



## Design and Implementation of a Solar-Powered Smart Irrigation System

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## **Abstract**

According to the Department of Agriculture Economic Research Service, Agriculture is a major user of ground and surface water in the United States, accounting for approximately 80 percent of the Nation's consumptive water use and over 90 percent in many Western States.

This paper addresses water scarcity and food crisis by designing and implementing a smart irrigation system. It presents the details of a solar-powered automated irrigation system that dispenses the exact amount of water required depending on the soil moisture, hence minimizing the waste of water. A network of sensor nodes is used to collect the humidity and temperature of the soil which is transmitted to a remote station. This data will be analyzed and used to remotely control the amount of water dispensed by solenoid valves. The designed project is currently operating at the university-owned agricultural experimental research station. The system can be tailored to the type of food or crop being grown. The design team incorporated the theory of digital control and feedback systems, and digital communication in the design and implementation of this project.

The automated drip irrigation system will help reduce the problems associated with water waste in farming, avoid evaporation, and as a result increase food crop production.

## **I. Introduction**

The Food and Agriculture Organization of the United Nations [1], estimates that agriculture accounts for 70% of all water consumption, compared to 20% for industry and 10% for domestic. Critical need therefore exists to implement water conservation practices in agriculture. There is an urgent need to create strategies based on science and technology for sustainable use of water, including technical, agronomic, managerial, and institutional improvements.

The objective of this project is to develop a system that will minimize the waste of water in an Agricultural Experiment Station farm. The smart system developed uses automated drip irrigation and uses the exact water required depending on the soil moisture. The farm site has greenhouses, crops and administration houses. The automated system collects data from the humidity, temperature, flow sensor, and soil moisture sensors. The data collected is sent

wirelessly to the cloud. The system is operated in two modes, either in a closed loop control mode where the microcontroller operates the opening and closing of the solenoid valve for the required amount of water needed for the crops, based on the average soil moisture reading, or the agronomist remotely use the cloud data to trigger a channel by writing a specific value. The link located below the channel is assigned to turn on and off a solenoid valve. Sensor data are collected using wireless communication to avoid loose running signal wires and cables in the field.

This is a one semester senior capstone project, involving four electrical engineering students. Senior Capstone Projects represent the culmination of the educational experience, integrating the classroom with real world problems. The students handle open ended engineering problems whose solutions require a synthesis of engineering knowledge, analysis, creativity, market needs, safety and esthetics. Projects are carried out by students and supervised by instructors and industry mentors.

The rest of this paper is organized as follows. The System Design is presented in Section II. Project Assessment and cost are discussed in Section III. Finally, the paper conclusions are provided in Section IV.

## **II. System Design**

### Energy Use in Irrigation

Irrigation requires a significant expenditure of fossil energy both for pumping and delivering water to crops. Annually in the U.S., it is estimated that 15% of the total energy expended for all crop production is used to pump irrigation water [2]. Overall the amount of energy consumed in irrigated crop production is substantially greater than that expended for rain fed crops [2].

Solar energy is the most abundant source of energy in the world. Solar power is not only an answer to today's energy crisis but also an environmental friendly form of energy. Photovoltaic generation is an efficient approach for using the solar energy. One of the applications of this technology is used in irrigation systems for farming. Solar powered irrigation system can be a suitable alternative for farmers in this present state of energy crisis. This is a green way for energy production which provides free energy after the system is developed. The Photovoltaic

energy generation system used in this project for powering the automated drip irrigation system is configured as shown in Figure 1.

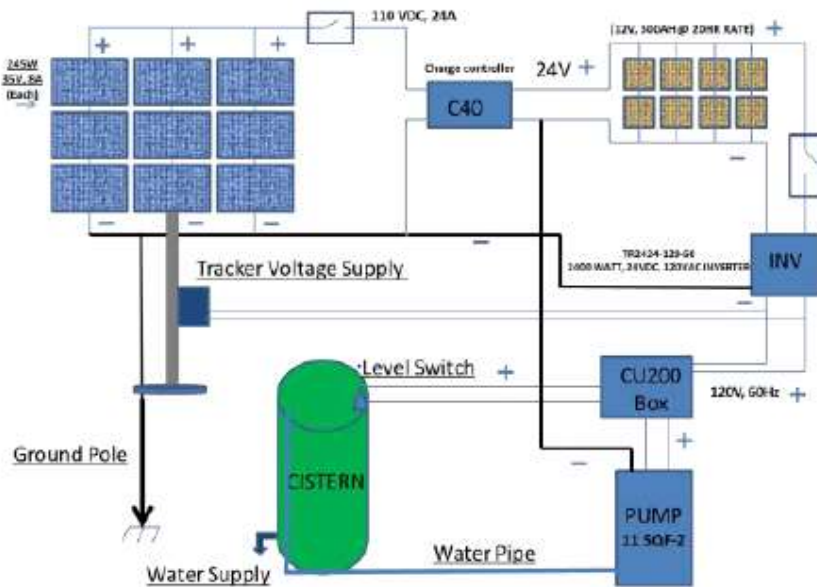
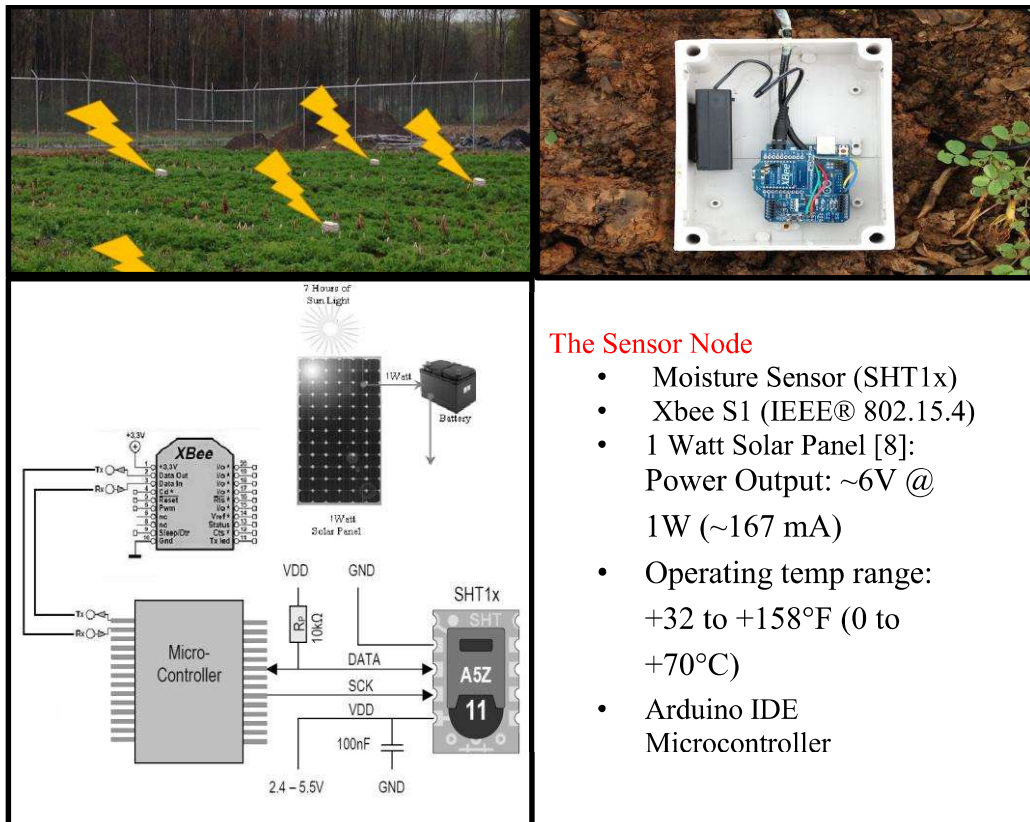


Figure 1: Renewable Energy Power System

The central power source is a two-axis solar tracking PV system [3, 4, 5, 6] mounted on a galvanized steel-pole. The photovoltaic array converts solar energy into a 2KW DC electrical power. The DC power is converted to AC through a 2.4KW, 115V, 60Hz inverter and provides adequate power to the automated irrigation system. In addition, various voltages are derived from the inverter to provide smaller AC voltages (i.e. 24V, 48V) through step-down power transformers. In the diagram, a 900W (30-300 VDC or AC) submersible pump delivers water from a 90-ft borehole into a 5000-gallon cistern for storing the ground water that will be used for irrigation. The cistern has a solenoid valve, flow meter, and plug-type sprinkler system attached. The battery banks with eight 12V 330AH deep cycle batteries configured as 24V 1200AH provide backup power for the automated drip irrigation system. The system has an estimated 3 to 5 days of autonomy when there is little or no sun energy.

## Soil Moisture Sensor Nodes:

Soil moisture sensors measure the water content in soil. Measuring soil moisture is important in agriculture to help farmers manage their irrigation systems more efficiently. Not only are farmers able to generally use less water to grow a crop, they are able to increase yields and the quality of the crop by better management of soil moisture during critical plant growth stages. After inserting a probe into the soil for approximately 60 seconds a meter indicates if the soil is too dry, moist or wet for plants. The sensor reads the amount of moisture in the soil. The soil moisture sensors used in this project are the solar powered SHT1x sensor series ICs from Sensirion [7].



### The Sensor Node

- Moisture Sensor (SHT1x)
- Xbee S1 (IEEE® 802.15.4)
- 1 Watt Solar Panel [8]:  
Power Output: ~6V @  
1W (~167 mA)
- Operating temp range:  
+32 to +158°F (0 to  
+70°C)
- Arduino IDE  
Microcontroller

Figure 2: The Soil Moisture Sensor Nodes

An energy efficient wireless sensor network is developed using Arduinos microcontroller and XBee modules. This allows us to collect a number of different readings from the sensors. The

design uses multiple sensors (SHT1x) strategically placed in a crop zone to collect soil moisture data. A 1W small solar panel module with a 9V rechargeable battery, powers each sensor node.

The soil sensor is interfaced to an Arduino UNO [9] and a Xbee transmitter. Each sensor node is a part of a Zigbee network in a Star topology [10] around a hub controller or concentrator. The ZigBee is a worldwide open standard for wireless radio networks in the monitoring and control fields. A coordinator radio sits at the center of the star topology and connects to a circle of end devices, which in this application are the soil moisture sensors. Every message in the system must pass through the coordinator radio, which routes them as needed between devices. The end devices do not communicate with each other directly. The data collected is transmitted wirelessly to the concentrator which uses an algorithm to smooth out the moisture content in the crop zone. This concentrator is also capable of collecting weather samples such as temperature, humidity and dew point from a weather station using the fully calibrated SHT1x A5Z11 sensor series ICs from Sensirion. The SHT11 and SHT1x sensors series are already fully calibrated and output digital values, so there is no need for sensor calibration or the use of any Analog to Digital conversion modules. The sensor power consumption is in the range 8-15 $\mu$ A which is a very low power consumption with 2 years longtime stability. Solar panel is implemented in each sensor node to preserve battery life. Temperature sensor in the field is important because the soil moisture sensor sensitivity is affected by temperature. The reason for this is that soil resistance changes with temperature.

#### Xbee S1

Xbee S1 with antenna has a long range data integrity and 300sq feet of range for the wireless communication. The low power current 45mA at 3.3V helps to have a system which does not draw too much power out of the battery. These stations are in charge of reading and collecting data from each sensor and send it as a digital output to the hub.

The data collected is sent to the cloud which is then displayed in various forms in this case, tabulated and graphing data accessible on a public website. A PID Process control algorithm is also developed to process the data received, and then sends trigger signals from the cloud to the solenoid valve to precisely control the amount of water flow to the soil.

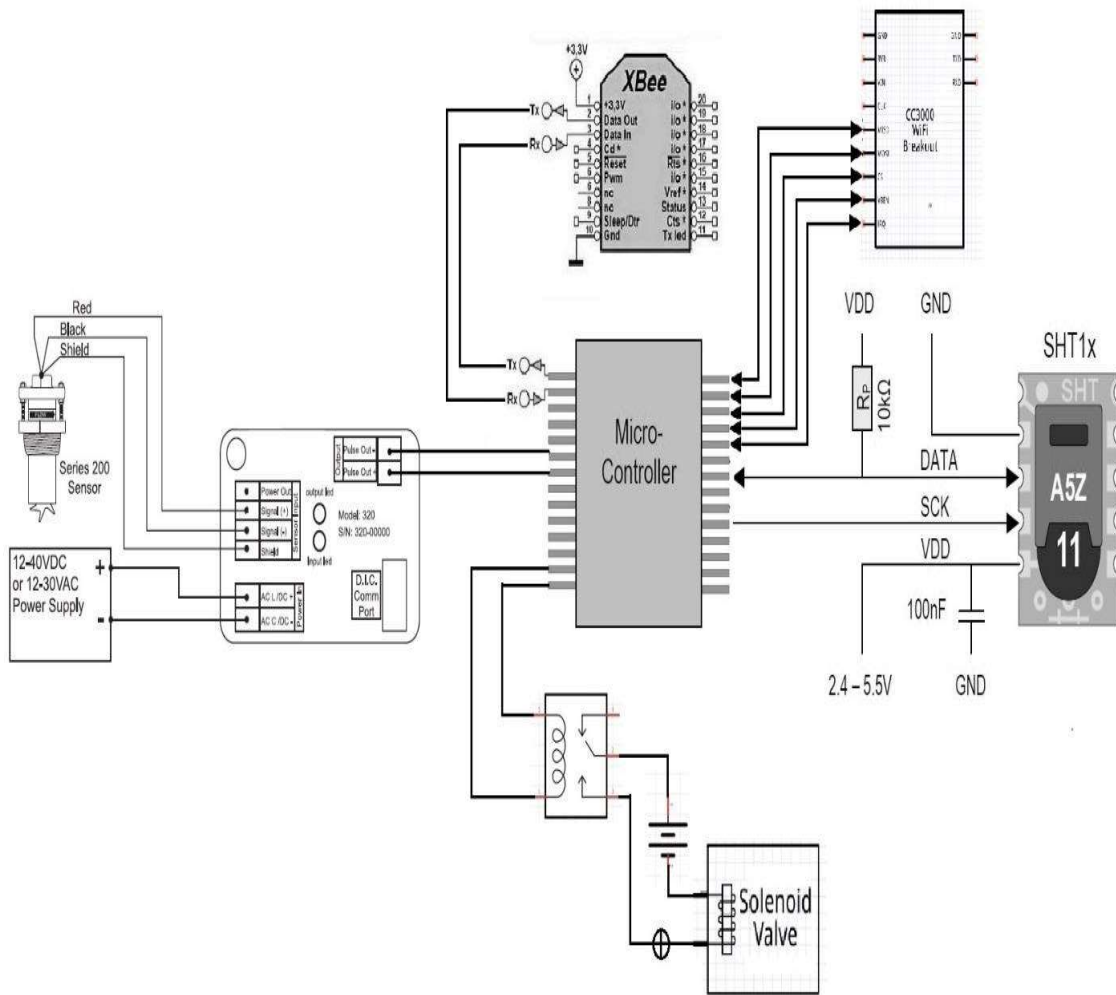


Figure 3: The Hub Controller Circuit Schematics and Interface modules

The hub is configured also with Arduino and Xbee devices as coordinator or concentrator. The circuit schematic is as shown in Figure 3. The masters or coordinator stores an average for each specific value (i.e., sensor readings) into an Arduino UNO. The hub controller also controls the flow sensor interfaced to the Arduino to measure the volume and velocity of the flow of water from the cistern. The Badger® ORION Series 228PV wireless flow sensor system [11, 12] and the flow meter with its integral microcontroller (SN: 320-0000 model) is used for the water flow measurement. This comprises of battery powered flow sensor and a radio frequency (RF) transmitter (complete with RF receiver/pulse transmitter). The transmitter sends pulse output signals approximately every four seconds to the RF receiver. The RF receiver is interfaced with

the Arduino. The pulse output is scaled or calibrated to represent the desired volume unit and number of output pulses per unit volume. To open and close the solenoid valve for the required amount of water needed for the crops, a PID Control algorithm is used; this calculates the error value in the average soil moisture sensor reading as the difference between a measured input and a desired set point. Then, all the average values for each sensor are pushed into the cloud. In the cloud, for remote operation, farm personnel will be able to trigger the data for each value manually if required, which means it will turn ON or OFF the solenoid valve depending on the average or threshold value assigned for the crop zone soil moisture, usually at 50% of soil MAD value. In real-time mode, the microcontroller uses average soil moisture sensor readings for 15 minutes to determine if to open or close the solenoid valve. SH11 or temperature and humidity sensor is hard-wired to the Arduino Uno and the Xbee to the Arduino Uno for the wireless communication.

The Wi-Fi shield [13, 14] used in the project is the TI CC3000 module which is a self-contained wireless network processor that simplifies the implementation of long-range wireless or Internet connectivity. The TI Wi-Fi network processor minimizes the software requirements of the host microcontroller which makes it the ideal solution for embedded applications using any low-cost and low-power microcontroller.

#### Power Consumption: AVR/Sleep Mode

Arduinos are better to be utilized since it allows easy interface to standard Wi-Fi shields, USB, I2C, power regulation, etc. The disadvantage of the Arduino hardware is the drain on battery power when it is in operation. Arduino UNO already consumes more than 15mA in idle mode. When powered by 9V alkaline battery which has a 450mAh, the Arduino will drain the battery within just 30 hours or less than two days (450mAh/15mA). To conserve the battery power in this application, the sensor node is used in the sleep mode, this means the Arduino will turn on, read from the sensor and transmit the data to the hub. Data is sampled for a few seconds





### The HUB

- (SHT1x)-Micro Weather Station
- Signal-Smoothing Algorithm
- PID controller algorithm
- (WDT)-Watchdog timer
- IOT-Internet of things

Figure 4: The Hub Waterproof casing

before putting the system back into the sleep mode. Using this configuration the battery will last 6 to 9 months. All batteries are rechargeable, and can be recharged from the renewable power system breakout boxes. The hub station runs completely with solar energy and collects the data from the different sensor and flow nodes, plus the outside temperature. All these components are located inside of a weatherproof pvc box to protect them from any climate change, as shown in Figure 4. This concentrator sends the data to the cloud.

### Signal-Smoothing algorithm:

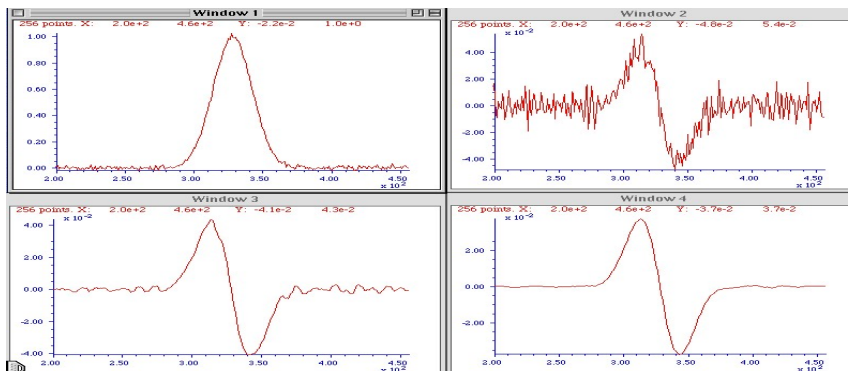


Figure 5: Smoothing the Signal

The simplest form of smoothing a signal is the "moving average" which is when each data value is replaced with the average of the neighboring values. If we want to avoid shifting the data to get a smooth signal, the best way is to average the same number of values before and after where the average is being calculated. In practice, adding more sensors can help the grower understand what is happening in the various parts of the field. Also, additional sensors can help average out some of the field and sensor variability to give a more representative average.

PID Controller Algorithm:

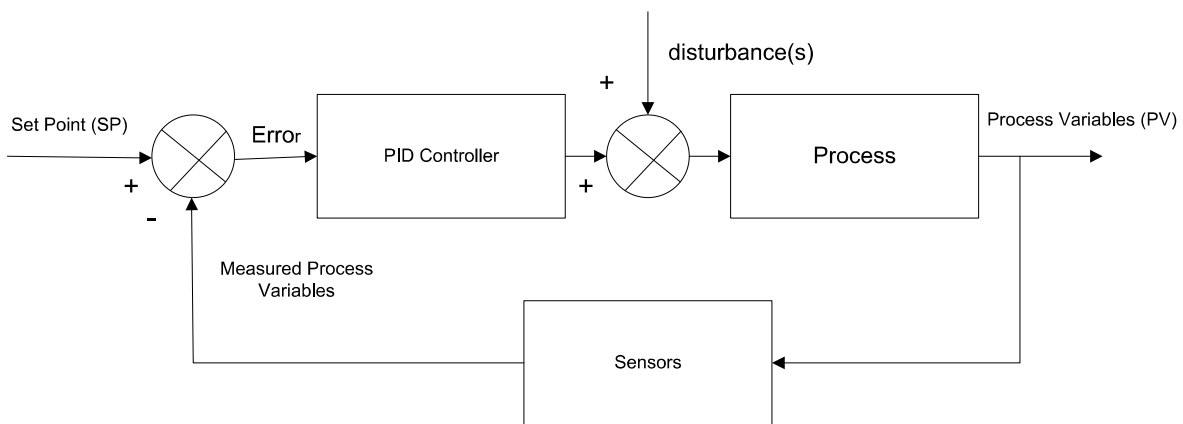


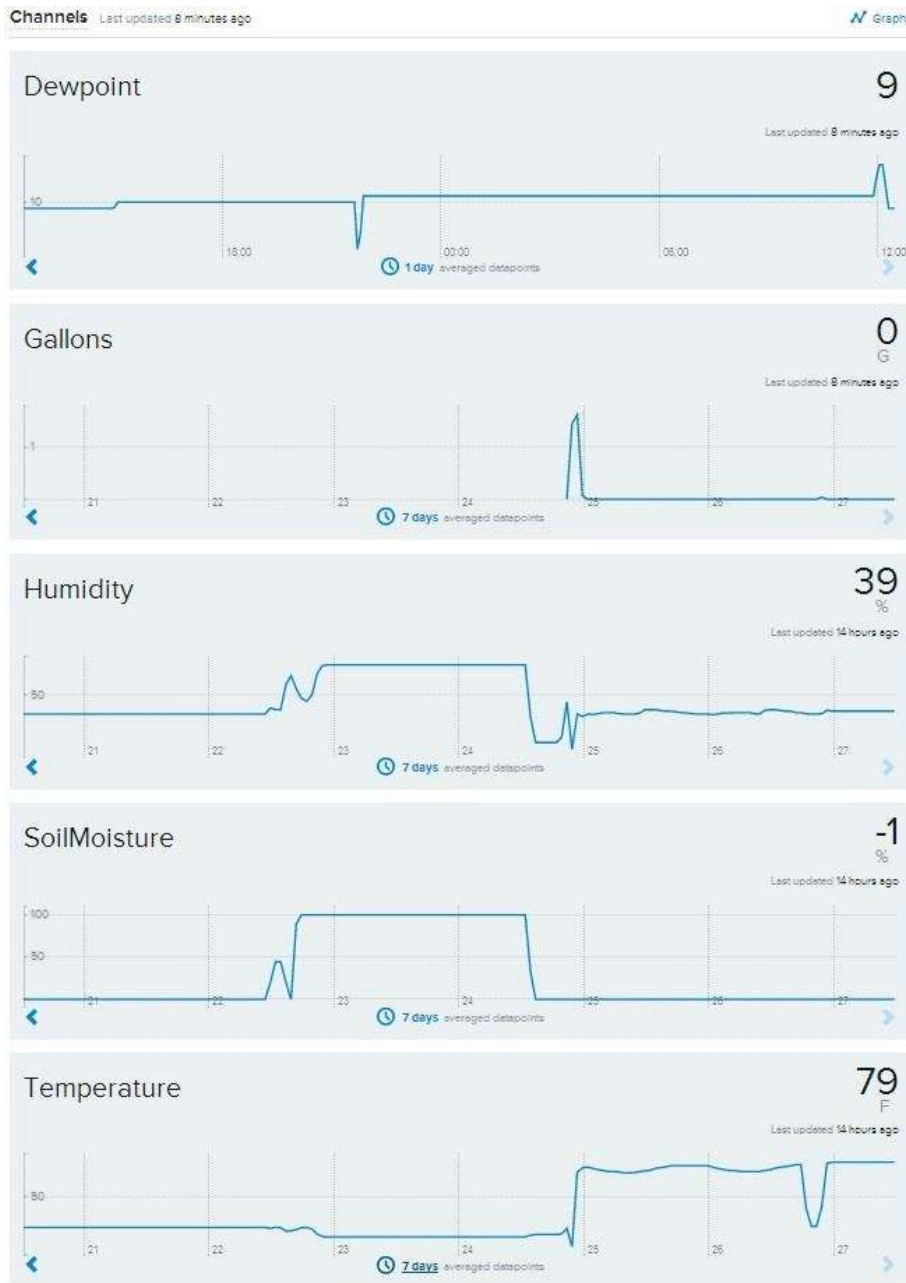
Figure 6: PID Controller

PID control is very important in distributed control systems. A PID Controller is shown in Figure 6 where the set point (SP) is the value that we want the process variable to be. As an example, the control system needs to activate the solenoid valve when the moisture in the field is less than 50%. So, the control system in the field may have a SP of about 50% or more of moisture. This means that, we want moisture in the field to achieve a steady moisture value of as close to 50% and more of moisture as possible". The input to the negative PID is error signal which is the difference between the set Point (SP) and the measured process variables. If the value of the error signal is positive, the set point is higher than the measured moisture, then the system will switch on the solenoid valve and in a couple of minutes the moisture of the crops will increase its level. The solenoid value is turned off when the value of the error becomes negative.

### Internet of Things (IOT) [15]:

There are many benefits using cloud to store data; the reduction of initial costs for hosting a service: with cloud computing platforms you do not need to set up the entire appropriate hardware infrastructure (that includes servers, network, routers, etc.) for storing your sensor data. Quality of service and guaranteed availability, the cloud service provider guarantees you no network failures as long as your system is well-developed. Another advantage is that you can have access anywhere as long as you can have any computer device and internet access. Last but not least, you do not need to back up your data or create a recovery system. The provider will take care of backing up your data which had been stored. Cloud services are very easy to use and affordable for any platform. It provides access to remote services and other applications.

The Arduino program in the hub averages the values collected so that it will create a single digit from the entire field. This number determines whether the soil moisture measured is too dry, too wet, or simply in a proper state. Consequently, this measurement will be pushed into a public website, displaying all the data collected from the farm which refers to the humidity, moisture, temperature, and gallons measurement. Sample of the cloud reading is displayed in Figure 7.



**Figure 7: The Cloud Readings**

**Phone Apps:**

A mobile App is developed for this project using the Conduit website services. Conduit is a website that allows you to design a mobile App for personal or business purposes. It is one of the top three websites in the market and has great reputations and customer service. The user creates an account to get an App code. Based on that code, you can design your App, edit it, and

uploaded on Apple store for apple products access, Google or Samsung market for Android devices or on Amazon for amazon tablets. The designed App will allow users to check the status of the irrigation project online from anywhere for as long as they have internet access. Figure 8 shows sample displays from the mobile App.

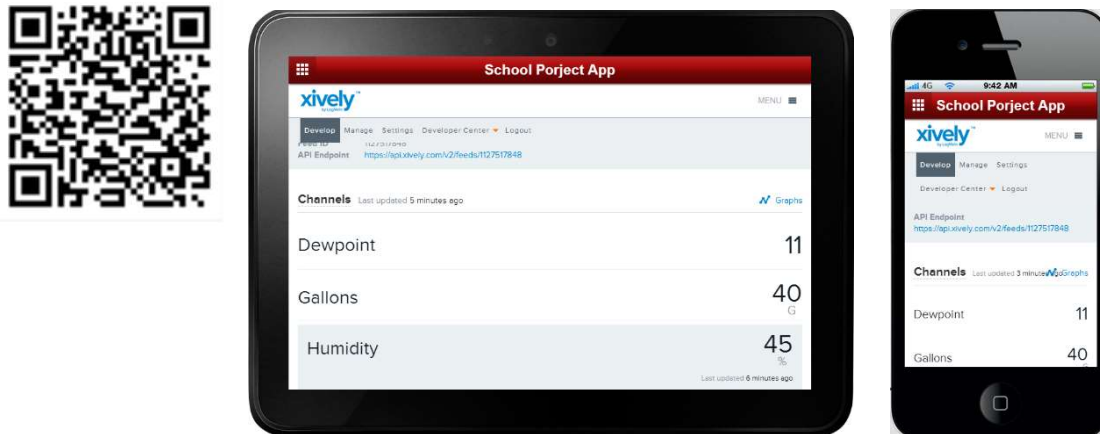


Figure 8: Mobile App Displays

### III. Project Assessment and Project Cost

The senior capstone design projects are assessed based on multiple realistic engineering design constraints and pertinent engineering standards. The following design constraints were considered for the Automated Drip Irrigation System.

1. Design a sustainable low-cost, low-power, drip-irrigation system to control and reduce water waste in farming;
2. The sub-system should use power from green energy;
3. The sub-system should be able to operate in real-time, and remotely without human intervention;
4. Economics should be kept in mind to keep parts and configuration costs as low as possible;
5. The design should be tailored to the type of crops being grown and the landscape;
6. Weather conditions are to be taken into consideration.

#### Pertinent Engineering Standards:

- IEEE STD 100-1984 data communication protocols; Use of IEEE 802.15 communication protocol facilitates communication between designers, customers, and vendors

- Use of IEEE 802.15 communication protocol standard in compliance with the Federal Communication Commission (FCC) rules.

Cost summary:

The project was built using cost-efficient components and can be easily duplicated. A cost summary is provided in Table 1.

Table 1. Project Parts Price List

<b>Component</b>	<b>Cost(\$)</b>
Badger Flow meter series 228PV ( <i>Donated by Badger Meter Company</i> )	564.32
Badger Meter Model 320 Pulse Transmitter/Receiver ( <i>Donated by Badger Meter Company</i> )	252
3 way diverter valve	56.99
2xSunfounder 2 channel 5V relay shield modules	16.98
8x Arduino UNO boards	400.00
CC3000 WiFi Breakout with uFL Connector for Ext Antenna	49.95
8x Xbee shields	440.00
6x SHT1X Soil Moisture Sensors + 1 Watt Solar Panels	120.00
1x Liquid Level Sensor	40.00
1 x SHT11 temperature-humidity sensor + 1Watt Solar Panel	19.90
2KW DC Renewable Energy Power System (from previous senior capstone projects) ~ \$26,000.00	-----
Miscellaneous parts	100.00
<b>Total</b>	<b>\$2,060.14</b>

#### IV. Conclusion

In this paper, the design and implementation of a smart irrigation system, powered by solar energy was presented. The design uses an automatic irrigation system that can be tailored to

the type of food crop being grown. The designed project is currently operating at the university-owned agricultural experimental research station.

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