to the correct size (too much unprotected wire causes noise interference in the signals)
    5.2. if you have 3 wires but need only two, twist the white and black together
    5.3. put a dot of solder on the end of the wire
    5.4. anchor the lead wires on to the part (use tape, epoxy, zip tie, etc)
    5.5. solder down to the free solder tab
    5.6. strip the other ends of the wires (strip this end more)
6. **Finishing up**
    6.1. Check for proper resistance (120 Ω)
    6.2. Check for a short to the specimen or part (is there voltage flowing between the wires/gauges and the specimen? Should be open / infinity)
    6.3. Put a thin layer of polyurethane coating over the top *(For a real product there will be a more complex coating procedure)

Wiring

Once the gauges were applied in the desired positions as indicated in the diagram below, they had to be wired.

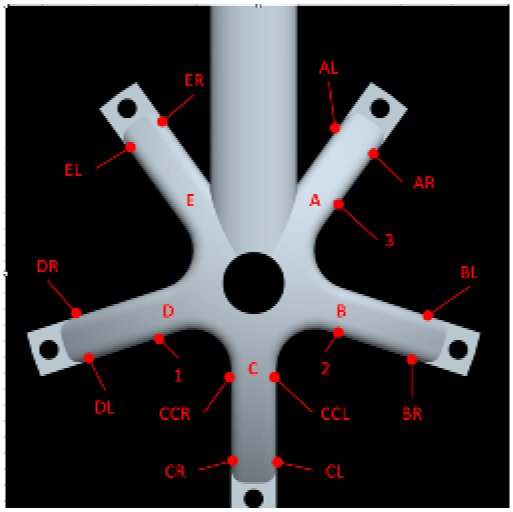


Figure R1: Strain Gauge Placement

The above instructions include the wiring of the actual gauges to soldering tabs also glued to the surface in convenient locations. These wires were small diameter coated copper wires for precise work. In addition to this, lead wires about three feet long were soldered to the other side of each soldering tab (See Figure R1).

Figure R2: Placement of Soldering Tabs and Wires

These lead wires were then used to send the strain signals from the gauges to a switch and balance unit (Measurements Group, serial IIT – 73175, model SB-10), and the data was read from the wide range strain indicator (Measurements Group, serial IIT – 73175, model 3800).

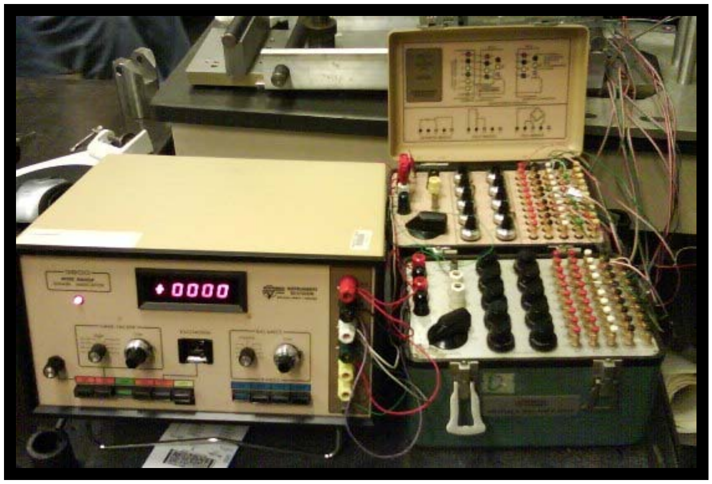


Figure R3: Switch and Balance Box with Strain Indicator

Note that this wiring scheme is simply for the purpose of initial data acquisition. The final will be compact, efficient, and the wires will be very short because the processor will be located somewhere on or behind the spider.

Testing

The machine that was used for testing the apparatus was the Instron tensile machine Model 4465. The apparatus used for testing was built at the Illinois Institute of Technology. It consisted of a spider, crank set, and chain rings as the set-up being tested along with a dummy spider, crank set, and chain ring. The reason for the dummy set-up was so that a chain could be used to secure the top set from rotating when pressure was applied because the chain ran along the bottom set which was made to be stationary.

Figure R4: Test Stand and Set-up

Figure R5: Test Stand in the Instron – Pulling

Figure R6: Test Stand in the Instron – Pushing

An additional steel plate was machined to anchor the test stand to the machine. Also, two different grips were used depending on whether the machine was pushing or pulling.

Figure R7: Base Plate for Test Stand Anchor

The testing procedure was relatively simple. Twelve gauges were used (labeled A through E and also CC [left and right]). The horizontal position of the crank arm was taken to be zero degrees. The apparatus was tested for 0, 20, 40, 60, and 80 pounds force (some of the later tests omitted 20 pound force because it had less resolution and was not necessary to form a straight line). These forces were applied at the angles 0, ±22.5, ±50, ±65°, & ±90°. Notice that ±90° should have a torque of zero because it is based on the horizontal distance from the acting force to the axis of rotation of the crank arm. For each angle, a force was applied and the switch and balance box was used to determine each strain gauge signal. Then, the next force was applied. **IMPORTANT – the knobs on the box must be carefully maneuvered sometimes to avoid bad data.

Data

The original data was taken as the strain gauge signals in micro-strain with respect to the load being applied by the Instron machine. The information that was actually of interest, though, was the torque being applied – which was based on the horizontal component of the lever arm. Below, are the graphs of the micro-strain versus the applied torque for each pedal and each angle that was tested.

Notice that some graphs seem to be missing the data for the first torque (at 20 pounds force). The reason for this was that in the interest of time, this point was left out due to the fact that the lower loads gave less resolution in data, and only three points were needed for a linear regression.

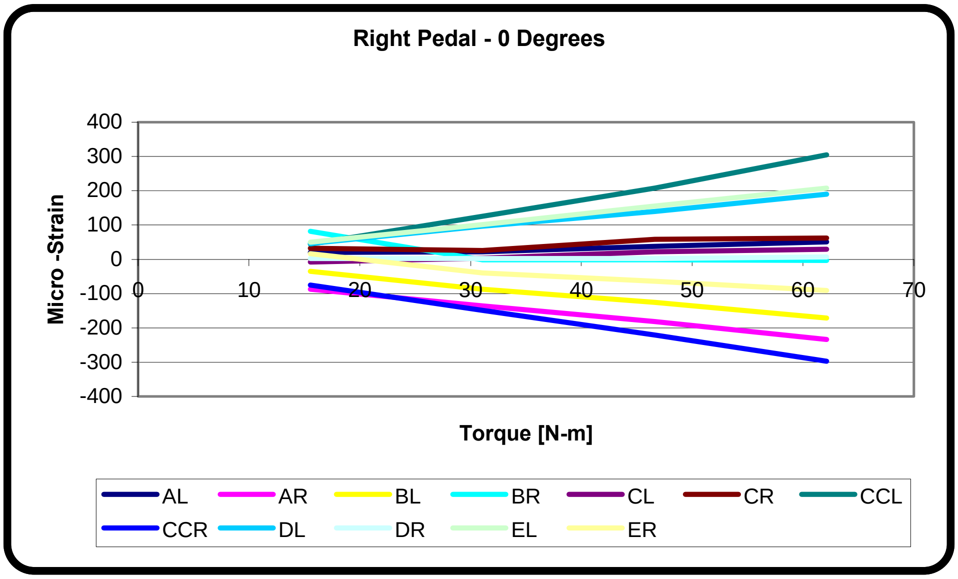


Figure R8: με Vs Torque – Right Pedal, 0 Degrees

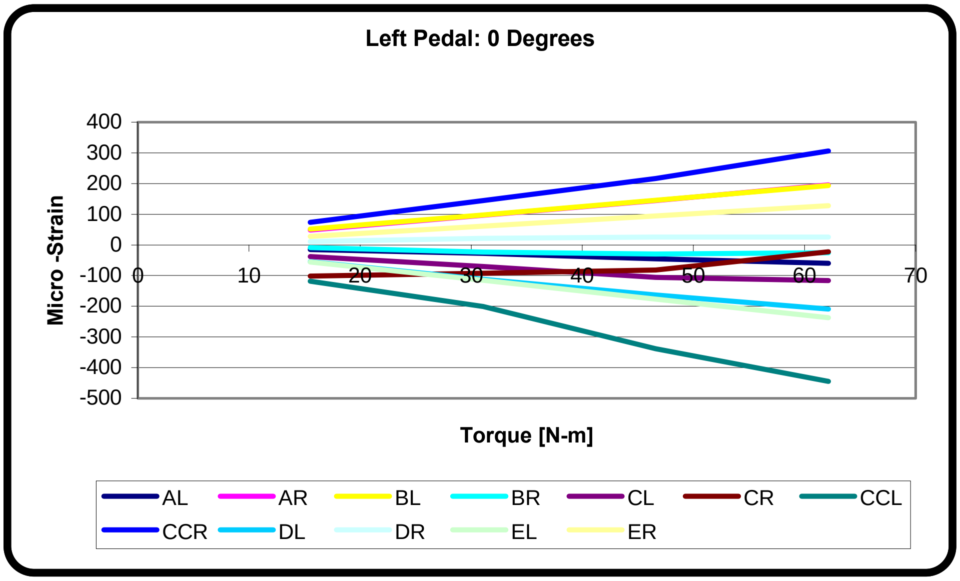


Figure R9: με Vs Torque – Left Pedal, 0 Degrees

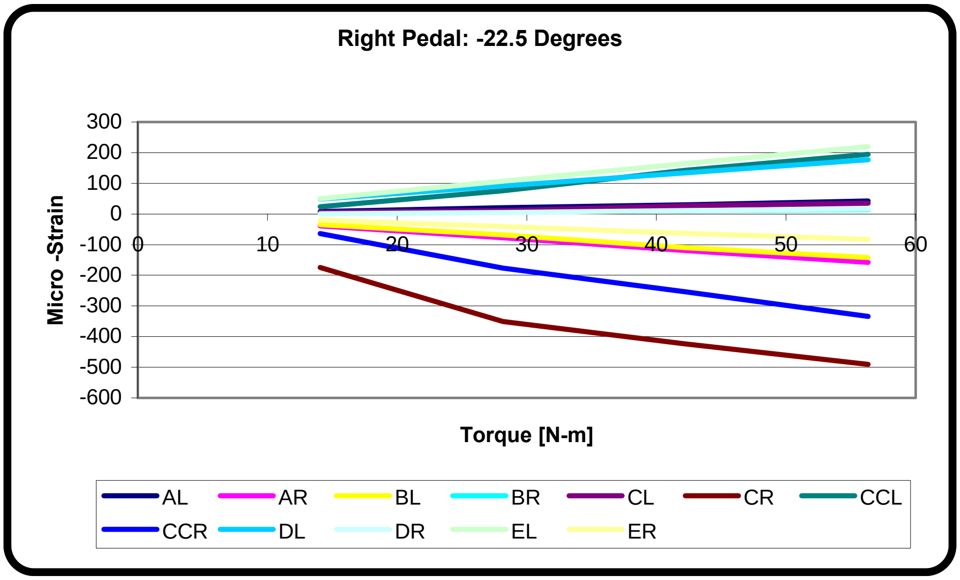


Figure R10: με Vs Torque – Right Pedal, -22.5 Degrees

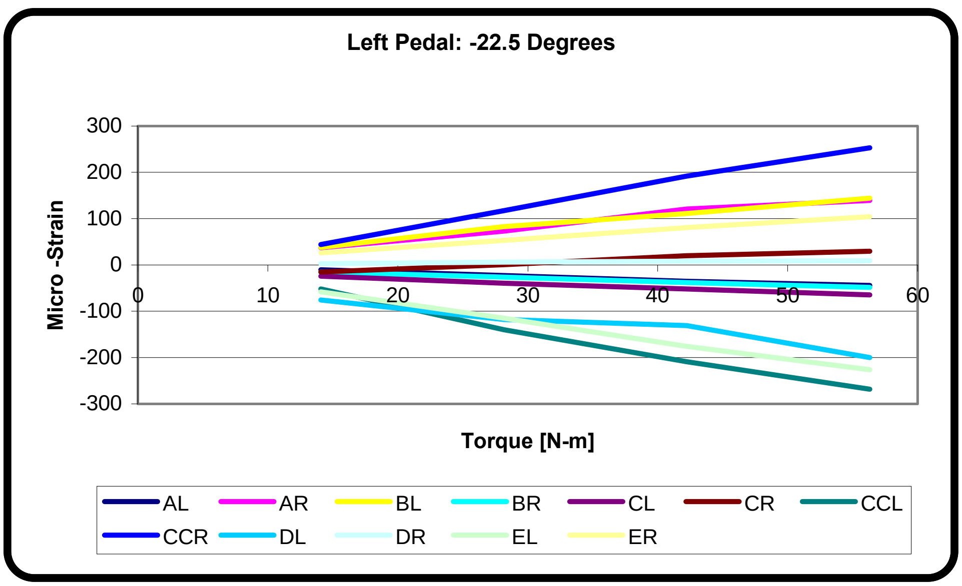


Figure R11: με Vs Torque – Left Pedal, -22.5 Degrees

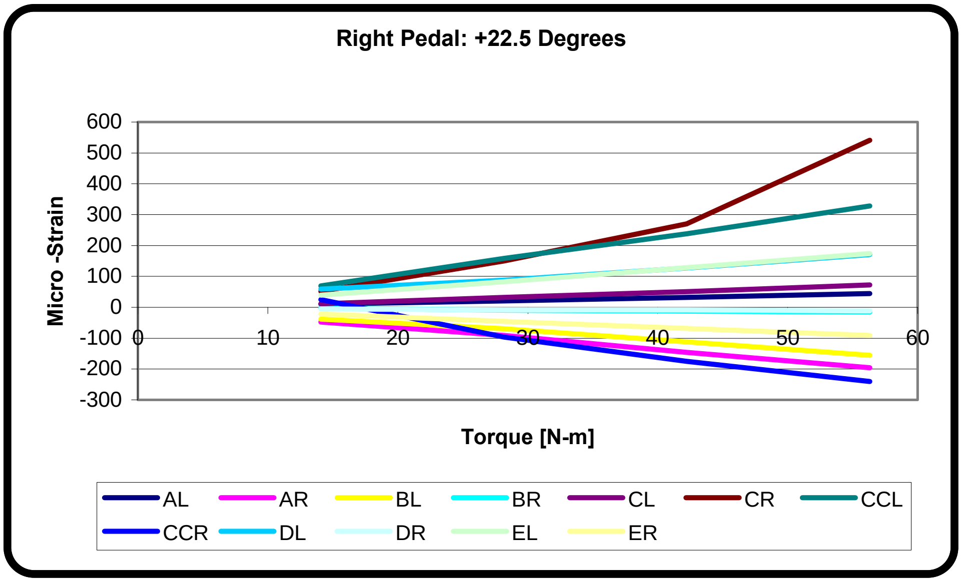


Figure R12: με Vs Torque – Right Pedal, +22.5 Degrees

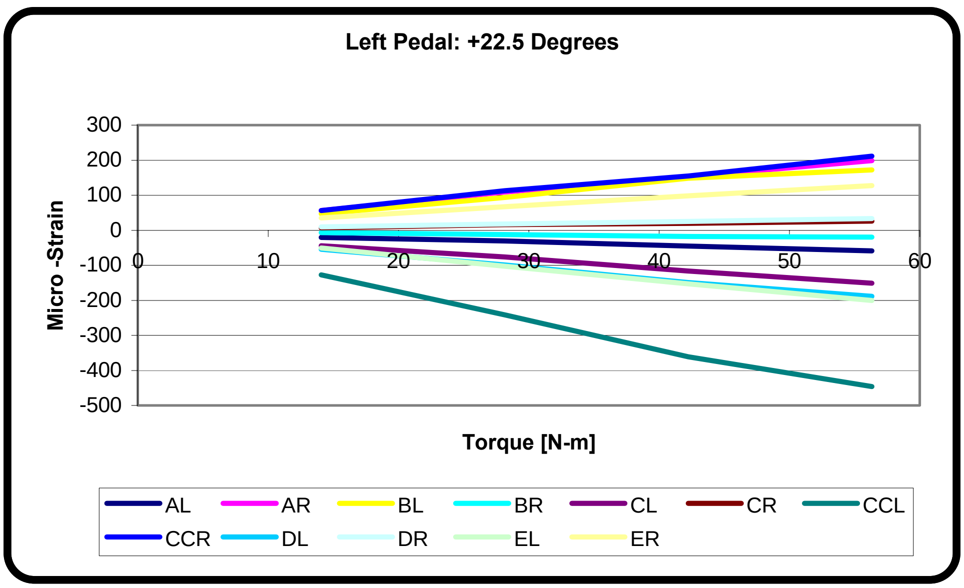


Figure R13: με Vs Torque – Left Pedal, +22.5 Degrees

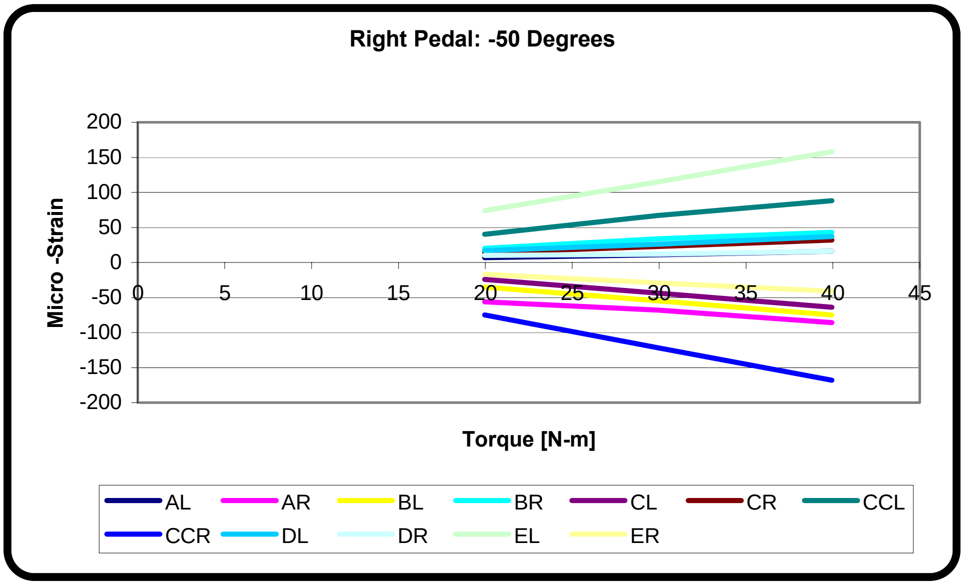


Figure R14: με Vs Torque – Right Pedal, -50 Degrees

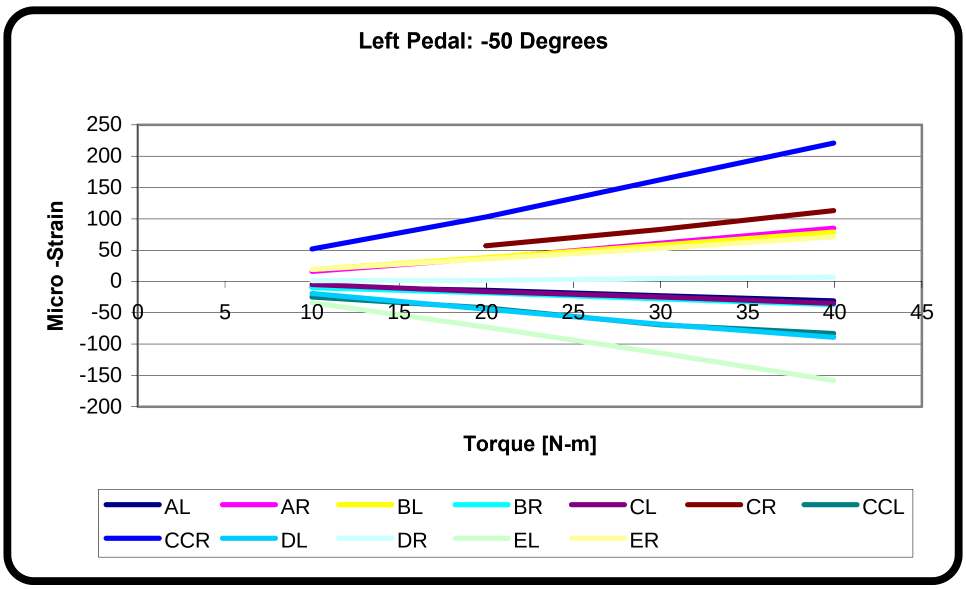


Figure R15: με Vs Torque – Left Pedal, -50 Degrees

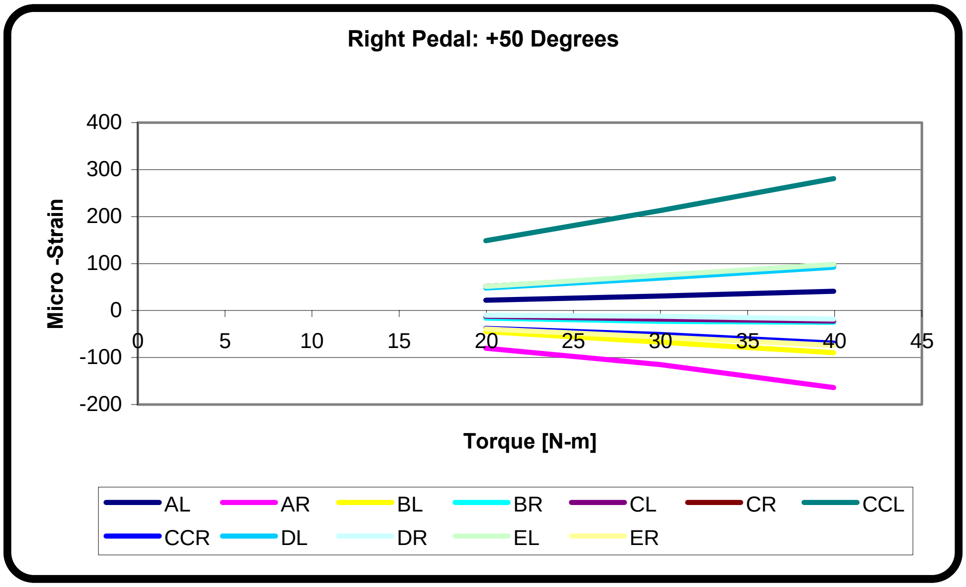


Figure R16: με Vs Torque – Right Pedal, +50 Degrees

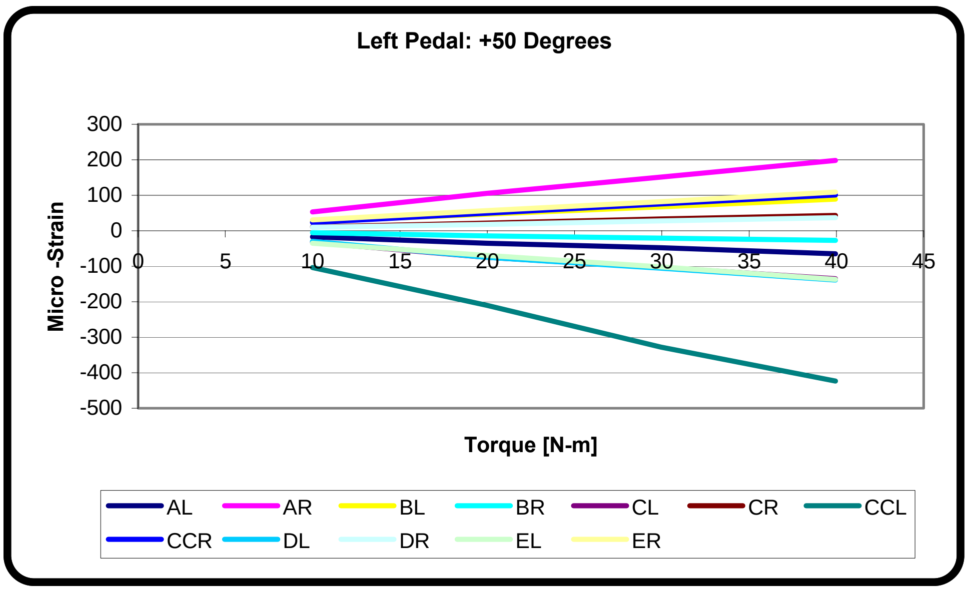


Figure R17: με Vs Torque – Left Pedal, +50 Degrees

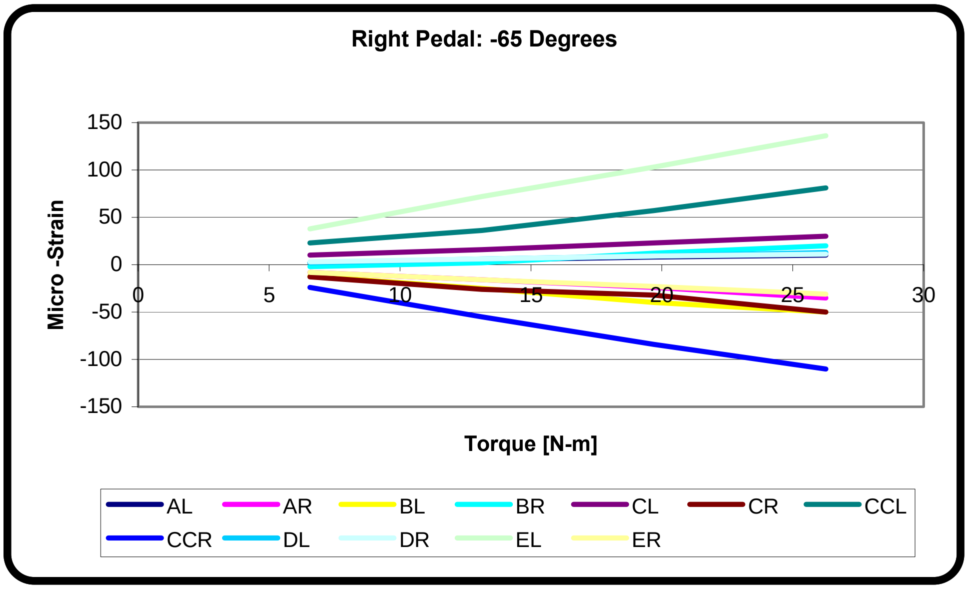


Figure R18: με Vs Torque – Right Pedal, -65 Degrees

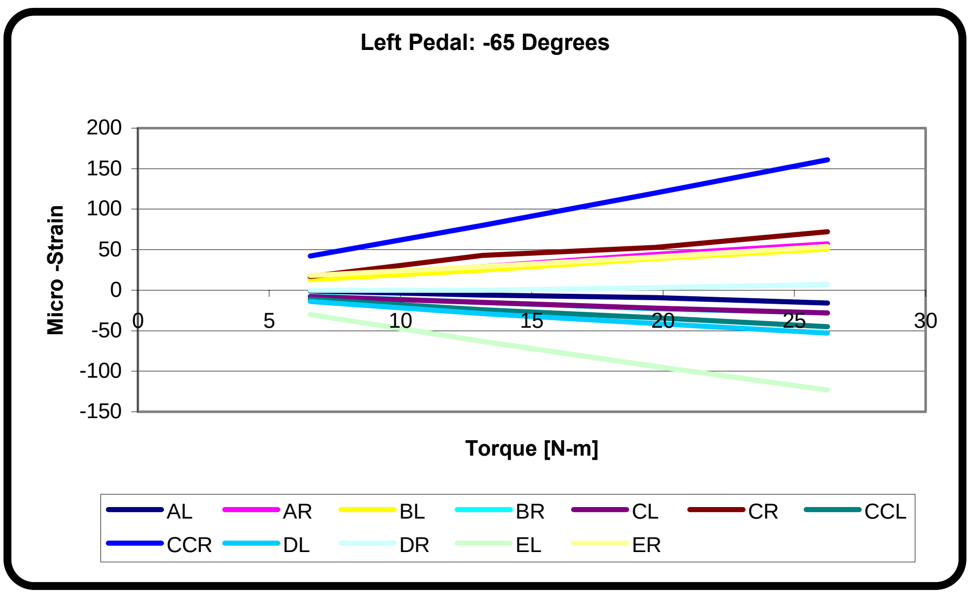


Figure R19: με Vs Torque – Left Pedal, -65 Degrees

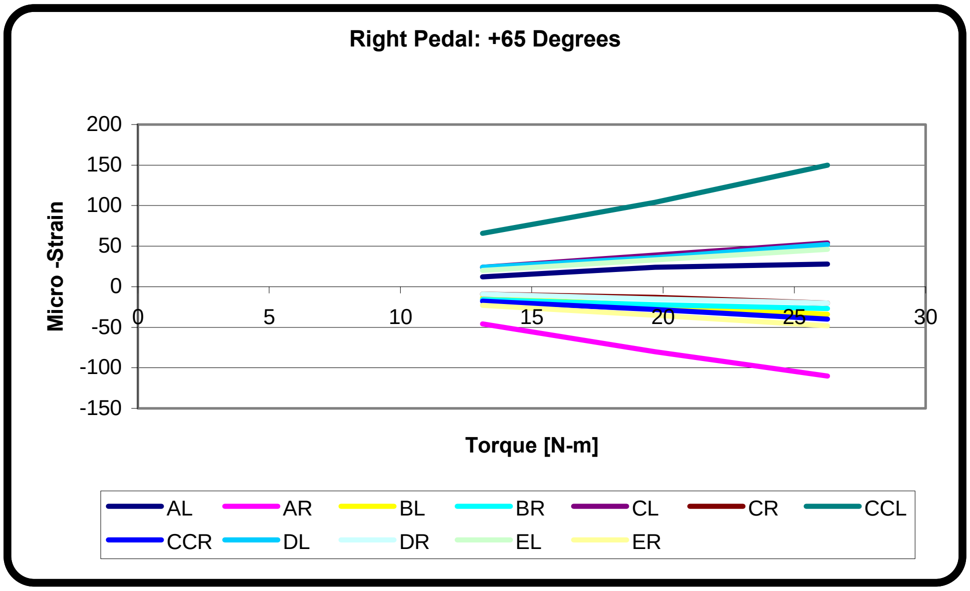


Figure 20: με Vs Torque – Right Pedal, +65 Degrees

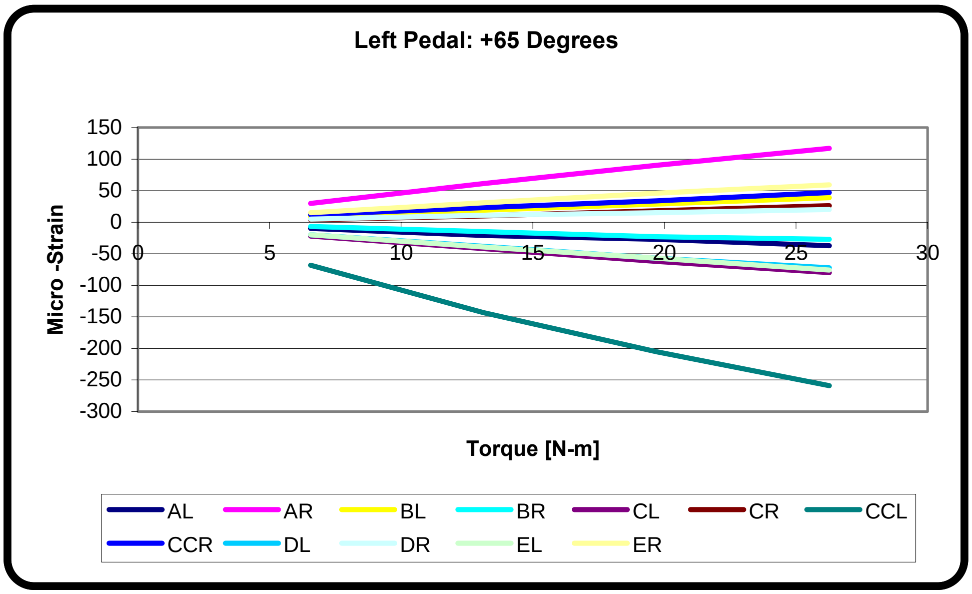


Figure 21: με Vs Torque – Left Pedal, +65 Degrees

Also, the same measurements were taken for ± 90 degrees as well, but of course these angles should have a lever arm of zero and therefore a torque of zero. The micro-strain versus applied load instead of torque was plotted below.

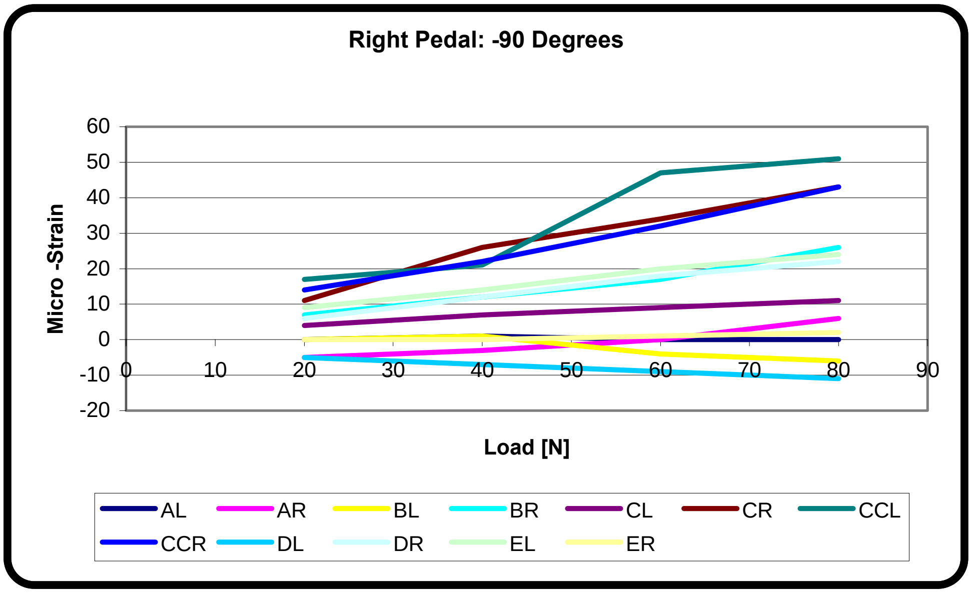


Figure R22: με Vs Load – Right Pedal, -90 Degrees

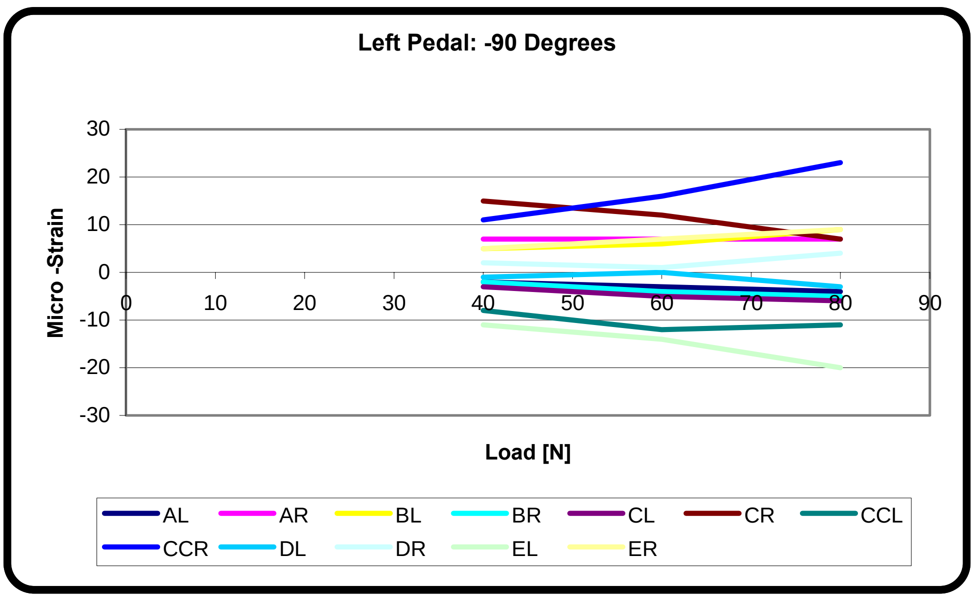


Figure R23: με Vs Load – Left Pedal, -90 Degrees

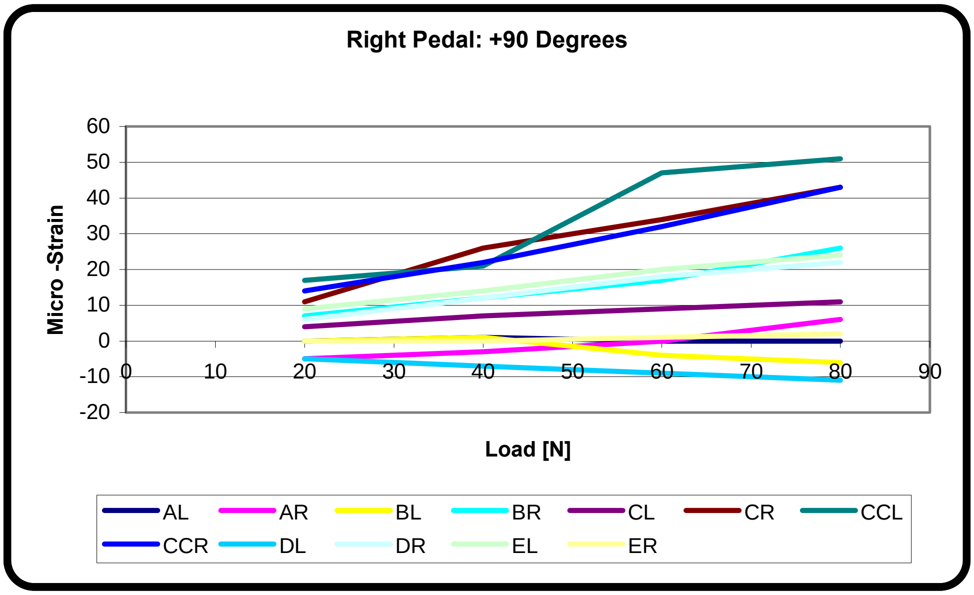


Figure R24: με Vs Load – Right Pedal, +90 Degrees

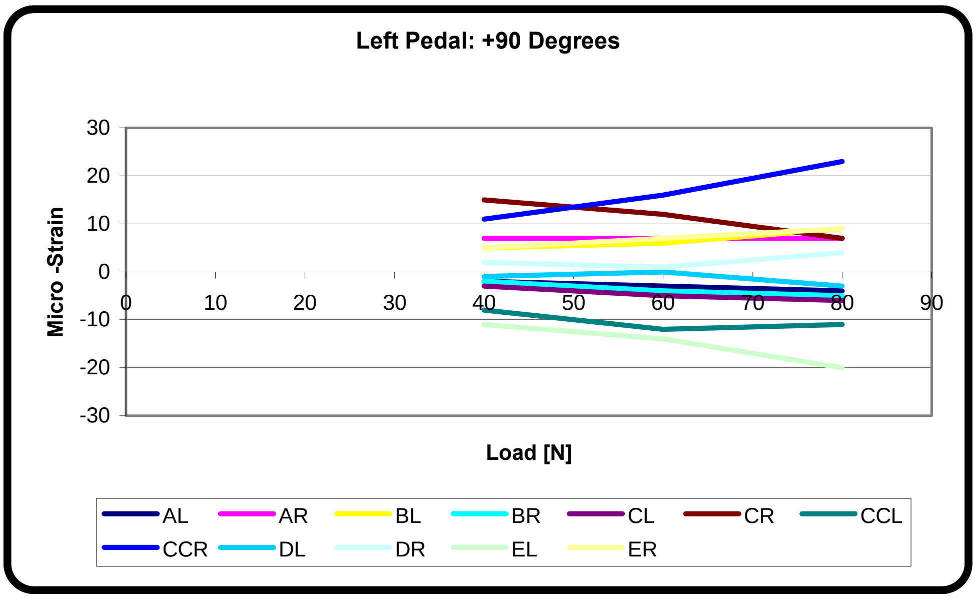


Figure R25: με Vs Load – Left Pedal, +90 Degrees

Obviously, the data did turn out to be linear (when measured carefully) as was expected. Unfortunately, there were offsets (the lines through the data did not go through zero) even though the equipment was adjusted for zero offset when the experiments were conducted.

Solid Modeling & Finite Element Analysis

Data Analysis

The data was analyzed by first finding the slope of each strain gauge at each angle and on each pedal by running a linear regression on each set of data. The process is summarized in the table below, showing the slopes, y-intercepts, and r^2 values for each.

Summary of Linear Regressions													
	Right Pedal	**AL**	**AR**	**BL**	**BR**	**CL**	**CR**	**CCL**	**CCR**	**DL**	**DR**	**EL**	**ER**
	Slope	0.702	-3.135	-2.877	-1.641	0.837	0.785	5.568	-4.750	3.058	0.097	3.399	-2.221
	Y-Intercept	5.5	-38	7	83	-21	14	-45.5	-1	-0.5	-0.5	-3.5	41.5
	R^2	0.930	0.999	0.997	0.619	0.972	0.754	0.998	1.000	0.999	0.600	1.000	0.956
	Left Pedal												
	Slope	-0.978	3.141	3.032	-0.354	-1.738	1.609	-7.196	4.944	-3.302	0.322	-3.894	2.144
	Y-Intercept	1	-0.5	4.5	-8	-15	-137	4	-7	-6.5	8.5	5	-5.5
0°	**R^2**	0.998	1.000	1.000	0.623	0.956	0.806	0.992	0.996	0.998	0.833	1.000	1.000
	Right Pedal	**AL**	**AR**	**BL**	**BR**	**CL**	**CR**	**CCL**	**CCR**	**DL**	**DR**	**EL**	**ER**
	Slope	0.780	-2.773	-2.529	0.216	0.718	-7.114	4.041	-6.180	2.975	0.355	3.950	-1.470
	Y-Intercept	-3	1	2	1.5	-6	-104.5	-35.5	14.5	6	-4.5	-6.5	1
	R^2	0.999	1.000	0.997	0.986	0.963	0.936	0.997	0.991	1.000	0.995	1.000	1.000
	Left Pedal												
	Slope	-0.794	2.466	2.411	-0.773	-0.948	1.073	-4.996	4.891	-2.682	0.139	-3.937	1.825
	Y-Intercept	0.5	4	7.5	-4	-11	-29.5	12	-24	-35	1.5	-2.5	0.5
-22.5°	**R^2**	0.994	0.974	0.990	0.999	0.999	0.987	0.992	0.998	0.932	0.952	0.999	0.998
	Right Pedal	**AL**	**AR**	**BL**	**BR**	**CL**	**CR**	**CCL**	**CCR**	**DL**	**DR**	**EL**	**ER**
	Slope	0.808	-3.456	-2.745	-0.293	1.407	11.057	5.971	-6.089	2.613	-0.125	3.135	-1.602
	Y-Intercept	-2	4	5	1	-9	-143.5	-16	97	17.5	-3.5	-6.5	1
	R^2	0.998	0.998	0.994	0.948	1.000	0.938	1.000	0.979	0.992	0.900	1.000	1.000
	Left Pedal												
	Slope	-0.892	3.296	2.989	-0.314	-2.515	0.425	-7.497	3.532	-3.170	0.530	-3.463	2.139
	Y-Intercept	-7.000	11.000	8.000	-3.000	-6.500	2.000	-25.000	7.000	-9.000	2.500	-2.500	5.000
22.5°	**R^2**	0.994	0.998	0.979	0.967	0.998	0.975	0.995	0.997	0.998	0.999	0.999	1.000
	Right Pedal	**AL**	**AR**	**BL**	**BR**	**CL**	**CR**	**CCL**	**CCR**	**DL**	**DR**	**EL**	**ER**
	Slope	0.451	-1.502	-2.003	1.152	-2.003	0.901	2.403	-4.657	1.001	0.300	4.206	-1.202
	Y-Intercept	-2.167	-25.000	5.000	-2.167	16.000	-4.000	-7.000	17.833	-3.333	3.667	-10.333	7.000
	R^3	0.996	0.987	1.000	0.984	1.000	1.000	0.995	1.000	0.997	0.964	1.000	1.000
	Left Pedal												
	Slope	-0.751	2.313	2.003	-0.911	-0.991	2.804	-2.013	5.668	-2.343	0.210	-4.136	1.732
	Y-Intercept	-0.500	-8.000	-1.500	-0.500	4.500	0.333	-4.500	-7.000	3.500	-1.500	8.500	1.500
-50°	**R^3**	0.988	0.999	1.000	0.998	0.999	0.998	0.986	0.999	0.998	0.969	0.999	1.000
	Right Pedal	**AL**	**AR**	**BL**	**BR**	**CL**	**CR**	**CCL**	**CCR**	**DL**	**DR**	**EL**	**ER**
	Slope	0.951	-4.206	-2.253	-0.451	-0.501	2.253	6.609	-1.552	2.203	-0.401	2.353	-1.752
	Y-Intercept	2.833	6.333	0.167	-7.833	-2.333	5.833	16.333	-6.167	3.667	-1.333	4.167	-3.833
	R^4	0.999	0.991	1.000	0.907	0.987	1.000	1.000	0.991	0.999	0.923	1.000	1.000
	Left Pedal												
	Slope	-1.572	4.817	2.103	-0.731	-3.385	1.072	-10.765	2.604	-3.575	0.911	-3.395	2.594
	Y-Intercept	-2.000	6.500	5.000	1.500	-2.000	0.500	2.500	-2.500	2.000	0.500	-1.000	5.000
50°	**R^4**	0.997	0.999	1.000	0.991	0.992	0.999	0.998	1.000	0.992	0.998	1.000	1.000
	Right Pedal	**AL**	**AR**	**BL**	**BR**	**CL**	**CR**	**CCL**	**CCR**	**DL**	**DR**	**EL**	**ER**
	Slope	0.411	-1.356	-1.965	1.158	1.020	-1.782	2.970	-4.371	0.548	0.411	4.950	-1.158
	Y-Intercept	-0.500	1.500	0.500	-11.000	3.000	-1.000	0.500	3.500	-1.500	0.500	6.000	-0.500
	R^5	0.992	0.993	0.994	0.976	0.999	0.966	0.984	0.998	0.997	0.992	1.000	0.999
	Left Pedal												
	Slope	-0.731	2.148	1.950	-1.081	-1.020	2.665	-1.706	6.047	-1.965	0.366	-4.722	1.828
	Y-Intercept	4.000	1.000	0.000	-0.500	-1.500	2.500	-0.500	1.500	-2.000	-3.500	0.000	5.500
-65°	**R^5**	0.976	0.999	0.999	0.989	0.999	0.972	0.997	1.000	0.997	0.873	0.999	0.999
	Right Pedal	**AL**	**AR**	**BL**	**BR**	**CL**	**CR**	**CCL**	**CCR**	**DL**	**DR**	**EL**	**ER**
	Slope	1.218	-4.874	-1.523	-0.838	2.285	-0.838	6.397	-1.675	2.132	-0.838	1.980	-1.904
	Y-Intercept	-2.667	17.333	6.333	-5.167	-6.000	2.500	-19.333	4.333	-4.667	1.833	-6.000	2.167
	R^6	0.923	0.999	0.997	0.997	1.000	0.976	0.997	0.997	0.993	0.997	1.000	0.999
	Left Pedal												
	Slope	-1.325	4.417	1.523	-1.036	-2.955	1.127	-9.672	1.767	-2.665	0.746	-2.833	2.239
	Y-Intercept	-2.000	2.000	-1.000	-1.000	-3.000	-4.000	-10.000	0.000	-3.000	0.500	-1.500	1.000
65°	**R^6**	0.989	0.999	1.000	0.980	0.999	0.996	0.995	0.998	0.998	0.994	1.000	0.998

Figure R26: Summary of Linear Regressions

Again, the y intercepts for these should have been zero, but were not – meaning there were offsets. Observe the r^2 values in the above table because these show the precision of the data in each regression.

A matrix [X] consisting of the strain measurement slopes with respect to test was created as shown below.

	AL	AR	BL	BR	CL	CR	CCL	CCR	DL	DR	EL	ER
-65 R	0.411239	-1.35557	-1.96481	1.157563	1.020483	-1.78204	2.970063	-4.37132	0.548319	0.411239	4.950105	-1.15756
-65 L	-0.73109	2.147584	1.94958	-1.08141	-1.02048	2.665441	-1.70588	6.046743	-1.96481	0.365546	-4.72164	1.827731
-50 R	0.450634	-1.50211	-2.00282	1.151621	-2.00282	0.901269	2.403383	-4.65656	1.00141	0.300423	4.205921	-1.20169
-50 L	-0.75106	2.313256	2.002819	-0.91128	-0.9914	2.803947	-2.01283	5.667979	-2.3433	0.210296	-4.13582	1.732439
-22.5 R	0.780337	-2.77298	-2.52913	0.215986	0.717631	-7.1136	4.041029	-6.17999	2.975033	0.355332	3.950454	-1.4701
-22.5 L	-0.79427	2.466421	2.410683	-0.77337	-0.94755	1.072963	-4.99555	4.891038	-2.68241	0.139346	-3.93652	1.82543
0 R	0.701626	-3.13479	-2.87731	-1.64142	0.836802	0.785306	5.567951	-4.75046	3.057545	0.096554	3.398703	-2.22074
0 L	-0.97841	3.141226	3.031798	-0.35403	-1.73797	1.609234	-7.1965	4.943568	-3.30215	0.321847	-3.89435	2.1435
22.5 R	0.808206	-3.45578	-2.74511	-0.29263	1.407393	11.05709	5.970968	-6.08941	2.612734	-0.12541	3.135281	-1.60248
22.5 L	-0.89181	3.295529	2.988968	-0.31353	-2.51519	0.425005	-7.49681	3.532417	-3.17012	0.529514	-3.46274	2.138958
50 R	0.951339	-4.20592	-2.25317	-0.45063	-0.5007	2.253172	6.609304	-1.55219	2.203101	-0.40056	2.353313	-1.75247
50 L	-1.57221	4.816781	2.10296	-0.73103	-3.38476	1.071508	-10.7652	2.603665	-3.57503	0.911283	-3.39478	2.593651
65 R	1.218487	-4.87395	-1.52311	-0.83771	2.284664	-0.83771	6.397059	-1.67542	2.132353	-0.83771	1.980042	-1.90389
65 L	-1.3251	4.417017	1.523109	-1.03571	-2.95483	1.127101	-9.67174	1.766807	-2.66544	0.746323	-2.83298	2.23897

Figure R27: Matrix [X] of Slopes of each Gauge at each Crank Angle on each Pedal

Then a matrix [F] was created of only 1's that was one column wide and the same number of rows as matrix [X]. This was used to solve for a group of coefficients – one coefficient for each pedal at a certain angle.

$$Coefficient\ Matrix\ [C] = \sum_{1}^{12} C_i \qquad \text{(Eq1)}$$

Where,
C_i = the Coefficient for a given angle and a certain pedal

Coeff															F
		0.411239	-1.35557	-1.96481	1.157563	1.020483	-1.78204	2.970063	-4.37132	0.548319	0.411239	4.950105	-1.15756		1
		-0.73109	2.147584	1.94958	-1.08141	-1.02048	2.665441	-1.70588	6.046743	-1.96481	0.365546	-4.72164	1.827731		1
		0.450634	-1.50211	-2.00282	1.151621	-2.00282	0.901269	2.403383	-4.65656	1.00141	0.300423	4.205921	-1.20169		1
		-0.75106	2.313256	2.002819	-0.91128	-0.9914	2.803947	-2.01283	5.667979	-2.3433	0.210296	-4.13582	1.732439		1
		0.780337	-2.77298	-2.52913	0.215986	0.717631	-7.1136	4.041029	-6.17999	2.975033	0.355332	3.950454	-1.4701		1
		-0.79427	2.466421	2.410683	-0.77337	-0.94755	1.072963	-4.99555	4.891038	-2.68241	0.139346	-3.93652	1.82543		1
	X	0.701626	-3.13479	-2.87731	-1.64142	0.836802	0.785306	5.567951	-4.75046	3.057545	0.096554	3.398703	-2.22074		1
		-0.97841	3.141226	3.031798	-0.35403	-1.73797	1.609234	-7.1965	4.943568	-3.30215	0.321847	-3.89435	2.1435	=	1
		0.808206	-3.45578	-2.74511	-0.29263	1.407393	11.05709	5.970968	-6.08941	2.612734	-0.12541	3.135281	-1.60248		1
		-0.89181	3.295529	2.988968	-0.31353	-2.51519	0.425005	-7.49681	3.532417	-3.17012	0.529514	-3.46274	2.138958		1
		0.951339	-4.20592	-2.25317	-0.45063	-0.5007	2.253172	6.609304	-1.55219	2.203101	-0.40056	2.353313	-1.75247		1
		-1.57221	4.816781	2.10296	-0.73103	-3.38476	1.071508	-10.7652	2.603665	-3.57503	0.911283	-3.39478	2.593651		1
		1.218487	-4.87395	-1.52311	-0.83771	2.284664	-0.83771	6.397059	-1.67542	2.132353	-0.83771	1.980042	-1.90389		1
		-1.3251	4.417017	1.523109	-1.03571	-2.95483	1.127101	-9.67174	1.766807	-2.66544	0.746323	-2.83298	2.23897		1

Figure R28: Matrix Algebra to find Coefficient Matrix [C]

Once these coefficients were determined, the torque could be calculated by using Eq2.

$$Torque\ [T] = \sum_{1}^{12} C_i S_i \qquad \text{(Eq2)}$$

Where
S_i = the signal from each strain gauge at a given angle and for a certain pedal.

Below are the least squares coefficients (Matrix [C]).

Least Squares Coefficients
-1.861
-0.8922
0.9811
-1.2742
-0.3047
-0.0237
0.4093
-0.177
-0.12
-0.3979
1.1639
2.7757

This table shows the actual measured torques compared to the estimated torques which were determined using the method outlined above.

Comparison of Actual Vs Estimated Torque									
	Right Pedal					Left Pedal			
	0 Degrees					0 Degrees			
Torque [N-m]	**20**	**40**	**60**	**80**		**20**	**40**	**60**	**80**
Measured	16	31	47	62		16	31	47	62
Estimated	30	66	69	79		15	48	60	54
	22 Degrees					22 Degrees			
Measured	14	29	43	57		14	29	43	57
Estimated	-12	18	30	31		37	44	79	83
	-22 Degrees					-22 Degrees			
Measured	14	29	43	57		14	29	43	57
Estimated	-1	21	28	42		34	52	44	73
	50 Degrees					50 Degrees			
Measured	10	20	30	40		10	20	30	40
Estimated		25	36	49		25	44	43	62
	-50 Degrees					-50 Degrees			
Measured	10	20	30	40		10	20	30	40
Estimated		46	50	62		31	41	51	64
	65 Degrees					65 Degrees			
Measured	7	13	20	26		7	13	20	26
Estimated		8	10	21		5	14	19	24
	-65 Degrees					-65 Degrees			
Measured	7	13	20	26		7	13	20	26
Estimated	26	34	35	49		17	19	24	35
	90 Degrees					90 Degrees			
Measured	0	0	0	0		0	0	0	0
Estimated	-13	-8	0	3			5	9	2
	-90 Degrees					-90 Degrees			
Measured	0	0	0	0		0	0	0	0
Estimated	7	1	4	-9			1	7	10

These values were not incredibly accurate. There was only the very minimum amount of data taken which leads to high inaccuracy. This is especially true because the equipment (specifically the switch and balance/ strain display) gave bad data when not carefully used. It is believed that the inaccuracy was predominantly a result from bad data only. After the electrical system has been developed to test at very high frequencies, these calculations should lead to very small errors.

Also, notice that for each angle, there seems to be a specific constant difference between the actual and estimated torques. It is difficult to analyze because the data is so scattered, but it seems that the difference in measured and estimated is roughly 15 for every angle (of course there are outliers due to errors in data which propagated to linear regressions and to torques). It was hoped that the data would not depend on the specific crank angle, this constant difference which seems to not be specific to each angle supports the original idea that the torque estimation may not depend on the crank angle. The data is simply not accurate enough to draw that conclusion at this point.

When certain gauges that were thought to be invalid were left off this analysis, the estimated torque seemed to become slightly more accurate. Notice that the left pedal at 65 degrees seems to have very little error in accuracy.

A second method was discussed that would have created some series of strain gauge bridges leading to a torque signal. The micro-strain signals obtained for 80 pounds of force (the best resolution measured) with the y-intercept offsets subtracted are shown in the table as follows.

All μ-ε Signals for 80 lbf load

(T = 62.14 NM)	Pedal	AL	AR	BL	BR	CL	CR	CCL	CCR	DL	DR	EL	ER
	Right	46	-196	-178	-86	50	48	351	-296	191	8	212	-133
0°	Left	-61	197	189	-17	-101	115	-449	313	-203	18	-242	134
(T = 56.32 NM)													
	Right	42	-162	-150	18	46	-461	183	-310	212	15	223	-84
-22.5°	Left	-45	135	137	-44	-54	60	-280	277	-165	8	-224	104
(T = 56.32 NM)													
	Right	47	-199	-160	-16	81	685	344	-337	154	-8	181	-92
22.5°	Left	-52	188	164	-17	-145	24	-421	204	-180	31	-198	122
(T = 39.94 NM)													
	Right	18	-61	-80	45	-80	36	95	-186	40	12	168	-48
-50°	Left	-31	93	81	-37	-40	113	-79	228	-93	9	-167	70
(T = 39.94 NM)													
	Right	38	-170	-90	-17	-20	90	265	-63	88	-17	94	-70
50°	Left	-63	192	84	-29	-133	43	-426	104	-141	37	-136	104
(T = 26.26 NM)													
	Right	11	-37	-51	31	27	-49	81	-114	15	11	130	-31
-65°	Left	-20	56	51	-28	-27	70	-45	160	-51	11	-123	49
(T = 26.26 NM)													
	Right	31	-127	-40	-22	60	-23	169	-44	57	-22	52	-50
65°	Left	-35	115	40	-26	-77	30	-249	47	-69	20	-75	58
(T = 0 NM)													
	Right	0	6	-6	26	11	43	51	43	-11	22	24	2
-90°	Left	-4	7	9	-5	-6	7	-11	23	-3	4	-20	9
(T = 0 NM)													
	Right	14	-50	1	-25	13	-21	29	-35	29	-26	2	-26
90°	Left	-3	1	0	0	-1	0	-11	0	0	-1	1	0

The team decided that if it was possible to use the coefficient method outlined previously, in real time, then that was the preferred method under the assumption that it would be more systematic; therefore, the matrix coefficient method would be more easily repeatable on any bicycle.

Experimental Findings and Resources

Findings

- The strains were directly proportional to the applied torque as expected

- It was discovered that the signals were larger near the center of the spider (giving higher resolution) Our 10 main gauges were placed near ends of the spider arms, but it seems that much of the energy there is dissipated into the bolts that hold on the chain rings.
- Whether or not the estimated torque depends on the crank angle was unclear with this level of accuracy and small amount of data points.
- The estimated torque is expected to be much more accurate with use of more data points as would be obtained with the recently developed electronics.

Resources

- IIT Materials Engineering Laboratory (Instron 4465 machine)
- IIT Machine Shop

Objectives Met / Not Met

Original Objectives:

- Develop a configuration of strain gauges ✓
    - Accurately measure the output of the strain gauges under various load conditions
        - Crank angle ✓
        - Direction of applied force ✗
        - Point of force application
            - Left pedal ✓
            - Right pedal ✓
            - Both left and right pedal ✗
- Develop an electronic processing unit for post-processing the strain gauge signals
    - Implement an algorithm to calculate the applied torque at the bicycle crankset ✓
    - Transmit the data wirelessly to the Garmin Edge 705 using the ANT+ protocol ✓
    - Must be power efficient ✗
- Package the system
    - Must work under realistic conditions ✗
    - Needs to conform to the space requirements associated with a bicycle ✗

Objectives Met, Not Previously Specified:

- Create a 3D model of entire test setup and conduct a rough finite element analysis ✓

Issues

Some of the issues that were discussed during the semester were:

- Whether or not to measure crank angle and rpm
- Which method (coefficients or bridges) to be used
- Will this be applicable to any existing bicycle?
- Insufficient IPRO budget
- What configuration/placement should the strain gauges be in?

Obstacles

During our design we had to answer on three main questions:

- How will the signal be measured? How the signal will be conditioned?
- How will the analog signal be converted to digital?
- How will data be transmitted between the microcontroller and the computer?

First, to get data from the strain gauges we decided to use quarter Wheatstone bridges. Because there are ten strain gauges, we had to modify the bridge by adding ten switches. A particular switch will connect required strain gage to the bridge. In addition, each switch has its own resistance, this resistance, creates an unbalanced bridge. In order to balance the bridge we have added a "dummy" switch, which is always "ON", to the other branch of the bridge. It turned out, that, even though we have added the "dummy" switch, the bridge is still unbalanced. The unbalanced voltage was high enough to set the amplifier in saturation mode. Thus, to balance the bridge we added a potentiometer to regulate a potential of one of the nodes, from which we take a measurement signal.

Second, the signal from the Wheatstone bridge is weak. As a consequence, to improve this signal we had to use an amplifier. Our first attempt to measure the amplified bridge signal yielded unexpected results. After investigating the problem, we added resistors on both inputs to eliminate input bias currents. Furthermore, because the instrumental amplifier is working in single supply mode, we had to set some offset for the negative values. In the instrumental amplifier there is a reference input and the value of the reference voltage is added to the output signal. Thanks to this we are able to get an output signal for the negative value of the input signal. To set the reference voltage we have used a simple voltage divider. This, after research, turned out to be an incorrect solution because the reference pin has to be supplied from the low impedance source. Thus, we have modified the reference voltage circuit by putting an op-amp buffer (very low output impedance) between the voltage divider and the reference input pin. The last thing we added to the amplifier circuit was a ceramic capacitor to stabilize and filter supply voltage to the amplifier. We also added a capacitor to each integrated circuit in our design.

Third, to convert analog signals to digital signals we used A/D converters. For the converter to work correctly, configuration registers needed to be set up with proper values. After reading the datasheet of microcontroller we have found these registers and their function in A/D conversion process. We set the bits responsible for prescaler operation, which divide main frequency to set the sampling frequency. We have also set the acquisition time responsible for charging the S/H capacitor.

Fourth, regarding ANT+, the datasheet was not entirely clear on how to process various control signals. We had to e-mail ANT for clarification. In addition, the timing between ANT+ and microcontroller is hard to match. Therefore, send/receive errors occur frequently.

Recommendations

Problems with balancing the bridge can be reduced by using switches with smaller "ON" resistance values. We found such a switch, the ADG811, which has a maximum "ON" resistance value of 0.8Ω at 125ºC. The only problem with these switches is that they are very tiny and it is hard to solder a wire to pin. Instead of soldering the wire I suggest to etch a PCB with the pin-outs and solder switches directly to the PCB. When these switches are used we can take off the Hex inverters from design. The second way to reduce bridge balancing problems is to use two full bridges composed of 4 strain gauges.

To reduce supply current and extend the battery life, resistors of higher value can be used in the reference voltage circuit. This can be done because of high input impedance of op-amp.

To reduce disturbances and noise from the signal, a low-pass filter with a single supply should be added between output of the instrumental amplifier and input of A/D converter. A guide on how to design the filter can be found in the Application Report by Bruce Carter listed in References.

To improve communication to the ANT+ chip the software should be rewritten to be interrupt based instead of operating in polling mode. Error handling for unacknowledged ANT configuration messages should be added with resynchronization of command signals. To fully comply with the ANT+ protocol, the MCU must also handle calibration messages sent from the Garmin computer. In order to completely verify communication the logic analyzer should be used.

References

Horowitz, Paul and Hill, Winfield, The Art of Electronics, Cambridge University Press, 2nd edition (Chapter14 Low power design).

Microchip, PIC18F2220/2320/4220/4320 Datasheet

ANT Development Kit Documents

Interfacing with ANT General Purpose Chipsets and Modules Rev 1.4

ANT Message Protocol and Usage Rev 2.12

ANT_AN05 - Using Epson S1C series microcontrollers with nRF24AP1 Rev 1.3

ANT+ Device Profile - Bicycle Power Rev 2.0

ANTAP1MxIB Module Datasheet Rev1.7

Nordic Semiconductor nRF24AP1 1.0 Product Specification

Websites Resources

Quarq patent - http://www.wipo.int/pctdb/en/wo.jsp?WO=2008058164

Quarq CinQo website – http://www.quarq.us

iBike website - http://www.ibike.com.ar/faq.html

Polar website - http://www.bikyle.com/PowerMeters.asp

Polar CS600 - http://www.bikeradar.com/gear/category/accessories/gadgets/cyclecomputers/product/cs600-cycling-computer-with-power-outputsensor17033?_brc=1

Saris PowerTap - http://www.saris.com/p-328-powertap-pro.aspx

Garmin – http://www.garmin.com

ANT+ - http://www.thisisant.com

National Semiconductor (Voltage Regulator)

Articles Cited

Austen, Ian. "Wired Cyclists Connect to Computers to Measure Pedal Power." NY Times. 27 July 2000 http://query.nytimes.com/gst/fullpage.html?res=9E04E5DA1E3AF934A15754C0A9669C8B63&sec=&spon=&pagewanted=1

Murray, Charles. "Wireless Power Meters Help Olympic Athletes." Design News. 8 July 2008 http://www.designnews.com/article/46896Wireless_Power_Meters_Help_Olympic_Athletes.php?text=+bicycle+power+meters

Willet, Kraig. "Comprehensive Power Meter Review - One Geek's Perspective, Take Two." 5 March 2003 http://www.biketechreview.com/archive/pm_review.htm

Carter, Bruce. "Filter Design in Thirty Seconds", Texas Instruments Application Report, SLOA-093 December 2001

Resources

Sergio Aguilar

Date	Hours Spent	Task
08/25/2008	1.0	Class
08/27/2008	1.0	Class
09/03/2008	1.0	Class
09/08/2008	1.5	ANT+ Research Class
09/10/2008	2.0	Quarq Cinqo Quarq Qranium ANT+ Development Class
09/12/2008	0.5	Garmin Edge 705 Research
09/15/2008	1.0	Class
09/17/2008	2.0	Project Plan - Objectives Class
09/22/2008	1.0	Class
09/29/2008	3.0	Lab Class
10/01/2008	1.5	Lab Class
10/06/2008	1.5	Lab Class
10/08/2008	1.5	Lab - Practiced soldering wires Class
10/13/2008	1.5	Lab Class
10/15/2008	1.5	Lab Class
10/20/2008	1.5	Lab Class
10/22/2008	1.5	Lab - Attempted to pair ANT+ devices to Garmin
10/27/2008	1.5	Lab - Worked with the ANT+ software demo
10/29/2008	2.0	Lab Class
11/03/2008	2.0	Lab - Looked at the ANT+ data sheets for bit pattern information Class
11/05/2008	1.5	Lab Class
11/10/2008	0.5	Class
11/12/2008	1.5	Lab - Assisted Ark with soldering Class
11/17/2008	2.0	Lab - Helped with soldering Class
11/19/2008	3.0	Lab - Looked at PIC coding Class
11/24/2008	0.5	Class
11/24/2008	1.0	Looked for brochure tutorials
11/25/2008	2.0	Looked at different brochure designs Got started on the brochure
11/26/2008	2.0	Worked on the brochure
11/29/2008	1.0	Changed the layout and design of the brochure
11/30/2008	3.0	Final adjustments to brochure
		Total Hours Spent: 48.0

Patrick Becker

Date	Hours Spent	Task
08/25/2008	1.0	Class Meeting
08/27/2008	1.0	Class Meeting
09/03/2008	1.0	Class Meeting
09/05/2008	2.0	Research Quarq crankset based power measurement. Research ANT Research Driving strain gauge bridges
09/08/2008	4.0	Class Meeting 1 hour Research ANT dev kit and budget 3 hours
09/10/2008	2.0	Class Meeting Correspondence with ANT tech support Forwarded ANT order info to Prof. Rempfer Research Budget
09/11/2008	2.0	Budget - pricing from Kinkos, and from Prof Rempfer
09/22/2008	1.0	Class Meeting
09/24/2008	1.0	Class Meeting
09/29/2008	1.0	Class Meeting
10/01/2008	1.0	Class Meeting
10/06/2008	2.8	MidTerm Presentation
10/08/2008	1.0	Class Meeting
10/09/2008	3.0	Program ANT+ serial interface
10/13/2008	1.5	Class Meeting
10/15/2008	1.5	Class Meeting
10/18/2008	2.0	Program ANT+ Serial interface
10/19/2008	4.0	Program ANT+ interface
10/20/2008	1.0	Class Meeting
10/22/2008	1.5	Class Meeting
10/24/2008	3.0	Program ANT+ interface functions
10/25/2008	4.0	Program and Test ANT+ interface functions
10/27/2008	1.5	Class Meeting
10/29/2008	1.5	Class Meeting
11/03/2008	2.0	Class Meeting, work to connect PIC to ANT
11/05/2008	1.0	Class Meeting
11/06/2008	3.0	Programming PIC to ANT interface and main program
11/10/2008	2.0	Class Meeting and Test PIC program
11/12/2008	6.0	Class Meeting and Troubleshoot PIC program
11/14/2008	8.0	Troubleshoot PIC to ANT interface
11/15/2008	3.0	Programming PIC to ANT interface
11/17/2008	4.5	Class Meeting and ANT troubleshooting
11/19/2008	3.5	Class meeting and Troubleshoot PIC program code
11/21/2008	2.0	Clean up ANT communication program.
11/24/2008	1.0	Class Meeting
12/01/2008	1.0	Class Meeting
12/01/2008	3.0	Final Report
12/02/2008	4.0	Final Report
12/03/2008	1.0	Class Meeting
12/03/2008	2.0	Final Report
		Total Hours Spent: 92.3

Daniel Gonzalez

Date	Hours Spent	Task
08/25/2008	1.0	Class
09/01/2008	1.8	General Research
09/03/2008	1.0	Class
09/06/2008	2.0	ANT+ Reasearch
09/08/2008	2.8	Class, Research
09/10/2008	1.0	Class
09/15/2008	1.0	Class
09/17/2008	1.5	Class
09/22/2008	1.5	Class
10/01/2008	2.0	Class, Lab
10/06/2008	3.0	Class, Lab
10/08/2008	1.5	Class, Lab
10/10/2008	1.5	ANT+ Manuals
10/13/2008	0.5	Class
10/15/2008	2.5	Class, Lab
10/20/2008	1.5	Class, Lab
10/27/2008	2.0	Class, Lab
10/29/2008	2.5	Class, Lab
11/03/2008	1.5	Class, Lab
11/10/2008	2.5	Class, Lab
11/12/2008	3.0	Class, Lab
11/17/2008	3.0	Class, Lab
11/18/2008	2.0	ANT+ Manuals
	Total Hours Spent: 42.6	

Bryan Kaminski

Date	Hours Spent	Task
09/13/2008	2.5	Project Plan - Methodology, Gantt Chart
09/15/2008	1.0	Class
09/17/2008	1.5	Strain Gauge Demonstration
09/22/2008	1.0	Class
09/24/2008	1.3	Lab - Reverse Engineering Attempt
09/24/2008	1.0	Contacted IC mfg for Sample Parts
09/29/2008	2.0	Lab - Pairing Garmin/Quark: ANT+ Development Kit
10/01/2008	1.5	Class
10/06/2008	2.0	Lab - Setting up PIC
10/08/2008	1.0	Went to get connector for PIC programming
10/08/2008	2.0	Lab - Programming PIC
10/13/2008	3.0	Lab - Setting up/Verifying operation of A/D Converter
10/15/2008	2.0	Lab - Working on A/D Converter
10/20/2008	1.5	Lab - Discussing Power Circuit, Talking with Mech. Team about strain gauge detail
10/21/2008	0.3	Contacting ANT+, Decrypting key
10/22/2008	1.5	Lab - Working with sample strain gauge and op-amp
10/23/2008	3.0	Pairing Garmin and ANT+ dev kit
11/05/2008	1.5	Class time
11/06/2008	3.0	PSpice simulation of opamp
11/06/2008	1.0	Meeting with Shital and other Professor about Strain circuit.
11/10/2008	3.0	Programming PIC for ANT+
11/12/2008	4.0	Soldering
11/13/2008	7.0	re-organized circuit breadboard: PIC, demultiplexer, op amp, testing A/D converter, op amp
11/14/2008	8.0	PIC -> ANT+ Communication
11/15/2008	4.0	Finalizing A/D converter Soldering analog switches
11/16/2008	4.0	Trying to figure out PIC -> ANT programming.
11/17/2008	4.0	PIC -> ANT
11/18/2008	2.0	Completing and testing operation of switching circuit
11/19/2008	7.0	ANT communication finalized
		Total Hours Spent: 76.6

Nathan Knopp

Date	Hours Spent	Task
08/25/2008	1.0	Class
08/27/2008	1.0	Class
09/03/2008	1.0	Class
09/06/2008	1.0	Research
09/08/2008	1.0	Class
09/10/2008	1.0	Class
09/12/2008	1.5	Gant Chart, Project Plan
09/14/2008	1.0	Project Plan
09/15/2008	1.0	Class
09/17/2008	2.0	Class, Lab
09/20/2008	3.0	FEM Model
09/22/2008	1.0	Class
09/23/2008	1.0	Research
09/24/2008	2.5	Lab
09/29/2008	1.5	Class, Lab
09/30/2008	2.0	Lab
10/01/2008	2.5	Class, Lab
10/06/2008	2.5	Lab
10/07/2008	2.5	Lab
10/08/2008	1.5	Class, Lab
10/13/2008	1.5	Class
10/15/2008	3.0	Class, Lab, Data entry
10/16/2008	1.5	FEA comparison
10/20/2008	1.5	Class
10/21/2008	3.0	Lab
10/22/2008	2.0	Class, Lab
10/27/2008	1.5	Class, Lab
10/28/2008	3.0	Lab
10/29/2008	2.0	Class, Lab
11/03/2008	1.0	Class
11/05/2008	2.0	Class, Help Organize Strain Data
11/06/2008	3.0	Create Linear Regression Spreadsheet
11/10/2008	3.0	Class, Least Squares Fit of Data
11/12/2008	4.0	Class, Least Squares Fit of Data
11/13/2008	5.0	Least Squares fit of Data
11/17/2008	1.0	Class
11/19/2008	1.5	Class, SLS Machine Info
11/21/2008	0.5	Helped Electrical Group w/ Strain Measurements
11/22/2008	2.0	Final Project
11/24/2008	1.0	Class
12/01/2008	1.0	Class
12/03/2008	1.0	Class
		Total Hours Spent: 76.5

Crystal Jankhot

Date	Hours Spent	Task
08/25/2008	1.0	Class
08/27/2008	1.0	Class
09/03/2008	1.0	Class
09/04/2008	2.0	Ipro Project Management
09/08/2008	5.0	Agenda, Research, & Class
09/09/2008	1.0	Agenda
09/10/2008	1.0	Class
09/13/2008	2.0	Project Plan/ Methodology/ Gantt Chart
09/15/2008	1.5	Agenda, class
09/17/2008	2.0	Agenda, class (First lab session)
09/22/2008	4.0	logbook, agenda, research, class
09/23/2008	1.5	strain notes, agenda, logbook
09/24/2008	2.5	Patent, Class - Applying strain gauges
09/29/2008	2.0	Agenda, Class
10/01/2008	3.0	Agenda, Class, Soldering wires between gauges and tabs
10/06/2008	3.0	Update email, Midterm review preparation, the Midterm Review
10/07/2008	0.5	Agenda
10/08/2008	1.5	Class
10/13/2008	1.5	Class
10/15/2008	2.5	Class, First Data Acquisition Session
10/20/2008	3.5	Summary of emails & graphs for Data1, Agenda/planning, Class - Data Acquisition Session 2
10/22/2008	1.5	Class/ Testing -- Left pedal +, - 50 degrees
10/27/2008	2.5	Agenda, Class (testing)
10/29/2008	1.5	Class/Testing
11/03/2008	3.0	Agenda, Making a composite of strain data, Class
11/05/2008	5.5	Making the Torque graphs, starting the linear regression graphs, Agenda + Final IPRO assignments + Class
11/10/2008	2.0	Agenda & Class
11/12/2008	2.5	Agenda Schedule & Class
11/17/2008	3.0	Agenda, emails, Class, Outline for Results
11/19/2008	6.5	Agenda, Class, part of Results, unintentional background "research"
11/20/2008	1.5	Fixing Background Section, Working on Results :(
11/22/2008	6.0	Results section
11/24/2008	6.5	Agenda, IPRO day submissions & plans, emailing team members for deliverables, Class, measurements and Pro/E solid modeling
11/26/2008	2.0	Poster critique, emailing, studying/editing ipro day stuff
		Total Hours Spent: 87.0

Brandon Marcellis

Date	Hours Spent	Task
08/25/2008	1.0	Class
09/03/2008	1.0	Class
09/08/2008	1.0	Class
09/10/2008	2.0	Class, Doing researsh
09/15/2008	3.0	Class and Background for Project Plan
09/17/2008	3.0	Class and Background for Project Plan
09/22/2008	2.0	Class and Research
09/24/2008	2.0	Class/Lab
09/29/2008	2.0	Class/Lab
10/01/2008	1.5	Class/Lab
10/03/2008	2.0	midterm presentation
10/06/2008	2.0	Mid term presentation
10/08/2008	1.5	class/lab
10/13/2008	1.5	class/lab
10/15/2008	1.5	class/lab
10/20/2008	1.5	Class/Lab
10/22/2008	1.5	class/lab
10/27/2008	3.0	Class/Lab
11/03/2008	1.5	class/lab
11/05/2008	1.5	class/lab
11/10/2008	1.5	class/lab
11/12/2008	1.5	class/lab
11/17/2008	1.0	class
11/19/2008	1.0	class
11/22/2008	2.0	Methodology for report
11/24/2008	1.0	class
12/01/2008	1.0	class
12/03/2008	1.0	class
12/04/2008	1.0	Ipro setup
	Total Hours Spent: 47.0	

David Poli

Date	Hours Spent	Task
08/25/2008	1.3	First Class Period
08/27/2008	1.4	Second Class Period
09/08/2008	1.3	Fourth Class Period
09/10/2008	1.3	Fifth Class Period
09/13/2008	2.0	Project Plan/Methodology/Gantt Chart
09/15/2008	1.5	Class
09/17/2008	1.5	Class
09/22/2008	1.5	Class
09/24/2008	1.5	Class
09/29/2008	1.5	Class
10/01/2008	1.5	Class
10/06/2008	1.5	Class
10/08/2008	1.5	Class
10/13/2008	1.5	Class
10/15/2008	1.5	Class
10/20/2008	1.5	Class
10/22/2008	1.5	Class
10/27/2008	1.5	Class
10/29/2008	1.5	Class
11/03/2008	1.5	Class
11/05/2008	1.5	Class
11/09/2008	3.0	Final Presentation Preparation
11/10/2008	1.5	Class
11/12/2008	1.5	Class
11/12/2008	3.0	Final Presentation Preparation
11/17/2008	1.5	Class

Total Hours Spent: 41.8

Ryan Ruidera

Date	Hours Spent	Task
11/16/2005	2.0	class
11/05/2007	3.0	class
11/06/2007	2.0	tests
11/08/2007	2.0	tests
11/19/2007	2.0	class
11/20/2007	2.0	lab
11/21/2007	3.0	class
11/26/2007	2.0	class
11/28/2007	2.0	class
09/03/2008	1.0	attended class
09/08/2008	1.0	attended class
09/09/2008	1.0	worked on project plan data and read up on bike computers
09/10/2008	2.0	attended class and looked at format for previous ipro project plan
09/13/2008	2.0	played around with bike computers and read info on how computers vary from companies.
09/17/2008	2.0	IPRO lab
09/18/2008	2.0	Project plan compilation
09/19/2008	2.0	Project plan finalization.
09/22/2008	1.0	attended class
09/24/2008	1.0	attended class
09/27/2008	3.0	learned why power means so much to cyclist
09/29/2008	1.5	attended class
09/30/2008	2.0	attached strain gages
10/01/2008	1.0	attended class
11/03/2008	2.0	class
11/04/2008	4.0	tests
11/05/2008	1.5	class
11/10/2008	1.5	class
11/11/2008	3.0	lab
11/11/2008	2.0	lab
11/12/2008	1.5	class
11/17/2008	1.0	class
11/19/2008	1.0	class
11/23/2008	3.0	ipro stuff
		Total Hours Spent: 63.0

Henrietta Tsosie

Date	Hours Spent	Task
09/01/2008	1.3	Class
09/03/2008	2.0	Worked on agenda on IGROUPS, attended class
09/08/2008	2.0	Updated agenda on IGROUPS, attended class :D
09/09/2008	2.0	Worked a little on 'Ethics'
09/10/2008	2.5	Class, Updating Info on IGROUPS, and Ethics Stuff.
09/14/2008	1.0	Read up on "Ethics"
09/15/2008	2.0	Attended Class, worked on updating agenda...
09/16/2008	2.0	worked on Team Charter
09/17/2008	1.3	attended class & lab lecture
09/18/2008	1.0	Team Charter
09/22/2008	2.0	Class, talked to russ, and updated files on iGroups.
09/24/2008	2.0	attended class, applied strain gauges, updated minutes on IGROUPS
10/13/2008	1.3	Class
10/15/2008	1.3	Class
10/20/2008	1.3	Class
10/22/2008	1.3	Class
10/27/2008	1.3	class
11/03/2008	1.5	Class, updated agenda
11/05/2008	1.3	Class
11/10/2008	1.3	Class
11/12/2008	1.3	Class
11/21/2008	1.0	worked on IPRO Deliverable--obstacles
11/24/2008	3.0	Class, worked on deliverable (obstacle), and assisted with poster.
11/30/2008	2.0	Edited poster, mechanical objectives, and ppt.
12/01/2008	3.0	Class, meeting minutes, and worked on deliverables
12/02/2008	2.0	Meeting Agenda, Deliverables...
		Total Hours Spent: 44.0

Jaewon Yoo

Date	Hours Spent	Task
09/08/2008	1.0	attended class
09/10/2008	1.0	attended class
09/11/2008	1.5	Read material about IRPO
09/15/2008	1.0	Class
09/17/2008	2.0	Class with first lab
09/24/2008	1.0	class
09/29/2008	1.0	Class
10/01/2008	1.0	Class
10/02/2008	1.5	Midterm presentation
10/04/2008	1.5	Research:Power supply
10/06/2008	1.0	Class
10/08/2008	1.0	Class
10/10/2008	2.0	Research : device and design
10/13/2008	1.0	Class
10/13/2008	1.5	Research: design
10/15/2008	1.0	Class
10/20/2008	1.0	Class
10/22/2008	1.0	Class
10/27/2008	1.0	Class
10/29/2008	2.0	class, research
11/03/2008	2.5	class, research
11/05/2008	1.5	class
11/12/2008	1.0	class
11/17/2008	4.5	class and lab
11/19/2008	3.5	class and lab
11/24/2008	1.0	class
11/27/2008	2.0	writing an electrical result
11/28/2008	2.0	writing an electrical result
11/29/2008	1.0	writing an electrical result
12/01/2008	1.0	class
12/03/2008	1.0	class
	Total Hours Spent: 46.0	

Arkadiusz Ziomek

Date	Hours Spent	Task
08/25/2008	1.0	Class
08/27/2008	1.0	Class
08/30/2008	2.0	Research: Amplifiers
09/03/2008	1.0	Class
09/08/2008	1.0	Class
09/09/2008	2.0	Research: Microcontrollers
09/10/2008	1.0	Class
09/12/2008	1.0	Research: Filters
09/15/2008	1.0	Class
09/17/2008	1.5	Class & lab orientation
09/19/2008	1.0	Research: Multiplexers
09/22/2008	1.0	Class
09/24/2008	1.0	Class & Lab
09/29/2008	2.0	Class & Lab: Wi-Fi data transmission
10/01/2008	1.0	Class & Lab
10/06/2008	1.5	Class & Lab
10/07/2008	1.0	Op-amp
10/08/2008	1.0	Class & Lab
10/13/2008	3.0	LAB
10/15/2008	1.0	Class & Lab
10/20/2008	1.0	Class & Lab
10/22/2008	1.0	Class & Lab
10/26/2008	2.0	Lab
10/27/2008	2.0	Class & LAB
10/29/2008	2.0	Class & Lab
11/03/2008	2.0	Class & Lab
11/05/2008	2.0	Class & Lab
11/06/2008	4.0	Design & Consulation
11/10/2008	1.0	Class
11/12/2008	5.0	Soldering
11/13/2008	7.0	Assembly, troubleshooting
11/14/2008	7.0	Assembly,programming,troubleshooting
11/15/2008	4.0	Assembly,programming
11/17/2008	5.0	Soldering,assembly
11/18/2008	2.0	Connecting uC to switches,voltage regulator and amplifier
11/19/2008	5.5	Assembly,Balancing bridge
11/21/2008	3.5	Troubleshooting, deliverables
11/25/2008	2.0	Troubleshooting, electrical schemes
		Total Hours Spent: 84.0

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