Homegrown Labs with PLCs

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Abstract

A number of lab experiences are discussed that cost little and challenge the student and give creative challenges to the instructor. They are designed around the Siemens S7-1200 PLC (programmable logic controller). The experiences are used to challenge students to experiences like in industry including motion control, PID (proportional integral derivative) control and other interesting processes. A text provides background for the student. The text “Hybrid Text” has been created over the years by the author and is found at his university website [1]. A second text at the same website has been started which describes many of the lab experiments from the “Hybrid Text” and has grown with the addition of other experiments as well. It is found under the title “Hybrid Lab Text” [2]. With COVID, a YouTube channel [3] has been added integrating the lectures from the text, the problem sets, and labs. All texts and YouTube materials are free.

Discussed are some of the lab experiences used in two EET courses, one at the sophomore year, one at the senior. These labs also form many of the lab exercises for an Electrical Engineering course in PLCs. A fourth course that uses many of the lab experiences is an Auto Controls course for EET and MET students. One area that is yet to be developed is a link to the EET Database course. Two new robotics courses may also be a candidate for experiments using the PLC in a manufacturing lab experience. As can be seen, the lab equipment can be useful across a broad number of courses in EET and EECS.

Historical Background

The thought of building labs in-house did not happen overnight. It grew from a number of experiences. One of these happened from observation of a rather expensive lab set-up that was later abandoned. The equipment was from an education vendor and cost about $40K. This equipment was abandoned due to equipment failure with no one able to adequately service it [4]. At that same time, there was a report from some senior exit interviews that had criticized efforts in the Advanced PLC course concerning one person-one lab setup. These interview comments were the last straw in convincing this instructor that if a lab were to be successful, there needed to be eight identical lab setups servicing eight groups so all could accomplish the same lab at approximately the same time. These two events led to the idea of trying to build lab experiences internally that were not too expensive and that included 8 complete setups. If a lab experience were considered for inclusion, it should be able to satisfy the criteria that it could be built in-house *and* with eight units.

A benefit of the work includes incorporating the HMI (human machine interface) screens platform into the lab experiences. Screens can be developed quickly and easily using the PLCs’ HMI developer. Screens may be played in the simulate mode on the screen of the computer bypassing any expense of additional HMI hardware. Creating buttons and digital displays on a screen was a move forward since the time needed to develop these screens was minimal.

First Trials

An early attempt at building labs in-house included a stepper motor and controller chip on a breadboard. The purpose of this lab was to gain an experience in single axis motion control, a skill needed in industrial automation. The first attempt never worked.

It had previously been found that the Siemens S7-1200 could output a stepper motor pulse signal capable of driving a stepper motor controller. The board-level attempt was never successful. However, an evaluation board was found that drove the stepper successfully.

This effort included trying to turn the two axes of an etch-a-sketch. While the etch-a-sketch failed to produce a good x-y picture, the stepper was kept and is still in use as a single-axis lab for students studying single-axis motion control [5]. See Fig. 1.

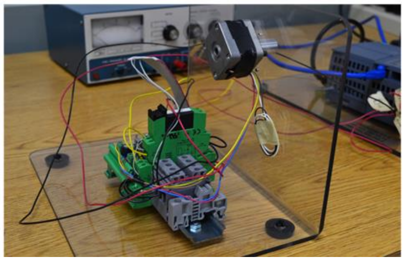

Fig.1. First lab, stepper controller turning as shaft.

A second early project was first observed at the ASEE National Conference in Atlanta, GA, in 2013. It included a ping-pong ball in a tube levitated by a fan. The purpose of this lab was to gain an experience in analog PID control, also a skill demanded by industrial automation. This lab was assigned to a capstone group and proved a good challenge. The group was successful, and the lab was expanded to eight stations which have been in use now for a number of years. The lab is used by both PLC and Auto Controls groups and demonstrates the use of a single PID block successfully controlling the height of the ball in the tube. A laser is used to sense the ball's position in the tube [6]. See Fig. 2 for the ball-in-tube lab.

It had been a goal to build something like the $40K process equipment left for the scrappers. The result of the effort was a single unit like the main portion of the $40K device. The purpose of this lab was also to gain an experience in analog PID control which could be a benefit in the PLC courses as well as in the Automation Control course in ET. The project is outlined in a number of texts as the self-regulating liquid tank [7]. Technical obstacles to overcome include measuring of water flow accurately (and cheaply). Also, the use of the fan motor in the earlier lab gave confidence in controlling a dc motor with pwm (pulse width modulation) output from the same Siemens S7-1200 PLC, which was used to control the bilge pump.

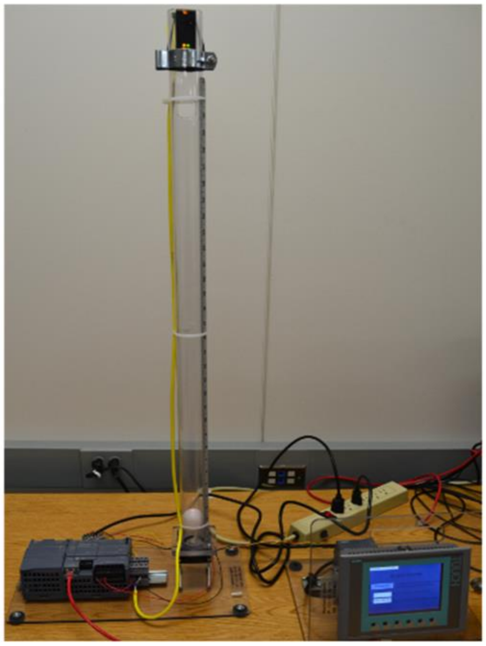

Fig. 2. Ball-in-tube lab.

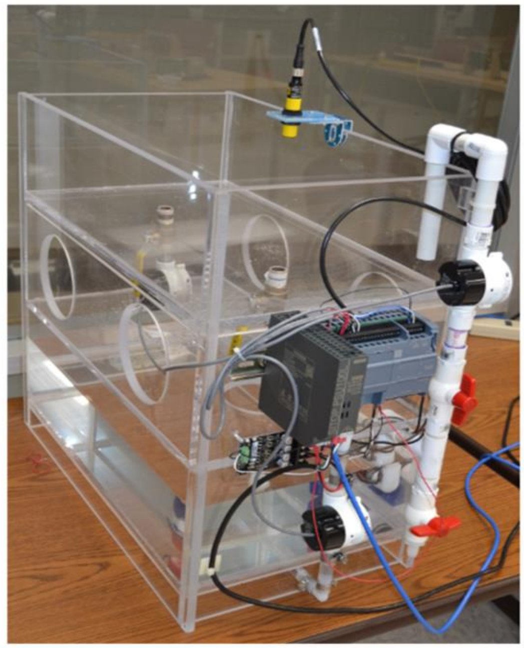

Fig. 3. Tank-over-tank lab.

This experiment was later upgraded to eight units and put in commission in summer 2021 for labs in Auto Control (EET 4450). Earlier PLC groups had begun programming the unit on a limited basis. It has been programmed with a variety of HMI and control programs. This lab has potential for several different types of labs including Simulink programming as well as PID control and loop-in-loop PID control. It can be useful for stability studies although it tends to be a very stable process. The total cost is about $1,500 per station. See Fig. 3 for the tank-over-tank process.

From Capstone to MS Student to Instructor

A lab that began as a capstone lab, then evolving to a MS project, and finally to a desk top project for the instructor was the rewind lab [8]. This lab has a number of different outcomes including PID speed control and position control as well as initialization of programming and general process design strategies. This lab has been a favorite since it has so many moving parts and combines electrical and mechanical challenges.

This lab started as an idea to re-wind toilet paper. It was first attempted by a capstone group. The attempt was a failure for a number of reasons including the flimsy design from the erector-set type skeleton. The later 80/20 material was much stronger and the results more successful. Also, getting away from toilet paper and going to a cloth tape helped. The winder concept with dancer roll tension arm has many applications in industry. Control of the two dc gear motors is accomplished with the pwm output from the same S7-1200 processor with power control board. Feedback is from the motor encoders. The motors use PID control to set a controlled speed. The speed of the windup motor is augmented by the position of the dancer roll. There are three PID control blocks in this lab with many variations on control design. This lab has yet to be built with eight stations. See Fig. 4 below. It costs about $500 to build.

The lab has a subset lab found in Chapter 21 of the “Hybrid Lab Text” [9]. This lab was also a lab studied from various educational vendors prior to implementation with the S7-1200 processor.

The lab below has yet to be built with eight stations.

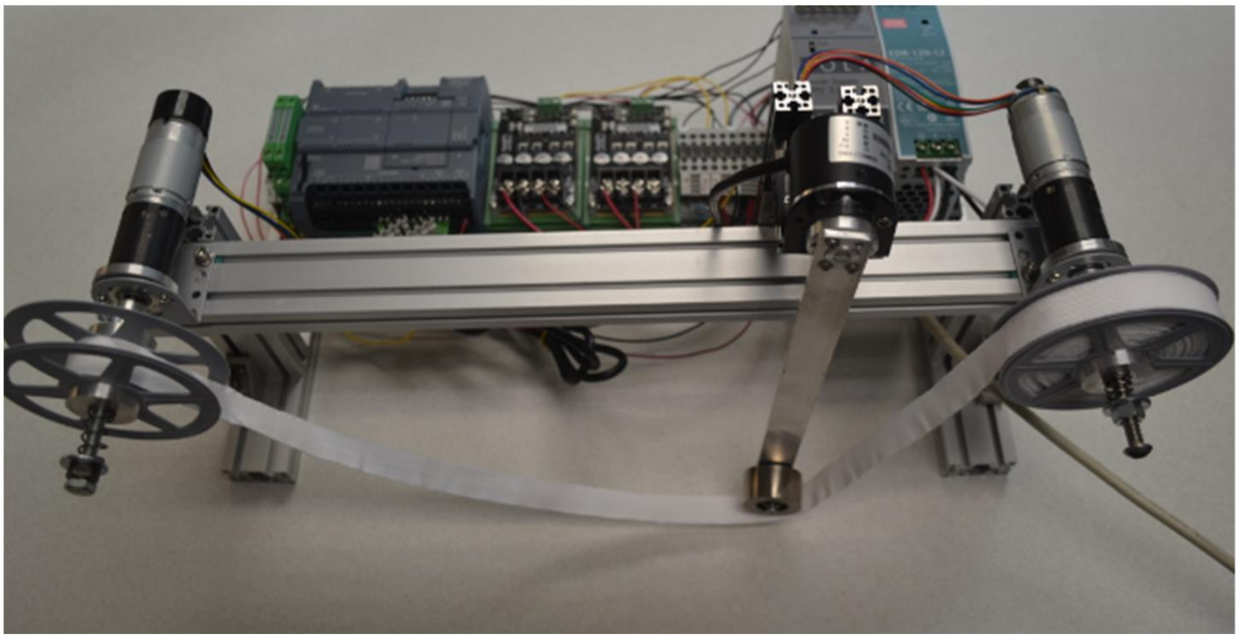

Fig. 4. Tap rewind with dancer lab.

Never To Eight Stations

One of the labs built by a capstone group is the batching system. The learning objective of this lab includes matrix and file manipulation as well as introduction of the UDT (uniform data transfer). The lab also emphasizes analog design of the scale interface. This lab has had great interest but due to its complexity and size, this lab will probably never be expanded to eight units [10]. This lab first introduced the instructor to 80/20 extruded aluminum building material. The lab was constructed by an excellent EET student with very good mechanical and electrical skills. The 80/20 material became the material to use when constructing labs after seeing the advantages of this construction method. While eight units would be bulky and the lab has many complicating factors to overcome, there may be additional systems built but not more than two or three systems total. This batching system is shown in Fig. 5.

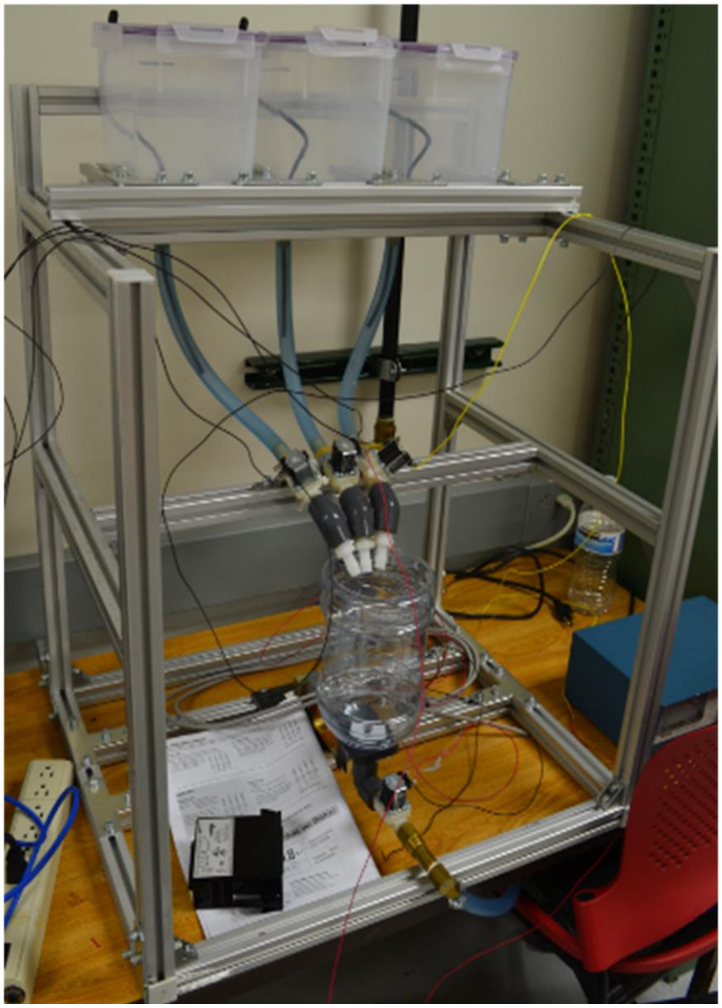

Fig. 5. Liquid batching system.

Fig. 6. Abandoned flow control valve.

Abandoned but Not Forgotten

One lab predated all the other home-grown labs. This lab consisted of a single valve on the wall controlling flow of water through a ¾ inch water pipe. It was the first lab introducing the student to PID control from the PLC. It was used from about academic year 2004 to 2020. The reason for its abandonment was that the water flow would sometimes back up in the drainpipes with the result of flooding in downstairs areas. The flooding in year 2020 was the last. This lab was sadly abandoned after this third major flood over the years from the experiment [11]. A ¾ inch water pipe can supply about 90 gallons of water per minute – a lot of water! This lab is shown above in Fig. 6.

In the Works

There are still plans for future experiments that challenge the student and keep the instructor actively designing new labs. The latest is a Bruder toy conveyor belt. First, the crank was removed and replaced with a gear motor (with encoder feedback). A sensor will be added at the base to sense either color or metal. Then a tracking program was added to track the coin or chip to the top of the conveyor and flip the coin or chip right or left into a waiting cup. The experiment uses sensors for part detection as well as pulse sensor for tracking. It could be used to sort poker chips at a casino. This lab experiment is shown below in Fig. 7.

Fig. 7. Conveyor for chip sorting.

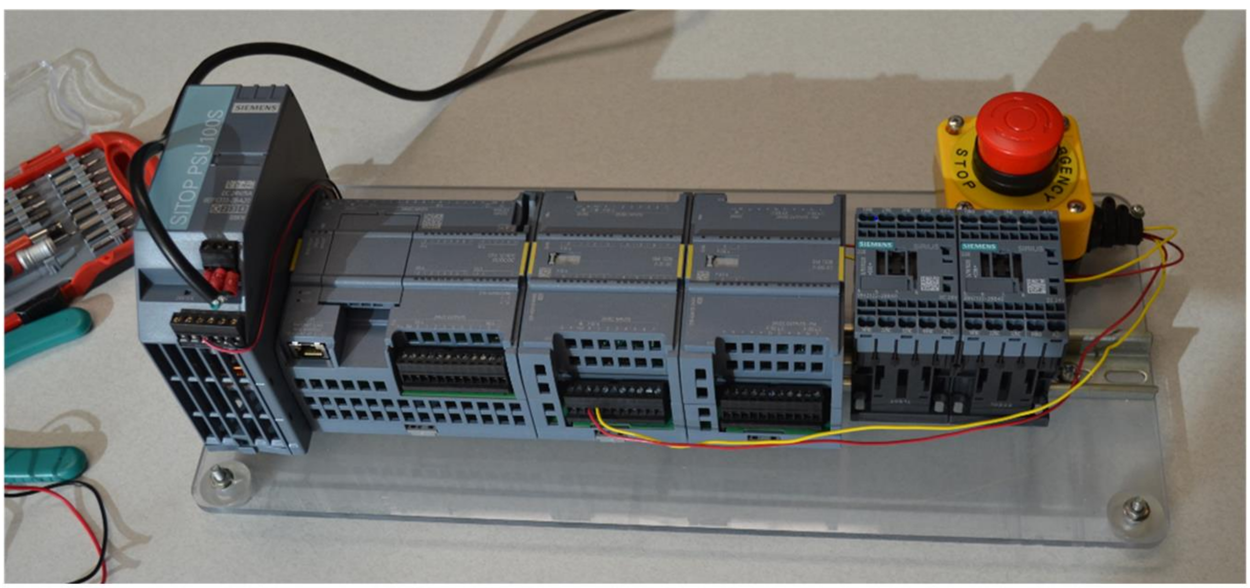

Fig. 8. Safety PLC lab.

Motivation

The biggest question concerning making experiments for use in labs has to do with motivation. Why spend time and energy developing experiments that may never be used while many education vendors already have developed standard experiments? Also, lab experiments need care if they are to be properly maintained. It can be said that this effort has evolved into a joy keeping the instructor aware of changes in the PLC software and hardware as well as finding a challenge for students wishing to excel in the classroom. It is a hobby of sorts. Also, it keeps one sharp in the developments of equipment from the maker industry.

Advanced students are always willing to tackle a difficult project and a capstone or MS project is an excellent place to challenge their creativity. It is a joy seeing the student become motivated to push their limits with projects that are beyond the regular lab experience. If one is motivated to keep current in the area of automation, labs such as these seem to emerge as ideas are bounced around from teacher to student and vice versa. Several students have contributed ideas for labs that have found a place in the present lab rooms. And labs continuously need to be improved, adjusted, tweaked, upgraded. There is always room for improvement and developing the labs in-house tends to push the instructor to add yet another idea to the list of projects to do 'next time'.

Needs

There are several common threads in these labs. First is the Siemens S7-1200 processor. It is very adept at controlling simple systems such as the ones outlined above. The Siemens designers were very good at identifying the market segment that could control a PWM or stepper output or have input from an encoder or other high speed pulse input – without additional hardware or cost. Just $189. That is an outrageously low price and one that is designed to entice the experimenter or student to buy one just to try things out. The price includes software and hardware (and the software has no time limit). It can be flipped and sold on Ebay for more if the student needs the cash! Think Arduino with a powerful HMI and very flexible I/O with a simple programming GUI (graphical user interface). If a PLC has never been tried for control of lab experiences, the observer should look again. The HMI development time alone should convince the developer to look at this type of solution.

Also, a good plastics guy is a must. Fortunately, we have one in Toledo. If interested, his contact information can be shared. He solved many mechanical problems not necessarily associated just with plastic in designing projects for us. They were many [12].

Also a good machining lab is vital. Many of these labs have an instrument mount or other device fabricated by this group on the lab experiments.

Sensor selection was also a consideration. While many times sensors could be found that cost significantly less, the industrial sensors were finally selected simply because they worked at all or continued working past a trial break-in period. The cost of a $200 industrial grade sensor is not a detriment to most lab experiments. The 4-20 mA standard adapts nicely to most analog input card topologies.

Some space on a desk or bench is also a must. Needless to say, these projects were not accomplished overnight. Many sat for days or months quietly until a new thought or insight moved the project forward. Some ideas were thrown out. Most were modified and tried again until success was achieved. Hopefully, these projects and the challenge to invent new, better ones will be taken up by others. It is well worth the effort. The cost of the Siemens PLC today (did I fail to mention) per unit is $189 including software, CPU, and analog and digital I/O.

It is planned to have the Hybrid Lab Text complete the process of describing the plans for building and programming each of the labs listed here. While this goal has not been reached, it is hoped in the next year that each of the labs will have a good bill of material and program listing available on the website, either in the text itself or down the website with the programs given to students. At present, the Siemens' TIA software version 16 is used as well as either the S7-1214 or 1215 DCDCDC model processor.

Other Labs "On the List"

Other lab experiences with purchased equipment and no or little enhancement include communications labs, RFID labs and safety labs. The first good safety lab is shown above in Fig. 8. The learning objective of this lab is to introduce the student to the practical aspects of implementing a safety PLC in a real-life application. This lab will be modified, adjusted, added-to as the students begin to absorb the lab as it now stands. The safety lab in Fig. 8 does not use the same S7-1200 processor as the other labs in the paper and costs significantly more than other labs. It is shown, however, since it was developed using the same criteria of eight lab experiences and has high value as a training tool for students entering industry. It was purchased directly from the Siemens distributor avoiding the mark-up pricing of educational equipment providers.

A new lab was completed this Fall 2021 semester by a graduate student in the EECS course. He used a VEX maker conveyor system and a Cognix camera (and a Siemens S7-1200) to sort good/bad parts on a conveyor. Bad parts were kicked off the conveyor with a solenoid valve. This project may well be found added to the Hybrid Lab Text at the time of the conference.

Future Labs

Yet to be explored are labs in more complex HMI development. Also, labs including robotic interfaces are in the future with the addition of a new Fanuc robotics lab (three robots) as well as UR Universal Robot. Recently the University acquired a complete Festo manufacturing system as well. The Fanuc and Festo equipment complement the work already completed and add high level sophistication. While there are not eight of these systems, they can be useful as demo units as well as special project assignments.

Interaction with the database labs is also being planned. The data derived from some of these labs will provide much good data for analysis and report generation.

Summary

Obviously, all experiments cannot be purchased for $1,500 or $26 (the cost of the newer stepper controller module plus stepper motor). There are lab experiences well worth the price and educators should be willing to purchase them.

The experiments above, however, have grown from a willingness to look at more expensive projects and either emulate them at a low cost or copy a portion of an industrial process using industrial controls but with small footprint. Also remember to try to provide the lab with eight stations. The goal has always been to create excellent lab equipment that works and challenges the student to gain a solid understanding of the control dynamics of the process.

A good plastics person helps tremendously. Also, a processor that costs $189 complete with software is a great find. A good computer, an idea and a little money is all that is needed. And one may learn that eight units can be affordable. If possible, students should not be standing around watching someone else demo the equipment. They should actually be performing the experiment in small groups of two or three and be responsible for their own data or writing code to control a process.

The sharing of labs may also be useful to someone outside academia wishing to begin a career in automation. The text ("Hybrid Text") and labs ("Hybrid Lab Text") are available to the public and can be self-taught. It is hoped that potential students seeing these labs will be inspired to join EET and make automation part of their career plans.

A note about the title "Hybrid Text": it was given this name due to the decision to provide a text that would discuss the Siemens PLC but not walk away from the US manufacturer, Allen-Bradley. A hybrid is usually stronger than either of the primary ingredients and it was thought that studying both of these PLC manufacturers together would be stronger than featuring exclusively. This has been achieved. The texts, labs and equipment are all stronger as a result of this decision. Students are likewise better prepared studying both PLC manufacturers as well as the processes in these labs.

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Biography

WM. TED EVANS is a professor of Engineering Technology at the University of Toledo. His educational background includes a BSEE in 1971 and MSEE in 1975. He received the PhD in Industrial Engineering in May 2005. Mr. Evans was also a practicing controls electrical engineer in industry for 15 years.