122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society

Paper ID #12906

A Hardware Enclosure to Increase Access to, and Reliability of, Data Acquisition Hardware while Enhancing the Student Laboratory Experience

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The Multidisciplinary Engineering Laboratory (MEL) at the Colorado School of Mines is a sequence of three courses that integrates and replaces traditional laboratories in electrical circuits, fluid mechanics, and stress analysis. Students are asked to build and analyze small, laboratory-scale systems. The experiments endeavor to move beyond basic theory verification by reorganizing knowledge to form connections between fundamental concepts spanning several courses.

Across the three-phase MEL sequence, experiments incorporate various types of transducers and means of gathering information. National Instruments' LabVIEW software and data acquisition (DAQ) hardware are used to facilitate the data collection and expose students to industry standard equipment. Students work in teams of two, where each team conducts their own experiment, collects data, and writes a lab report. There are twelve teams in the lab at any time, which requires twelve full sets of operational equipment.

Background

Until recently, the lab was equipped with PCI based data acquisition cards (National Instruments – NI PCI 6024) that were hosted by desktop personal computers. The PCI cards provided mostly reliable operation for several years. Some students had difficulties understanding the concepts of data acquisition, and the hardware involved, since the PCI cards are hidden from view within the PC case. Students accessed the DAQ system through a connector block interface (CB-68) with 68 screw terminals that became stripped and worn after years of rigorous use. It is also evident that the CB-68 interface does not have the most intuitive layout; for example, wiring for a differential voltage measurement requires connecting to channel 0 and channel 8 represented on CB-68 as terminals 68 and 34, or wiring for referenced single ended voltage measurement requires connecting to channel 1 and a ground terminal represented as terminal pins 33 and 67. Students were often confused by the unclear interface and occasionally made wiring errors that were difficult to troubleshoot.

Figure 1: National Instruments - NI CB-68 after years of student use.

In addition, laboratory experiments involving strain measurement incorporated a signal conditioning card (NI SC-2043-SG). These cards were first released on the market in 1996 and were used in MEL for over 10 years. The signal conditioning cards (SC-2043-SG) involve setting jumpers for half and full bridge configurations and tuning on-board potentiometers that are not easily understood by the students. Instructors themselves were known to have spent in excess of one entire lab period just learning how to use them. In addition, as could have been predicted, over the years, these cards have gradually started to fail in various ways. These compounding factors made the experiments very difficult to execute. Students, as well as the instructors and teaching assistants, essentially spent most of the time troubleshooting and very little time on actual measurements or interpretation of the data. Students became very frustrated and extrapolated their sentiments to the extreme opining that none of the equipment in the lab works or is reliable.

After careful consideration, and due diligence, the lab was re-equipped with an up-to-date external USB DAQ system (NI CompactDAQ) consisting of:

- CompactDAQ chassis - cDAQ 9174 – used to host up to four modules, USB connected to the PC;
- NI 9219 - 4 channel, 24-bit universal analog input module – offers build in quarter, half and full-bridge support, build-in voltage and current excitation, thermocouple, voltage, and current measurements;
- NI-9215 - 4 channel, differential analog input module;
- NI-9262 - 4 channel, analog output module;
- NI-9403 - 32 channel, digital input/output module.

This system offers several advantages over the existing equipment:

- Modular - modular hardware prevents replacing the entire system if a student damages the equipment;
- Portable – can be moved from PC to PC or used elsewhere in different lab;
- The PC is not required to have a PCI slot;
- Can host different combinations of modules and be expanded;
- Simulates industrial practice as graduates are more likely to find USB solutions in the field.

A challenging part of the implementation of this system was addressing the different types of interfaces required by each module, which appear delicate and unlikely to hold up to repeated daily use, connecting and disconnecting, over the course of many semesters. In addition there was not a straight forward solution for securing the equipment to the lab bench to protect against theft. To address these concerns we began considering alternatives that took the form of readily available enclosures, or modifying existing products to help secure the equipment. In addition a reliable, easy to maintain, and student friendly connecting interface would be attractive to include in the solution. Cost, as always, was a factor, as the funding allocated for the cDAQ system did not include the enclosure or interface.

Specialized enclosures are not offered by the manufacturer of the cDAQ system but are clearly needed in an educational laboratory environment. Through our discussion with National Instruments representatives it became apparent that we were not the only university facing this challenge; two other institutions in the area had already implemented solutions of their own creation. One of our contemporaries graciously provided a picture of their solution to us. Their enclosure consisted of a powder coated rectangular metal case with viewing window, color coded binding posts connecting terminals on the vertical surface, and painted labels designating each of the modules. While we instantly liked their enclosure, the cost of producing this type of enclosure would have been prohibitive. In addition, re-producing the metal front panel would require significant resources in the case of future expansion or change in the system.

As an alternative we looked at ready to use metal or plastic enclosures, which could be further modified to serve our purposes. Some of the solutions we found were close in size and cost; however, in all cases significant redesign of the front panel to accommodate our system and all terminal connectors was required. Having given these alternatives ample consideration the decision was made to study an "in-house" solution that is cost effective and addresses the requirements for implementation of the new cDAQ system.

Design Considerations

Factors influencing our design:

- The foot print size was carefully considered as there is limited space available on our laboratory bench tops;
- Security – the enclosure needed to provide a means of securing the equipment against theft;
- Viewing window – the enclosure needed to provide a view of the cDAQ system for the students, thus helping to avoid the "black box" phenomenon;
- Provide means of reliable and robust connections;
- Terminal connectors to be replaceable and color coded;
- Sufficient space between connectors and convenient approach angle of the "work surface";
- Front panel interface to duplicate the modules interface and provide the same description as given on the module;
- Provide sufficient cooling to the cDAQ system;
- Provide sufficient protection to the cDAQ system and be portable;
- Provide means of connecting to PC and external power source;
- Provide means of maintenance and easy access to the system;
- Components must be easily replaced in the event of accidental damage or future improvements;
- Most components to be produced "in-house" and be cost sensitive.

Implementation

An enclosure was designed to host the cDAQ system. Below is a discussion on some of the most important elements that influenced our design.

1. Connectivity

Several types of connectors were considered – spring loaded, screw type, binding post terminals, etc. We chose the binding posts since they offer several advantages, especially in the educational lab environment: they allow multiple ways of executing connections, multiple wires can be connected at the same time, ability to troubleshoot easily, can be color coded, inexpensive, and are easily replaced if damaged. We also benefit from consistency between devices since other equipment located on the workbench, like power supplies, feature similar connectors.

To enhance student's understanding of the cDAQ system, all "positive" or "high" terminals connectors were color coded in red and all "negative" or "low" terminal connectors were coded in black.

Consideration was also given to the distance between connectors, such that an average person can easily manipulate the binding post connector. The resulting distance between connectors is not less than one inch.

Terminal connectors are arranged and described to match the module's interface within the box. Thus when students reference the user manuals and diagrams they see the same arrangement as depicted on the front panel. Furthermore, when students later encounter the actual hardware, the geometry will already be familiar. The accurate portrayal of connections is a critical component of the design, which addresses concerns that students using the hardware are unfamiliar with the configuration of the hardware itself.

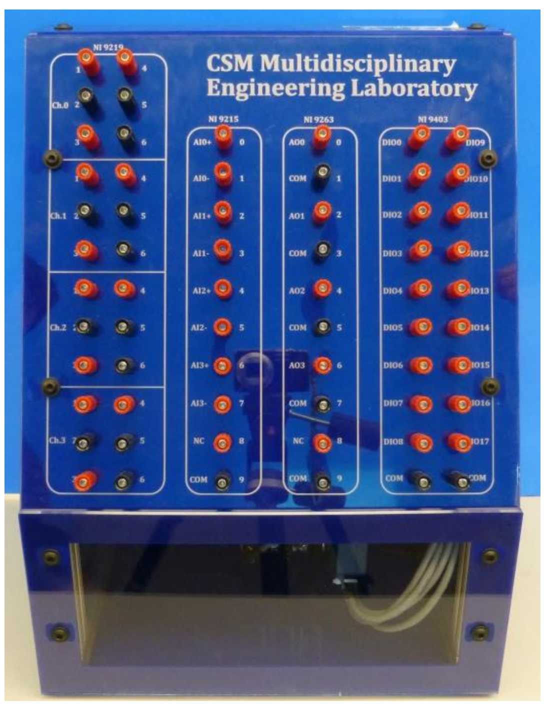

Figure 2: Enclosure in vertical configuration, front panel close-up.

The physical connection between the binding posts and the module's interface is provided by wires arranged in cable form. One end of the wire uses crimped spade connector to attach to the binding posts' stem with a nut. This connection was chosen since it can be serviced easier than more permanent soldered connection. The completed front panel hosts 64 terminal connectors.

The cDAQ system is connected to the PC using standard USB cable. One "through enclosure" USB adaptor is used per system. Power is provided by way of a switchable, panel mounted, power entry connector.

2. Enclosure case

As described earlier, off-the-shelf metal cases were both expensive and required significant modification to accommodate this particular interface. Therefore we decided to experiment with acrylic panels, which can be engraved and cut in-house using an Epilog Laser tool. This approach offers several advantages:

- Acrylic is not expensive and readily available in a variety of colors, transparencies, and thicknesses;
- Production is straight forward as design files can be printed directly to the engraver;
- The case is made of seven panels that are bolt connected to six aluminum profiles (8020 Inc.). Considering that the enclosure would rest on the lab bench for the majority of its life, this approach provided sturdy construction with two possible configuration – horizontal and vertical. Varied orientation is more conducive to the available bench space.

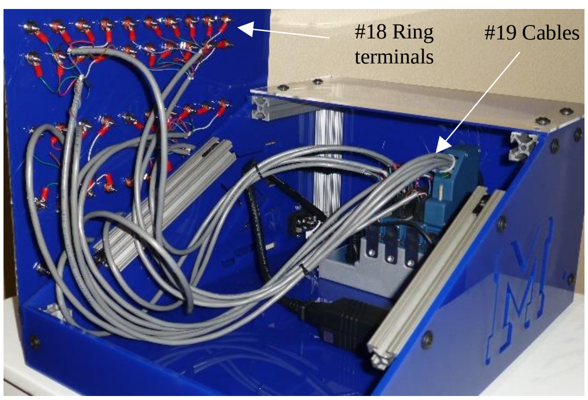

Figure 3: Enclosure in horizontal configuration, front panel removed.

- The front panel is sloped for easier access. This works well in both – horizontal and vertical configurations. Alternative configurations are achieved by flipping the front panel and standing up the case;

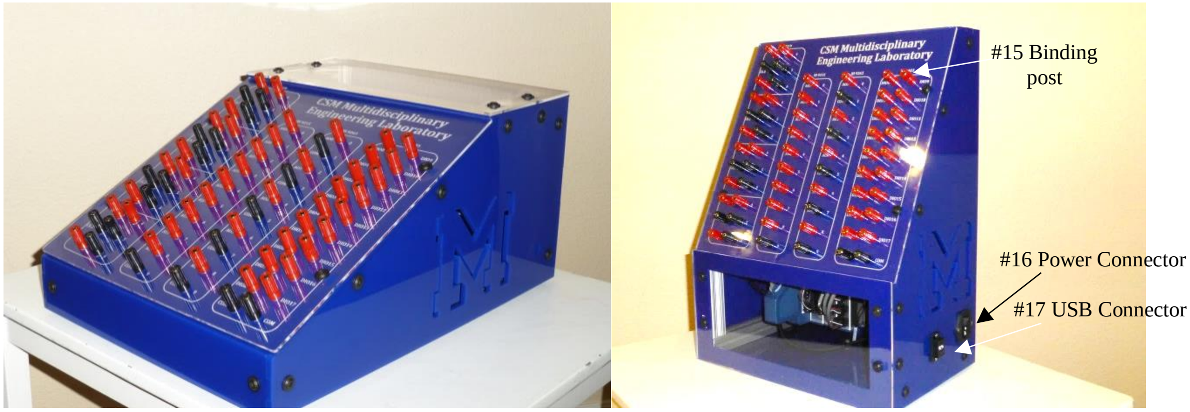

Figure 4: Enclosure in horizontal and vertical configuration.

- Individual panes are easy to remove for maintenance or replacement;
- In case of future modifications or damage to any of the panels, replacement can be produced in only few minutes, and at cost of the material only;
- One of the top panels was produced by sandwiching two 1/8" acrylic plates: a non-transparent blue frame – to form a window, and transparent clear cover through which the students can see the DAQ hardware;
- The front panel was also produced by sandwiching two 1/8" acrylic plates: a non-transparent blue – to form the base, and transparent clear cover engraved with all labels. A mirrored image was engraved on the inner surface of the transparent plate; this way all labels are protected from dust and grime, and student's creative touch;
- Two sets of holes for security cable are provided – one for each configuration;
- Power and USB connectors are on the side panel as this location works for both configurations.

The low cost enclosure, was designed, built and assembled by students and faculty. Several students were involved in the process, from freshman (see the nice school logo on the side panel) to graduate teaching assistants. Student participation was essential throughout the process, each contributing to an improved MEL experience. Most of the time spent on the production of the box went toward design and selection of components; several iterations were necessary to achieve the front panel that was envisioned. Apart from the design, there was significant time required to install the connections from the cDAQ components to the front panel but we are confident that the robust system will endure rigorous student use for years to come.

In total, fifteen enclosures were built for a total parts cost of less than $3000, which, fortunately, agreed nicely with the budget remaining to finish the implementation.

So far we had two occasions when modules from the cDAQ system required removal from the enclosure to be returned to the factory for warranty work. Since the system is external to the PC no special IT support personnel were required to open the top panel and remove the modules. Swapping the bad modules was quick and effortless.

Parts List and Drawings

The following figures show the basic assembly with major dimensions relevant to the overall design; for those interested the corresponding author will by happy to provide detailed drawings or parts files upon request. Prices and part numbers are listed as actual at time of purchase.

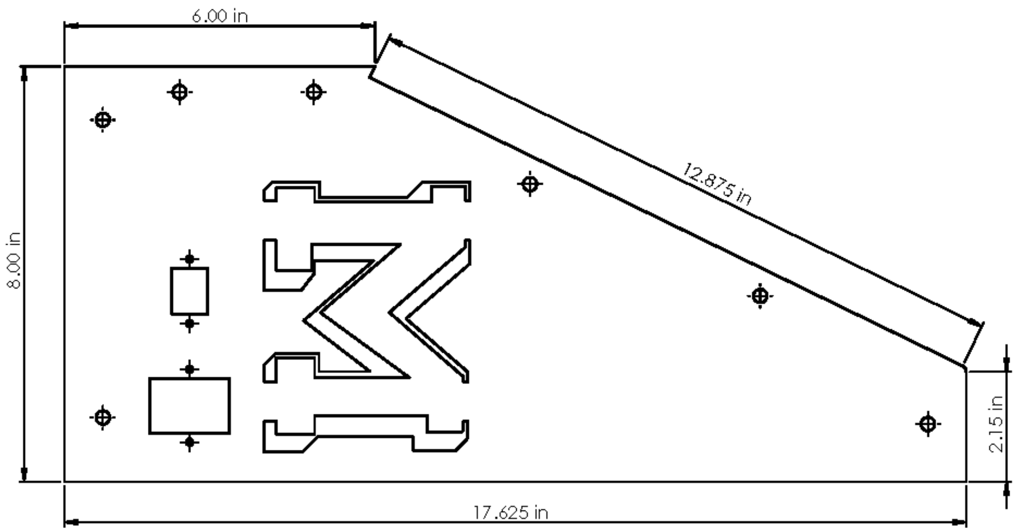

Figure 5: Side panel.

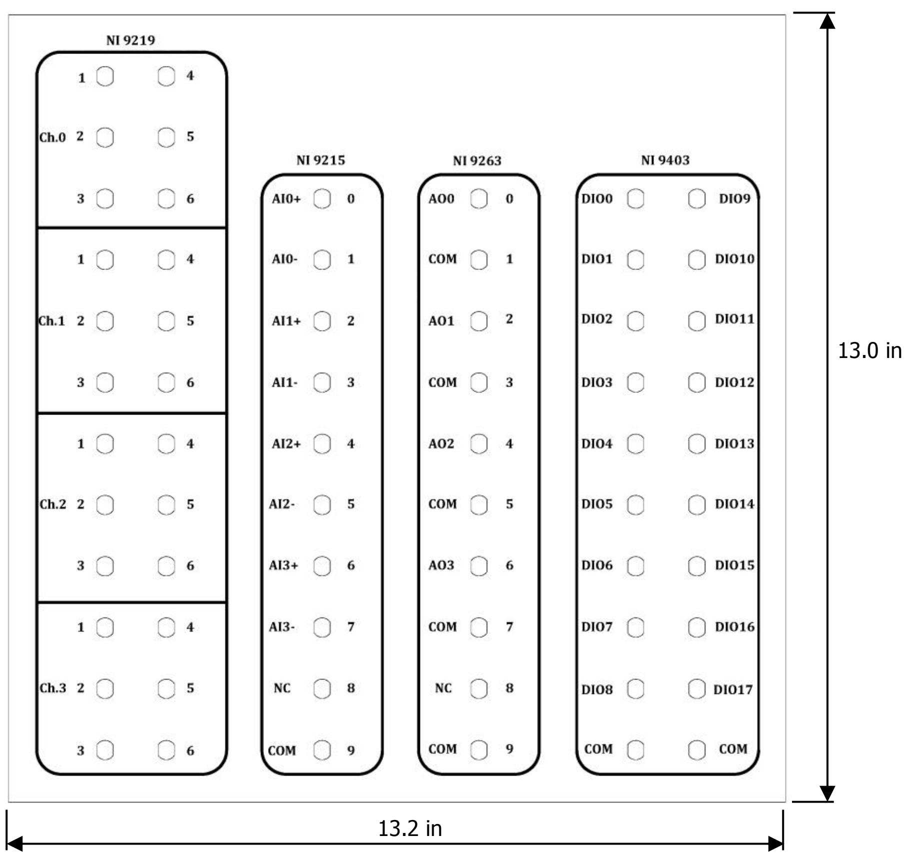

Figure 6: Front interface panel.

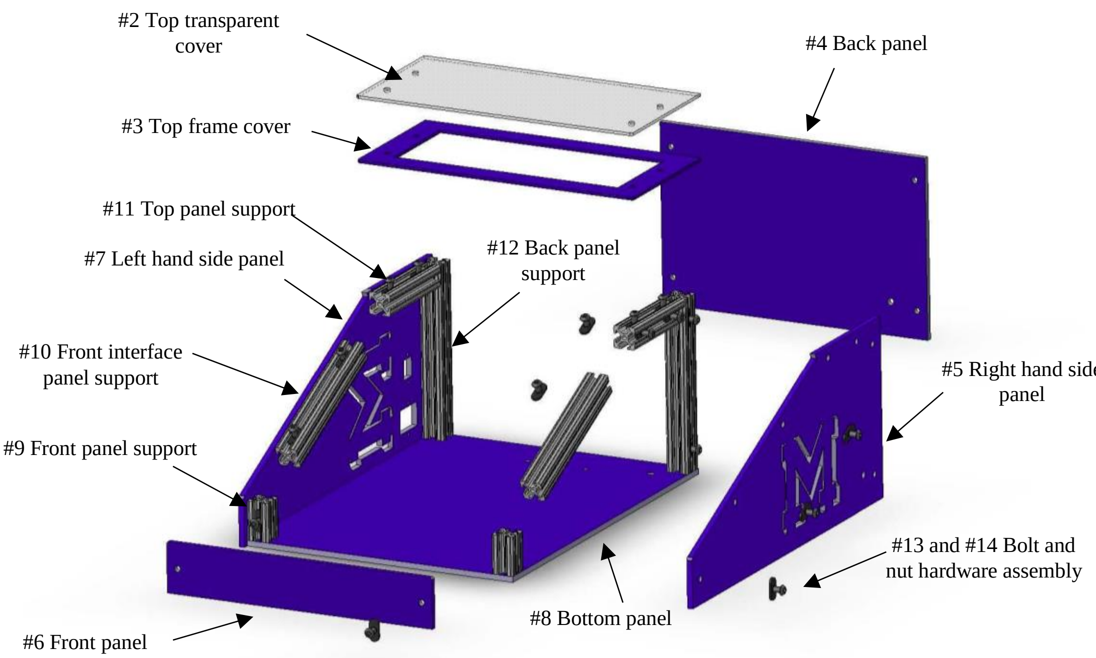

Figure 7: Enclosure exploded view. Front interface panel, DAQ system, and connectors are not shown.

Part #	Count	Description	Manufacturer part number or material	Supplier	Unit Price
1	1	Front interface panel	1/8” clear acrylic + 1/8” solid color acrylic	Local supplier	*
2	1	Top transparent cover	1/8” clear acrylic	Local supplier	*
3	1	Top frame cover	1/8” solid color acrylic	Local supplier	*
4-8	1 ea.	Side, back, bottom, front panels	1/4” solid color acrylic	Local supplier	*
9	2	Front panel support - 1.75in	1010-97 80/20 Inc.	Fiero Fluid Power	$0.23/in
10	2	Front interface panel support - 7.0in	1010-97 80/20 Inc.	Fiero Fluid Power	$0.23/in
11	2	Top panel support – 4.50in	1010-97 80/20 Inc.	Fiero Fluid Power	$0.23/in
12	2	Back panel support – 7.80in	1010-97 80/20 Inc.	Fiero Fluid Power	$0.23/in
13	32	Bolt ¼-20x1/2	3342 - 80/20 Inc.	Fiero Fluid Power	$0.30
14	28	T-Nut ¼-20	3382 – 80/20 Inc.	Fiero Fluid Power	$0.04
15	44	Binding post - set of two	GIP001-R (77691)	Jameco	$1.39
16	1	Power connector	CCM1917-ND	Digi-Key	$9.08
17	1	USB connector A/A	ECF504B-UAA	L-Com	$6.13
18	64	Ring terminal	423952	Lowes	$0.16
19	12	Belden multi-conductor cable – 28.5in length	9536 060500	Mouser Electronics	$379.00 /500ft
20	2 pkg	Heat shrink tubing 1/4in	20958	Lowes	$2.16
21	1	Power cord	AE9895-ND	Digi-Key	$4.58

* - total cost of acrylic per enclosure was approximately $59.

Table 1: Parts list. Part numbers as shown on figures 3, 4, and 7.

Conclusions

The low cost enclosure, now integral to the lab experience for a third semester, has been performing well and exceeding the initial expectations. Wiring and troubleshooting has been easier for the students; they have accepted this solution very well and always had positive comments about the cDAQ system. Another interesting finding is that when improving student's experience in one area, they have better perception about the whole lab and our lab equipment in particular. The new cDAQ system and enclosure have helped us move in a positive, growing direction.