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Prototype Design of a Solar Greenhouse Incorporating Clean Energy Manufacturing Concept

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Abstract

This paper discusses an educational effort that incorporates green energy manufacturing concepts for the prototype design of a solar greenhouse in a senior design project. The goal of the senior design project was to provide the design of a greenhouse module integrated with renewable energy as an initial stepping stone for the future construction of manufacturing plants in industry. The renewable energy integrator component in the project seeks to explore the technology of renewable and eco-friendly sources of electricity on a large scale. In addition to researching the subject, a prototype of greenhouse has been built for future students to learn green energy manufacturing as part of engineering and technology programs. Through this project, students learned how to provide a green design method for evaluating the characteristics of clean energy manufacturing. The students incorporated real-world experience with innovative design with the reduction of energy waste and use of renewable energy, as well as incorporating green manufacturing. For the sake of comparisons for green energy manufacturing, experiments were conducted, including sensor monitoring and process control. A concluding section discusses the student learning experiences during this project.

Introduction

The field of renewable energy technologies has changed dramatically over the last two decades due to significant progress and advancement in wind turbines, power electronics, controls, solar energy, photovoltaics and fuel cell technologies, instrumentation and electric machines. People at all levels must be educated regarding the need for new energy technologies, the uses for these technologies, and their role in the energy solutions of the future manufacturing. In addition, it is imperative to create a highly educated workforce who can contribute to overcoming energy challenges in manufacturing. One method of supporting workforce development in future energy solutions is to incorporate new and emerging technology directly into required undergraduate coursework. Engineering and technology educators must develop new curriculum solutions in advanced energy technologies to fill the gaps in existing coursework and prepare the next generation of students to support renewable energy, energy efficiency and sustainability[1-2]. Moreover, according to a survey of U.S. electric utilities, the Center for Energy Workforce Development, the power and energy industry is already beginning to experience a shortage in engineers and skilled workers, which will become more severe in the next ten years, when roughly one-half of the workforce will retire. There are also rapidly growing demands for training engineers and technicians in these areas, through courses and training sessions[3-4].

Sustainable green manufacturing encompasses the concept of combining technical issues of design and manufacturing, energy conservation, pollution prevention, health and safety of communities and consumers. Many industries are directing their resources to reduce the environmental impact of their produced products and services. To remain competitive in the global economy, these industries need to train engineering and technology professionals to understand the impact of their decisions on the environment and society. It is important for universities to prepare these future engineering technologists to meet this need. Many technology programs do not offer this type of information to their undergraduate students. However, the Accreditation Board for Engineering and Technology (ABET) requires that graduates be able "to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."[5-8]

The topic of sustainability has become ubiquitous. It is part of corporate strategy, consumer choice processes, university initiatives, engineering, and technology programs within the business discipline. This moves toward more sustainable business practices and education is a direct result of an increasing awareness of the significant green manufacturing covers a broad spectrum of manufacturing, from development of green technology products, implementation of advanced manufacturing and production technologies, and introduction of energy efficient and environmentally friendly manufacturing processes and systems, from the plant floor to the enterprise level, and the whole supply chain. Here, we interpret green energy manufacturing as follows: 1. Manufacturing of green technology products, in particular, those used in renewable energy systems and clean technology equipment; 2. Manufacturing process and system control to address energy and environmental concerns, such as reducing pollution and waste, reducing emissions, minimizing natural resource and energy usage, recycling and reusing what was considered as waste before, etc., and 3. Changing the education to include sustainability, green manufacturing, and efficient design into the engineering and engineering technology curricula[9-13].

The purpose of this paper is to describe a capstone senior design project involved in the clean energy manufacturing[14]. The experience to introduce the use of renewable energy and the construction of a green factory in the project is discussed. Our senior design project course is a 3-term core course sequence usually taken by the students during their terminal year in the Engineering Technology program at Drexel University. The design involves an educational effort that incorporates clean energy in the senior design project. During the past several years, our senior design capstone course teams have designed case studies such as wind energy turbines, fuel cell controllers, solar cell maximum power tracking controllers, and other similar projects. The paper also explores the students' motivation for undertaking an interdisciplinary project and looks at how they were able to remain motivated. Initial results show that students' motivation remained high as long as the project remained challenging. In addition, the interdisciplinary subject matter, laboratory techniques, and interactions between students, faculty, and sponsors all played a role in the project success. Finally, the paper explores how participation in these interdisciplinary projects influenced students in their subsequent career choices.

Background and Problem Statement

The objective of the project was to develop an off-grid energy production and consumption, using renewable energy technology as the source. Analysis is the first step in solving any problem. Fortunately, ample research and investigation have already been translated into easily-accessible material, ripe for the picking. With the information on hand, and the financiers behind, system design and construction could be resolved. The project was in collaboration with Strizki Systems - Renewable Energy International in New Jersey[15]. The company is a leading worldwide consultant and engineer of distributed energy generation, storage, and point-of-use solutions using renewable, clean, and carbon-free technologies. Strizki Systems combines existing, proven technologies with innovative designs and proprietary controls to provide its customers with integrated, turnkey systems. Site-specific considerations and the customer's needs determine which technologies are employed. Strizki Systems also works closely with major component manufacturers, providing them with valuable field data and engineering experience to assist them in their product development.

Design Process

The goals of the senior design project were to build a prototype green factory and to develop an automated system specifically for controlling energy flow. The initial design involved green energy manufacturing to incorporate the following requirements: 1. Introduction of renewable energy, 2. Construction of a green factory, 3. Implementation of hardware and software for applications, and 4. Automation of the green factory system. The team received the references of Strizki Systems as feedback, and tweaked their ideas to include those references. To address these challenges, the team decided that the best solution would be to have the following system configuration with computer-aided design green factory as shown in Figure 1.

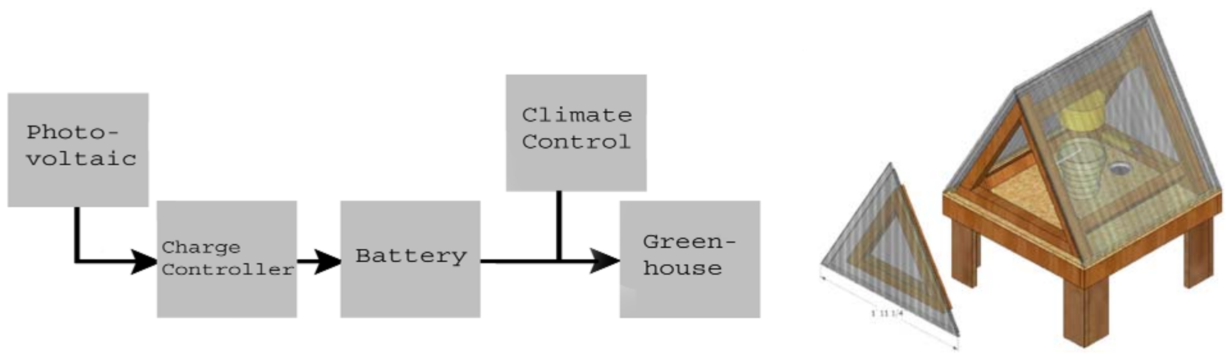

Figure 1: Block diagram of the system configuration of the green factory

These are the solar panels that capture energy from sunlight. The photons in sunlight knock electrons in the solar panel out their orbits, and when connected as part of a closed loop, the electrons flow; the base definition of an electric current. Each 225-W panel used in the system is rated for 30 V at 7.7 A, and has a 21% power density). All efforts go toward keeping the battery charged; it is the nucleus of the entire system. The batteries in the bank are connected in parallel to maximize the lifetime of a charge as well as keep the voltage at a minimum. Rated at 32 A-hours each, the parallel configuration yields an equivalent battery of 128 A-hours. A rough estimate of current drawn by the loads together (6 A) translates into a 21-hour and 20 minute projected battery lifetime. The absorbed glass mat (AGM) batteries are a product of MK Battery.

The C40 model charge controller, a product of Xantrex, accepts input voltages up to 125 V DC. No rating was found for the maximum current input, so the law of conservation of energy was utilized to find the answer. Multiplying the 40-A nominal current output and the 48-V maximum voltage output, the product is 1.92 kW. Dividing the output power by the maximum input voltage of 125 V DC, the quotient is 15.36 A. This is assuming a 100 percent conversion efficiency. Working backwards, conversion efficiencies lower than 100 percent will yield an even higher input maximum. The climate control system is in place to maintain the greenhouse interior conditions. Four in particular are managed by an Arduino microcontroller: heating, cooling, irrigation, and sunlight augmentation. Conditional logic is used to control the actuators.

The greenhouse system is the terminus of the power in the system. Maintaining constant conditions within its confines represents the demand of a full-scale industrial application. Moreover, the variation in power demand corresponding to changes in weather mandate that the power supply system be suited for other than steady-state conditions. In contrast to a mammoth manufacturing plant which it represents, the greenhouse itself occupies only four square feet of real estate (2' x 2'). The small size makes it easily transportable, which came in especially handy after the decision was made to relocate the system. Moving a greenhouse with a 16-square foot base would have necessitated special travel arrangements. The triangular cross section of the greenhouse has two main benefits: a slanted roof resists snow accumulation, and there is less surface area than a traditional Quonset-style (semicircular) structure to lose heat.

Modular Design

To further facilitate easy installation and/or transportation of the greenhouse, the polycarbonate canopy can be removed from the base. The polycarbonate panels are removed together as a unit, held in place by a wooden frame. Non-toxic pressure-treated wood was used in anticipation of exposure to the outdoor environment. The base unit is simply a table with a box frame around the perimeter, supported by four legs. Two layers of 8mm twin-wall paneling were used to enclose the growing space, secured by a combination of Power Grab adhesive and roofing nails. The roofing nails feature a large plastic washer around the head to distribute the force. Nails with standard heads would either crush the polycarbonate or would pull through. In the same fashion as roof overhangs on large building roofs, the polycarbonate paneling was cut to overhang the edges of the base. This prevents rain water from finding its way from the sheeting to the base and possibly the electronic components housed beneath the frame. Choosing the right polycarbonate panel is a question of thermal and optical considerations. Of the materials examined, the paneling used has an R-value of 2.5. (A material's R value is a measure of how well it conducts heat, with higher R-values being more desirable for insulation)

All of the climate-control system components are mounted on the underside of the base, except the heater, grow lamp, and the sensors. Disposable plastic containers enclose the microcontroller and relay board. A maze of wires and jumpers connecting the parts are strung throughout the components, color-coded for ease of analysis as well as safety. Consistency in the wire coloring is used to clarify the function of each wire, as well as for safety reasons. Exceptions to the wire coloring scheme are the jumpers on the Arduino and relay boards, wires connecting the power monitors, and the wires connected to the fan. Otherwise, all black wires are connected to the negative terminal of the battery. Three 14-gauge extension cords are used: green is the connection to the battery bank, the wide blade of the plug is negative; white connects the heater to the screw terminal strip, and brown connects the grow lamp to the screw terminal strip. Red is used for positive voltage, be it 12 V or the 3.3 V reference used by the analog sensors. Small-gauge green wire is used for analog input leads. In the case of the power monitor, ribbon cable is used. Brown is ground, followed by voltage and then current.

Power System Design

An important constraint of green energy generation is that it requires an evaluation of geography and topography, whereas power from a power plant goes wherever the wires go, regardless of site characteristics. The evaluation looks at two basic characteristics: insulation and wind availability. The former is a measure of how much solar energy reaches the surface; the latter is a measure of how much useful wind blows through the site. An initial survey of the site determined that the wind available is insufficient to justify a wind turbine. Consequently, solar panels are the sole source of energy. The chosen test site is in Hopewell, NJ at approximately 40.4 degrees latitude, atop Sourland Mountain. According to NASA's Atmosphere-Ocean Model website[16], the average annual insolation for the year 2011 at this location was 327.7 W/m^2. The Weather Channel website[17] provides long-term temperature averages for Hopewell, NJ. The National Renewable Energy Laboratory (NREL) is a U.S. Government agency providing information for those interested in Photovoltaic power systems[18].

In keeping the proverbial cart behind the horse, determining the power demands comes first in sizing any system. Establishing the power required prevents the generation side of the system from being either over- or undersized. The minute greenhouse draws little power; a mere 84 W for the climate-control equipment, plus an estimated 6 W for the Arduino microcontroller components. This estimate is for a cold winter's day that would require the 65 W heater to be on almost continuously. Dividing the 70 W by the nominal battery voltage of 12 V yields a current of 5.83 A. Multiplying by the length of time the system is expected to go without solar power (24 hours), the battery capacity required is nearly 140 A-hours (139.92 AH). The next step is to determine the size of the photovoltaic array needed to keep the batteries charged. A solar panel's power rating is based on ideal conditions; it is not -its continuous output. However, the conditions are usually suboptimal. Cloud cover is the most frequent cause of reduced power output, with the exception of the setting sun. In the case of the Hybrid Energy Integrator, the power demands are small, not warranting a grand array. However, in the interest of ensuring a detectable charge/discharge cycle, additional solar panels were incorporated into the system.

Automated System Design

A high-wattage resistor mounted to a large-finned heat sink is used to keep the greenhouse interior temperature from dropping too low. Using the high current capacity of the batteries, a 1.3-ohm resistor can dissipate 65 W (the product of 12 V and approximately 5.5 A). As an added feature, the heater fins are oriented such that they are in line with the air flow from the ventilation fan into the greenhouse interior. Solid copper wire leads are snaked through holes in the heat sink to remove mechanical stress on the lug-type leads of the resistor. Solid wire was readily available at the time of construction, but more flexible stranded wire is more forgiving in such an application. The grow lamp is covered with two pieces of tissue wrapped with transparent plastic wrap to create a light diffuser. The beam of light from the grow lamp sans diffuser is blinding to say the least. The tissue paper softens and spreads the lamplight, preventing the plants within from developing patches of sunburn. The plastic wrap protects the tissue paper. A solenoid-actuated water valve provided a base block around which the remainder of the irrigation system was designed. The valve is designed to mate with a one-inch diameter pipe and requires a minimum of three PSI to open. One-inch diameter pipe has a cross section of about 3.14 square inches. Taking the specific weight of water (0.03611 pounds per cubic inch), inverting it to cubic inches per pound (27.69), and then multiplying it by 9.425 pounds, results in 261 cubic inches. This is the volume of the water pressing against the solenoid valve. Dividing this volume by the cross-sectional area gives 83.1 inches.

It is important to note that if the outlet of any fluid line is elevated above such a valve, then the supply must be the appropriate distance above that outlet. Since this is the case in the greenhouse, the supply tank had to be 83.1 inches above the potted plant. The mechanism behind this phenomenon lies in the self-leveling property of fluids. Lowering the position of the supply tank brings it closer to the height of the water outlet, and the pressure difference on either side of the valve disappears. Although the valve rating says a minimum of three PSI, it actually means three PSI *more* than the pressure on the other side of the valve. To prevent the large-diameter tubing from letting water rush into the greenhouse and drown the plant, a manual ball valve was included to regulate the flow rate down to a trickle. To preserve the three-PSI requirement, the flow control valve was placed after the solenoid valve, between the solenoid valve and the outlet. An in-line duct fan is affixed to the underside of the greenhouse floor, with a PVC pipe elbow directing the air flow up into the greenhouse. Functionally speaking, the ventilation fan is oversized for the need. However, the ventilation fan may draw in moist air, necessitating a water-resistant component. The 135 CFM in-line fan, manufactured by rule, is designed for ventilating fuel tanks of marine vehicles. A PVC pipe elbow directs the flow into the greenhouse, and a similarly-sized hole at the far end of the greenhouse floor serves as the return air port. Wires for the components mounted on the canopy use the return air port to reach the electronics.

Experimental Apparatus

The climate control system necessitated more analog inputs than the Arduino UNO model has, so the larger Arduino Mega was substituted. Featuring 16 analog inputs, the Mega is more than capable of meeting the system's needs. To record data without leaving a computer unattended and connected to the Arduino, a specialized board (a “shield” in Arduino parlance) with a memory card slot as well as a real-time clock (RTC) for time stamping data points. Sensor readings are translated to integer values from 0 to 1023. All of the climate control actuators are managed with conditional logic. The only subsystem that requires two conditions to be true is the sunlight replication system. The program uses the real time clock to determine if the grow lamp should illuminate, or remain off to maintain a day/night cycle. If the hour (found using the “now.hour” instruction) falls between six and nineteen, a variable called “TimeOfDay” is set to equal one. Otherwise, TimeOfDay equals zero. As such, the grow lamp will only illuminate if two conditions are met: the light reading falls below the threshold and the TimeOfDay variable equals one.

In contrast to the numerous analog input puns, only four of the digital output pins are used, and they go to an external relay board, manufactured by SainSmart. The digital outputs control the heater, ventilation fan, grow lamp, and the solenoid water valve. Additionally, the board must be connected to the Arduino board's ground and to the five-V pin for use as an I/O reference voltage level. The conditional logic for climate control is effected using digital outputs, described in further detail in the “Interfacing” section. The data logging shield referenced above is manufactured by Adafruit industries. Shields are equipped with header pins, which slide into specific pin receptacles on the base Arduino board; a feature called "stacking." The Adafruit shield provides soldering holes that allow the user to access the now-occupied pins. A blank PCB on the shield provides a good place for pull-down resistors and trimpots to be installed. Two trimpots were installed on the board, one to adjust the soil water moisture threshold, and another dummy trimpot if the need for one should arise. The center pin on the trimpot is tapped into the analog inputs, creating a self-contained voltage divider similar to the TMP36 thermistors.

The primary function of the Arduino is to regulate the climate, but the operation is moot unless a record can be kept to verify its performance. Like the countless other climate control programs in use, the one written for this project uses thresholds (determined experimentally). When a sensor reading crosses a corresponding threshold, the appropriate action is taken. All outputs are turned off when the program executes the initial setup, and sensor reading variables are set to values outside the range they can possibly read. This was done to facilitate smaller data file sizes. If a snapshot of the system status was taken every second for an interval of more than a few hours, any attempt to process it in a spreadsheet would likely overwhelm a computer. To cut down on the file size, data is only logged when some input reading changes. A tolerance was included to compensate for the continuous but typical bounce in sensor readings. The tolerance is programmed around the most recent reading from a given sensor. If a reading is outside the tolerance range, a variable named "PrintFlag" is set equal to one. Additionally, a variable prefixed with "Prev-" is set equal to the current sensor reading, but only when a reading outside the tolerance is detected. Most spreadsheet processing programs automatically interpolate between data points.

When the PrintFlag variable is true, it satisfies the requirement of an "if" statement whose subsequent function is to take a snapshot of the entire system. Logging the status of the entire system regardless of how many things change aids in organizing and processing the data collected over the course of the experiment. Only after the data is logged does the PrintFlag get reset to zero. A drawback to the real-time clock is that when any number, be it year, month, day, hour, minute, or second, is less than ten, a leading zero is omitted. Not having that zero placeholder changes the time value by whole orders of magnitude. In other words, the time cannot be sorted sequentially. For example, 1:01 AM would be logged as "11", 2:01 would be "21", but 1:10 would be logged as "110". In reality, 1:10 comes before 2:01, but when sorting by time stamps, the order is lost and difficult to recover. This is why the program includes "if" statements before each time component. If the time component is less than ten, a zero is appended to the time component. All of the analog sensors used to measure environmental conditions are in essence voltage dividers. To further break down their role, each sensor used is a variable resistor. A voltage divider, is used to set the value of specific voltage drops across them. The objective is to obtain specific voltages from sources greater than that which is desired. In the case of the sensor circuit, the analog sensor was connected to the source voltage, and a pull-down fixed resistor is connected to ground. The analog input to the Arduino microcontroller, discussed in the next section, connects at the junction of the sensor and pull-down resistor. As the voltage across the sensor changes (corresponding to the resistance change), so too does the voltage across the pull-down resistor. The Arduino monitors the voltage across the fixed pull-down resistor. The exceptions are the two identical TMP36 thermistors. They have an internal voltage divider, so their three leads are connected to ground, analog out, and the 3.3V reference. The five-volt reference can be noisy, so the 3.3V is used.

Characterizing the moisture content of the soil as a discrete water level will simplify the explanation of the soil moisture sensor, consisting of two electrically-conductive probes inserted into the soil at a predetermined depth. As the water level in the soil drops below the threshold, the circuit is opened, and a voltage appears across the probes, eliminating any voltage across the pull-down resistor. The light-monitoring circuit uses a GL5528 light-dependent resistor (LDR) and best conforms to the generalized schematic shown in Figure 2.

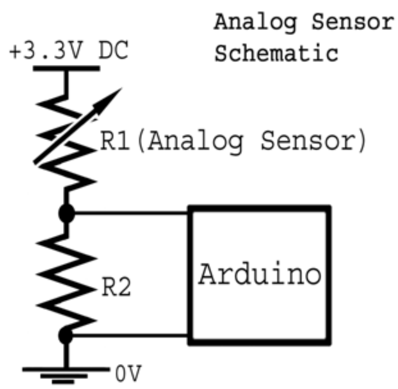

Figure 2: The Arduino and pull-down resistor having a common ground, effectively wiring them in parallel

Interfacing Between Microcontroller and Hardware

The relay board features a total of 16 relays, each rated to handle 250 VAC or 30 VDC, both at 10 A. Sixteen is far more than necessary for the application, especially considering that smaller boards with exactly four relays are widely available. However, at the time of purchase, additional relays were needed to control other components in the original system.

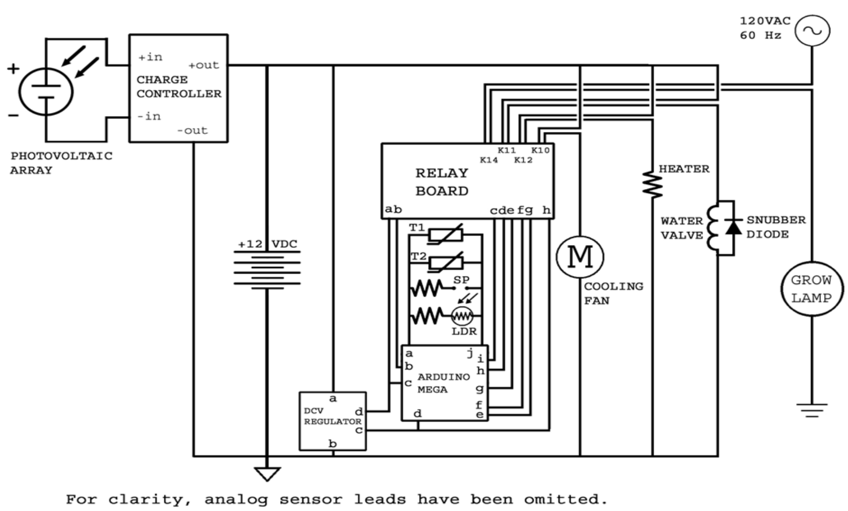

Figure 3: The circuit schematic shows the power source at left, the loads on the right, and the interfacing between them and the Arduino in the center.

The relay board is designed to be active low, meaning that to turn on a relay, the corresponding pin must be set low. The inverse variables (identified by an "INV" prefix) that appear in the program are used for data logging. Figure 3 shows the schematic of the system, with attention given to the pin configurations between components.

Experimental Results

As shown in Figure 4, this greenhouse is a structure built to maintain environmental conditions to aid the growth of plants. A greenhouse is built with covering materials such as glass or plastic to allow light and heat to enter inside and trap them to enhance plant growth. Though heat and light are the key elements for plant growth, there are still other factors like watering plants and circulating air and moisture that play an equal vital role in plant growth.

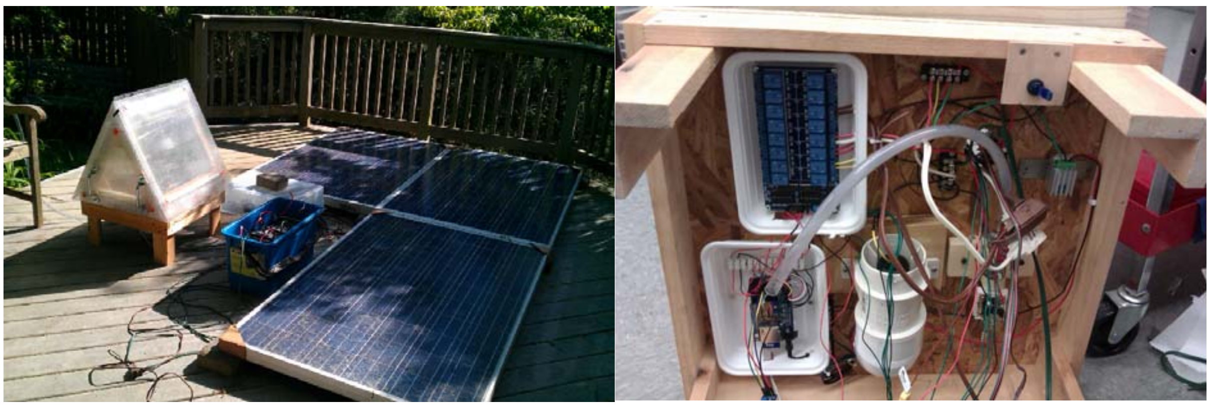

Figure 4: Greenhouse prototype and automated system

Glass covering allows heat to be trapped inside but during extreme weathers such as during summer seasons, this might hinder the growth of plans by overheating the greenhouse. Thus there is always the need for human assistance to monitor the conditions inside the green house. This project answers the above and other challenges involved with greenhouses. It aims at tackling the issue of a gardener performing a mundane task of monitoring the plants inside the greenhouse. Using technology the process of monitoring and controlling the different parameters that aid in the growth of plants can be automated so that the gardener can be involved in doing other higher level important tasks. Like said before the a typical greenhouse can only heat up the space inside it, but for the better growth of plans there are other factors that need to accounted for, monitored and controlled. The parameters that are monitored and controlled in this project are temperature, lighting conditions and soil moisture conditions. This work discusses the system developed for the automated control. The Arduino ADK is the controller used in this system and the control algorithm is written on the Arduino platform. A Computer which runs LabVIEW communicates with the Arduino for live data streaming. The sensors include:

1. Thermocouple (temperature sensor): A thermocouple coupled with a MAX31855 for communicating with Arduino. The MAX31855 library processes the incoming data from the thermocouple and converts the data to readable temperature in Celsius and Fahrenheit.

2. Light dependent resistor (LDR, light sensor): The LDR returns a numerical value between 0 and 1024 for the Arduino interface corresponding to the amount of light illuminating the LDR.
3. Soil moisture sensor: The soil moisture sensor is a simple switch that is used to detect if the water level in the soil.

The actuators include the following:

1. Light bulb: This is to illuminate the greenhouse if the amount of light inside the greenhouse drops below the required amount. The light bulb illuminates light in the tri-band spectrum range.
2. Ventilating fan: The cooling fan is to cool down the system if the temperature inside the system rises beyond permissible levels.
3. Heater solenoid: The heating element is heat up the greenhouse if the temperature drops down too much
4. Water control valve: The water control valve is to open and close the water flowing to the plants.

The Arduino is mounted with a data logging shield, this shield has a real time clock that can be used for time stamping and acquiring and saving data. Initially data was collected and stored onto a SD card for further analysis. But this method was inconvenient and was not user friendly. This was later developed to be interfaced with a computer for live data viewing and logging, discussed in later sections. The real time clock on the shield is utilized to time stamp the incoming data. The control system is written on the Arduino Platform. The three parameters that are controlled and monitored are the temperature, the lighting and watering plants. The following section discusses the algorithm involved in controlling these parameters and the next section discusses the results obtained from experiments run on the system.

The temperature is obtained from a K-type thermocouple that is coupled with the MAX31855 for communicating with the Arduino. The temperature is read by the Arduino and the heater solenoid and the ventilating fan are used for controlling temperature within the green house. The temperature is maintained between 23 and 28 degree Celsius. The lighting is controller to supplement plants with light when natural light is not sufficient enough. During cloudy days or during winter days when the amount of light is not sufficient, this lighting supplements natural light for plant growth. This lighting system is active only during the day i.e. after 6pm irrespective of the light conditions lights do not go on.

The watering system is switched once every day. The plants are watered until the soil moisture switch reads HIGH. The amount of water the plants are watered can be altered by varying the distance between the switch electrodes. The data is transmitted via the serial port for live plotting and saving for later analysis. An interface is created on LabVIEW for live streaming data and saving for further analysis. Figure 5 shows the LabVIEW interface.

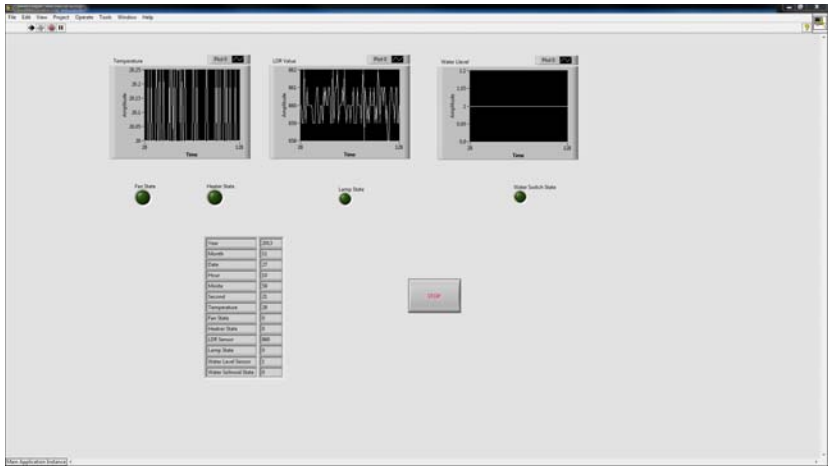

Figure 5: LabVIEW Interface for live data streaming

The following section describes and discusses experiments performed. An experiment was run on the system for about 150 min. The greenhouse prototype was run autonomously without any human interference. The following data in Figure 6 is obtained from this experiment. The LabVIEW interface running on a computer collects and plots the data and finally saves it. Later analysis is conducted on MATLAB.

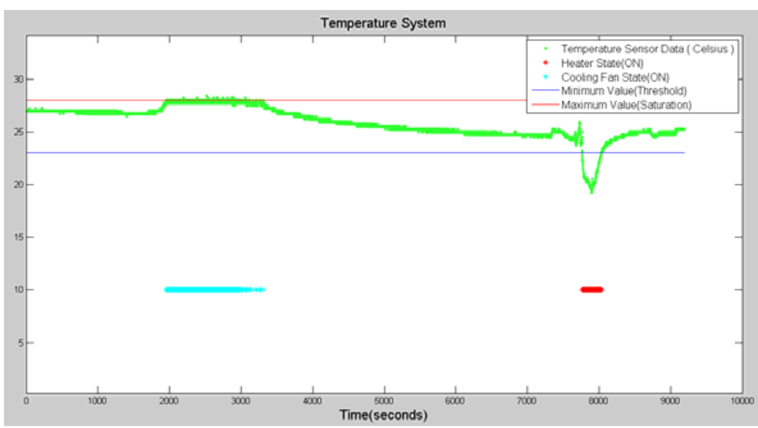

Figure 6: Temperature control system

Figure 7 shows the sensory and actuator data obtained from the temperature system. The green dotted line shows the temperature data obtained from the thermocouple sensor, ^{o}Celsius at each second. The red line and the blue line represent the desired temperature limits. The Cyan and Red dots represent the actuator switched ON Status. While obtaining this data the system was given disturbances externally, an external heating element was placed inside the greenhouse to heat up the system and the greenhouse system compensated for the external heating by switching on the ventilating fan (shown by the cyan dots), this can be observed between time intervals 2000 and 3000 seconds. Cold air stream was also used to cool down the system and green house switched on the Heating element to warm up for compensating the cold air.

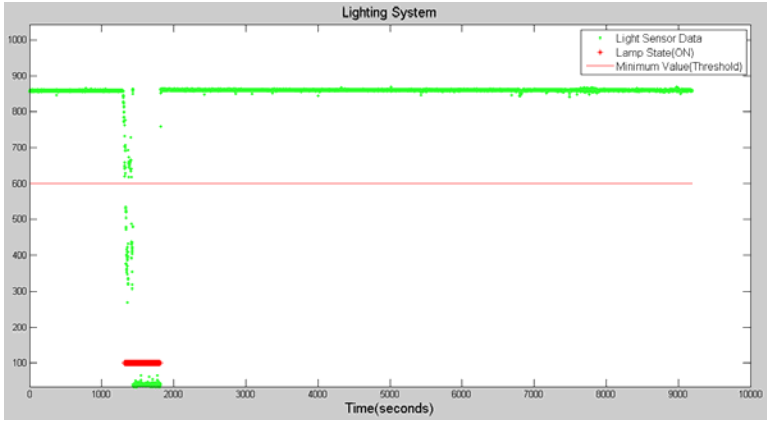

Figure 7: Lighting system

Figure 8 shows data obtained from the lighting system. The LDR is place right outside the greenhouse to obtain the lighting conditions. It was determined experimentally that a digital value of 600 (of 1023) is an optimal threshold value for the lighting system. Between time interval 1000 and 2000 seconds the lighting can be seen to drop below the desired range (>600) and due to this darkness the light bulb was switched on. This represented with the red dots in the plot.

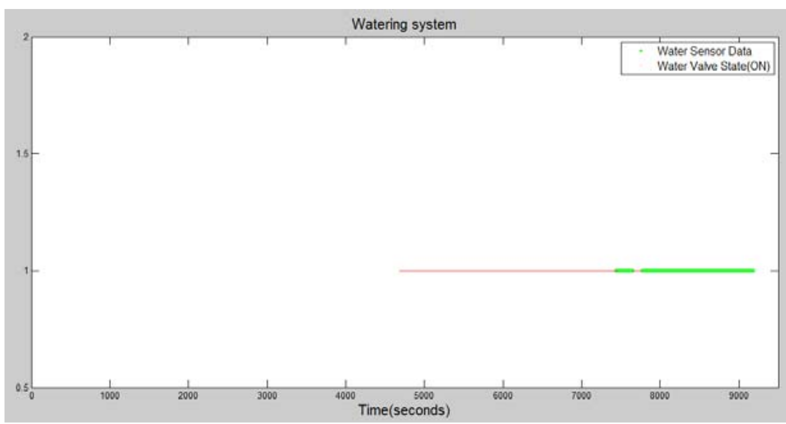

Figure 8: Watering system

The watering system is switched on for one hour every day. The system is configured to water the plants between 3pm and 4pm every day. Figure 5 shows the watering system data. The test was started to run at around 1:45pm and about 1hour and 15 min (4500 seconds) later the watering system went on. After watering for a while the soil moisture switch closed and the water valve was closed. The Figures 7, 8 and 9 show experimental data of the three different systems in a single experiment. All three systems work simultaneously and autonomously without interfering with each other.

Figure 9 shows the power consumed by the system during the experiment. The major power consuming elements are the actuators viz. heater, ventilating fan, the water solenoid switch and the light bulb. It can be noticed from Figure 9, between time intervals 2000 and 3000 seconds the average power consumed is approximately around 6.5 W. Comparing with the temperature system, Figure 2, this is the period where the ventilating fan was switched on. Similarly around time instance 8000 seconds it can be seen that the heating element was switched on and at this time the around 22 W is consumed. The heater filament, like observed from this plot, is the highest power consuming element in the system. Time interval between 4900 and 7500 seconds can be compared with the Watering system where the water valve was switch on. It consumes a negligible power of 0.3 W. It should be noted that the total run time 153 min, including Heater ON time 4 min, ventilating fan ON time 8 min, and water valve ON time: 42 min. The total power consumed was 9.421 KW, therefore the average power consumed is

$$\text{Average Power Consumed} = \frac{\text{Total Energy Consumed}}{\text{Total Run Time(in Seconds)}} = 1.025 \text{ W}$$

It should be noted that average power 22.26 W was consumed by heater and 6.43 W was consumed by ventilating fan. Therefore, the average power 0.31 W was consumed by water solenoid valve.

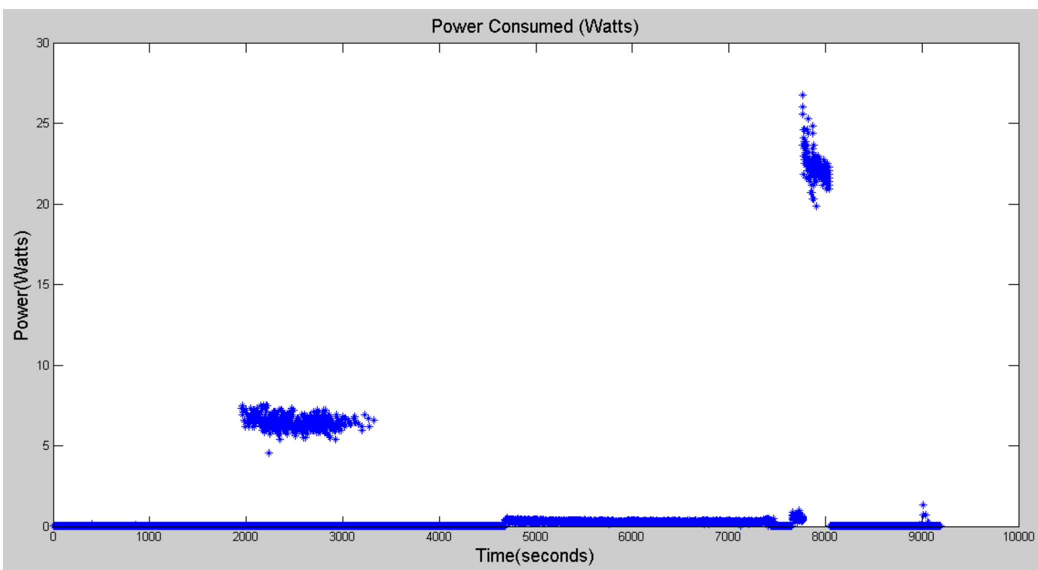

Figure 9: Power consumed

Student Learning Experience for Green Energy Manufacturing

For the past years, our focus has shifted towards incorporating renewable energy manufacturing topics in our senior design course. In the first senior design project term, we assign to our students the project topics related to renewable energy, power systems, or green energy manufacturing. These projects provide multi-disciplinary collaboration and valuable hands-on experience to the students. In addition to useful lessons on teamwork and project management, the projects provide working demonstration of green energy manufacturing systems. During the first fall quarter of the course, each team is given with guidelines for the senior design projects. Each team demonstrates the senior design proposal to the entire class and then a written proposal summarizing the proposed activities is handed-in as one of requirements of the senior project design course. To enhance the hands-on experience, the senior design course has been restructured as a project based course. Students are required to analyze, design, simulate, and build a completely functional system by the end-of-term project. The goals of all the projects are to explore and enhance student understanding of the fundamental concept of design-for-environment (dfE) and hands-on learning of green energy manufacturing.

Conclusions

For engineering technology students, a senior design project is a sequence of tasks required to achieve learning objectives. Typically, the objectives are to design a device or process that has value to industry. The project begins by defining a performance problem associated with applications and ends with a prototype for a green energy manufacturing solution. The problem drives the learning required to complete the project. Managing the project requires the students to demonstrate effective teamwork, clear communication and the ability to balance the social, economic and environmental impacts of the project. We believe that problem-based learning, as exemplified by a capstone senior design project such as this one, provides students with important knowledge about renewable energy and green design. In addition, such projects provide students with the essential project management and engineering skills required to bring complex projects from idea to completion.

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