5-2015

Smart Carabiner

Craig Manning

SMART CARABINER

by

Craig Manning

**Thesis submitted in partial fulfillment
of the requirements for the degree**

of

DEPARTMENTAL HONORS

in

**Electrical Engineering
in the Department of Electrical and Computer Engineering**

Approved:

____
Thesis/Project Advisor
Dr. Don Cripps

____
Departmental Honors Advisor
Dr. V. Dean Adams

____
Director of Honors Program
Dr. Kristine Miller

**UTAH STATE UNIVERSITY
Logan, UT**

May 2015

Smart Carabiner

Final Report

Electrical and Computer Engineering Department May 2015
Jeff Lunt
Craig Manning

Table of Contents

Introduction

Users of common climbing safety equipment rarely understand exactly the loads and forces they are exerting on the equipment at a given time. All climbing equipment comes with a certified safety rating for the amount of force, in kilonewtons, that particular piece of equipment can take. Unfortunately, calculating dynamic load strain on-the-fly is nearly impossible. There needs to be a reliable, easy way of knowing exactly what load is being placed on a piece of equipment at any given point of time.

In addition to safety ratings for a single high impact event (slipping and falling), some climbing equipment, such as climbing rope, can only handle a finite number of such events. The question is "What is a high impact event?" It's a guessing game at best based on how far you fell, your weight, how your gear was attached to the rock, and the condition of your gear. Safety shouldn't be this guessing game full of gray areas and hand waving.

The objective of this project is to create a reliable, high quality, and affordable carabiner that can measure and report its load to a user in real time. If the carabiner approaches its safety limits, the user can immediately be notified via a smartphone app. The user can also be notified of long-term equipment strain, a count of high impact events, and when it may be time to replace old equipment.

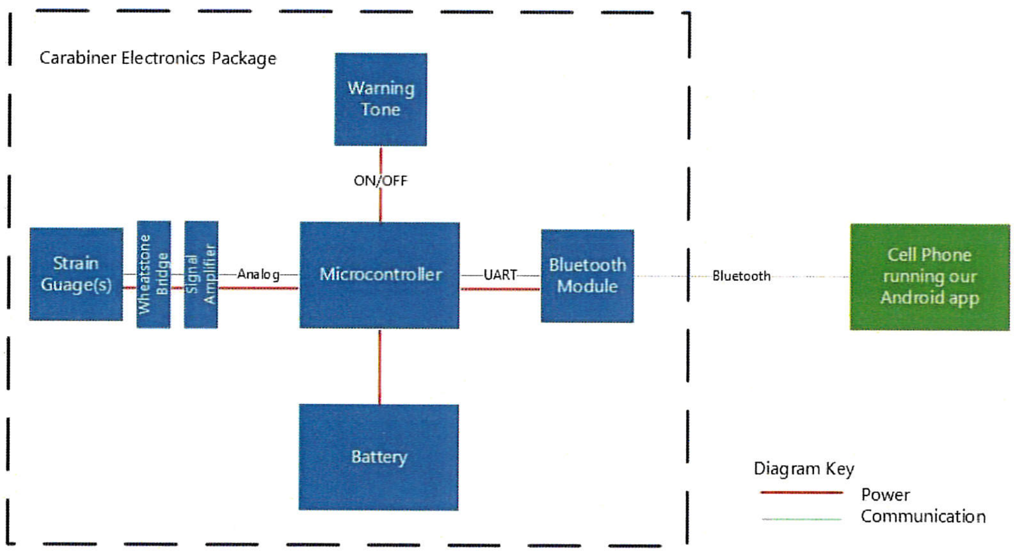
This report details the design, implementation, testing, and status of our first prototype. The finished product, with more compact electronics and Bluetooth connectivity with a mobile device, will come in future revisions.

Method

We chose to integrate the desired electronics into a carabiner because of its versatility in a climbing safety setup. It's a connection point for rope and other climbing gear, and is rigid enough to be able to house a small electronic circuit board.

Carabiners are small, strong, rugged pieces of equipment that are used in a huge range of environments. From the beginning we wanted to create a design that only expands on a carabiner's usefulness, without reducing safety in any degree. Our design needed to be small, simple, and robust, but also easy to use so as to never distract the user from the task at hand.

Below is the original system diagram of our smart carabiner design.



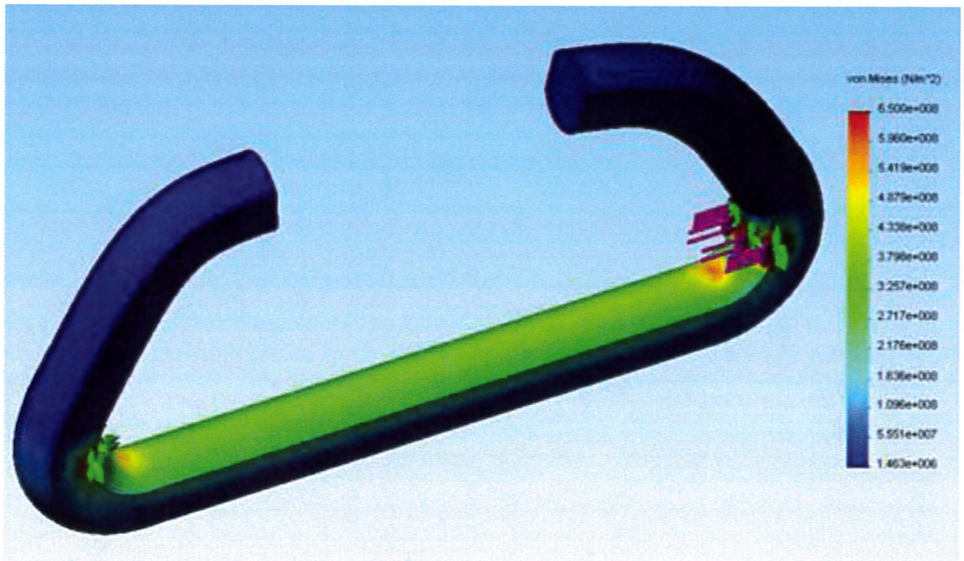
As it currently stands, not every module from this system diagram has been implemented in our prototype. Emphasis was placed on fine tuning the functionality of the core electronic components, namely the strain gauges, amplification circuits, and microcontroller. Those three components working together, along with a computer to gather data from the microcontroller, form the basic proof-of-concept of our design. The next step in the months to come is to finish adding the remaining components to create the first smart carabiner.

Even once it's completed, the diagram above shows the uncomplicated design of our smart carabiner. After the core sensing components, all that remains are modifications to allow portability: a battery as a power source, and Bluetooth for wireless communication.

Strain Gauge

The strain gauge is the most fundamental piece of our system. Essentially a strain gauge is a resistor that varies its resistance based on compression or stretch. When a load is exerted on any material, there will be a varying degree of physical change to that object.

Our carabiner is made of aluminum and will stretch in a predictable way. The placement of the strain gauge was a major consideration. Different parts of the carabiner react in a different way to stress. The "elbow" of the carabiner typically will experience the most strain but is a common place for the rope to lie and only provides enough room for a single strain gauge. According to the figure below, a logical place to measure accurate strain is on the inner spine of the carabiner. This placement allowed for room to fit two strain gauges where the metal has similar elongation properties under stress.



Carabiner Stress Analysis

Signal Amplification

When a constant voltage is applied across the strain gauge, the voltage output from the strain gauge changes based on the whether the strain gauge is being compressed or stretched. A circuit that is sensitive enough to detect the tiny changes in voltage across the strain gauge is called a Wheatstone bridge, shown below.

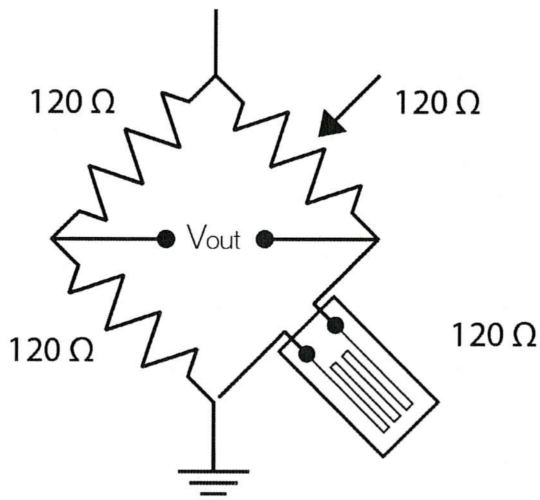


Diagram of our Wheatstone bridge setup. The strain gauge is in the bottom right leg of the bridge, with the other legs holding normal resistors with a resistance that matches the strain gauge

Once in this configuration, a voltage can be read from the strain gauge that is proportional to the amount of compression or stretching the strain gauge is undergoing. The change in voltage is too tiny to be useful at this point, but the voltage can easily be amplified using an instrumentation amplifier.

The instrumentation amplifier we used was an integrated circuit ordered from Texas Instruments. The amplifier was compact and allowed configurable gains ranging from 5 to 10,000. Even with the amplification at the lowest level with a magnitude of 5, the amplifier was able to bring the signal level up high enough for our microcontroller to read.

Microcontroller

In choosing a microcontroller, some key necessities needed consideration. First, an analog to digital converter is a module of the microcontroller that will read an analog voltage from a pin and convert it into a digital value. Second, a UART module is needed to communicate the data to either a Bluetooth module or across a serial cable.

After the core functionality of the device has been established, another large concern is size. Many microcontrollers come in different sizes and configurations. In addition to the physical footprint of the device, we needed to ensure the carabiner would have adequate battery life with minimal battery size, so low power consumption is an essential consideration as well.

With some research into different brands and styles of microcontrollers, we decided to use the Texas Instruments MSP430 line of microcontrollers. The MSP430G2553 is the specific model used. This model includes all necessary modules, with additional modules, such as timers, to assist in the data acquisition and transmission.

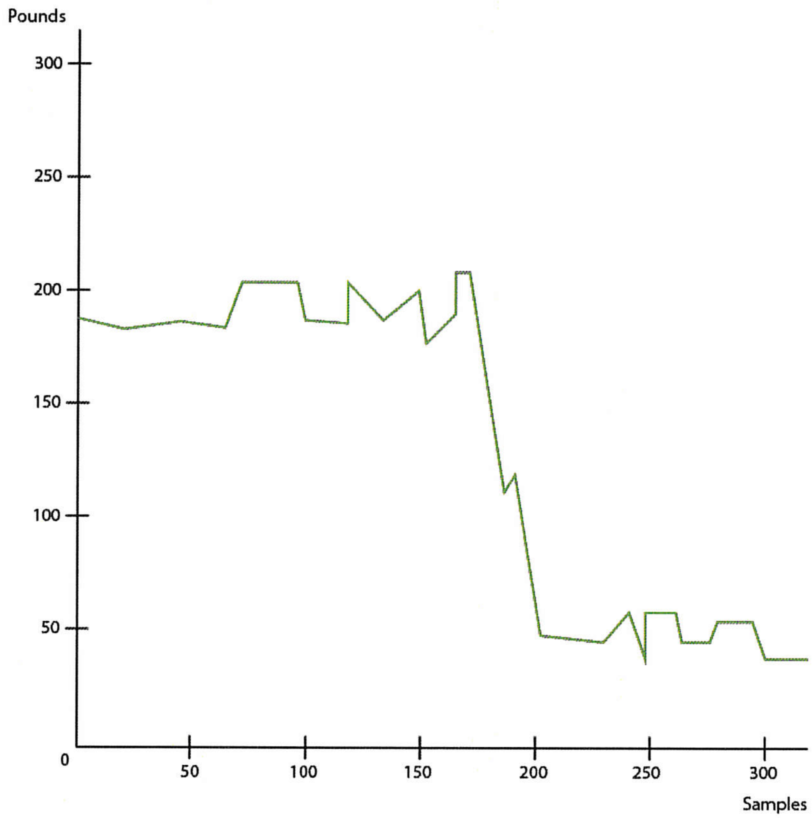
Serial Communication

Without Bluetooth functional in our prototype yet, we needed to get data from our microcontroller to a computer over a serial line. Data was sent over a USB cable using the simple UART communication protocol at a leisurely 9600 baud rate to a laptop running a Python script.

The script processed the raw binary data, accounted for lost or corrupted data, and gave a very approximate conversion to pounds for a real-time graph to display for senior design night. In future revisions, data will be sent over Bluetooth to a mobile device that will run similar data processing for the user to review at their leisure.

Results

In our initial tests a 170 pound adult man hanging on the carabiner in a room with an ambient temperature of 69°F created a difference in voltage of 13 mV. This gives us a resolution of about 1 mV per 13 lbs. With reference voltages from 0 - 1.5 V and a 10 bit analog to digital converter on our microcontroller, we would theoretically be able to measure a static weights up to 19,500 lbs. or the equivalent dynamic force. Below is a graph showing the resulting output of our carabiner when we hung on it.



On the right are the oldest samples, with the most recent samples being plotted on the left side of the graph. The y-axis denotes a rough estimate of pounds, but the measurements were about 50 pounds off, since there was no weight on the carabiner before Jeff started hanging on it.

During senior design night we discovered that additional compensation for temperature change will need to be added in future revisions. Strain gauges are so sensitive that even the slight expansion from being out in the sun will cause huge changes in readings. At one point with the sun shining directly on our carabiner, a 170 pound adult male hanging on the carabiner gave a resulting voltage 2-3 times higher than the voltage measured indoors.

The power consumption for our microcontroller is 230 μA in active mode and 0.5 μA in standby mode. A typical button cell battery has a capacity of around 150 mAh. Assuming standby mode is used more than 90% of the time, the battery life based on these estimates would be around 5 months of continuous data sampling. Bluetooth could affect battery life significantly depending on use, but without constant communication, battery life would still be quite good.

Analysis

As far as expectations go for a first prototype, we couldn't be more proud of the performance we were able to get. Despite variations in data due to temperature fluctuations during senior night, the carabiner performed excellently throughout the night. We feel that we have a solid proof of concept that shows real potential for a much more compact and durable design in the future.

Naturally we would have loved to have all the hardware that will be present in our final product also present in this prototype, but we ran into several roadblocks that didn't allow us to implement a couple hardware modules.

Our first cause of problems was a lack of more in depth research into the hardware available to use. We ended up choosing an instrumentation amplifier and Bluetooth module that were very compact, but very complex and difficult to interact with. Had we spend a greater amount of time looking at different hardware options instead of going with the first one that was 'good enough,' we could have saved ourselves a huge amount of headaches.

Bluetooth proved to be much more complicated to work with than we originally anticipated because we wanted a smaller Bluetooth module rather than the larger easier-to-work-with modules offered on Sparkfun.com. Our module required a confusing and very detailed Bluetooth stack that we ultimately decided would take too much time understand enough to implement in this prototype.

Conclusion

The Smart Carabiner has experienced a successful start to its development. From the initial idea to the first working prototype, we have learned many important lessons and concepts. All of the individual components we chose and worked with were unfamiliar to us, which provided a good challenge. Some of the most substantial lessons learned were about instrumentation and Bluetooth.

For the product to continue in development, considerable time and effort will need to be spent improving the accuracy and consistency of our data readings. While we got roughly accurate data, this type of device would require complete accuracy in nearly all types of environments. Looking ahead we will need to research if this product is worth pursuing in terms of patent conflicts or other issues. Money is also always a concern and funding will be considered heavily as a deciding factor.

Works Cited

1 - "Carabiner development", Web, http://www.crabdev.co.uk/comp%20fea.htm