$T_{calc} = C_1\varepsilon + C_2$

This method is useful because it can be utilized to calculate a torque for an arbitrary angle and an arbitrary strain. Also, since a polynomial is being approximated for the strain at an arbitrary angle, small errors in measurements will be averaged out. One of the downfalls of this method is due to the fact that only a single channel is used for data. Another problem with this method is that the coefficient is calculated for a known chainring, and does not apply to both like the system of equations method.

P3 Strain Indicator

Software for use and manual found on IGROUPS under ME and P3.

Special Thanks to Russ Janota for his help and support.

degrees, and can be approximated by two polynomial equations. Staying within the reference frame of either above or below 180 degrees, two polynomial equations can approximate the maximum strain and a reference strain at an arbitrary angle in the reference range as seen in the following equations:

$$\varepsilon_{max} = a_1\theta^6 + a_2\theta^5 + a_3\theta^4 + a_4\theta^3 + a_5\theta^2 + a_6\theta + a_7$$

$$\varepsilon_{ref} = b_1\theta^6 + b_2\theta^5 + b_3\theta^4 + b_4\theta^3 + b_5\theta^2 + b_6\theta + b_7$$

This will provide two sets of two polynomial equations for the angles above 180 degrees and the angles below 180 degrees. Then, since the relationship between strain and weight is linear, these two polynomial equations within each set can be linearly interpolated for an arbitrary strain using an equation of the following format:

$$W_{calc} = \frac{W_{max} - W_{ref}}{\varepsilon_{max} - \varepsilon_{ref}}\left(\varepsilon - \varepsilon_{ref}\right) + W_{ref}$$

This weight can finally be used to calculate the torque for an arbitrary strain and arbitrary angle within the reference range as seen in the following equation:

$$T_{calc} = grW_{calc}\sin\theta$$

Two three-dimensional equations for angles above 180 degrees and below 180 degrees with two variables of angle and strain have now been formulated. However, these equations can be further simplified and combined by solving for a constant angle. This will provide two coefficients that can be calculated using the following format:

$$C = gr\sin\theta\begin{bmatrix} \dfrac{W_{max} - W_{ref}}{\varepsilon_{max} - \varepsilon_{ref}} \\ W_{ref} - \varepsilon_{ref}\dfrac{W_{max} - W_{ref}}{\varepsilon_{max} - \varepsilon_{ref}} \end{bmatrix}$$

These coefficients can then be used to calculate the torque for an arbitrary strain at a known angle using the following equation:

chainring by the slope of this graph to acquire the unknown torque, as seen in the following equation:

$$C_n = \frac{dT}{d\varepsilon_n}$$

Using this derivative, the slope of each channel can be calculated to achieve a set of n coefficients. To minimize error, a range of torques can also be selected with which to calculate this slope. If each channel is treated as a resistor in a parallel electrical circuit, an overall coefficient can be calculated using the following equation:

$$C = \frac{1}{\sum C_n^{-1}}$$

The final coefficient can then be simplified and expressed in terms of torque and strain as seen in the following equation:

$$C = \left(\sum \frac{d\varepsilon_n}{dT}\right)^{-1}$$

This coefficient is then used in the following equation to calculate the torque for arbitrary strains on each channel at a defined angle:

$$T_{calc} = C \sum \varepsilon_n$$

This method is very accurate because it factors in each available channel. Also, since all the strains are added together, any channel that is more sensitive or produces higher values will have a greater effect on the final calculation. The only downfall of this method is that the coefficient is calculated for a known chainring, and does not apply to both like the system of equations method.

Equation Fitting

When plotting the relationship between angle and strain for an arbitrary weight, a graph resembling two parabolic arches exists. These parabolas intersect at an angle equal to 180 coefficients can be calculated to make the set of equations true. This system is given by the following equations:

$$C_1\varepsilon_{a_{large}} + C_2\varepsilon_{b_{large}} = T_{large}$$

$$C_1\varepsilon_{a_{small}} + C_2\varepsilon_{b_{small}} = T_{small}$$

The coefficients for this system of equations can easily be calculated using Cramer’s rule. However, since data was collected at various torques, the coefficients for each set of data must be averaged in order to accurately calculate these values at arbitrary strains. Once a range of torques has been selected, the starting and ending torques can be defined as T_S and T_E respectively. The following equation is then used to calculate the two final coefficients at a defined angle:

$$C = \frac{1}{T_E - T_S + 1}\sum_{n=T_S}^{T_E}\left(\begin{bmatrix}\varepsilon_{n,a_{large}} & \varepsilon_{n,b_{large}} \\ \varepsilon_{n,a_{small}} & \varepsilon_{n,b_{small}}\end{bmatrix}^{-1}\begin{bmatrix}T_{n_{large}} \\ T_{n_{small}}\end{bmatrix}\right)$$

These coefficients are then used in the following equation to calculate the torque for arbitrary strains on defined channels a and b at a defined angle:

$$T_{calc} = C_1\varepsilon_a + C_2\varepsilon_b$$

This method is very efficient because the calculated coefficients apply to both the large and small chainrings. Averaging the coefficients over the variable torque range appears to produce minimal error as well. The only downfall of this system is that it does not utilize all of the available channels.

Parallel Derivatives

It is known that the relationship between the torque and strain at a defined angle is linear, and also that zero strain will be measured with zero torque, causing a plot of this data to intersect at the origin. Therefore, one can easily multiply an arbitrary strain for a defined

7. Secure the RWBG wire so that it cannot pull the wiring junction off.

Reed Switches

Reed switches are glass tubes with a set of contacts inside. Reed switches can be normally open or normally closed. When a magnet or an electromagnet passes in the vicinity of the reed switch it either closes or opens based on the type of switch. For this circuit it is preferred to use a switch that is normally open to reduce the power consumption of the circuit. The black wire of the reed switch assembly is connected to a high voltage through a resistor to manage the current and when the reed switches pass by the magnet they close and bring the input up at the PIC. There is a green reed switch collocated with the right crank arm that is position 0 and is connected via a green wire to a dedicated PIC input. The remaining 7 reed switches are connected to a separate input on the PIC via a blue wire.

Calculation Procedures

There are currently three independent methods to calculate various coefficients for our bicycle crankset:

System of Equations

When two independent channels are used in a system of equations, coefficients can be calculated to fit the data between the large and small chainrings. Using arbitrary channels a and b, two equations can be formulated which express the torques exerted on both the large and small chainrings. Since the strains on both channels a and b are unknown, two

Soldering Strain Gauge Wires

1. Prep the wires.
    a. Cut sets of 8 wires to the exact same length for each Wheatstone bridge.
    b. Strip both ends of each wire by placing between the soldering tip and the solder until the wire is in a drop of solder.
    c. Wait for the solder to melt the insulation.
    d. Trim the exposed wire to the length of the tab that it will be applied to.
2. Clean surfaces to be soldered with Eraser to remove any oxide layer.
3. Apply a small amount of Flux to the surface to be soldered and apply a bead of solder to the Strain Gage tabs and to the Wiring junction tabs.
4. Solder one end of each wire to the strain Gauges.
5. Solder the other end of each wire to the Wiring Junction.
    a. Solder either tension or compression strain gauges first.
    b. Check the resistance, two tabs connected to one strain gauge should give the resistance of the strain gauge, two connected to different strain gages should give an infinite resistance.
    c. Apply an epoxy to the first set of wires so that when the second set is applied the first set stays in place.
    d. Check the resistances, should get the resistance of a strain gauge or (1/R + 1/3R)^(-1).
    e. Apply the epoxy to the second set of wires.
6. Solder the Red, White, Black, Green wire to the wiring junction.

a. Take about a 2-inch piece of Mylar tape.

b. Stick one end of the tape next to the gage.

c. Slide thumb firmly and quickly along the tape over the gauge. This is done to avoid static electricity.

d. Peel the tape slowly, at a very low angle to the case, until it is past the gage. Then pull the rest of the tape off.

e. Apply the strain gauge to the sanded surface. Peel the tape back slowly similarly to step d. Peel just past the gauge.

f. Apply a very thin layer of drying catalyst (Xylene in student kit) to the bottom surface of the strain gage. Before applying to the strain gage wipe the brush of the catalyst on the top of the jar 10 times. Then apply the catalyst to the bottom of the strain gage. Let this dry for 1 minute on the strain gauge.

g. Place 1 drop of super glue on the sanded surface directly beneath the strain gauge. Then quickly run thumb firmly over the tape and gage. Press and hold for approximately 1 minute. A piece of gauze should be used to do this so hands do not get super glue on them. (There is better glue that can be used for longer life)

h. Peel off the tape back onto itself. Peel off at an angle of almost 180 degrees.

i. Cover the gauge completely with a piece of Mylar tape until ready for soldering.

j. Once ready for soldering, peel off the tape and reapply so that one edge just overlaps the soldering points.

a. Add mild acid (Phosphoric acid-red top bottle in student kit) to the end of 400-grit sandpaper. Shake of the excess acid on the sandpaper. Sand the surface. Sand an area slightly larger than the strain gauge.

b. Use gauze and wipe from the center, of the sanded surface, out to one side, then fold the gauze and wipe from the center to the other side of the sanded surface. Be sure to throw away the gauze.

c. Add mild acid to a Q-tip. Shake of the excess acid. Clean the surface in a circular motion with the Q-tip. Start from the center and work way out. If the Q-tip gets too dirty, throw it away and continue process with new Q-tip.

d. Repeat step b

e. Add neutralizer (Ammonia water-blue top bottle in student kit) to a Q-tip. Shake of the excess. Clean the surface in a circular motion. Start from the center and work way out.

f. Repeat step b

2. Gauge Preparation

   a. Add neutralizer to a piece of gauze. Clean the surface of the plastic strain gage case with the gauze.

   b. Use gauze and wipe from the center out to one side, then fold the gauze and wipe from the center to the other side.

   c. Use tweezers to take gauge out of its package. Grab near the soldering points. Carefully place on the top of the case. Do the same for the soldering tabs.

3. Gluing

the dropdown, click the New button, and add the following directory:

C:/<path to MCC18>/lib/

Assuming you've chosen the default installation directory, this location should simply be:

C:/MCC18/lib/

Apply the settings, and the project should be ready for building.

Compiling the Code

To build the code, simply click the "Make" button on the toolbar (or "Make All" if you wish to rebuild the entire project). Be sure to select the proper build type from the dropdown on the toolbar (DEBUG if the ICD-3 debugger is going to be used on the chip, and RELEASE if the final version of the code is to be programmed into the chip).

Mechanical Documentation

Strain Gauge Application

1. Prepare the Surface

Setting up MPLAB IDE for compilation

There are several configuration issues encountered when setting up MPLAB IDE for use on the PIC18LF2331 using C compilation. Please refer to the introduction of this section for information on obtaining the proper software.

Once the software is installed, a project must be either created or opened. If the project already exists, simply double-clicking on the project icon should open up the project and be ready for editing and compilation. This is the situation in most cases.

If, however, a new project is created, the following steps must be followed. First, a new project should be created with the project wizard found in the Project->Project Wizard menu item. The PIC18F2331 should be selected as the Device. In the next dialog, the wizard asks for Toolsuite. First make sure that the Microchip C18 Toolsuite is selected in the “Active Toolsuites” dropdown, then select the MPLAB C18 C Compiler (mcc18.exe) in the Toolsuite Contents menu. Then click next, give the project a name and location, and click next again. In this final dialog you can add any existing files to the project. Once complete, MPLAB IDE should open your project.

Before compilation for the 2331 will work (assuming you’ve added the proper header files) you will need to ensure the linker knows where the object files for the libraries reside. To do this, select the Project->Build Options->Project item from the menu, click on the Directories tab, select Library Search Path from maximum voltage with open switches is 0.1V.

ANT+ Communication

ANT+ (version 3) is a wireless communications protocol created and offered to developers by Garmin. Although it is not certified by the FCC for consumer products, it is an easy way to implement wireless communications in a laboratory setting and is compatible with the Garmin 705e used for the user display unit.

The ANT+ development kit (ANT-DKT-3) comes with several components. Currently the circuit uses one of the wireless transceiver modules to communicate with the Garmin display unit. Also available are USB transceivers that can be plugged directly into a computer and used for debugging.

Microprocessor Programming and Operation

The microprocessor used in this circuit design is the PIC18LF2331. The development environment used is the MPLAB IDE, currently available at http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1406&dDocName=en019469&part=SW007002 for free download. In addition to this IDE, the MPLAB C Compiler for PIC18 MCU's (MCC18) must be downloaded and installed. It is currently available at http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1406&dDocName=en010014&part=sw006011.

Signal Amplification

The maximum level of the signals is approximately $400\mu V$. The INA122 instrumentation amplifier has an adjustable gain controlled by the gain resistor R_G, here set to 914. Gain is set by the following equation, which can be found in the datasheet:

$$G = 5 + \frac{200k\Omega}{R_G}$$

Cadence Sensor

Magnetic reed switches are employed to determine the angular position of the crank. The switches are normally open and close when they are near enough to a magnetic field. To determine the angular position there are 8 switches on the crank set positioned 45°apart. One is connected to a digital input pin on the microcontroller, while the other 7 are connected in parallel to another digital input pin. The isolated switch is used as a 0°reference.

The switches connect the +3V signal to the respective input pin when magnetized. The 100k_ resistor to ground provides a load when the pin goes high. When the switches are open, there is 0 potential at the input pin, and when they close it goes high to +3V.

The resistors were chosen as 100k_ because the higher the impedance, the less power they consume. However, the voltage at the input of the microprocessor must be less than 0.45V for a logic low (per parameter D030 of the PIC18LF2331 datasheet). The leakage current is around $1\mu A$, so the

Other parts

20 MHz Crystal SMD [Y1]

http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&name=XC1254CT-ND

Circuit design considerations

The general operation and notable design decisions of the various parts of the sub-circuits are detailed in this section.

Strain Gauge Power Supply

The strain gauges are powered by a fixed 1V signal from the precision voltage regulator LP3879. 1V was chosen because it simplifies calculations later in the microprocessor. When looking for the voltage differential in a bridge, the microprocessor takes the V/V strain signal and multiplies it by the bridge input voltage, so multiplying by 1.00 allows the processor to assume that calculation.

Input Signal Switching

There are 8 low-voltage signals coming from the four bridges. The circuit makes use of only one signal amplifier to save space and cost. In order to do this, the octal switch ADG714 connects them to the microprocessor one at a time. It is controlled by the microprocessor via the SPI interface.

Resistors

Designator	Value	Size	Manufacturer	Supplier
R1	220 Ω	1/8 W, SMD 1206	KOA Speer	Mouser
R2	47 kΩ	1/8 W, SMD 1206	Vishay	Mouser
R3	47 Ω	1/8 W, SMD 1206	Vishay	Mouser
R4	10 kΩ	1/8 W, SMD 1206	KOA Speer	Mouser
R5	100 kΩ	1/8 W, SMD 1206	Xicon	Mouser
R6				
R7				
R8				

Capacitors

Designator	Value	Size	Manufacturer	Supplier
C1	4.7 uF	50V, SMD 1206	Murata	Mouser
C2	10 nF	50V, SMD 1206	TDK	Mouser
C3	10 uF	50V, SMD 1206	Kemet	Mouser
C4	100 nF	50V, SMD 1206	Kemet	Mouser
C5				
C6				
C7				
C10				
C11				
C8	18 pF	50V, SMD 1206	Murata	Mouser
C9				

Off The Shelf Components

System Function	Product
Human-Interface Display (HID)	Garmin Edge 705
Wireless Data Transmission (circuit->HID)	ANT+ Development Kit: ANT-DKT-3
Microprocessor Debugger	MPLAB ICD2

Power Source

3V Coin Cell Lithium Battery

http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&name=P028-ND

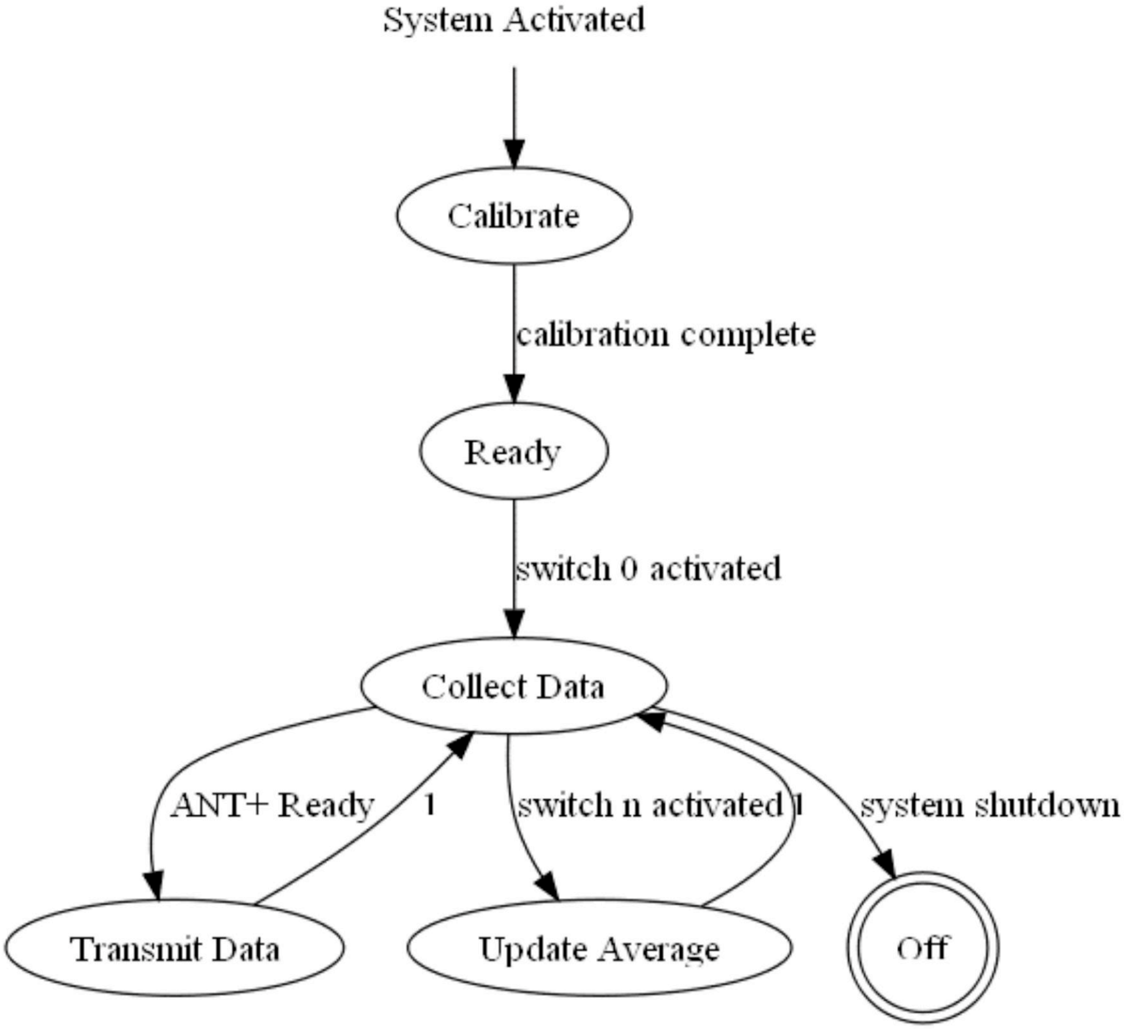
Integrated Circuits

Designator	Part #	Manufacturer	Package	Supplier
U1	LP3879	National Semiconductor	PSOP-8	DigiKey
U2	ADG714	Analog Devices	TSSOP-24	DigiKey
U3	INA122	Burr-Brown / TI	PSOP-8	DigiKey
U4	LMP7702	National Semiconductor	SOIC-8	DigiKey
U5	PIC18LF2331	Microchip	SOIC-28	DigiKey

Connectors

MOLEX 52991-0208 [CONN3]

http://search.digikey.com/scripts/DkSearch/dksus.dll?vendor=0&keywords=WM24007-ND



FSM of general system operation

Components List

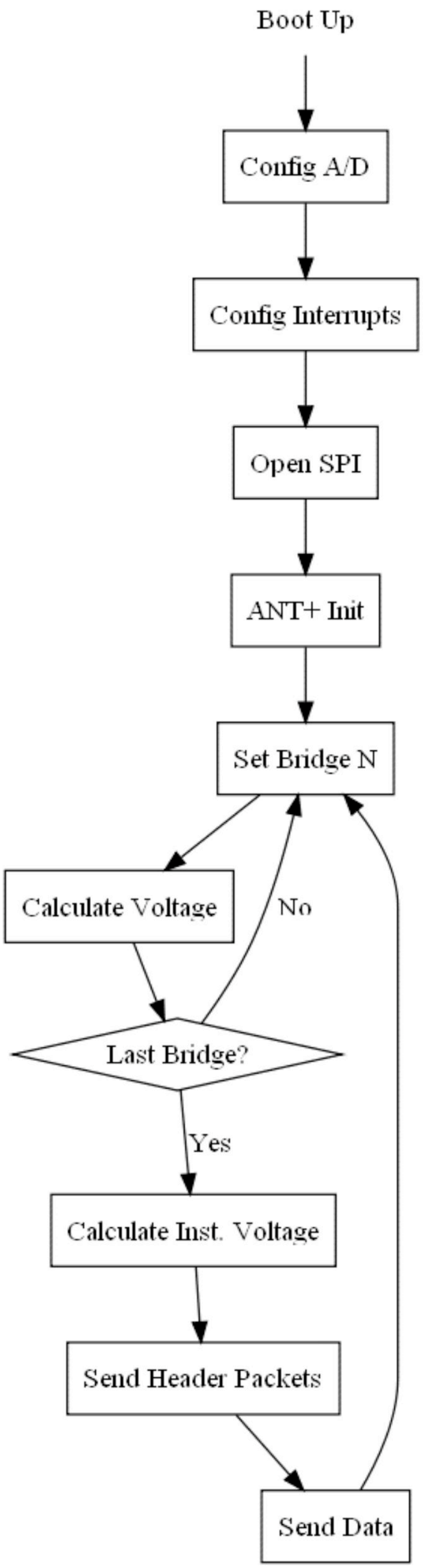
This section outlines the components that are used in the current system. We have done our best to provide information for obtaining new sets of components.

Finite State Machines

This is a list of finite state machines representing the operation of the circuit. All of the logic in the circuit takes place within the microprocessor. The various other hardware is used for data acquisition, signal clean-up and amplification, and wireless data transmission. The state machines below, in general, describe the operation of the microprocessor; however there exist transitions generated by hardware outside of the micro

General System Operation

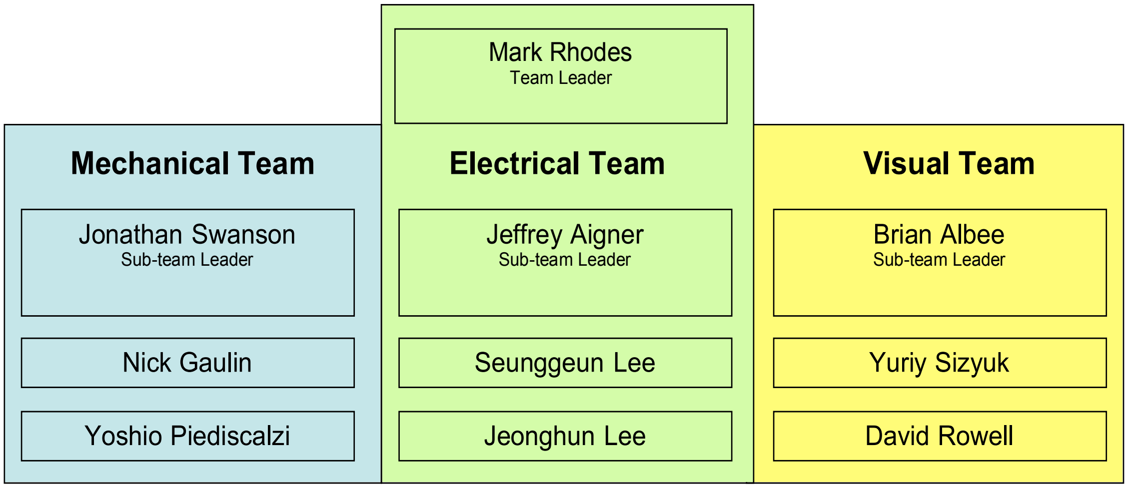
The system operates in a very simple loop. First the system is calibrated. Once this is complete, the system waits for the 0th switch on the crankset to pass the sensor.



Flow Chart of Microprocessor Operation

Microprocessor Operation

Below is a diagram that illustrates the basic operation of the microprocessor. This is the main logic of the system, gluing together the various functions of the circuit to produce output.



Budget

Item	Price
Carbon Fiber Crankset	$350.00
Electrical Components and Tools	$400.00
Bicycle Repairs	$50.00
Storage Units	$40.00
Bike Lock and Pump	$100.00

Electronics Documentation

Flow Charts

a PCB layout. The team was able to complete the task by increasing the number of layers from two to four. Unfortunately, the PCB layout and new housing were not completed in time to test before the end of the project. Additionally the electrical was unable to configure the ANT+ communication with the cyclocomputer to test the circuits, however a workaround with a slip ring was created so that mechanical testing could be performed with the use of a model circuit and oscilloscope. The slip ring allows wires to be run from the bicycle to external components and equipment without becoming tangled on the bicycle. The circuit and power measurement were tested for operation but not accuracy, demonstrating that the system works in principle.

Conclusions and Recommendations

Based on the results obtained, it is recommended that the new circuit design and housing are completed so the system can be used in road tests. Future teams will have to debug the current microprocessor code to provide accuracy and wireless capabilities, manufacture the new housing unit, and explore other innovations within the current systems limitations. The completion of these tasks will allow for a complete road test of the system, and future consumer market research.

Appendices

Team Members and Team Structure

through The Institute of Electrical and Electronics Engineers publications in order to optimize the circuitry for interference reduction, stability, and power management. Power management is an especially important design consideration for the electrical team, by reducing the power consumption batteries need to be replaced less frequently reducing the environmental impact. The mechanical team retested an aluminum crank-set from previous semesters in order to calculate the correct coefficients for use in the microcontroller code. Additionally, a new carbon fiber crank-set was obtained and static testing was performed on the crank-set in order to determine the torque versus strain relationship. This was done to meet the demands of cyclists using a crank set made from these two popular materials. At the completion of static testing all three teams contributed to dynamic testing of the carbon fiber crank-set. This was accomplished by collecting data while riding the bicycle on a Computrainer©, which provides an independent and accurate power output of the bicycle. This data can then be compared with data collected by our new power measurement system and checked for accuracy. The visual team assisted the electrical and mechanical teams by researching component prices, availability, and coordinating the groups' supply needs.

Analysis and Findings

The electrical, mechanical and visual teams worked together to create an updated prototype design, allowing for universal application of the device to road bicycles and preventing interference in the operation of the bicycle. The visual team designed a new, universal housing while the electrical team designed a new printed circuit board (PCB) layout which implemented interference prevention. The circular shape for the circuit board presented problems for the electrical team as they had not previously designed such market are very expensive ($800 and up) and not universal. Our IPRO worked on providing a much less expensive solution to the problem using the method of measuring strain in the crank set of a bicycle. Based on our findings the system works in principle but requires more work to finalize and test.

Purpose and Objectives

Competitive cyclists want an accurate measurement of their training progress. Historically cyclists have used heart rate data along with mileage and speed to provide a measurement of how hard the athlete is working during training. The problem is that an individual’s heart rate can be affected by sleep patterns, eating patterns, stress, time of day, and other factors independent of the amount of power the athlete produces. Also, the time taken to complete a course can be affected by wind and terrain. Therefore, a better method has been devised to accurately measure the amount of power the cyclist produces during a training session. There are currently several commercially available products, priced between $800-$3000 USD per unit, that measure a cyclist’s power output within 2% accuracy. These prices are perfectly acceptable for professional, sponsored cyclists but are prohibitive for many other cyclists. The goal of this IPRO is to continue the development of a new low cost power measurement system that is as accurate as those currently available. This new system uses the measurement of strain in the crank spider along with cadence (RPM) data to calculate power output.

Organization and Approach

The team was divided into three sub-teams: electrical, mechanical and visual to achieve the IPRO’s goal. The electrical team researched good circuit design practices

Executive Summary

Power output is the most accurate measurement of a cyclist's performance. As a result devices that can provide this information can become a valuable tool for professional athletes and amateurs alike. However, these kind of devices currently on the

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Power Measurement for Performance Bicycles

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