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BYOE: Fabrication, Implementation, and Design of a Remote Lab Setup for a Sensors and Transducers Course

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BYOE: Creating the STAND: Sensors and Transducers Active eNgineering Design-bench.

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Abstract: (BYOE) This paper presents the design, fabrication, and implementation of a remote lab setup for a sensors and transducers course. Traditionally, a Sensors course (or otherwise called Instrumentation course) has learning goals focused on engaging students in laboratory exercises seeking to extract numeric values from experiments by using laboratory equipment. For example, this could be measuring the temperature of water while heating, and depending on the major and student experience, assembly of the associated electronics during the lab period is often included. Presently, labs are often either: 1) a series of disconnected/disjointed labs only focused on a single-sensor-application or 2) pre-fabricated equipment setups purchased from education companies, which are often costly and have a small scope with very limited possibility for future modifications. Both also suffer from "cookie-cutter" type approaches, which stifle students from experiencing true engineering design methodologies. Both existing solutions often have no flexibility to be switched between in-person and online teaching; if it is even possible to be implemented online.

In this BYOE presentation, we present the design, fabrication, and implementation of a hybrid Sensors and Transducers Active eNgineering Design-bench, or *STAND*. The *STAND* was constructed at the University of Georgia in Fall 2019 and Spring 2020 to provide a laboratory experience with multiple sensors and actuators in a connected setup. The STAND has been used in Summer and Fall 2020 to provide remote students with real experimental data performed real-time. This BYOE paper will focus on the STANDS's capabilities in terms of instruction. Hence, we will discuss the possible experiments that can be performed, the adaptability and robustness the STAND has in developing new future experiments, and highlight the fabrication and steps needed for creating. Finally, a discussion about the needed technology support and computer software will be presented along with pros/cons for using different types of technology. Presently, there are over 10 sensors installed and a live experiment using the equipment will be performed to show the validity of the results presented. The experiment will show the unique features of the STAND that allow for students to engage in higher-level thinking.

Tags: STAND, sensors, transducers, actuators, laboratory, multidisciplinary, instrumentation, STEM, experiment, equipment, online, best-practice

Summary

A sensors course, also called instrumentation at universities, is a multi-disciplinary class that introduces students to data-acquisition techniques. This paper gives a summary of how an in-house multi-purpose laboratory design bench, called the STAND, sensors and transducers active engineering design-bench, can be constructed to give students a unified platform for remote labs learning. An example laboratory is shared, highlighting the future modality available for a unique experience to future students. Readers should be able to take the concepts presented to create various STANDs, and adapt them to their unique instructional roles.

Pedagogical Context

The field of instrumentation engineering focuses on using sensors, transducers, and actuators to measure continuous physical variables. This can range from native electrical measurements, such as a measuring current and voltage levels in a power application, or to non-native applications such as measuring the pH of a solution for a chemical engineering application. Regardless of application, one of the defining characteristics is that the physical variables measured are often continuous and analog. For most applications the general block diagram shown in Figure 1 can describe the necessary path to capture a measurement from a change of physical variable to a variable stored in computer memory (or used for feedback).

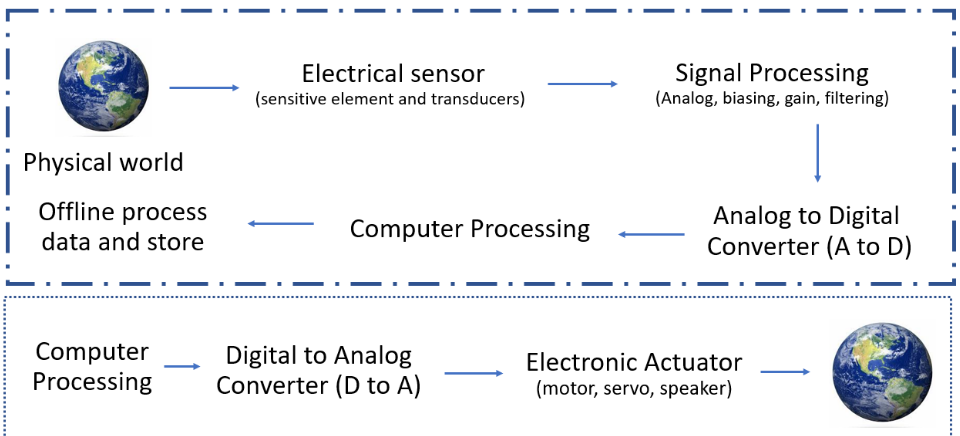

Figure 1: Steps needed to build a sensor system.

Sensors class is a natural choice for a course that has a hands-on laboratory component. In designing a laboratory setup there are many inherent challenges. A list is presented summarizing the main challenges*:*

- *Building a coherent laboratory setup that students can use throughout a 16-week semester.*
    - This is in-contrast to piece-meal labs that are each independent of one another.
- *Students come from a wide variety of degree backgrounds. The percentage of each major can change semester to semester.*

  - A 3-hr electrical circuits course is the only required pre-req for sensors. Often electrical and computer engineering students have far more electronics knowledge than other majors.
  - Students from other majors may have taken circuits years ago a need information refreshed.
  - A wide variety of student experience exists in both standing (sophomore vs senior) and industry experience. More advanced students may have also had design courses.
  - Laboratories cannot be too focused on a single topic. Only a basic knowledge of Physics I and II can be assumed for all students.
- *Accessibility*
  - With the changes COVID-19 has created, building a setup that can be accessed remotely allows for greater flexibility. It also allows for an online course.
  - Giving students the real electrical noise, implementation challenges, and other physical factors in a remote setting is non-trivial.
  - Scalability issues. If 1 great test bench is built, students have limited access to it.
- *Budget constraints*
  - Many companies offer laboratory setups, often in excess of >$20,000, that only provide a few labs in a specific discipline. For example: A vibration table may allow for measurement of position, velocity, and acceleration. The main focus is not on sensors and data-acquisition techniques, but vibration theory. Which, requires a working knowledge of vibrations that most students won't have.
  - Pre-fabricated units in excess of >$5,000 often can only be purchased during times of major renovation where external money is available. Tenure-track faculty may have funding for research equipment, but non-tenure track faculty certainly do not. The scalability issue is also present.
  - Many universities provide lab fees. With pre-built hardware it is difficult to modify labs for continuous improvement (kaizen).
- *Academic Dishonesty Concerns*
  - After an arduous process of building a laboratory, will students next semester have the same learning experience when the solution is "out"?
  - Even if variables can be changed, is the solution path the exact same with only minor algebra changes?

All of these challenges exist on top of the pedogeological desires for our students to achieve the higher levels on a learning taxonomy (Anderson and Krathwohl, 2001). In practice, instrumentation presents a slew of interesting challenges and tradeoffs and engineer must consider. Unfortunately, it is quite easy to reduce the classroom problem to simply following a list of do's and don'ts based on available hardware. This leaves no creativity or true problem solving left to the students, or in other words, there is no or only little room for analyzing, evaluating, or creating. Students are reduced to following instructions.

To resolve the design issue, we interfaced the STAND with MATLAB's Simulink program. Forthcoming are the specifics on the design, but effectively through the use of the vast Simulink libraries and the “blank canvas” approach Simulink takes, the user can interact with the hardware and create a unique solution. This solution can cater to personal skills. Before describing this the description, the STAND is presented.

Apparatus Design and Hardware

One of the hallmark characteristics of the STAND is the versatility. It is expected with small lab fee contributions each semester, sensors can get upgraded and/or changed for variety. Figure 2 shows the sensors and actuators on the STAND. The STAND was built in-conjunction with the university machine shop. Fundamentally, the STAND is assembled sheets of acrylic. Acrylic is easily machinable and has suitable yield strength and dielectric properties. In the STAND there are three areas as shown in Figure 2. The design was intentionally partitioned so that a ‘wet’ area would be secluded from the electronics.

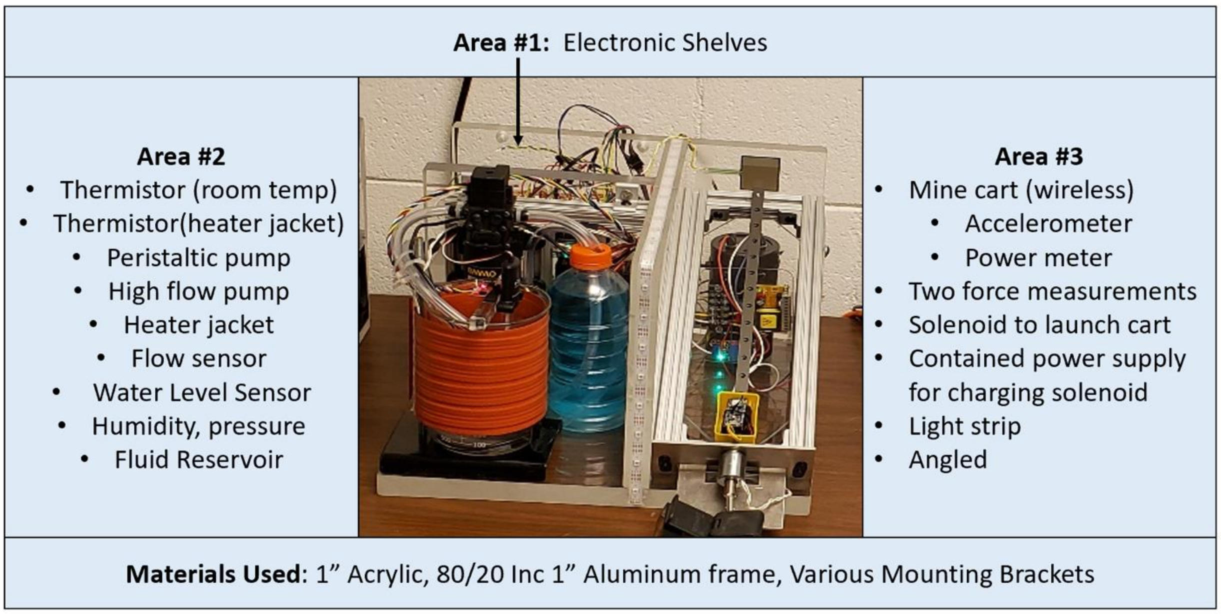

Figure 2: Fundamentals of the STAND.

A common 60W PC power supply is used to take 120VAC to +5V, +12V, and -12V. Two popular microcontrollers are used in interfacing. At the time of writing, a custom PCB board is in-progress to replace the “rats’ nest” wiring the breadboard can blossom into. There are various electronic components are employed to interface the sensors with the microcontrollers. Figure 3 shows a general signal flow pattern. A webcam is used to view the STAND. Microcontroller #1 interfaces with all of the onboard sensors. It also has safety code on it should temperature or power exceed predefined levels, the system will shut off.

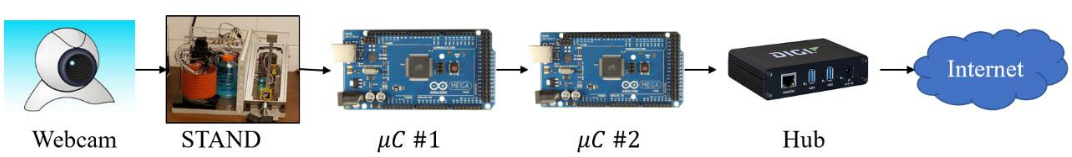

Figure 3: Connectivity of STAND.

Through the university login, a student access to a 'remote desktop'. Thanks to the widespread adaptation of the internet, this can happen from almost anywhere in the world. After the student has logged into the university systems, the student can select a remote lab. Currently there are three to choose from, and this is sufficient for average course enrollment (~40-60 each semester). The final setups and are shown in Figure 4.

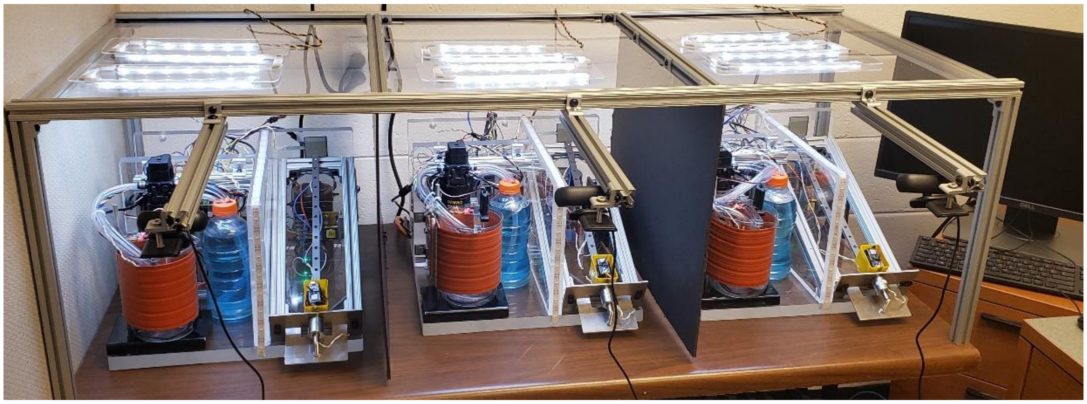

Figure 4: Final STAND setups.

In the present time of writing, a student will run a pre-programmed script that opens a pre-configured base Simulink code. This is shown in Figure 5. The computer running Simulink has a direct connection to Microcontroller #2. When this code runs, the obfuscated portions configure the COM Port settings, and also provide a security code to Microcontroller #1 to enable the STAND. The student is then able to program as desired in the remaining Simulink workspace to interact with the inputs and outputs of that particular laboratory.

For example, in Figure 5, the obfuscated code block also provides internal signal processing needed to determine the resistance values of the light-dependent resistors (LDR) on the STAND. So, students receive the data as they would working with the 'raw' LDR as they would in a physical laboratory where resistance changes with light level. Given the large number of sensors on the STAND, and the flexibility the obfuscated code blocks provide, this allows a multitude of unique laboratories to be generated. Likewise, since the hardware was built in-house, small upgrades can be made along with code upgrades each semester as learning goals change. This also provides laboratory customization based on student major percentages.

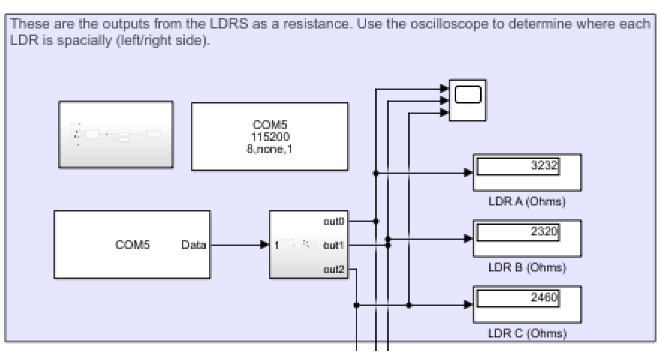

Figure 5: Simulink Start-up Code.

Sample Applications

Building off of the discussion presented about Figure 5, consider designing a laboratory that uses an LDR. Given we have the raw resistance inputs of three LDRs, a laboratory with three progressing exercises could be constructed: 1) Create a transfer function between light level and resistance values, 2) Perform signal processing to bring the range to a voltage between [0, 5] V (i.e. Wheatstone bridge and op-amp implementation in Simulink), and 3) Create a fault detection device that alerts a user when the light level is about 50%. While the first two exercises are concepts that would be directly covered in lecture material, there still are a variety of implementations. The third exercise would also provide a plethora of options. A computer engineering student might write a script to meet the requirements, whereas an electrical engineering student may choose to virtually implement hardware in Simulink. It would be expected that each group have a unique implementation. In future semesters, the value of the LDR could be scaled in the obfuscated code, or a new lab could be used correlating light level to fluid level in the tank. Both changes require minimal investment in instructor preparation time.

For students performing the laboratory with a poor internet connection, there still remains a viable path to success. Any real time data can be saved to the university interfacing computer and downloaded at a later time. Likewise, offline coding and brainstorming on the problem-solving aspects can be copy and pasted in with minimal internet bandwidth.

Anecdotal Student Feedback

The STANDs were implemented in Fall 2020. Most of the initial challenges associated with the STAND were IT related. Creating a link between a hub or computer and the equipment is not trivial, but should be a task most IT departments can overcome. After connectivity issues were overcome, this was live tested with 2 classes.

Talking about the students' feedback and future work, it is noteworthy that we plan to expand the STAND's use in the sensor courses (and beyond where applicable). This further development and use expansion will take the latest student feedback and the lecturer's personal impression into account, so a more in-depth analysis is to come. For this BYOE paper, we will share some selected student comments. Most of the students' comments refer to both using the STAND and performing the same laboratory in a hands-on setting:

"I believe I learned a lot more in the hands-on mode than I did in the remote setup regarding thermistors and circuit building. However, I learned a lot about Simulink and how it works in the remote lab. Switching between the two was only difficult due to Simulink being new to me. However, I personally believe the hands-on lab helps me learn more."

"I would say the advantages is seeing the remote lab come to fruition. What I mean by that is it was cool to build and observe the thermistor in action after doing it virtually. A challenge was developing an idea of how to construct the necessary system with the materials we had. Simulink has a large variety of components, but a hands-on lab does not have as many."

"I had the labs the opposite way around. I think one advantage of the way I had it was that the remote lab was very easy to organize, so that we did not need to both learn how to make the

circuit and the software at the same time. However, doing the in-person first did not allow to completely understand the inner workings of in amps until week two, because the in-person lab simply had a pre-made one."

"I think it did help with my learning of the material. I think it is important to get a sense of doing an experiment in both ways. As an engineer, the typical process may be to build something using computational tools and then verify it in the real world. This experiment gave a pretty good look at that."

The initial feedback is very exciting the for the authors. It is to be expected that some students will only be satisfied using hands-on equipment. However, student feedback showed the flexibility of Simulink, and that the virtual laboratory caused them to think in a more fundamental way. Finally, the instructor, who has taught 19 sections of this course, noticed anecdotally, a stronger connection between theory and hardware implementation. Another interesting outcome showed that students could work on the remote lab one-step at a time, as opposed to a fixed 2hr session. Overall, student feedback showed the design goals of the STAND to be verified.

Bill of Materials

Many materials were used from existing sensors laboratories. It is suggested that the reader be resourceful with existing supplies. Presented in Table 1 are the key components for the STAND. This does not include the additional frame seen in Figure 4.

Table 1: BOM.

Part	Description	Manufacturer	Qty	Est Price ($)
Acrylic	1" width, 4' x4' sheets cut to size	Grainger	1	350
Slotted Al	1" t slotted aluminum, allows for various brackets to be mounted, 8ft cut to length	80/20 Inc or Grainger	1	100
Microcontroller	Depends on how much I/O desired	Digikey	2	60
Sensors	Various sensors and electronics	Digikey	-	200
Hardware	General mounting hardware	McMaster	-	50

Conclusion

With this BYOE paper, we display a complex, custom designed laboratory set-up for sensor instruction, which can be used in both a face-to-face and online mode. This gives the instructor the possibility to combine advantages of face-to-face teaching experiences and online experimentation. In face-to-face lab classes, direct student interaction can enhance the teaching and learning experience. Furthermore, the development of hands-on skills by the students can be supported. However, the displayed set-up can also be used in online teaching settings and, hence, expand both the overall flexibility for interacting with the equipment and the students' opportunity to use the equipment in a much more self-guided and self-paced way than it is possible in classical, time- and space-constrained lab lasses. So far, the system has been pilot tested. The student feedback is very positive so far and the instructor could anecdotally document the positive impact of STAND to the course outcomes. However, educational research going beyond the technical evaluation and student satisfaction data is still lacking. Because of its flexibility, the authors foresee STAND to remain an integral part of future course delivery, even after the current social interaction constrains will have been lifted again. This will open up the opportunity for promising educational research efforts using the equipment in both face-to-face instruction and online experimentation.

References

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