Session 2068

Instrumentation and Control of an Ecological Life Support System in a Laboratory Project

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1. Project Laboratories

The laboratory structure in the Department of Electrical and Computer Engineering (ECE) at Texas Tech University is somewhat different than most university laboratories.[1-10] There are 5, three hour credit required laboratory classes. Although all of the laboratories have pre-requisites, they are not associated with any one class. In all of the ECE labs, the students are provided with a basic statement of the project objective and the names of the other members of the team. The student teams each have a project advisor, separate from the lab instructor and teaching assistant associated with each lab.

The faculty advisor for the project is the customer and, as such, is a technical evaluator for the project. The ECE labs operate in a matrix style of management. The lab instructor is the primary supervisor and project director. The ECE undergraduate lab director's staff (Teaching Assistants) act as resource and quality control managers. Normally at least two members of the management team attend the lab sessions.

In cooperation with the faculty advisor, the lab instructor and the teaching assistant and within one week after receiving the project, the project team must develop a detailed project plan. Although all projects and project plans are dynamic, it is imperative that a detailed plan is developed initially and continually examined to properly execute the project within time and budget constraints.

Most of the projects in the EE labs are team projects. Although each team member is assigned specific actions by the team, all team members are equally responsible for successful completion of the project. Team members are measured for their contribution to the team by their advisor, lab instructor, lab director's staff and the team itself.

2. Laboratory Project Requirements

For all projects each student gives periodic (weekly or bi-weekly) oral progress reports. These oral reports are presented by the project group or team with each student reporting on the portion of the project for which they are responsible. Oral progress reports must include:

- restatement of the tasks that were to be completed for the week and indicate the status of each individual member's weekly tasks,

- technical details on the project and verification of the tasks' completion (diagrams, flow charts, schematics, design decisions, parts selection, etc.),
- updated project schedule with changes indicated,
- tasks to be completed for the upcoming week,
- identification of problems,
- updated budget with changes indicated (put in actual hours work),
- indication that project advisor has approved the progress report.

All oral presentations must be well organized and include visual aids. Each member of the project team is required to speak during each oral presentation. These presentations must be organized so that each student has approximately the same amount of presentation time. These presentations are mini-design reviews and must contain enough technical information for the other students, the lab instructor and the lab assistant to fully understand the direction of the project. The presenter must be prepared to answer any questions concerning the project. Although each team member will have specific deliverables, ALL team members are equally responsible for successful completion of the project and ALL team members should be prepared to answer questions on the whole project.

The oral presentations provide a focal point for the project and the project team. Each individual team member is measured on his/her ability to meet the designated deliverables, to clearly present information on the project, to demonstrate an understanding of the technical aspects of the project and to work effectively with their team. The first three items are measured by the lab instructor, the lab assistant and the other students in the class (excluding the team members). The last item is measured by the team members themselves.

Each individual's oral presentation style and effectiveness is evaluated and the results are available to the student before the next week's class so that improvements can be made. Some of the presentations are video taped. Each student is asked to evaluate his/her own presentations and develop plans, with the lab instructor and staff, for improvement. The written plans are used later in the semester to assess improvement.

Approximately half way through the course, interim project reviews with individual project groups are held in lieu of oral progress reports. These interim project reviews consist of an in–depth presentation on the project by the group with interactive critique from course instructors, faculty advisors and other invited guests. Interim project reviews include both written and oral presentations. For the interim project review students must be prepared to defend their concepts and approach. The written interim project review serves as a major portion of the final project report. All reports are graded and returned for corrections to be made on the final report.

Each project team must demonstrate their completed project to their faculty advisor and their lab instructor. Each project team must keep a project notebook. This notebook must be up-loaded to the designated ECE lab web site. All project related written work and reference material should be kept in this notebook as far as practical.

Each student is required to make a final, formal oral presentation on each lab project to the other lab students, the lab instructor, TA, faculty advisor and other invited guests. A formal technical paper by each student is required at the completion of each laboratory class. Copies of all final presentations, final reports and notebooks are kept for future reference.

3. Projects

The projects in laboratory are large open-ended projects that usually last the entire semester or for the senior labs may last both semesters. All projects in the first 3 labs are team projects with an average of 3 members per team. In the senior labs the projects go from single member teams to over 6 member teams, depending on the project. To provide projects that last a single semester is not always easy or desirable. On-going projects that may last several semesters are frequently more meaningful and realistic. This also helps to integrate research projects into the laboratory. A sample of some of the projects offered during one semester of the senior lab is listed below. As is evident from even the brief title of the projects, many of these projects can be long term projects that may not be completed in one or two semesters. This paper describes one of these continuing projects as an example.

- Restaurant identifier
- GPS Mapping
- Chaos demonstration
- Acoustic Vision
- Clean Combustion Engine running on H_2 and O_2 plus H_2O
- Truck backing up along a line
- Snake Robot
- Sub-Nanosecond Breakdown Phenomena
- Hybrid electric HMMWV
- Hybrid electric hydrogen fueled Future Truck
- NASA plant management control system
- Jitter Measurement
- Class D Audio Amplifier Measurements
- CAN Transceiver E&M radiation
- Wavelet Based Analysis of EEG
- Phase Active Micromirrors
- Molecular Beam Epitaxy
- Design of a Class D Amplifier
- Rail Gun
- Motorcycle Tracking

4. NASA plant management control system

A number of years ago, NASA developed a Controlled Ecological Life Support System Engineering Development Unit (EDU). The EDU was designed to simulate a life-supporting environment away from the Earth. This involves growing plants in isolation outside of the earth's atmosphere and attempting to re-create the ecological processes that naturally occur on earth supporting the life of humans and plants. To accomplish this, the EDU contains about ninety sensors and actuators controlled by external software that monitors the environment contained within the sealed EDU. The software monitors and controls the nutrients, ph, and conductivity of the nutrient solution that feeds the plants, as well as the relative humidity, light-exposure, temperature, and levels of oxygen and carbon dioxide in the air inside the EDU. The sensors and actuators inside the unit are controlled by a series of Data Acquisition boards which transmit the sensory data serially through an RS232 link to a PC external of the EDU. Figure 1 shows the actual EDU.

The EDU was developed as a prototype in the 1990s. As part of a NASA contract, the College of Engineering at Texas Tech University has been maintaining and updating the EDU for use in plant research since the summer of 2000. Part of this task has been accomplished as senior laboratory projects in the Department of Electrical and Computer Engineering with support from the Mechanical Engineering and Industrial Engineering Departments. This paper presents the details of this complex, long term project involving many instrumentation and control systems with many students over a number of semesters. One of the main points of this paper is to show that long term, complex projects can become part of an undergraduate laboratory experience using a continuing project concept.

Figure 1. CELSS EDU Open and Closed

Figure 2 shows the alarm monitoring signals for the EDU, but also provides an overview of the whole system. The light bank is in the very top of the unit. The plants grow in the top half below the light bank. The nutrient tray is in the top of the lower half. The different tabs indicated in Figure 2 refer to the different monitoring and control systems in the EDU, which include controls for nutrients, lighting, oxygen scrubbing, pressure/CO_2 , condensate, relative humidity/temperature, and lower temperature loop/medium temperature loop (LTL/MTL). A more detailed description of the system is given in the appendix to show the level of the complexity of the system.

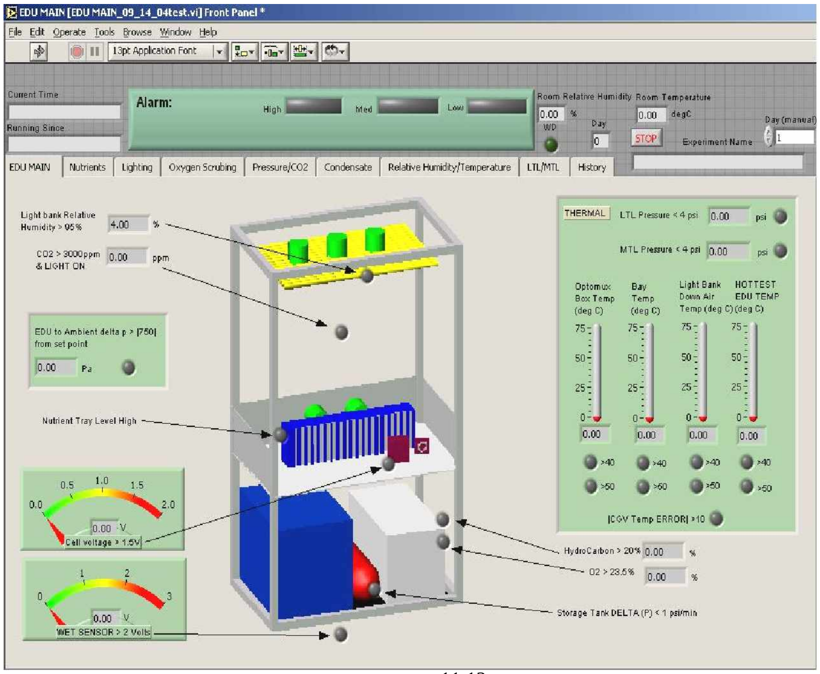

Figure 2: EDU Alarm Monitoring[11,12]

5. Continuing EDU Laboratory Project

The CELSS EDU monitors and controls all aspects of plant development, including light, temperature, water, Ph content, nutrients, air content (CO_2, O_2) and pressure. The power requirements for the system are a 120V at 100 Amps (Lights, Power Supplies, HVAC Blowers) and 208V at 30 Amps (Two Chillers). The system was received in May 2000. The first ECE laboratory project was to reassemble the system and evaluate it. [13] This required rewiring a room to accommodate the power requirements.

The CELSS EDU system was found to have a total of 54 analog inputs, 14 analog outputs and 17 digitally controlled relays. For I/O communications between the PC and the EDU, NASA choose to use Optomux Data Acquisition System's Opto22s. Each Optomux I/O unit consists of a removable brain board and an I/O mounting rack. The removable brain board contains a microprocessor that communicates with the host computer and controls the plug-in I/O modules. The Optomux system communicates with the host computer over an RS-485 serial communications link. The PC software package was based on DOS 6.0. Although the system was able to power up to some degree the software was not able to run. [13] It was decided to replace the software with National Instruments' (NI) Labview. Also, at this time, the EDU was relocated to a greenhouse complex with the move completed in January 2001.

In the spring of 2001 an ECE lab project to upgrade the control system began.[14] An RS 232/485 adaptor was modified for use in the system. An old NI driver was also modified for use. The legacy software was large and complex with 98 different viewable screens 20 of which were for user input and monitoring. Since there was no theory of operation for the system, the legacy software had to be mimicked to a large degree. Still every effort was made to group the Labview blocks by the function performed. By the end of the project the basic code was complete. However, numerous hardware problems continued throughout the project with many actuators, sensors wires and gaskets failing.[14]

During the summer of 2001, the Labview software was completed. The screen shots in the previous section of this paper are from the current Labview program. In the fall of 2001, an ECE lab project was to implement an alarm notification system, develop a web link to the system and make necessary hardware/software modifications. The EDU system has a number of different priority alarms. Since the system is made to run continuously, it is necessary to warn users of possible problems in the growing cycle due to shut downs of the system. Thus, an alarm notification system was put into place that would automatically dial a pager and leave a numeric page in the case of a high alarm.

A number of hardware problems continued to occur on the system. One new problem involved a watch dog timer. The hardware timer requires the PC to send it a signal periodically or it will shut down the whole system. The original timer was fixed at ½ second and was continually shutting down the system. The timer was replaced by an adjustable timer of 2 to 8 seconds, which seemed to solve the problem. Some progress was made on the web interface, but there was no web connection in the greenhouse at that time.[15]

In the spring through the summer of 2002, projects on the EDU continued to stress the troubleshooting of the hardware and upgrading of the software. One of the problems in troubleshooting the legacy hardware was the lack of a complete service manual. The previous service manual was written in terms of the legacy software and was no longer applicable. It was decided that a new service manual could greatly assist the troubleshooting effort and was made part of the project objectives. The manual was completed and posted on the web for easy access. The web interface was completed except for the web link into the greenhouse.[16]

The EDU was basically operational at this point and continued maintenance was taken over by a staff member that could dedicate more time to the repair of the system when needed. A successful plant experiment started on December 17, 2002 and ended January 31, 2003, lasting 42 days. Although the experiment terminated upon a cooling loop failure, the EDU exceeded the documented 30 day operational limit and yielded useful data. Another successful experiment ran 60 days from March 6, 2003 through May 6, 2003. The experiment was run to completion without being terminated by failures. The EDU did experience minor issues, but manual intervention preserved the integrity of the experiment and prolonged the run.[17]

A number of failures continued to occur from time to time. The most serious failure was a unique mechanical vane that had apparently been manufactured for the EDU. A portion of the vane had to be machined, which caused a substantial delay. From the beginning of the project the computer used was periodically upgraded along with the operating system and the Labview software. Once the vane was repaired and replaced, the watch dog timer problem reappeared. Our staff member also left and was replaced by another staff member with no prior experience with the system.

In the fall of 2003 we assigned another project to evaluate the software for the system to determine if that was the issue with the watch dog timer. The student found that since the Labview program had been written following the structure of the legacy software it was difficult to read and understand. In addition it was very inefficient.[18] The student began the task of rewriting the software in a more structured form while improving its efficiency. This project has continued through the spring of 2004.

By the fall of 2004 the software was basically rewritten, but the watch dog timer problem remained. Another laboratory group was assigned the project of further evaluating the software to determine the problem and develop a solution.[11,12] The following are excerpts from a final report on the project.

> "To improve the structure and flow of the LabVIEW software, all inputs, outputs and VIs were prioritized into three main categories – low, medium and high. The variables, such as pressures and nutrient injections, that change quickly were placed in a high priority. Items such as humidity and temperature were considered as low priority due to slow changes. Since the current system was doing everything as quickly as possible, categorizing the information to be processed at one time should allow the system to be slowed down. The categories selected are:
>
> High:
> - Nutrients: Acid Controller, Base Controller, and Conductivity Controller
> - O2 Scrubbing: O2 Scrub High
> - Pressure/CO2: Pressure 1 and Pressure 2
> - Relative Humidity/Temperature: Vane Controller
>
> Medium:
> - LTL/MTL: CGV Blower PID
> - Nutrients: NDS Pump and Nutrients
> - Pressure/CO2: CO2 Controller and Tank Alarm
>
> Low:
> - Condensate Recovery: Condensate Recovery 1 & 2 and Drain Rate
> - Lighting: Lights
> - LTL/MTL: Pump 1, Pump2, and Pump 3/Light Bank
> - Pressure/CO2: CO2 Average and CO2 Flow
> - Relative Humidity/Temperature: Relative Humidity
>
> Next, timers were added to the high, medium, and low priority subsystems to slow down the processing of data. The timers were set at different times depending on the priority. The timer in the high priority loop was set at 1 second. The medium and low priority loops had 5 and 10 second timers. After testing, the CPU usage was still at 100%.
>
> Debugging was performed on the modified software to determine what further adjustment was needed to improve the performance of the program. The debugging tool allows users to evaluate and troubleshoot by being able to watch the execution take place. Since the three timers did not help lower the CPU usage, each loop was debugged to locate the problem. It was determined that the VI worked correctly but some required input values from the EDU in order to function properly.
>
> So to solve this problem, it was decided that timers should be added in every individual loop. After timers were added, the modified program was tested. The CPU usage percentage dropped from 100% to almost 0%.
>
> Every VI was added with a timer and tested to see the CPU usage that each VI loop produced. Table '1' shows the result of our testing.

Low Priority: Time = 10secs				
	VI Controllers	**EDU**	**CPU % W/O Timers**	**CPU % W/Timers**
Lighting:	Lights		100%	2%
Condensate Recovery:	Drain Rate		2%	2%
	Condensate Recovery	✓	100%	1%
	Condensate Recovery2	✓	100%	1%
Relative Humidity:	Relative Humidity		100%	2%
O2 Scrubbing:	O2 Average	✓	100%	1%
LTL/MTL:	Pump1		100%	2%
	Pump2		100%	2%
	Pump3/LightBank Blower		100%	2%
	Solenoid Valves		100%	2%
Medium Priority: Time = 5secs				
Nutrients:	Nutrients	✓	100%	1 - 3%
	NDS Pump		100%	2%
Pressure/CO2:	CO2 Controller	✓	100%	0 - 3%
	CO2 Flow		2%	2%
	Tank Pressure Alarm		2%	2%
High Priority: Time = 1sec				
O2 Scrubbing:	O2 Scrub	✓	100%	3 - 4%
Relative Humidity:	Vane Controller	✓	100%	1 - 4%
Pressure/CO2:	Pressure1	✓	100%	4%
	Pressure2		100%	2%
Nutrients:	Acid Controller	✓	100%	1 - 2%
	Conductivity	✓	100%	1 - 2%
	Base Controller	✓	100%	1 - 2%
Entire System Running				**14 - 57%**

Table 1: System Results with Timers[1]

After every VI loop was added with timers and tested, the entire program was tested to see if improvements were made. The CPU usage dropped drastically from 100% to 14-57%. Every ten seconds the CPU usage will spike but that is nothing to be concern about because it is the result of the timer settings of the high, medium, and low at 1, 5, and 10 seconds. Figure '3' shows the CPU usage when the entire system ran with the new modifications.

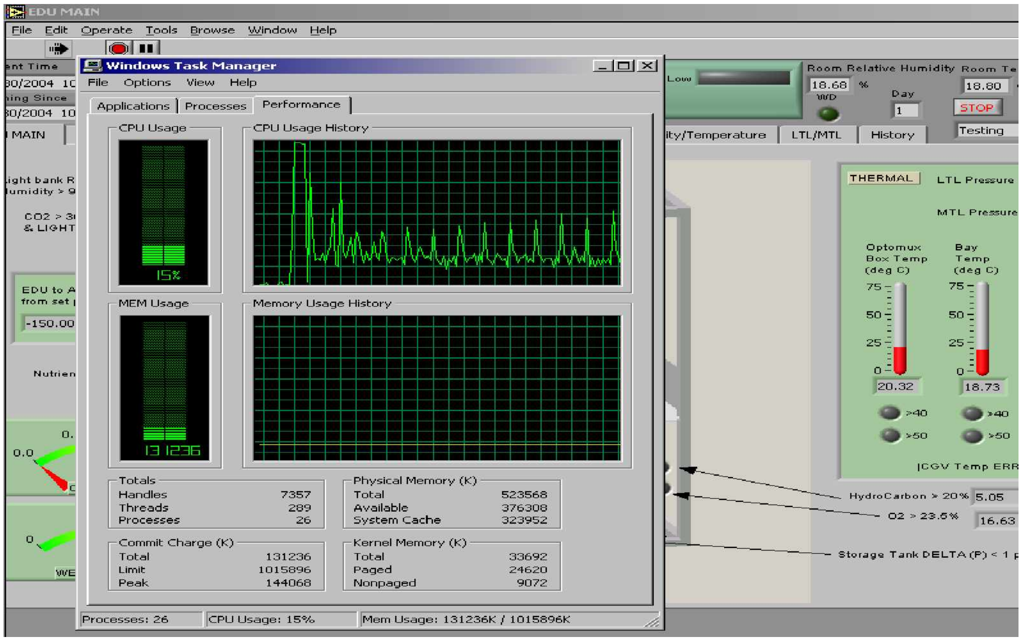

Figure 3: CPU Usage with Final Modifications

The NASA Engineering Development Unit (EDU) was designed to simulate and study life supporting environment outside of Earth. The simulation includes the study of the effects of high level percentage of carbon dioxide on green onions grown in the EDU. Conditions such as temperature, nutrients, CO_2/O_2 levels, relative humidity, and light conditions, in the EDU chamber are monitored and evaluated to see the reactions that the plants display due to these conditions. In order for this to be possible, the current software needed to be modified. Tabs and VIs in the current software have being analyzed. Understanding the flow and structure of the software helped modifications possible by organizing the program and its priorities. Creating the three different alarm priorities helped organize the program. Then by adding timers to each VI loop helped slow the process of the program down allowing the CPU usage to drop from 100% to an efficient 14-57%. The EDU system is currently at run and appears to be running strong." [1]

6. Conclusion

The EDU project is a large, complex project that has been on-going for 5 years. Equipment failures, lack of documentation, vendor issues, measurement issues and construction problems must be addressed by the project teams. This provides a more realistic environment than in a fixed laboratory structure. Some of the project teams made substantial progress on the project while other teams struggled. The teams are graded on many factors through out semester including oral and written presentations. They are also graded on the progress made on the project in moving it toward completion.

Results from these types of projects and discussions with the students indicate that large complex projects are possible in an undergraduate laboratory environment. Large complex projects are more realistic and the students enjoy working on projects they see a reason for doing. It is difficult to develop realistic projects that must be completed in a very short time period for a normal laboratory project, even a semester long project. The project described here is only one of many that we have used and are continually using. We feel that it is an exciting and useful way to improve the laboratory experience.

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Micheal E. Parten

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Appendix

The overview shown in Figure 2 indicates a number of monitoring and control sub-systems. These systems are briefly described in this appendix.

The nutrients screen in Figure 4 shows the control and monitoring of the ph of water, conductivity of the nutrient, and the circulation pump that pumps the nutrient into the nutrient tray. Although the normal operation is automatic the system can be operated manually. The ph section allows the user to set a ph point. When the system is in automatic mode, the system will maintain the desired ph. The screen displays the total acid and base dispensed in ml as well as the total number of injections. The conductivity screen shows monitoring and control similar to the ph screen. The conductivity set point injects the correct amount of hydrosol and calcium nitrate into the nutrient reservoir in order to maintain the desired set point. The circulation pump circulates water and nutrient solution in the tray under the plants. A sensor is used to shut the pump off once the tray fills. The level of the nutrient tray tank reservoir is also shown. The automatic controls use individual PID loops.

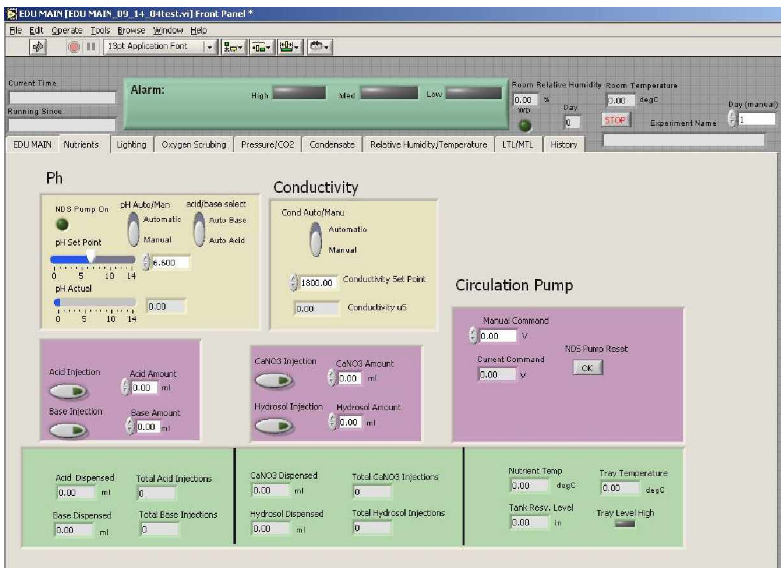

Figure 4: Nutrients Screen[11,12]

Figure 5 shows the monitoring and control of the light level inside the system. There are five different sets of three lights that can be turned on to simulate varying times of day. The user can specify at what time and for how long each light is activated. The light band humidity displays the humidity near the lights. The light level and light band humidity are also displayed for user monitoring.

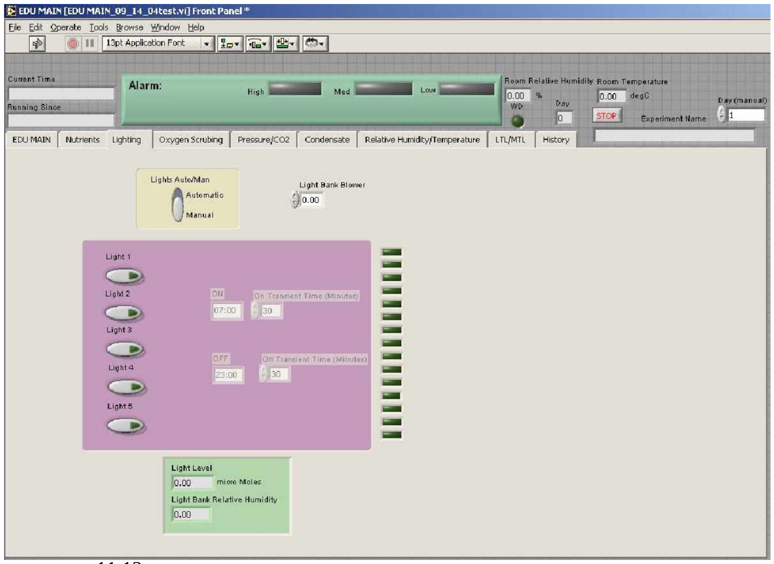

Figure 5: Lighting Screen[11,12]

Figure 6 shows the monitoring and control of the oxygen scrubbing system. This system monitors and regulates the percentage of oxygen in the air inside the EDU. The user initializes the desired CO_2 and O_2 concentration for the chamber. Once the oxygen set point is made, the system will try to maintain it at the level. Naturally plants produce O_2, so the oxygen scrubber uses de-ionized water to extract extra oxygen from the air of the chamber in order to control the carbon dioxide to oxygen ratio. PID controllers are used to maintain the levels.

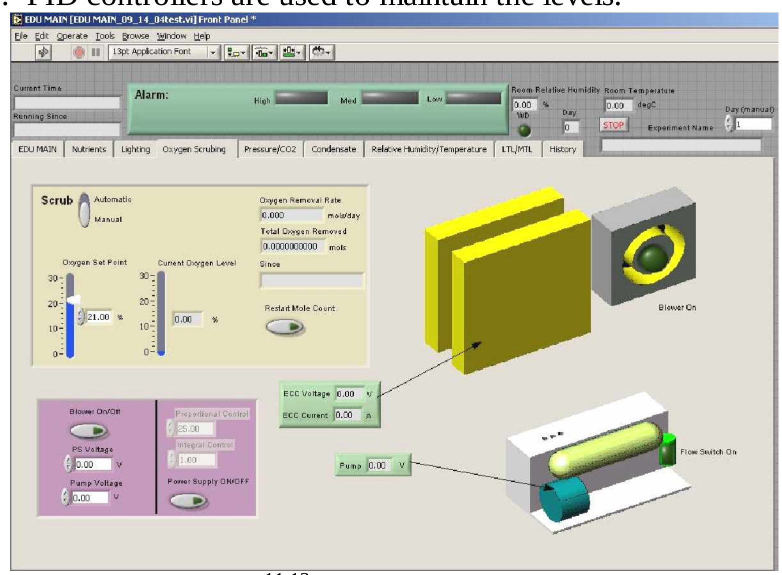

Figure 6: Oxygen Scrubbing Screen[11,12]

Figure 7 shows the monitoring and control of the pressure/carbon dioxide system. Initially, a tank external to the EDU is pressurized to 27psi. When the EDU is closed and sealed, a compressor pressurizes the EDU to 27psi. The carbon dioxide level can be set at a desired concentration and the system uses proportional and integral gain to maintain this set point.

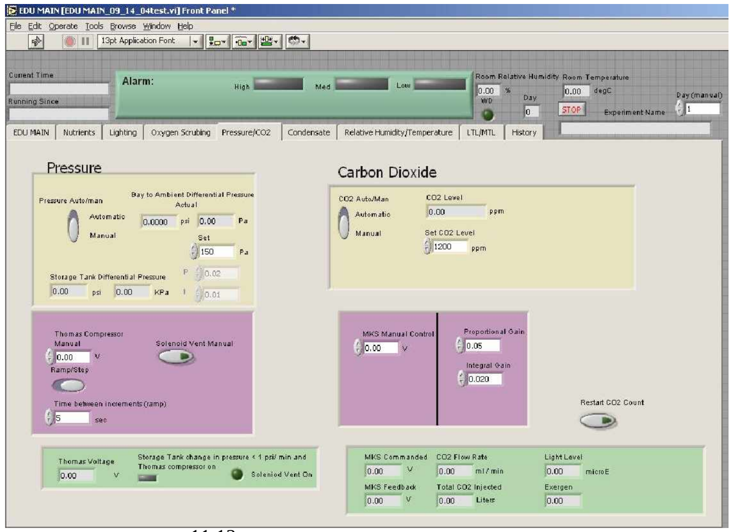

Figure 7: Pressure/Carbon Dioxide[11,12]

The temperature and humidity are controlled and monitored through a number of different systems. The low temperature loop (LTL) cools the system consisting of the central gross volume (CGV), where the plants are grown, and the equipment bay, as shown in Figure 8. An external chiller provides coolant to heat exchanger 1. The CGV and equipment bay can be connected in series or parallel by appropriate solenoid and pump settings. The temperature and relative humidity at different locations around the LTL loop are monitored while controlling the temperature.

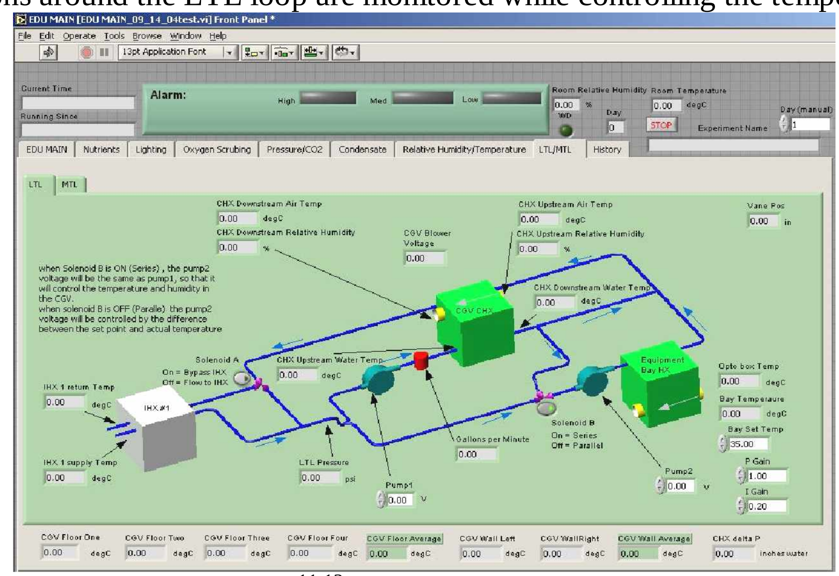

Figure 8: LTL Screen[11,12]

The medium temperature loop (MTL), shown in Figure 9, cools the light bank and the power supply used for the lights in the system. Another external chiller is used to supply coolant to heat exchanger 2. Aside from the control of the temperature in this loop, the screen also shows other temperatures and relative humidity.

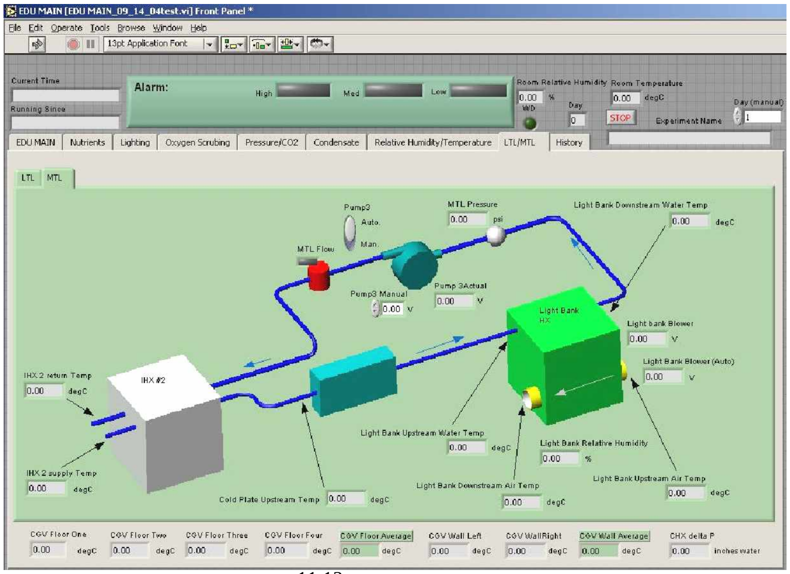

Figure 9: MTL Screen[11,12]

Figure 10 shows the monitoring and control of the condensate inside the EDU, which is related to the humidity. The level of water inside the standpipe is monitored by two sensors. When the water is low, the heat exchanger is activated. This causes the heat exchanger to dehumidify the air in the chamber and fill the standpipe. When the water is high, the water in the standpipe is automatically pumped into the nutrient reservoir. The condensate system monitors the nutrient reservoir and oxygen reservoir levels. If the nutrient reservoir is low, the drain pump turns on and empties the water from standpipe into the nutrient reservoir. When the oxygen scrubbing reservoir is low, the solenoid and drain pump activated to flow water from the standpipe into the oxygen scrubbing reservoir. The condensate system monitors and displays the level of water in the standpipe and contained water while also displaying the volume that has been drained from the standpipe.

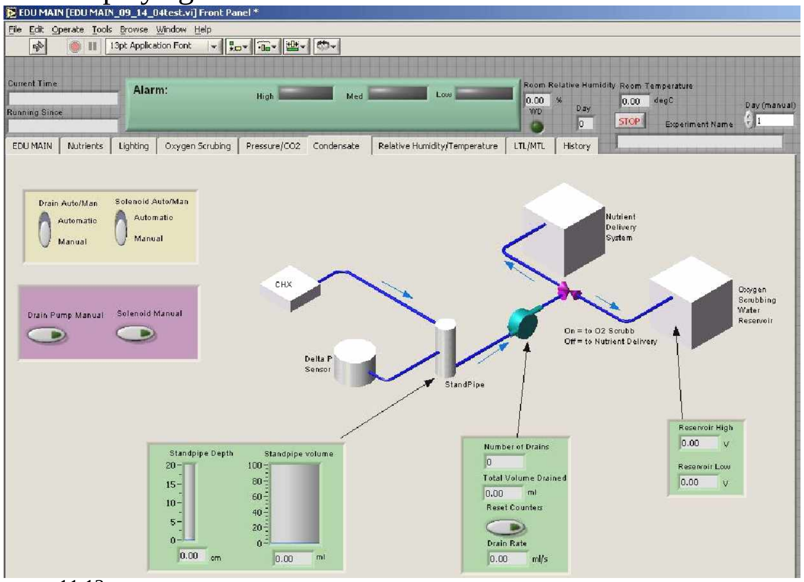

Figure 10: Condensate[11,12]

The relative humidity can be set to different levels at day and night. Water is injected into the

EDU to raise the humidity. The relative humidity system also keeps track of the amount of water that is injected from the internal storage tank. An air vane, located under the nutrient tray, is used to alter the air flow in the growth chamber. When the vane position is set on automatic, the flap will adjust according to the desired temperature.

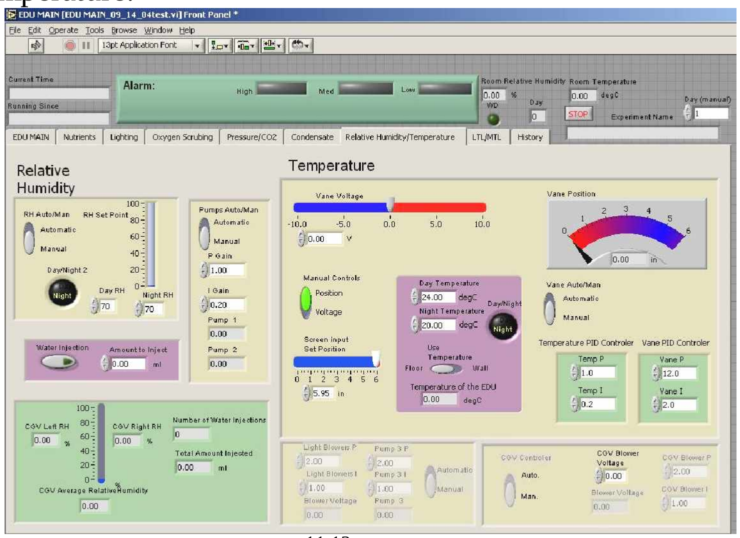

Figure 11: Relative Humidity/Temperature[11,12]