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*Research paper*

# Controlling irrigation in a container nursery using IoT

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**Abstract:** The demand for water has increased while the supply has been stagnant. This may be attributed to population growth, land-use dynamics and climatic factors. The availability of a sustainable source of water for food production is forecast as a critical issue facing agriculture. The recent EPA Strategic Plan emphasized the need to ensure waters are clean through improved water infrastructure and sustainably manage programs to support the different uses of water. This plan though broad dictates the need to develop new technologies that can help optimize the use of water via sensor-based irrigation. The goal of this project was to design a prototype irrigation controller using the internet of things (IoT). The controller is a closed-loop design which uses the soil moisture data to turn on and off the irrigation system based on specified thresholds. The data and control was hosted in an online IoT platform. The IoT platform provides real-time monitoring and control via a simplified online Graphical User Interface (GUI). The system was developed at the Sensor and Automation Lab of Edisto-REC, Clemson University and then field tested at McCorkle Nurseries in Dearing, GA during summer 2017. During the four month field test a number of challenges were identified including signal transmission and hardwire connections although overall, the prototype achieved the six objectives established for the system.

**Keywords:** internet of things; controlled irrigation; remote monitoring; sustainable agriculture; conservation

## 1. Introduction

The UN Educational, Scientific, and Cultural Organization (UNESCO) noted that industry, agriculture and progressive urban populations are creating too much pressure on our water supplies [9], thus there is a need to properly manage irrigation to optimize water use in agriculture [7]. Site specific irrigation is an efficient tool to address the optimization of water [10]. This not only provides benefits to the plants but also to growers as well, as it minimizes operating expenses by only irrigating plants that need irrigation.

Sensor-based irrigation is not a new concept [8,12,13,17]. Testezlaf et al. [18] and Jacobson et al. [12] used an irrigation system that would automatically irrigate greenhouse containers. Kim and Evans [13] developed software for an in-field wireless sensor network (WSN) to implement site-specific irrigation control. Coates et al. [6] developed site specific applications using soil water status data to control irrigation valves. Although the system described by Kim and Evans [13] can be accessed wirelessly, the system is running on a point to point protocol which means, the software is running on one computer and can be accessed through remote login to the computer where the software is being hosted. This might be good if there is only one user but will not work with multiple users. Sensorweb [14] system controls valves based on soil moisture information but does not have the capability of changing the threshold or range of values when triggers will operate. Thus, these current systems would not allow growers to adjust irrigation of one area based on the type of plant species or specific water requirement. Other irrigation control systems use weather data which may not be accurate if the weather station is located far from the irrigation platform.

Unlike previously developed systems (e.g. Acclima; Sensorweb) our system uses an open platform based on IoT. The main difference between our system and Acclima and Sensorweb is the design of our controller. Our main controller connects directly to the internet and irrigation is controlled on the main controller not on the node. Sensorweb is one component of a large Federally funded project that collaborated with commercial companies (e.g. Decagon). Sensorweb includes a weather node that was used as part of their irrigation decision support process. Though goals of our project and Sensorweb are similar, the main difference is on how we implement our system. We use the IoT paradigm, meaning less hardware compared to Sensorweb. Their node has a soil moisture and valve control and the node connects to a laptop/PC that is connected to the internet [14,15]. The laptop/PC where nodes are connected serves as a webserver. In contrast, our system directly connects the controller to the internet and streams data directly to the cloud using a dashboard (Ubidots). The system described in this paper uses the concept of IoT that requires less hardware and the connection is faster since it only needs to connect the main controller to the internet. Another advantage of our system compared to Sensorweb is that the dashboard used for visualization of our data resides on the cloud which minimizes the power consumption. Our system requires 1 Watt compared to Sensorweb which requires power for the PC/laptop and webserver.

The other related irrigation control system described by the University of Florida [1] was based on a modified irrigation controller and switching tensiometer as the soil moisture trigger. It is difficult to change the range of the soil moisture using this system based on how it connects to a modified regular irrigation system. Also, this system does not provide a web interface and thus there is no real-time data visualization and control.

There is a strong interest in automatic irrigation in nurseries using sensors which will result in more efficient water use [3–5,14–16,19]. This project evaluated an automated irrigation system for container nurseries which can be controlled either manually or based on data from soil moisture sensors. The system does not need to be variable rate as it also monitors soil moisture in real-time when the system starts to irrigate. The system has advantages over other irrigation control systems in that it can connect directly to a standard WiFi (802.11 b/g/n) network which is widely used and there is no need for an additional gateway, special routers, or virtual serial Internet Protocol. The IoT system was used to irrigate blocks of container-grown plants exposed to three soil moisture levels.

The system described in this paper was built as part of a grant project. The objective of the project was to correlate the level of water stress with aerial images using a multispectral sensor. To establish and control the water treatments we needed a system that could either manually or automatically control the irrigation system remotely. The system developed for these experiments is a proof of concept and unlike previously developed systems (e.g. Acclima; Sensorweb) and uses an open platform based on the IoT. The overall requirements in developing the system were: (1) irrigation controller that could monitor soil moisture and temperature data on multiple pots, (2) based on an open platform using IoT, (3) rugged and able to perform under outdoor nursery conditions, (4) user friendly, (5) data accessible on the cloud for easy visualization, and (6) able to remotely control irrigation valves and change thresholds for the soil moisture trigger.

## 2. Materials and method

### *2.1. System design requirements*

The following are requirements for the automatic irrigation system: 1. Able to irrigate 225 pots, 2. Monitor 9 soil moisture sensors with 3 soil moisture sensors for each moisture treatment, 3. Irrigation may be remotely controlled 3a. manually, or 3b. using the soil moisture data, and 4. Multiple users can view the real time data from both sensors and valves.

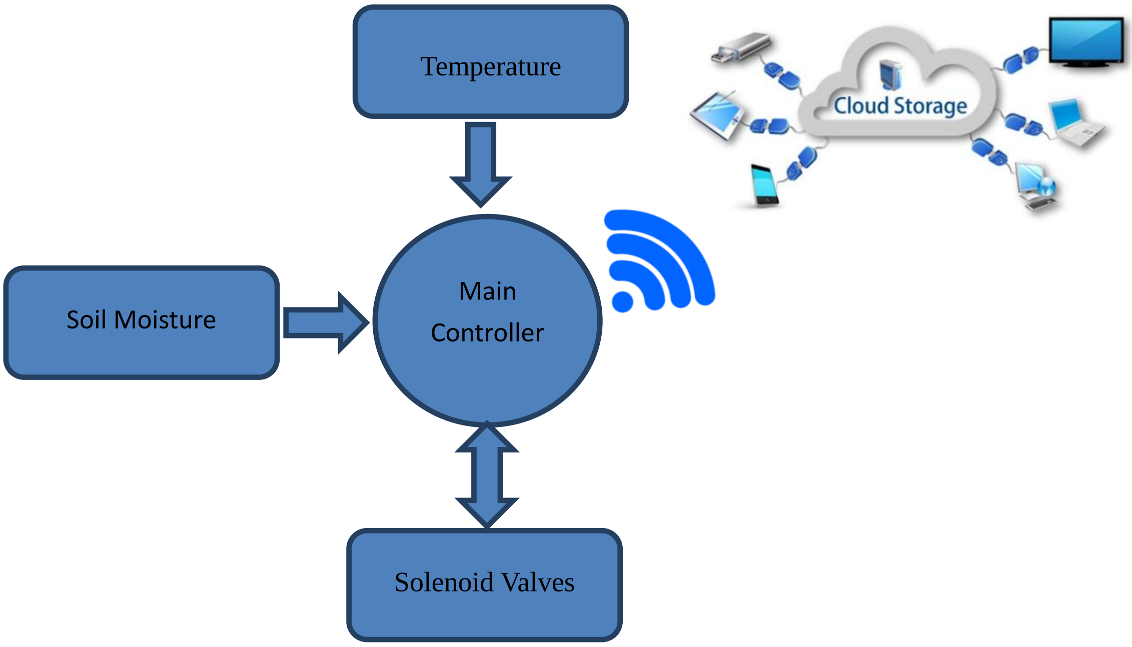


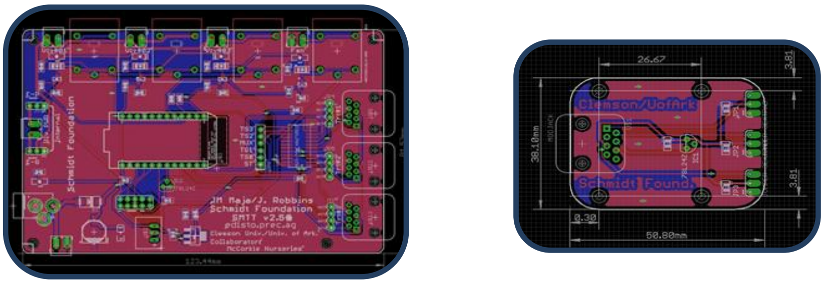
**Figure 1**. Schematic flowchart for automatic irrigation system.

Figure 1 illustrates the schematic design of the automatic irrigation system. It consists of interfaces to the soil moisture sensors, temperature sensors and triggers for solenoid valves. The system also connects to a WiFi network where the data and information are uploaded to an IoT platform (ubidots, Ubidots LLC, FL, USA). Data from the IoT platform were used to create a graphical user interface (GUI) to visualize real time data from the system. There are two GUI created for this system, the first GUI was a visualization GUI where data from soil moisture and temperature sensors, and state of the solenoid valve were plotted in real time. The second GUI is an administrative GUI which controls the overall power, and to update the setting of the soil moisture trigger threshold. All data were then uploaded to the cloud with 10–15 seconds interval.

### *2.2. Main controller*

The irrigation systems used a microcontroller (STM32F205, ST, Geneva, Switzerland) due to its high-performance 32-bit Flash based on ARM Cortex-M processor. It comes with a 1 Mb flash and 128 Kb of Random Access Memory (RAM). The microcontroller has multiple serial ports and General Purpose I/O pins that could be configured for digital and analog signals and has built-in eight analog channels with 10-bit resolution. The microcontroller code was developed to enable the microcontroller to read data from the temperature sensor and soil moisture at pre-determined intervals. The system used an ARM Cortex M3 microcontroller with a Broadcom Wi-Fi chip.

The main printed circuit board layout (Figure 2a) is 123.4 mm × 81.5 mm with a 2.4 GHz ceramic internal RF antenna. For this project, an external antenna was used to increase the coverage of the Wi-Fi reception. The control of the irrigation system was implemented using C Language.



(a)

(b)

**Figure 2**. (a) Main controller board layout, and (b) extender board with a temperature sensor.

The main controller board consisted of 3 RJ45 connectors for the soil moisture and temperature sensors, 4 relays (3 for the water solenoid valve and 1 for the fan inside the controller box). The microcontroller has only 8 analog to digital converter (A/D) pins but the main board needs a total of 13; 9 for soil moisture sensors, 3 for temperature sensors located on each of the three extender board (Figure 2b) and 1 temperature sensor at the main controller board. A quad-analog multiplexer (MC74HC4067, On Semiconductor, CO, USA) was used to increase the number of A/D pins to accommodate the total number of A/D required pins for the design. Five of the original A/D pins of the microcontroller were used as address selector (4) and (1) enabled pin which creates 16 additional A/D pins ($2^4 = 16$). Four (G*n*T*m* [*n=1…3, m=1…4*]) of the sixteen A/D pins where routed to each of the RJ45 or ModJack connector as shown in Figure 3.

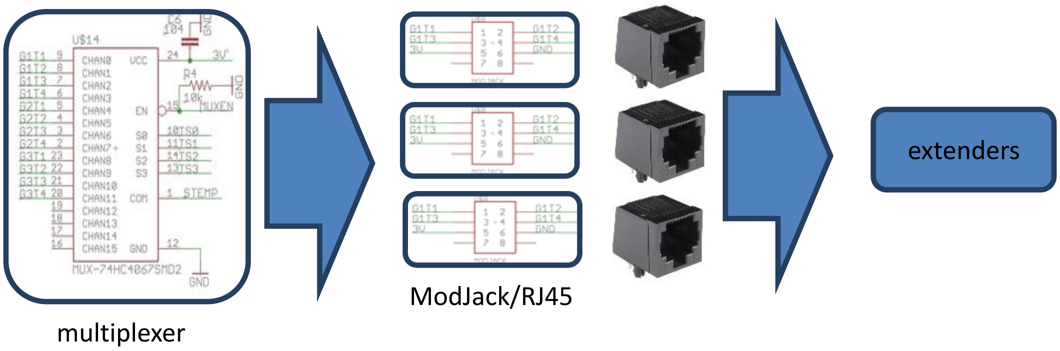


**Figure 3**. A quad analog multiplexer was used to increase the number of adc pins of the microcontroller.

The main controller board temperature sensor (TMP36, Analog Devices, MA, USA) is located at the bottom of the main controller. The temperature sensor was used to measure the temperature of the box where the controller board will be located to trigger the exhaust fan on the box once the temperature exceeded 27 °C. The extender board (Figure 2b) provides an easy to connect multiple soil moistures to the main controller. A standard RJ45 cable was used to connect the extender board to the main controller board. The extender board used a servo cable (3 pin) connectors to connect three soil moisture sensors. A 3.3V power supply was used for the soil moisture and temperature sensor in the extender board.

### *2.3. Soil moisture sensor data and water weight*

A capacitance soil moisture sensor was used to measure the soil moisture of the container substrate. The soil moisture sensor is custom-built capacitance type with an added temperature sensor. The capacitance pads were moved to the bottom layer to minimize the electromagnetic interference with the temperature sensor located on the top layer of the sensor. The soil moisture sensor can be powered by 3.3 V to 5 V DC and has an output voltage from 0~3.0 V DC. The sensor was positioned 10 cm away from the stem and 50 cm below the substrate surface. Soil moisture thresholds were established in a preliminary experiment based on three container-grown plants using the same substrate and size of container plants at McCorkle Nurseries (wilting experiment). The amount of available water was determined in a preliminary experiment using tomato (*Lycopersicon* x BHN602; Bonnie Plants, Union Springs, AL) plants following the methods of Argo and Biernbaum [2]. The preliminary study was conducted in a climate-controlled glass greenhouse at the Clemson University, Edisto Research and Extension Center, Blackville, SC. Three tomato plants were grown in #2 containers (PF 800, 23.5 cm top diam. × 18.5 cm bottom diam. × 23.8 cm height, Nursery Supplies, Chambersburg, PA) with the same substrate used in the main experiment. The preliminary experiment was initiated when the roots of tomato plants reached the outer wall of the container. At 0900 on 17 May 2017 all plants were watered thoroughly and then allowed to sit for one hour to establish a container capacity (CC) weight. Following this, no additional water was supplied to these plants. Over the next 2 days, tomato plants were monitored hourly during work hours to observe the first signs of visible wilt and containers with plants were weighed and the moisture sensor reading noted (Figure 4). The difference between the CC and wilt weight was used as an estimate of the total amount of available water held in the root media. Available water and sensor readings for the 3 replicates were averaged and a regression analysis performed on the mean values. The calculated available water was used as the target sensor reading in the main irrigation experiment for the #2 containers at the nursery.

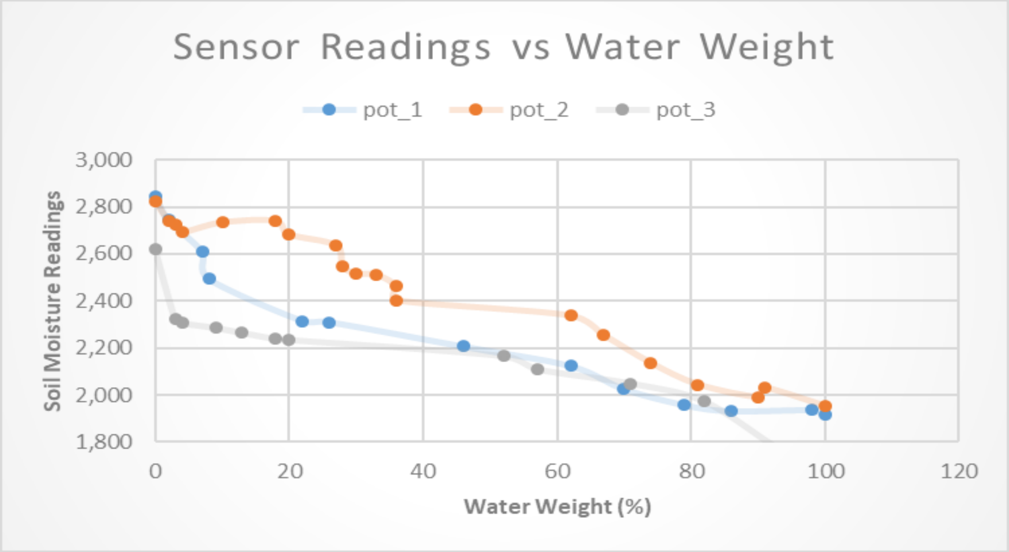


**Figure 4.** Sensor reading and water weight plots results during the wilting experiment.

### 2.4. Firmware and software

Two programs were written for this project, one for the main controller board (firmware) and the other for the visualization and control (software). The firmware is based on the microcontroller used and provides a low-level programming which pulls data from the sensors and also provide triggers for the solenoid valves and fan when certain conditions are met. The software side technically is using data on the cloud to visualize and to control the main controller as depicted in Figure 5.

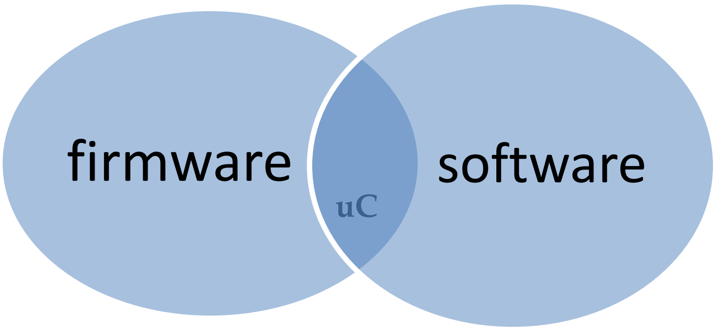


**Figure 5**. Firmware and software shared activity with the main controller (uC = microcontroller).

The firmware pulls sensor data and transmits the following messages; $temp_1$, $temp_2$, $temp_3$, $sm_1$, $sm_2$, $sm_3$, $w_1$, $w_2$, and $w_3$ to the cloud. Each transmission automatically concatenates the date and time of the transmission.

- $temp_1$, $temp_2$, $temp_3$ = temperature data from extender 1, 2, and 3.
- $sm_1$, $sm_2$, $sm_3$ = average of the three soil moisture data in extender 1, 2, and 3.
- $w_1$, $w_2$, $w_3$ = triggers status for each solenoid valves (1 = ON, 0 = OFF)

The designation (*1~3*) of temperature, soil moisture and trigger status was due to the three treatment that was used for the experiment.

The firmware flowchart is shown in Figure 6. The firmware was written in C programming language and constantly runs in an infinite loop. It will only start to re-initialize if power is either restored or if the system has been rebooted. Over the entire project the firmware has been updated five times to address some issues related to the development of the system, e.g., random data from the cloud when the main controller board initiate to download cloud settings. Note that the main controller firmware still works even if the WiFi connection is down.

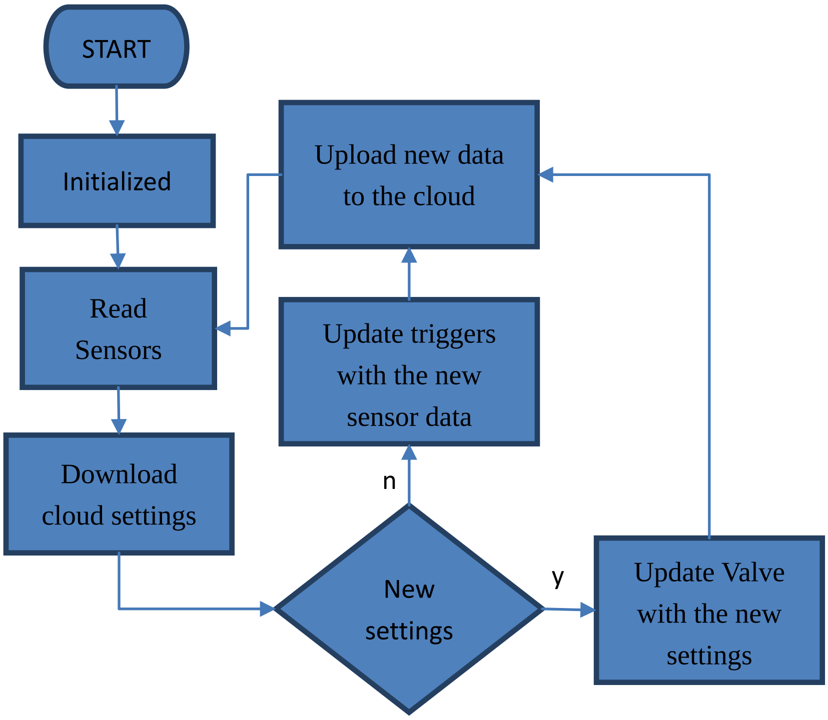


**Figure 6**. Firmware flowchart for the main controller board.

The software flowchart (Figure 7) main function is to process the new data uploaded by the main controller board and is checked if there are new control settings updated on the dashboard. Aside from the visualization, control to the main controller was designed as “settings”, so when the main controller is connected to the cloud it downloads settings and compares the current to the newly downloaded settings thus performing necessary actions based on that settings. Potential settings can be: turning on valves, fan or turning off the automatic irrigation. All controls can be accessed through the dashboard.

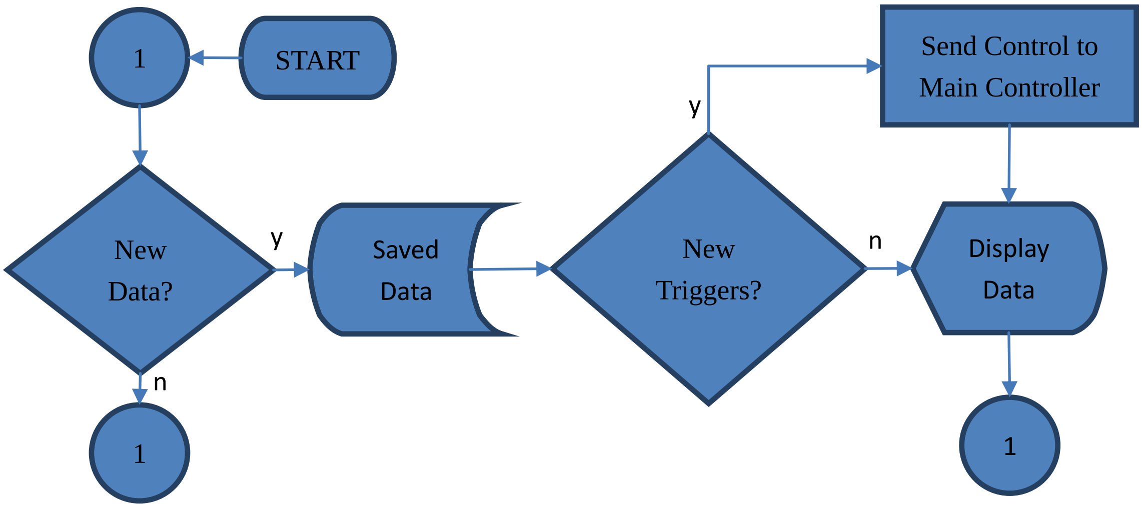


**Figure 7**. Software flowchart for the dashboard.

### *2.5. Dashboards*

The dashboard was created to configure data received from the main controller board and also control the valves and fan which are attached to the main controller. There are three dashboards created for this project: visualization, valve control, and threshold settings. The visualization dashboard is for public access where anyone can view the data in real time. The two control dashboards can only be accessed by the administrator and provide control to the valves and threshold settings (Figure 8).

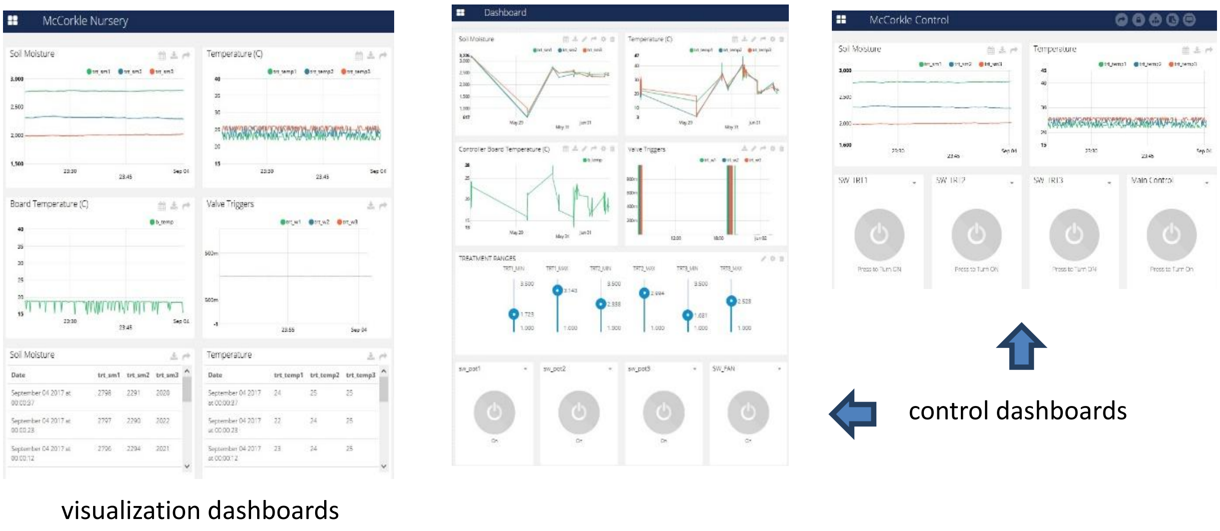


**Figure 8**. Dashboards created for this project.

### *2.6. Scalable system*

The system was installed at McCorkle Nurseries, Dearing, GA (33.359882N, 82.393853W). There were a total of 225 pots grouped into blocks of 25 for three irrigation treatments and three replicates. Each treatment used three soil moisture sensors and one temperature sensor. Based on the results from the preliminary greenhouse experiment, available water thresholds of 10%, 60%, and 80% were used as trigger values for this experiment. Figure 9 shows the experimental layout with the control box located on a post near the pots.

**Figure 9**. System installation at McCorkle Nurseries.

The current system can be used and is easily scalable. Additional sensors can be added and the dashboard can be easily configured for other threshold values. The control setup can be easily relocated and use the same dashboard.

## 3. Results and discussion

The dashboard was tested for the duration of the project at McCorkle Nurseries. The control board was setup to use McCorkle's WiFi during the first two weeks of installing the system. Unfortunately, there were issues with the intermittent connectivity due to the firewall and security on the nursery system. To resolve this issue the control board was re-configured to use a 4G LTE (ZTE Mobile) Hotspot. Updates were mostly in real time and displayed all the pertinent information as shown on the dashboard. Since McCorkle Nurseries is about 1.5-hour drive from the Clemson REC, having a remote-based system allowed for an efficient method to address issues in a timely manner. At least once per week the system was remotely accessed to verify the system was working as programmed. Part of the system check involved controlling the valve manually via the dashboard and verifying the soil moisture response. The test provided a quick assessment on the state of the whole system (control, sensor, and irrigation). For example, on one test, the soil moisture response was very slow as compared to when the system was initially installed. The problem was identified as a broken irrigation tube which resulted in not enough water going to the pots where the soil moisture sensors were installed. This maintenance event happened about three times over the duration of the project.

Another unexpected system issue involved the connection between the extender board and soil moisture sensors which is sensitive to water. Water corrodes the metal connectors and thus needed to be cleaned regularly. To address this issue the board was wrapped with plastic to minimize the water issue. Overall, the system performed well under real-world condition for four months. There was only one issue that caused a complete system shutdown and this was due to a total power outage at the nursery.

## 4. Conclusion

An irrigation controller using the internet of things (IoT) was developed. The controller is a closed-loop design which uses the soil moisture data to turn on and off the irrigation system based on specified thresholds. The data and control were hosted on an online IoT platform. The IoT platform provides real-time monitoring and control via a simplified online Graphical User Interface (GUI) or dashboard. Though several issues were identified through field testing of the system these were resolved fairly easily. The experiment demonstrated the value of this simple system to remotely operate an irrigation system under nursery conditions. The system has advantages over other irrigation control systems in that it can connect directly to a standard WiFi network which is widely used and there is no need for an additional gateway, special routers, or virtual serial Internet Protocol.

The implementation of the system met the goals for the following requirements as mentioned above. Overall the system (1) was able to monitor soil moisture and temperature data on multiple pots, (2) was implemented based on an open platform using IoT, (3) performed well under outdoor nursery conditions, (4) was user friendly, (5) data was accessible on the cloud for easy visualization, (6) was able to remotely control irrigation valves and change thresholds for the soil moisture trigger. Success of the research was determined based on an assessment of the six objectives outlined for this project. During the four month field test a number of system challenges were identified including signal transmission and hardwire connections.

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## Conflict of interest

All authors declare no conflicts of interest in this paper.

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