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Towards Efficient Irrigation Management With Solar-Powered Wireless Soil Moisture Sensors and Real-Time Monitoring Capability

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Abstract

Judicious use of water for irrigated agriculture is going to be paramount for sustainable intensification to meet the food demands within the realistic constraints of available land, water, and other resources. Water and nutrient use efficiency are the key goals of the ongoing efforts in smart agriculture led by the primary author at the University of Maryland Eastern Shore (UMES).

Recently a subsurface drip irrigation (SDI) system has been installed on a 15-acre farm at UMES. The SDI system has 20 zones for which the user can activate valves to turn the water on and off in the drip lines. In this paper, we will report the preliminary efforts in deploying a solar-powered wireless solar-powered soil moisture sensor network in the field. The network uses a cellular gateway to transfer the field data to the web. The data can be viewed in real-time on the web. The installation details and conditioning of the sensors will be highlighted. The smart farming research team is also looking into installing compatible rain gauges in the field and instrumenting the set-up for automated activation of the valves to turn the water on and off in the drip lines based on soil moisture readings. Online real-time monitoring capability proved useful for demonstrating the set-up to undergraduate students in the online junior level "Instrumentation course (ENGE 380)" offered by the author in fall 2020 using screen sharing capability of the Blackboard Learning Management System (BLMS). Two students attending the class have been involved in supporting a graduate student for the preliminary field deployment efforts outlined in the paper. It is anticipated the exposure will generate interest among other undergraduate students to participate in the extensive field instrumentation efforts in the ongoing smart agriculture program at UMES. In addition to exposure to smart agriculture field instrumentation, the students in ENGE 380 class also got hands-on experience with sensors and instrumentations take-home kit based on Arduino-microprocessor board.

At the time of writing this paper soil moisture and temperature data has been collected for over two weeks from more for more than three dozen sensors that have been deployed in the field in different zones of the 15-acre field for a preliminary trial. The field which uses corn, soybean, and wheat rotation, was growing soybean during the preliminary trial reported here. A six-band multispectral camera that simultaneously images in the visible, near infra-red, and thermal bands have also been flown on a DJI Inspire II drone to collect aerial imagery.

1.0 Introduction

According to United Nations Educational, Scientific, and Cultural Organization (UNESCO), only 20% of the cultivated land is irrigated and provides 40% of the global food basket, the rest of the 80% of farmland is rain-fed and accounts for only 60% global food basket [1]. Growth in world food demand will reflect the population growth, which is anticipated to be around 10 billion by 2050. Limited availability of arable land and increased food demand can be met by bringing more arable land under irrigation and sustainably managing water and other inputs [2]. The selection of irrigation technologies and management strategies involves a variety of considerations [3]. It may be worthwhile mentioning here that UMES is an 1890 land grant Historically Black Institution (HBI). It has more than 350 acres of farmland which is largely rain-fed. Center Pivots and Subsurface Drip Irrigation (SDI) lend themselves to be used sustainably for row crops using precision irrigation technologies that can conserve water use without adversely impeding crop yield [4]. SDI systems are more expensive but limit soil surface wetting and can lead to a significant reduction in evapotranspiration (crop water use) [5]. This has been one of the key considerations behind installing the SDI system in one of the 15-acre farms in the UMES Agriculture Experiment Station. The SDI system has 20 zones for which the user can activate valves to turn the water on and off in the drip lines to implement precision irrigation based on sensor feedback. Installation of the solar-powered wireless soil moisture sensor network stems from the desire to determine the variable irrigation needs in the different zones and develop a demonstration platform for precision irrigation management for sustainable intensification [6].

2.0 Solar Powered Wireless Soil Moisture Sensor Network Deployment

In fall 2020 preliminary efforts of field deployment of wireless solar-powered soil moisture sensor network and recording of data for the 15-acre SDI field on campus was initiated. Irrometer's IRRO*mesh* IoT solution offers an affordable, and real-time soil water management solution. The IRROmesh system has an array of relay nodes communicating with each other using a radio communication vehicle in the Fresnel Zone transmitting data to the base station node. There are several ways the data can be retrieved from the base station. The data can be logged on a data-logger and retrieved manually with a laptop computer; the base node can be wired to a PC-Link and the PC Link can connect to a computer within 400 ft. of the base via USB cable and the data can be streamed to the internet; or, data can be automatically transferred to the internet by a cellular gateway, where it is viewed and stored using the SensMit platform (http://www.otaconsystems.com/sensmit/) that utilizes LoRa technology [7]. Since the SDI field and most of the other agricultural fields in the UMES campus are somewhat remote where the campus Wi-Fi is unable to reach, the option that used a cellular-gateway was chosen. A schematic from the IRROmesh manual is reproduced in Figure 1 for ready reference. The interested reader can find additional information at the URL (https://www.irrometer.com/pdf/instruction-manuals/IRROmesh/745%20IRROmesh%20Manual-WEB.pdf).

Each zone of the SDI field covers 12 rows of crop and is approximately 300 feet wide. A node was placed in each of the 18 zones and two Watermark Granular Matrix Sensors(GMS) were embedded within the top three inches of the surface spread across the zone to monitor the soil moisture status of the zone. Each node also has an internal and external temperature sensor. In general, each node can be wired to three soil moisture sensors, a rain gauge, and an irrigation on-off switch. Future plans include attaching rain gauge sensors to one or two nodes and irrigation switches to all of the nodes. Watermark Soil Moisture Sensors are about 3 inches long (Figure 2) and are normally inserted in the ground vertically. The resistance of GMS sensors decreases with wetness. As the soil dries out, the sensor dries out, and resistance to the flow of electricity increases. The resistance to the flow of electricity and the soil temperature is used to determine soil water tension (SWT) in centibars (cb). SWT is the pressure needed for plant roots to extract water from the soil. Larger SWT values indicate drier soil with low soil moisture content. SWT of

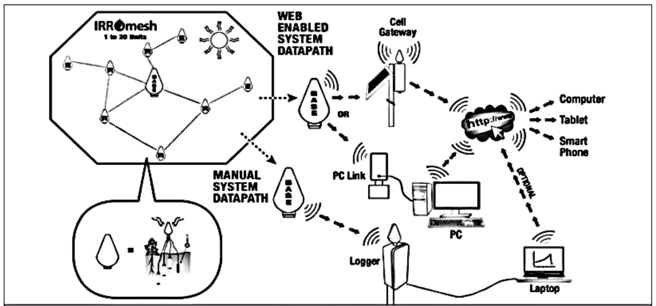

Figure 1: IRROmesh Data (Gateway, PCLink, Manual)

Figure 2: Watermark Soil Moisture Sensor

the GMS sensors parallel the interaction of plant roots with soil. As a rough rule of thumb 0-10 cb indicate the soil is saturated, 10-20 cb indicate that most soil types are adequately wet except coarse sand, 30-60 cb is the range of SWT for most soil types (except clay soil) and crops to begin irrigation, 60 -100 cb usual range for irrigation for heavy clay soil, 100-200 cb is dangerously dry soil and will inhibit all crop growth and should be avoided. The specific recommendations vary with soil type and crop. Interested readers can find additional information at the URL (https://www.irrometer.com/basics.html).

Users can log in to a cloud-based web service that receives and processes wireless network data at the URL (https://sensmitweb.com/account/login) which is hosted at Amazon Web Services (AWS) Domain Name System (DNS) site. Users can then view, extract, and manage data, as well as, chart and display results. The GPS latitude and longitude coordinates of the node locations can be entered for each node in SensMit and the software uses satellite imagery to show the location of the node in the image (Figure 3). Figure 4 shows the locations for all 18 nodes in the satellite image of the UMES SDI field after GPS values are entered for all of the nodes. Figures 5 and 6 are actual photographs of the base node and cellular gateway, and, the relay and end nodes in the preliminary test set up in the UMES campus.

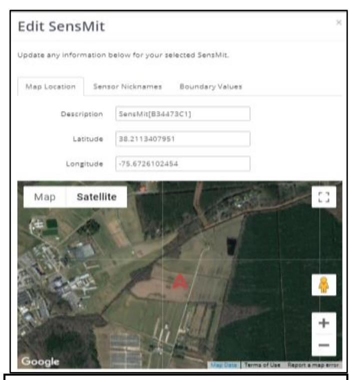

Figure 3: A Node Location

Figure 4: All Nodes

Figure 5: Base Node

Fig 6: Nodes in field

Figures 7 and 8 show the screen capture of the web interface of the data from two soil moisture sensors and external and internal temperature sensors, associated with one of the nodes in the field, beginning mid-September to early November 2020. As expected the two soil moisture sensors

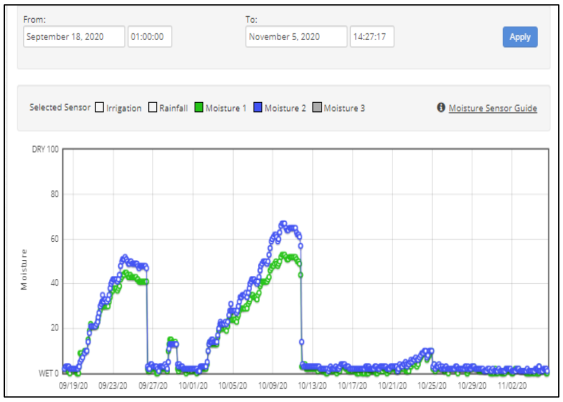

Figure 7: Soil Moisture Sensor Data

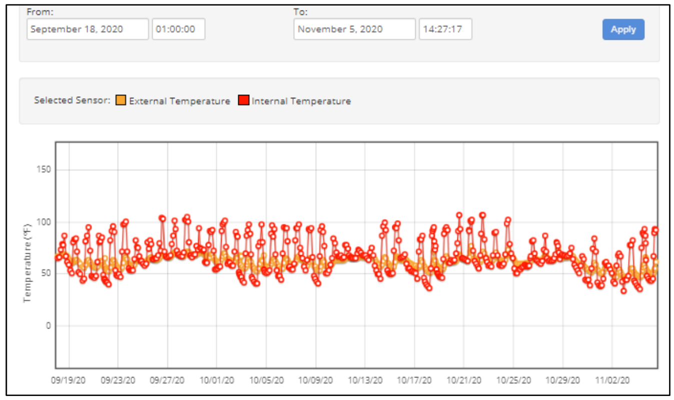

Figure 8: Node Temperature Sensor Data

track one another and the variations are correlated with the precipitation patterns in the area. As mentioned each node can be interfaced with a rain gauge sensor and the precipitation data can also be recorded and transmitted wirelessly to the internet. The external temperature sensor (yellow) tracks the temperature patterns, it should be noted however the internal temperature sensor in the node experiences a greenhouse effect resulting in the daily daytime spikes in the recorded values.

The set-up also records the voltage of the photovoltaics at the node. The daily variations of the voltages recorded at one node are shown in Figure 9 from September 18 to September 21, 2020. As expected the voltage rises in the daytime with the sun and drops in the night as captured in the recorded data. A six-band multispectral camera (Altum) was flown on a DJI-inspire II multirotor drone over the field (Figure 10). For the growing season soybean was planted in the field which undergoes corn, soybean, and wheat rotation. The six band sensor of the Altum camera captures images in blue, green, red, red_edge (visible), near-infrared (NIR), and thermal band (11µm). The drone imagery was processed using mapping software (Pix4Dmapper). The visible bands provide information on crop health and are routinely utilized by the smart farming research team at UMES for nitrogen management. The thermal band captures the crop canopy

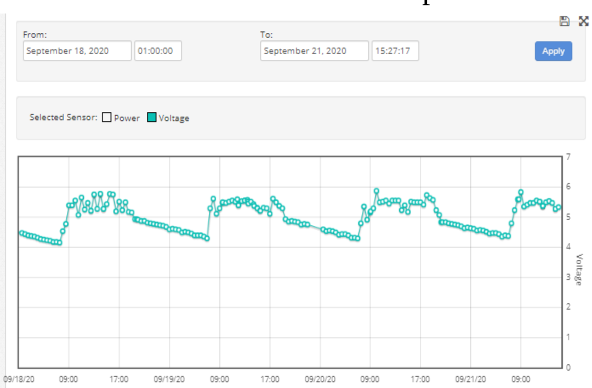

Figure 9: Daily variation of Node Voltage

Figure 10: Drone & Multispectral Camera

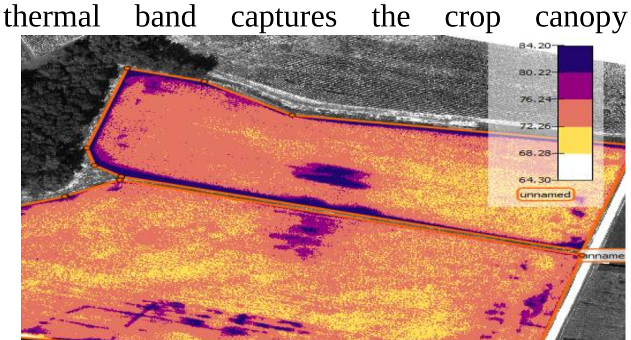

Figure 11: Thermal Image of Field

temperature. Crop canopy temperatures are likely to vary with crop water stress and soil moisture levels. For the field thermal image captured in September 2020 (Figure 11), there was very little variation in canopy temperature for the region from which soil moisture data was being recorded in the field. Additional field trials will be undertaken with the set-up during the early stages of growth of the corn crop next summer. The preliminary field trial has been very educational for the graduate student and two undergraduate engineering students who were involved with the effort. The undergraduate students were also students in the Instrumentation course (ENGE 380) that the author offered to juniors in the engineering program at UMES in fall 2020. For the interested reader, the syllabus of the course is available at the URL Instrumentation (ENGE380) Syllabus .

3.0 Pandemic Related Adaptation of Instrumentation Course

Fieldwork reported here was conducted with appropriate social distancing and safety protocols. The undergraduate student assistants readily acknowledged the relevance of the experience with the course material. The campus administration decided to advance the semester by two weeks due to the pandemic so that the semester did not stretch beyond the Thanksgiving holidays and encouraged faculty to offer all courses remotely. Instrumentation, as well as other courses offered by the primary author, were taught remotely using the Blackboard Learning Management System (LMS). The cloud connectivity of the wireless solar-powered soil moisture sensor network allowed the author to demonstrate project results to all the students in the Instrumentation course by screen sharing. It may be worthwhile mentioning here, to provide an exciting hands-on component albeit remote in the Instrumentation course, all students in the course were provided an Arduino UNO microprocessor board kit with a few sensors and actuators (Figure 13) [8]. The kit was integrated with the project assignment in the class (see Appendix –I). As outlined in the project assignment besides other aspects of the project which included familiarizing themselves with the sensors on instrumentation on board some of the NASA satellites (NASA/JPL Earth Now) and AC and DC PHET circuit simulations (https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-ac-virtual-lab) students got together in teams of 2 and interfaced the various sensors and actuators in the kit with the Arduino UNO to get familiar with the Arduino microprocessor board and the Arduino IDE. The Grove-Shield that came with the kit allowed students to connect all components with the four-wire connectors provided without any need for soldering. It is anticipated the hands-on exposure with the Arduino kit will generate interest among the students to participate in the NASA Rock-On program. The Rock-on program provides students experience to build an experimental payload using the Arduino microprocessor board, sensors, and instrumentation for deployment in a Sounding Rocket flight (https://www.nasa.gov/centers/wallops/education/students/opportunities/rockon/index.html).

Figure 13: Grove Starter Kit for Arduino

The students used the office hours, the course room in Blackboard, screen sharing, and other capabilities of the LMS to come up to speed. Each team also came up with a novel implementation that integrated as many of the sensors and actuators in the kit as possible. Student teams could also participate in ongoing field projects on campus with appropriate safety precautions, as an extra credit option. As mentioned before a couple of the students from the Instrumentation course participated in the field layout of the wireless soil moisture sensor network and data recording related efforts outlined in this document in an earlier section. In the last week of the semester, all teams gave a project presentation on Blackboard by screen-sharing. The quizzes, exams, and tests were conducted on Blackboard using “Lockdown browser” and “Respondus monitor”.

4.0 Learning Outcomes and Future Plans

Given challenges related to the pandemic, the preliminary field implementation trial with a solar-powered wireless soil moisture sensor network went fairly well. The students involved with the project readily agreed they learned a lot from the experience. The information on the vendor’s website and the technical support staff provided a lot of information in advancing the installation efforts. Future plans include interfacing a couple of compatible rain gauge sensors at selected nodes for wireless monitoring and recording of the precipitation data for the field. Students and farm personnel will work with the primary author to develop autonomous activation of the irrigation valves for the appropriate zones based on soil moisture sensor readings for judicious management of irrigation water while enhancing crop yields. A faculty member in the Aviation program at UMES conducted the drone flights for acquiring the multi-spectral imagery that was processed by graduate students in the smart agriculture project team. More effort will be devoted to refining the drone aerial imaging efforts and in particular correlating the thermal imaging data, with crop water stress, and soil moisture data at an appropriate stage of crop growth.

The field efforts described and the remote implementation of the Instrumentation course with active learning components have provided undergraduate engineering students with a broad exposure that transcends traditional disciplinary boundaries and is strongly aligned with the ABET learning outcomes 5 through 7 [9].

Most students in the Instrumentation course have indicated they learned a lot from the course and were pleasantly surprised with the active learning components that were integrated with the remote implementation of the course. Although only two students in the class were actively engaged in the field efforts related to the preliminary test set-up for the wireless soil moisture sensor network, all students got to learn about the set-up details and could see the live data readings of the field sensors using the web interface during a class presentation.

All tests and quizzes for the course were administered using “Lockdown Brower” and “ Respondus Monitor” (https://web.respondus.com/wp-content/uploads/2019/08/RLDB-Quick-Start-Guide-Bb-Student.pdf). There was some pushback from the students concerning the requirement for using “Lockdown browser” and “Respondus monitor” for taking exams, however, it was decided to persist with them to enforce the integrity of the assessment process despite logistics challenges.

5.0 Acknowledgment

The funding from the Maryland Space Grant Consortium (MDSGC) and National Institute of Food and Agriculture (NIFA) for student support and capacity building for advanced technology-driven educational and research efforts in smart farming and precision agriculture are gratefully acknowledged. Support from the UMES aviation program and farm personnel is also acknowledged with thanks.

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Appendix I

INSTRUMENTATION (ENGE 380) FALL 2020

Project (ENGE 380) Due: November 9, 2020(10 AM) or Earlier

1. Get together as teams (of 2) and plan steps to execute the class project as outlined below
2. Provide a plan and progress report by September 30 for execution goals
3. Prepare final presentation and short report by November 9, 2020(10 AM). [Have fun while you learn!]

(I)BASIC SENSOR AND ARDUINO UNO INTERFACE

Using the kit with Arduino UNO, Grove Shield and Sensors & Accessories learn basic interfacing of each component with the Arduino board and document the results. (see https://www.youtube.com/watch?v=1Rc_OiebDPo for an introductory video demo)

In discussion with your team come up with a plan that will demonstrate the use of as many of the kit accessories and sensors together to implement a project idea of your choice (without purchasing any additional items).

Extra Credit: Within a limited budget of $15 identify additional sensors (or other items) to implement an innovative Arduino-based project involving any sensor data-acquisition and related application.

The following URL will provide a basic introduction to Arduino and Grove Shield and Sensors. All team members should download the Arduino IDE on their laptops to learn basic coding with Sketch and Arduino basics. Arduino IDE can be downloaded from)

https://www.arduino.cc/en/Guide/HomePage https://www.arduino.cc/en/Main/Software

http://www.seeedstudio.com/document/pdf/Introduction%20to%20Grove.pdf

(II)AC DC Circuit Simulations

As discussed in class download the PHET simulation software for circuits from the URL below:

https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-ac-virtual-lab

- Demonstrate the use of the simulation tool for DC circuits with resistors in series and parallel. Also, simulate a Wheatstone bridge circuit and demonstrate half-bridge and full-bridge implementation. Confirm simulation results observed using Ammeters and/or Voltmeters with hand calculations.
- Demonstrate the use of the simulation tool for RLC series and parallel circuits with AC source voltage as discussed in class. Confirm simulation results (amplitude, phase, and any other appropriate outputs) by hand calculations.
- Solve RLC circuits in series and parallel in AC that were discussed in class using the simulation tool. Validate simulation results by hand calculations.

(III) Download Earth-Now (JPL/NASA) App on your laptop/tablet/cell-phone. Observe all the vital signs related to sensor data captured by the satellites. Explore the web documentation and other sources to document briefly the sensors that NASA/JPL uses to capture these data.

EXTRA CREDIT OPTION (Document your efforts properly in your report for credit consideration. Make sure you follow all safety and social distancing protocols)

(a) Download any acceleration measurement app on your cell-phone (Sensor-Kinetic) is what I have on my cell-phone. The paid version cost me 99 cents and it allows me to capture linear acceleration and rotational acceleration data that can be uploaded on EXCEL.
(b) Using a similar app record data of a short ride in your car. Interpret the data about when you have pressed the accelerator and/or brake pedal.
(c) Work on CAUTION to get it ready for field data collection (discuss with Jewell and Brandon if you want to get involved with this). The set-up needs to be fixed and sensors for environmental data collection appropriately interfaced.
(d) Work with PixHawk, Mission Planner, and RTK GPS integration with Unmanned Ground Vehicle project. Interface and calibrate a PAR (photo-synthetically active radiation sensor) on the system to record geo-located sensor data on an SD card on Arduino UNO. Discuss with Mr. JesuRaj Pandya and me to get more information if you would like to assist.
(e) Work with the installation of a solar-powered wireless soil moisture sensor network with Mr. Travis Ford and me.