An Engineering Technology Capstone Project: The Snow Load Network

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Capstone project courses have become an increasingly important part of Engineering Technology programs [4,5,6]. These hands on projects can be useful in improving student outcomes and generating assessment data for accreditation. Administering capstone project coursework can be challenging for faculty. Depending on the number of students in the program finding projects with the appropriate technical scope can be problematic. Obtaining materials and funding can also be a substantial obstacle, particularly for undergraduate work.

One approach to administering Capstone projects that is gaining popularity is for faculty and students to partner with industry to connect students with real world engineering problems[4]. This kind of academia/corporate collaboration has its own set of challenges. Depending on the company and the project, there will be various kinds of risk assumed by the involved parties. Students are typically focused on meeting program requirements and graduation. Faculty may be looking to support scholarship, perform curricular assessments, and to maintain future collaborations. Companies are usually focused on resource allocation, time to market, and cost.

This work describes an Engineering Technology Capstone project that took place over a two-year period with a team of five undergraduate students, two faculty members and a corporate mentor. The industry sponsor was a small two-person company that specializes in the design and assembly of mechanical and electrical sensing systems. Several state and federal programs provided funding for materials and student compensation.

The goal was to develop a solar powered remote network of sensors that could be installed on a building's roof. The purpose of this network is to measure the characteristics of the roof's snow load. For the experimental installation, mobile applications were developed to monitor the network's data stream and issue warnings of possible hazardous structural conditions. The original prototype used open-source programmable microcontrollers that supported wireless communication and global positioning systems (GPS). The resulting systems were evaluated and tested. Several follow on revisions were developed to optimize the power budget and casing into a commercial product that could be manufactured at a competitive price point. The project provided students a significant technical challenge, was funded, supported faculty scholarship, and helped a small company successfully launch a new commercial product.

Introduction

UNH-ET Capstone Project Program

The University of New Hampshire Engineering Technology **(UNH-ET)** capstone project course has several educational purposes. ETAC of ABET requires that student objectives be specified and assessment data be collected periodically. The senior capstone project can be major source of data for this process. Objectives are measured and assessed through grading/evaluating student work on projects by faculty, project sponsors, and volunteer evaluators.

For the UNH-ET capstone course each individual student works on an eight credit two semester project approved by faculty. Depending on the projects scope students can work independently or in groups. The projects can have a corporate sponsor and require the student to work directly with a technical advisor. Other projects may be part of a faculty research project or a project defined by students with faculty permission. This work describes a specific project that resulted from the collaboration of a team of UNH-ET faculty and students with a company, 2KR Systems LLC, based in Barrington NH.

2KR Systems LLC

Started in 2009, 2KR develops and manufactures innovative commercial, industrial, & municipal products used for environmental monitoring, rapidly deploying unmanned vehicles and remote sensors. They have created systems to extend cell tower equipment life and partnered with a company that measures and automates the application of deicing products from spreader (plow) trucks. The founder is a UNH alumnus and has over 20 years of experience in product development, design, engineering, manufacturing, customer and employee training, and consulting. 2KR was looking for an academic partner to help in securing state funding and provide student workers to aid in commercialization of an existing product line that was being used for a different application.

Funding

UNH-ET and Computer Technology programs possessed the technical resources 2KR Systems needed to develop essential hardware and software components for the proposed project. This collaboration on the system would create a viable product that could increase revenue at 2KR and lead to potential job growth in NH. The project also addresses a substantial hazard to the community where no viable affordable solutions were currently available. These elements made the project a good candidate for available state funding programs that stated an economic and academic development missions. Two sources of funding were identified; New Hampshire Innovation Research Center **(NHIRC**); and The Experimental Program to Stimulate Competitive Research New Hampshire **(EPSCoR-NH)**. The funding was to compensate students for their time working on the project, pay summer research stipends to the faculty, and pay for prototype materials. 2KR offered matching in-kind funds for their contributions.

From the NHIRC and EPSCoR-NH webpages the following missions were stated. **"**The NHIRC was created in 1991 by the New Hampshire Legislature to support innovations through industry and university collaborations, thereby increasing the number of quality jobs in the state. Since its inception, the NHIRC has awarded more than $6 million in state funds to support research projects and has been responsible for the creation or retention of 650 jobs. Awardees have received more than $32 million in federal SBIR grants and over $900 million in investment/acquisition capital." [7]. "NH EPSCoR strategically directs federal investments in world-class research infrastructure to support scientific research and STEM education that benefits New Hampshire" [8].

The Problem

Snow-related roof collapses create a sudden convergence of urgent environmental, safety, structural and economic challenges that are costly, dangerous and can lead to long term building closures. For these reasons facility managers and owners must proactively monitor snow conditions, weather forecasts and when necessary take action to reduce these loads. Though a number of methods exist for monitoring snow loads, such as rooftop measurement stations and roof truss deflection (bending) sensors, they can be relatively expensive, difficult to install and calibrate, and frequently come with significant operational limitations.

Adaptation to climate change plays a role in future of snow load monitoring. Although a general warming trend exists, forecasts call for more erratic weather patterns[3]. For example, the North America climate models predict longer periods of both precipitation and drought along with more intense wind and storm events[3]. Better insulated roofs will conduct less heat into the snow, reducing traditional melting rates thus maintaining loads for longer periods of time. If the system is demonstrated to be an effective tool in reducing insurance claims for roof collapses and damage sustained to rooftops as a result of snow clearing then insurance companies may promote the product and even provide financial incentives for its purchase as they do in other situations in which they encourage capital purchases leading to reduce claims.

In 2009, 2KR Systems developed a ground-based, light weight and rapidly deployed system called the SnowScale[1] to measure snowpack water content (measured in *snow water equivalents* or SWE). It was used by water resource managers to assess melting snowpack driven flood risk and predict late winter and springtime reservoir inputs. Units are deployed in NY, NH, PA, UT, ID and AK. The City of NY operates 38 SnowScales to monitor the snow mass in the Catskills Mountains which supplies drinking water to 8 million people. The overall system was large, bulky and had many sophisticated systems such as data loggers, data radios, and solar charging systems.

It is not uncommon for scientists and researchers to operate and maintain devices of this complexity. However, for wide spread application in commercial and industrial markets a turnkey and simplified product on all levels was mandatory. In addition, the rooftop environment readily allows for low power wireless communications to seamlessly pass data, and modern design tools make possible the ability to place nearly all electronic functionality on a single affordable circuit board.

Key features of the device include:

- Rapid single person assembly and initialization
- Placement and relocation virtually anywhere on the roof by one or two people
- Units can be relocated at any time to any rooftop location or facility
- Low profile base for high accuracy measurements under changing conditions
- Solar powered with rechargeable cold weather battery (no rooftop power cables)
- Data is saved and accessible during building power and internet outages
- Wireless bidirectional data transfer using low energy long range ZigBee (XBee Pro) radio protocol. No usage fees or limit to number of stations per roof.
- GPS module places the unit on a Google Earth/Maps style aerial view of the facility and is viewed from the web application
- Remote snow load monitoring via web and mobile apps
- Email, text and audio alerts.

Initial System and Subsystem Technical Description

The Rooftop Snow Load Measurement System is composed of three subsystems, mechanical, electrical, and software as shown in Figure 1.

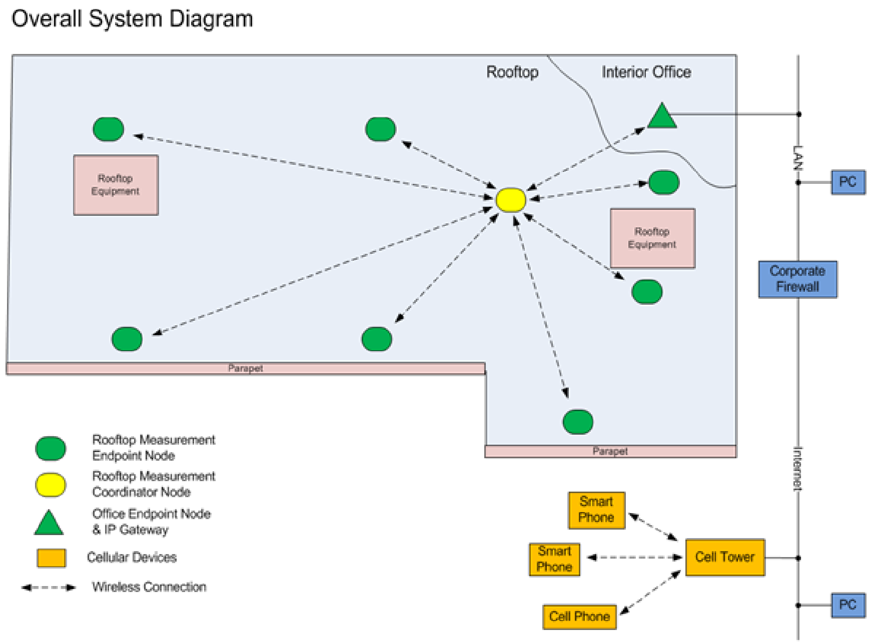

Figure 1

Mechanical Subsystem

All mechanical design was conducted using the industry standard SolidWorks2013 solid modeling software. SolidWorks Simulation 2013 a finite element analysis (FEA) tool was used to simulate mechanical loads and component stresses. The staff of 2KR systems had the background and expertise to execute this portion of the project.

<u>Frame and Weighing Plate</u>

The 39kg (87lbs) SnowScale frame and weighing plate will be basis for the roof top system design, shown in Figure 2. The new design featured minimal assembly steps and was light in weight and assembled quickly in the field. The frame and weighing plate needed to mimic the rooftop temperatures for realistic snow accumulation and melting performance.

<u>Electronics Housing</u>

The weatherproof electronics housing, shown in Figure 3, was designed to securely hold the PCB, battery, solar panel and wiring harness. A printed circuit board (PCB) mechanical layout drawing, wiring harness and connector specification were created for use by the electrical engineering team.

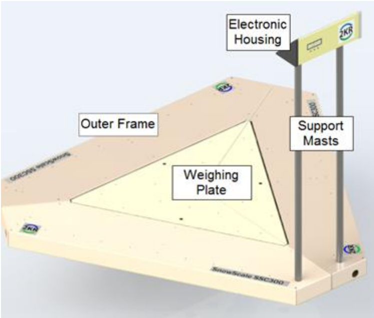

Figure 2

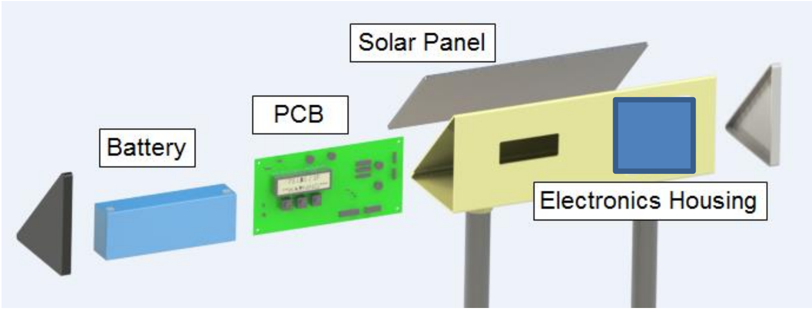

Figure 3

<u>Loadcell</u>

The loadcell assembly is the heart of the rooftop system as they precisely convert the weight of the snow to a meaningful electrical signal. Since the SnowScale was first developed, connectors and cabling have become a significant expense. Efforts were made to reduce the effect of this increasing cost.

Figure 4

Electrical Subsystem

The electrical system, shown in Figure 5, will be controlled by a central microprocessor, which issues and receive commands wirelessly and deliver load cell data through a digital interface. The wireless transmission allowed for communication between Endpoint, Coordinator, and Office Endpoint nodes.

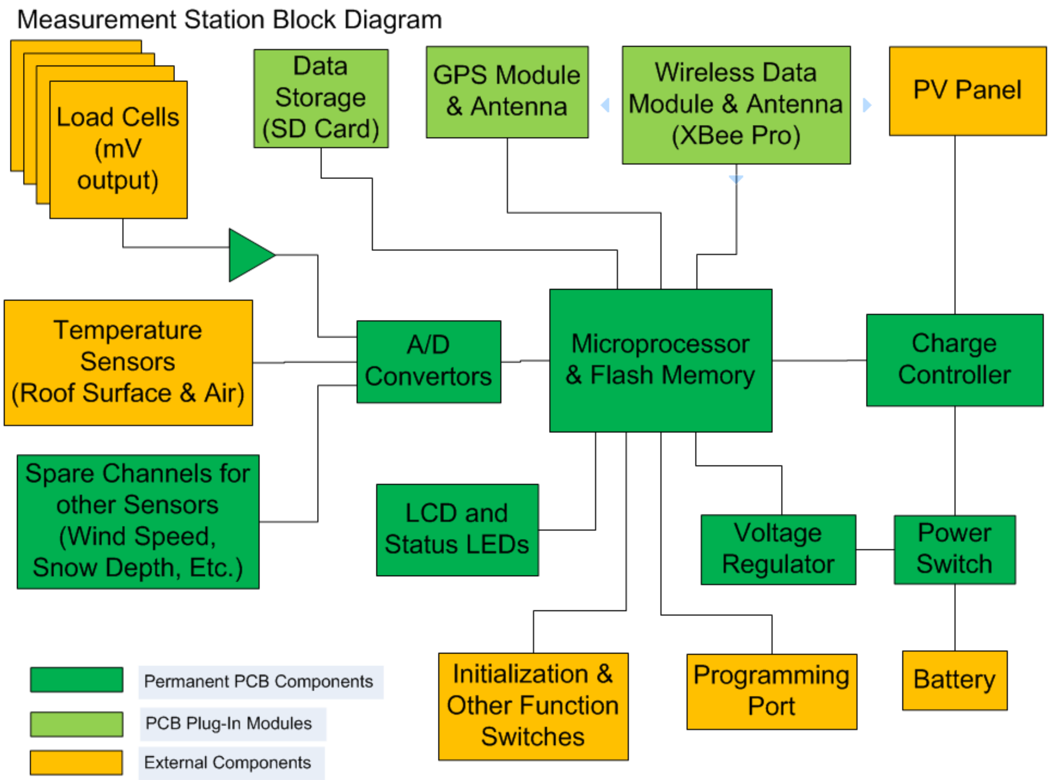

Figure 5

Microcontroller

The microcontroller sub system included a central CPU, GPS Module, Wireless module, and a non-volatile storage device. The platform chosen was the Arduino Mega board, which can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling signals, sensors, and other instrumentation. The microcontroller on the board was programmed using the open source Arduino programming language and the firmware programs were stored on a non-volatile flash device. This work will required skills in the area of open source Arduino coding, and implementation of firmware source code to a microcontroller system.

Periphery circuit design

The periphery circuit design consisted of developing an interface to the load cells with buffering. The buffered signal interfaced an analog to digital converter. Additional channels were needed for sensors measuring optional things such as temperature, wind speed, etc. This work required skills in the area of analog system design, in particular the sensor interfacing circuits with operational amplifiers, and instrumentation amplification. Additional design effort were required to interface the multifunction switches and LCD (Status, Load & Function Display)

Power management and delivery system

A power management and delivery system was designed using photovoltaic (PV) cells. The Rooftop Snow Load Sensor Network system operates entirely off solar power. A detailed power budget was developed for the entire system. The budget allowed for the appropriate choice Photovoltaic cell configuration. A charge controller managed the power harvested by the PV cells and the charge cycle of the battery. A voltage regulator was to be included to maintain consistent power to the microprocessor. This work required skills in the area of analog system design, in particular voltage regulation, and PV cell usage.

Printed circuit board

Once each sub system was designed and prototyped, a final printed circuit board needed to be designed. Since this is a low bandwidth design (one sample every ten minutes), low interconnection counts, a relatively low cost multilayered board (two to three layers) was implemented. Eagle software was used and since the board was only two levels the open source version was acceptable.

Software Subsystem

ConnectPort X gateway

ConnectPort X gateway provides IP network connectivity for end-point devices in wireless XBee networks. The gateway collected the end node data, processed it, and sent it to the software system using a LAN connection. The gateway was programmed to stream measurement data to a web server application using HTTP GET request to send latitude, longitude, temperature, and load data. The HTTP Get request is performed by passing a URL.

Cross-platform Apache, MySQL, and PHP run-time environment

The cross-platform run-time environment consisted of: Apache HTTP server 2.4.4, MySQL database server 5.6, and PHP processor 5.5.3. Database server (MySQL) managing a database with relational tables that store measurement data (latitude and longitude, load sum, temperatures, and status and diagnostics parameters) for each monitored station. Apache HTTP server and PHP processer were integrated with MySQL server to support server-side processing of data (storing and retrieving).

Backend software system

A PHP server application was be implemented to:

- Retrieved HTTP GET request data from the wireless network & sent to the database.
- Interfaced the database with the web and mobile client applications.

Web and mobile applications

Web and mobile client applications provided the following functionality:

- Allow users to enter station parameters: station #, building name and address, load limit for each location (lbs./ft^2 or kg/m^2)
- Represent overlay colorized station locations (using GPS) and ID # onto aerial view of building. Colors indicated degree of safety: green = % below threshold, orange = close to threshold, red = at or exceeded threshold.
- Plot load, temperature(s) and building load limit vs. time (selectable time scale, i.e. day, week, month, years, etc.) for any station

- Sent alert messaging (text and email).

All development and production software and programming languages were free and open source: Apache HTTP server, MySQL database server, PHP processor, JavaScript engine, web browser, App Inventor mobile app development platform and language, XHTML, and CSS3. A dedicated virtual server with software server installations in the Computing Technology department was used for development and testing of the software components.

Work Plan
The work was divided over a team of three EET students and two Computing Science students. The third EET student was split time between electrical design and software development. 2KR Systems was responsible for assembling and integrating mechanical components into the system.

Deliverables

1. Mechanical & Sensing
   a) Weighing Plates and Frames for 5 rooftop measurement stations (Redesigned SnowScales for rooftop application)
   b) Functioning load cell assemblies for 5 rooftop measurement stations.
   c) 5 Weatherproof electronic housings and support masts.
2. Electrical
   a) Functioning microcontroller implementation and firmware source code, with GPS and wireless capabilities.
   b) Functioning power management system.
   c) Printed circuit board assembled and tested
   d) Documentation including electrical schematic, Gerber and NC drill files, net list, etc.
   e) Operational test of 5 measurement stations, including initialization, communications, data collection, storage and retrieval, and diagnostics.
3. Software
   a) Cross-platform Apache, MySQL, and PHP run-time environment installed and configured on dedicated virtual machine server.
   b) Relational database designed and operational on a MySQL database server.
   c) Backend software system written in PHP and MySQL to provide database services to client applications
   d) Web and mobile applications interfaced with backend software.

System Prototype, Deployment
The UNH-ET faculty met with 2KR over the academic summer break to formalize the funding requests which were submitted in October. In the first semester senior capstone class students were put on teams and given tasks. Weekly meetings were conducted and milestones were defined. Initially 2KR was driving for a very aggressive schedule and was hoping for working prototypes in the first winter. The teams started the work prior to receiving funding approval. The team was notified of the funding awards in December.

Over the first year the electrical team created a working prototype in a generic plastic enclosure. One challenging aspect of design was getting the appropriate battery chemistry that would work with the solar charging system in a demanding extreme cold environment. The students developed a very detailed power budget to help with choosing the appropriate components. A lot of work was done with getting the appropriate Wi-Fi equipment and antenna. By the end of the second semester the students had built several stations of working prototypes.

The software team held weekly meeting to work out bugs and to refine the user interface. Many decisions were collectively made by the team to determine how data would be collected stored and formatted. Figure 6 is an early prototype of the web application.

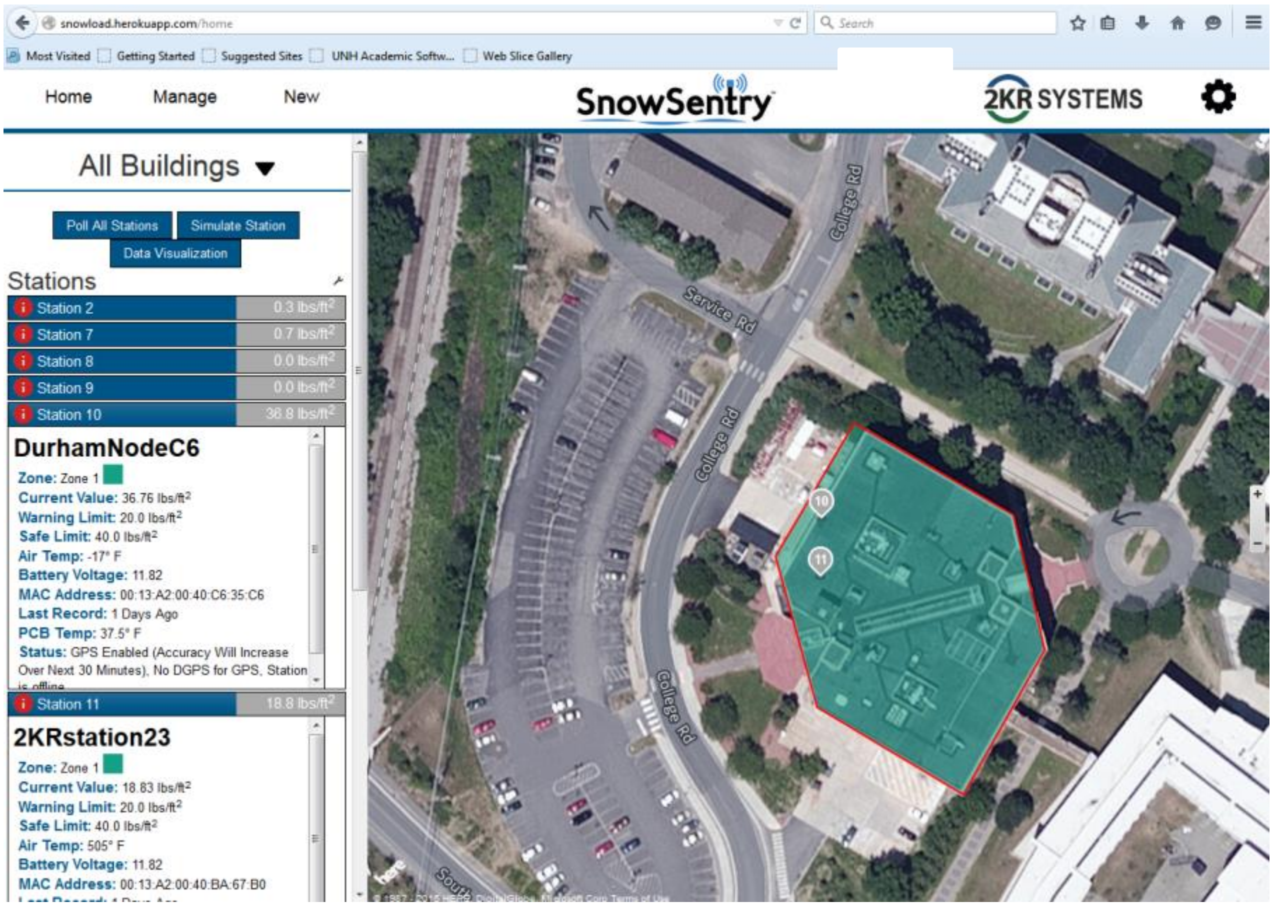

Figure 6

In the spring semester it was clear that a commercial version of the system would not be ready before the students graduated. Most of the team had employment commitments after semesters end, however; one of the electrical and one of the software team had some outstanding requirements to finish their degree. These students worked over the summer and into the fall to finalize the project. Most of the team that was no longer affiliated with the University after graduation did offer volunteer services to help push the project forward. For the electrical team the most important outstanding task was developing a commercial printed circuit board. The board was developed and fabricated and populated by a commercial manufacturer, see Figure 7.

Figure 7

The initial printed circuit board design had some design flaws in the placement of the analog charging circuitry and the digital output of the microcontroller. After some debug the charging system was disconnected from the circuit board and a second printed circuit board was used for the charging system, see Figure 8.

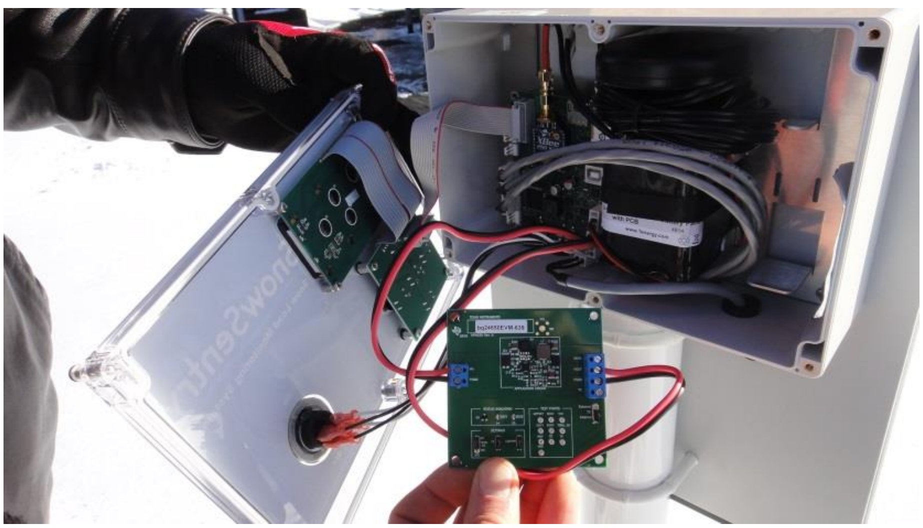

Figure 8

By the winter of the second year a fully working electrical, mechanical, software system was built and placed on top of the UNH Mores Hall, see Figure 9. The teams developed procedures and documentation for deployment, the key items are listed below.

- Web Hosting
- Cloud Configuration
- Hardware Configuration
- Security
- Branding
- Support
- Testing

Figure 9

Conclusion

The Snow Load Network project demonstrated a very beneficial industry academic partnership. Through the use of grants students were compensated and materials were purchased to build the initial prototypes. The resulting system addresses a very problematic issue in areas that have heavy winter precipitation events. This project exposed students to the competitive nature of entrepreneurship and small business development. With the help of the mechanical expertise of the company owner and university faculty the project was broken down into manageable tasks. Schedules were created and students were held accountable to finish tasks.

One of the most challenging issues of this project was aligning and managing expectations. At the onset of the project 2KR was driving to have commercially ready prototypes within two academic semesters. This proved to be too aggressive, by the end of that period of time the team had managed to build a system that met the specification but was not ready for production and still buggy in both hardware and software. Several of the students stayed on to work the project and others that graduated volunteered some time to help out after graduation.

As of 2017 the first two commercial systems were installed in New England. Since the end of the student participation 2KR has hired a dedicated professional contractor to continue development on the systems. Several more printed circuit boards have been developed, the charging system has gone over some modification and the load cell mechanical structure has been modified. Overall this was a great experience for students to get exposed to seeing a system go from concept, funding, development, prototype, testing, and commercialization.

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