A Low-power Wireless Sensing Unit for Hydro-System Automation

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***Abstract*—Farms, greenhouses, orchards, ranches, and vineyards are all dependent on irrigation systems. Modern irrigation systems are equipped with an assortment of water reserves, sheds, and tanks to store water for later use or to manage the flow, time, or quality of the water delivered to the crops. In comparison to expensive, huge, complex, proprietary, cloud dependent, often manual, and very energy hungry industrial solutions out on the market, Hydro-System Automation (HA) is a cheaper, smaller, simpler, modular, smart, and sustainable Hydro-System. The design entails sensing and actuating units as well as a wireless communications subsystem between said units. The Sensing Units (SU)s are composed of cheaper, smaller, simpler, and more sustainable sensors, micro-controllers, electronics, solar panels, and batteries than those used in current industrial solutions available. Future SUs will be packaged in 3D-printed casings which are cheaper to produce, can be custom fabricated to incorporate specific designs, fit in tight spots, and meet a variety of environments, installation requirements, and quality standards. The Actuating Units (AU)s are composed of automated pumping and/or valve stations which are powered via solar panels. The wireless communications sub-system is responsible for maintaining the overall cohesion of the system via a custom routing protocol atop a transport layer such as LoRa and a wireless physical layer utilizing RFM95 Radio Modules in the 915/916 MHz frequency band. Prototypes of the SUs have proven the cost effectiveness, simplicity, and energy efficiency of their design.**

***Index Terms*—Agriculture, Automation, IoT, Irrigation System, Water Tank, Wireless**

I. Introduction

Agriculture is dependent on water. Farms, greenhouses, orchards, ranches, and vineyards are all in need of irrigation systems. Modern irrigation systems are equipped with an assortment of water reserves, sheds, and tanks to store water for later use or to manage the flow, time, or quality of the water delivered to the crops.

Irrigation systems are a strong candidate for agricultural automation via an Internet of Things (IoT) approach [1]–[3] as they include many mechanical components such as pumps and valves that lend themselves well to automation and control. Pumps can be turned on when more water is needed in the system and turned off when the system is full or off duty. Valves can be opened or closed based on sensed need in the system or an optimal irrigation schedule [4] that changes when seasons change or when crops are rotated. For example, a rancher who rotates his live stock between different pastures (graze lands) will have need for an irrigation system which diverts water to the currently in use pasture only. Hence certain water tank(s) will need to be filled and kept filled via a certain chain of valves that open and close at the appropriate times as well as certain pump(s) which turn on and off at the correct times when the valves are opened or closed. Many industrial grade irrigation system solutions exist which utilize complex, over sized, energy inefficient, and cost prohibitive components. Such solutions are thus only accessible for purchase, installation, and maintenance to big agribusiness or well-off customers. This leaves out smaller local farms and ranches as well as nearly the entire agriculture of the developing countries where farmers and ranchers are forced to utilize more labour intensive yet less energy efficient and/or less environmentally friendly methods of transporting water from the source to their crops [5].

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In this paper, we present the design and development of cheaper, smaller, simpler, modular, smart, and sustainable Sensing units (SUs) as part of a larger Hydro-System Automaton project. HA is a phased project which as a whole is beyond the scope of this paper. From a bird's eye view, the project design entails sensing and actuating units as well as wireless communications between said units. The Sensing Units (SU)s are composed of cheaper, smaller, simpler, and more sustainable sensors, micro-controllers, electronics, solar panels, and batteries than those used in current industrial solutions available. The SUs are also to be packaged in 3D printed casings which are cheaper to produce, can be custom fabricated to incorporate specific designs, fit in tight spots, and meet a variety of environments, installation requirements, and quality standards. The Actuating Units (AU)s are composed of automated pumping and/or valve stations which are powered via solar panels. The wireless communications sub-system is responsible for maintaining the overall cohesion of the system via a custom routing protocol atop a data-link layer such as LoRa and a wireless physical layer utilizing RFM95 Radio Modules operating in the 915 MHz frequency band.

This paper is solely focused on the SUs which prototypes of have successfully been designed, built, and field tested. The Communication subsystem is currently under development and testing and the AUs are still in the prototyping phase. AUs and the finer details of HA's communications subsystem are thus beyond the scope of this paper.

The following sections will explore the consumers needs in Section II, the existing solutions in Section III, and the features, design, and evaluation results of SUs in Sections IV, V, and VI respectively. Finally, sections VII and VIII will present the work in progress and conclude the paper.

II. Consumer Needs

Farmers and Ranchers need a reliable system for automating the monitoring and filling of water reserves (such as tanks) that is cost effective, easy to install, simple to use, and energy efficient.

Cost effectiveness as a requirement is self evident; however, it must not come at the cost of low quality. The system's components must not be too fragile to make working with them impossible nor should they have a short lifespan. This is of course heavily dependent on the environment in which the system is intended for and its components are certified for.

Cost effectiveness is also tied to the ease of installation. Professional installation of equipment is often costly and in remote locations (or developing countries) even cost prohibitive as such locations can easily fall outside of the regular service radius of the providers and thus require expensive third party installation services. Customers prefer a ready and robust box which they can easily install with minimal or no instructions. This simplicity of installation must then translate to a Simplicity of usage. If the devices are hard or impossible to interact with or reconfigure once on site, then a lot of time and money are wasted to produce and maintain the correct setup. Yet another benefit of simplicity in a system is that it contains fewer points of failure. For example, if consumers can simply plug-and-play rather than spend hours pouring over menu options, then there are far less ways in which the configurations can go wrong.

Consumers also need these systems to communicate with each other in an intelligent manner that provides redundancy and increases ease of use. Communications must be able to work over long distances and have high interference tolerance so that communications function accurately for the sparse distribution of water tanks consumers normally have.

And lastly, having energy efficient and energy independent units is a huge cost saving advantage which is sought after be more than just the environmentally conscious customers. For instance, If the units are capable of working off-grid via solar and battery power, then the cost savings of the system can translate into system expansion, upgrade, and continued uninterrupted operation and thus reduce the varying number of risks associated with automating the irrigation system such as the risk of power loss.

III. Related Work

A simple internet search for water tank monitoring systems will return a plethora of products and services all boasting of current buzz words such as IoT, Cloud Storage, LoRa technology, etc. Though very few even consider energy efficiency and low cost. These products are (1) industrial grade and thus extremely expensive, too complex, too large for end user installation and/or maintenance, and energy inefficient; (2) smaller and more energy conscious, yet costly and/or reliant on cellular or wired Ethernet communication; or (3) more focused on selling customers a "cloud solution" rather than actual consumer needs. Current industrial solutions on the market are large as a result of utilizing technology such as sonar and can range from several hundred to several thousand dollars for the sensor alone. One such product is the Radar Distance Level Measurement Meter made by GN in China [6]. This device has a range of 0 to 30m with an accuracy of 3 to 5mm and can operate in temperatures of -60 to 250°C. At the time of this writing, the dimensions and weight of the device are not listed on the company's website, but the site claims that the device has a small antenna size and is easy to install. However, as can be seen in the photographs on said site, the instrument is rather large. In addition, installation must be precise, as sonar signals need room for propagation. Therefore, the instrument cannot be installed too close to any of the sides of the water tank or it will generate inaccurate readings. This implies that smaller tanks can not be equipped with this instrument and thus can not benefit from this solution. Another cost prohibitive issue with this solution is that the operation of the device also requires an external power source and thus significantly increasing the cost of installation especially if no electrical outlets are already present at or near each water tank.

Another product on the market is the Smart Water Wireless Water Level Monitoring System by Syba Systems [7]. This system costs $499 and includes a display unit, tank transmitter unit, and level sensor. The price of this system makes it prohibitively expensive especially if additional units are needed to accommodate multiple tanks, at $319 for each additional tank up to a total of 9 tanks. The tank transmitter unit communicates 2.5 miles with line of sight or 6 miles if upgraded (for an additional cost), and runs off of a solar panel or AC. The design does not include any repeaters or relay units which limit the area of coverage significantly. The level sensor measures the liquid using pressure and comes in 4m and 10m cable length. The display unit which provides alarms and 30-day history can be hooked up to a pump controller, but is sold separately and costs an additional $279.

A yet different product on the market is the TSM Series Monitor by Tank Scan [8]. This system measures the tank level using micro-power impulse radar and has embedded Zigbee radios for wireless communication up to only 1000ft at 2.4GHz. Other communication methods such as Ethernet or the GSM cellular network are supported if an additional gateway is purchased. More downsides of this system are that it operates on a battery that needs to be replaced periodically and that it does not appear to operate with a pump controller, so it provides monitoring only.

IV. Features of the Hydro-System (HA) Sensing Unit (SU)

HA is a low cost, simple, modular, smart, and sustainable Hydro-System composed of relatively small yet robust components. In this section we present the features of HA's Sensing Units (SUs). Figure 1 shows a complete and fully functional prototype of an SU.

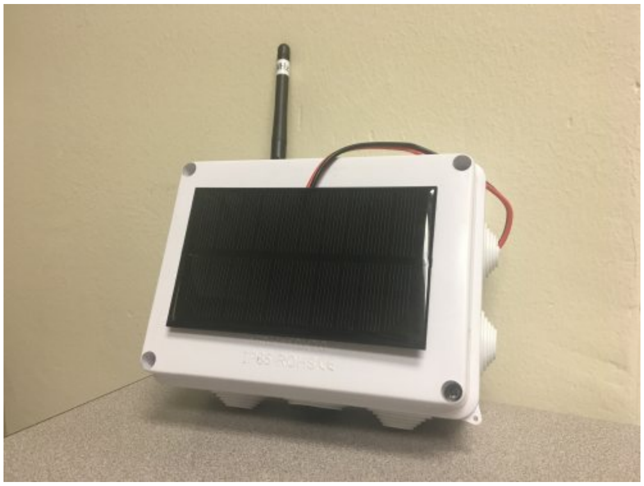

Fig. 1. Sensing Unit: A complete SU with an attached solar panel, radio antenna for the LoRa module and ultrasonic sensor.

A. Low Cost

The proliferation of ATmega328P chips in the form of Arduino micro-controllers has enabled simpler and cheaper system design and development. As will be evident from this paper's Design and Implementation section for less than $100 we are able to produce SUs which are robust, light weight, energy efficient, energy independent (utilizing an on-unit solar panel), and modular yet also very precise in their measurements using cheaper ultrasonic sensors in place of expensive sonar technologies. Additionally, the SU's ease of production keeps the overall hydration system's production costs at a minimum. The reduced costs can then be passed on to the consumer through a much cheaper per-tank price tag.

B. Small Size

Replacing sonar technology with ultrasonics shrinks the design considerably and allows all sensing, computation, and communication components to co-locate in a hand sized box and even the same circuit board. Hence SUs are contained in small water proof encasement that are exponentially smaller than industrial systems currently on the market.

C. Simplicity

The SU's design is relatively simple both in hardware and in software thus resulting in fewer points of failure. The components are all available off the shelf and the software has been written with usability, modularity, and human readability in mind.

Additionally, The small size of the SUs significantly improves the ease of installation compared to bulky industrial systems that are heavy and require professional installation. SU's are plug-and-play and thus can be self-installed by consumers with minimal effort and within a minimal amount of time. The addition of a water tank to an irrigation system may be difficult due to the on-site construction or transportation and placement of the tank, the needed installation of the water pipes to and from the tank, its distance from access roads, etc. However, adding the tank to HA and hence automating its monitoring and flow control is easy. The on-unit solar panel eliminates the need for external power sources or grid connectivity which simplifies the installation process considerably. An SU can easily be affixed to the lid or top of the tank via screws or other means and powered via its internal battery regardless of the solar conditions of the day. The sensor readings will commence immediately and the communications subsystem will add the new network node to the system so its readings can be recorded and its energy saving sleep cycles can be set according to the network's configurable sleep policies.

D. Modularity

The encasement of the SUs are designed to be opened and resealed easily so internal changes and upgrades to the hardware can be made easily. The micro-controller has many unutilized pins and the circuit board and encasement have ample room for additional components such as different sensors - which extend the SU's functionalists beyond its primary responsibility - to be connected and housed within the unit. The software also follows industry standards and best practices. The software is modular and thus the change or addition of different components will not have a ripple effect through the system. The modules are fairly independent and well tested to ensure that a minor change to a module does not result in the reworking of other modules.

E. Smart Communication

HA's communication subsystem utilizes a robust and long range wireless communication design implemented as LoRa technology. The SUs are responsible for taking real world measurements and transmitting their findings and status to the AU(s) through the communication subsystem. An AU located at a pumping station or a water routing (valve-control) station decides when to operate pumps or open and close valves based on individual SU's reported water levels. Hence, the communication must be precise, guaranteed, and full-duplex. SUs will communicate with other SUs or Relay Units (RUs) in their range and pass along their combined information upstream to the AU they are assigned to. This implies both a mesh and a star topology for HA. If the tanks are relatively close to one another then each SU, without any loss of generality or need for additional hardware, will also serve as an RU for its surrounding SUs. If the tanks are relatively far from one another or spread in a non-signal friendly environment such as mountainous, densely packed forest trees, or building structures then the subsystem will utilize stand alone RUs which serve as signal bouncing stations. The stand alone RUs are composed of a Whisper Node, antenna, solar panel, rechargeable battery, and recharging apparatus housed in a weatherproof 3D printed casing. They allow the SUs to be outside of the direct range or line of sight of the AU they are assigned to and therefore enable communications to continue so long as any path from a given SU to the intended AU exists. As a result the system is able to grow and support bigger

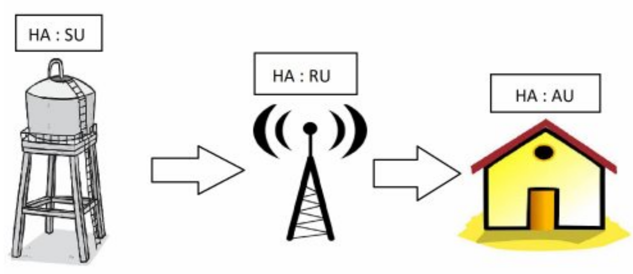

Fig. 2. A Sensing Unit (SU) on a water tank communicates with an Actuating Units (AU) in a pumping station through a relay unit (RU).

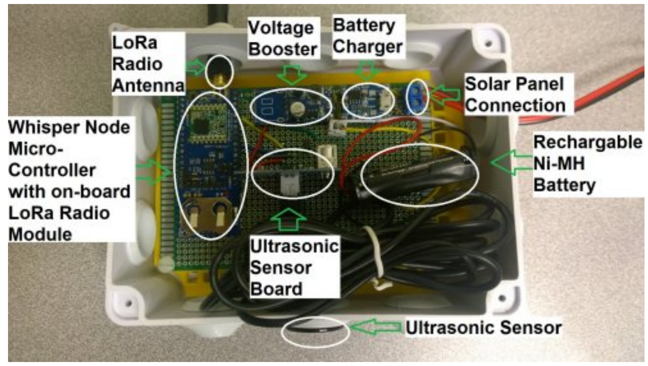

Fig. 3. The details of the circuitry within a SU

irrigation systems than the LoRa modules alone are able to support. Furthermore, this ensures redundancy for the overall system.

Lastly, it is worth noting that LoRa is not the only, although default, communication protocol at HA's data-link layer. Other additions, permitted by the SU's modular design, are WiFi (for personal home or warehouse settings), GSM, and LTE (for remote monitoring scenarios). Research and development on all said integrations are underway in parallel at Santa Clara University's IoT Lab and Frugal Innovation Hub.

F. Sustainability and Energy Efficiency

HA runs on renewable energy and uses a rechargeable battery as energy storage which is maintained at near capacity by the SU's built in solar panel. This is a huge advantage in comparison to the larger industrial solutions on the market which require an external power source or power grid connection due to higher voltage operation. In addition, during an allotted period of time determined by the AU they are assigned to, SUs enter a low-power sleep mode where no communications nor sensing is conducted. After this period of time the SU will wake up and immediately determine if it has a below capacity water level and reenter sleep mode after the tank has been refilled. In extremely energy efficient scenarios, the SUs can also be put to sleep for the duration of the tank's filling, only to wake up momentarily for a final check on the successful filling of the tank. As a result SUs will operate at a high level of energy efficiency and promote sustainability.

V. Design and Implementation

As Figure 2 shows, SUs are deployed on water tanks and other water reserves in the farm, orchard, or ranch; AU's are deployed at pumping stations and any valves that are to be automated; and RU's are set up at key locations in order to provide hops for the LoRa signal in between the SUs and AUs if the need arises. RUs provide line of sight for SUs and AUs that are separated by obstacles.

A. Sensing Unit (SU)

Sensing Units are installed on the ceiling of water tanks with their ultrasonic sensors facing downwards onto the surface of the water inside the tank. Figure 3 shows the implemented sensing unit.

Ultrasonic Sensor. A JSN-SR04T-2.0 waterproof ultrasonic sensor [9] provides distance measurements between the surface of the water and the ceiling of the tank. The ultrasonic sensor is operated by a micro-controller. The minimum range of the sensor is around 20.3 centimeters or 8 inches and its maximum range is around 4.5 meters or 14.8 feet. If the measurement of a distance outside of this range is attempted, it will usually read the maximum 4.5 meters. This distance range is enough for the application of water tank level measurement as the height of standard tanks are within this range. This sensor is very similar to the HC-SR04 [10] sensor which is a standard ultrasonic sensor model for Arduino devices. Hence the connection, configuration, and programming of the JSN-SR04T-2.0 is rather straight forward.

In order for the module to operate properly it must be powered by 5V. There are two different options for providing power to the sensor: (1) The sensor is directly connected to the same power source (i.e. battery or solar panel) as the micro-controller. (2) The sensor is powered via a digital pin of the micro-controller only when readings are requested by the micro-controller.

The first design option provides simplicity of design and software development. However, it is the less energy efficient of the two as the sensor is continually operational even when the micro-controller has entered sleep mode. The second design option takes advantage of the power disruption effect on the sensor as a result of the micro-controller's sleep cycle. However, the voltage difference provided by the micro-controller's pins are within the 3.3V neighbourhood and not the 5V neighborhood that the sensor requires. Even though a pull-up resistor can be utilized to address the voltage issue with the second design option, we chose the first design option though modified our design to include a 2N3904 transistor as a switch to control when the sensor is on or off.

Micro-Controller and communications. AUs, RUs and SUs all include an ATmega328P micro-controller, a LoRa radio module for communication, a solar panel, rechargeable battery, and a charging and voltage boosting apparatus.

SU's are operated by the relatively new Talk[2] Whisper Node - AVR LoRa micro-controller which is an ultra-low powered Arduino compatible micro-controller with a built-in LoRa Wireless communication Radio produced by Wisen labs in Australia [11]. This board is built for efficiency and abstracts the internal communications of the Arduino micro-controller and the LoRa radio into a single programmable board.

The Whisper Node has an on-board Semtech SX1276 transceiver [12] which has a RFM95/96 LoRa radio for communication. To increase the range of the communication, a SMA upgrade kit containing a female SMA edge connector for connecting a larger antenna was soldered on.

Energy Storage: Battery, charger, and voltage booster. HA runs on a single 1.2v rechargeable single nickel metal hydride AAA battery. To charge the battery a MCIGICM TP4056 battery charger [13] connected to the solar panel is utilized. In order to prevent current back flow from the battery to the solar panel when the sun goes down, a 1N4007 diode is used. The battery is then connected to a TE110 DC-DC converter step up boost module [14] to provide 5V to power the Whisper Node, and ultrasonic sensor.

Power Source. SUs use a 5V, 200mA solar panel to recharge their Ni-MH battery. Our current design does not include a battery charging regulatory policy and charges the battery to its full capacity. Recent studies have shown that battery lifetime can be extended by avoiding full-battery charge cycles [15].

Sensing Unit Casing. Since SUs are installed inside or near water tanks, and the humidity of such environments can be assumed to be 100%, the SUs casing must be resilient to humidity. Furthermore, occasional splashing, periodic sprinkling, and the possibility of being rained upon further indicate the necessity of the SU's water proof casing requirement. Hence, all of an SU's components are housed within a waterproof and shock-resistant LeMotech ABS plastic junction Box with dimensions: 5.9" x 4.3" x 2.8" (150mm x 110mm x 70mm). Inside the box, the circuit board is fastened to a custom 3D-printed mesh using plastic screws and nuts. The Mesh ensures that the internal components such as the circuit board, are not floating around and even helps with air circulation on the under side of the circuitry if any overheating occurs. It is important to note that no overheating has been observed in an SU even after continued usage for long periods.

Sensing Software. The ultrasonic sensor measures distance by timing a sound wave's travel time between itself and the surface of the water by sending out a sound signal above the human audible range and waiting to hear the reflection of that signal from the water surface. To this end, the Whisper Node triggers a pin to turn on the transistor which completes the sensor's path to ground and thus powers the sensor. The Whisper node then waits a short period of time before triggering the sensor to start sending sound waves. The sensor's logic board then calculates the duration of each sound wave's travel to and from the surface of the water and then converts it to distance using the following equation:

$$d = (v \times t_{\mu s})/2 = t_{\mu s} \times 0.017 \quad (1)$$

where v is the velocity of the sound wave and $t_{\mu s}$ is its travel time in μs. The factor of 0.017 comes from the propagation of sound in air. Sound travels at a speed of 340.29 m/s. And the division of 1/29 by 2 results in 0.017. The division by two is to account for the round trip time of the sound ping as it had to travel to the surface of the water and then reflect back.

Once an SU has calculated the distance, it sends that data to the AU it has been assigned to via its on-board LoRa Module. To control the Whisper Node and its features we use the Talk^2 library [11]. This library works with the Radio Head [16] and Low Power [17] libraries to control communication and power consumption. To achieve a low power consumption when the Whisper Node has finished sensing and transmitting data, it is ordered to enter sleep mode for a determined amount of time by the AU it has been assigned to.

An SU (or more precisely the SU's micro-controller) can be put to sleep in several different ways, two of which we will explore here: (1) An SU can be put to sleep using the Low Power Library by RocketScream. The RocketScream Low Power Library uses a watchdog timer to wake up the system. (2) A forever sleep mode which then requires an external interrupt from a RTC for instance.

Enabling a watchdog timer through the RocketScream library is relatively easy. However, there are a few problems with using a watchdog timer. The biggest drawback being that the maximum allotted sleep time per sleep cycle is only 8 seconds. This is due to the number of bits that can be used to set a watchdog timer, allowing it to only be implemented for a time between 16 milliseconds and 8 seconds based on the prescalar [18]. If the micro-controller is to use this timer for more than 8 seconds then it will need to loop through modulo(8) iterations of resetting the watchdog timer. This means the micro-controller (and any connected components which draw power from the micro-controller for their operation) wakes up and returns to sleep every 8 seconds which consumes power and adds tear and wear to the system.

These drawbacks can all be avoided if an on-board RTC is utilized instead. A RTC is an ultra low power Real-Time clock which keeps track of time and wakes up the micro-controller when its timer ends or if a set time is reached. To this end, a specialized low power Real-Time Clock (RTC) upgrade kit [19] containing a Maxim DS3231M I^2C RTC chip was soldered onto the Whisper Node.

B. Actuating Unit (AU)

The AUs are responsible for changing the state of the irrigation system to match the preset conditions of the system using data collected from its SU(s). This includes the operation of water pumps and/or valves to direct water through the system and fill the tanks to their predetermined max levels.

These units have a different design than the SUs and use more power. The AUs will have bigger solar panels and batteries to support pumping and valve operations. Our team is currently in the process of building an AU prototype which will control a water pump as well as a set of valves in our test-bed's pumping station.

C. Wireless Communications Sub-System

The wireless communications sub-system is composed of a wireless network of LoRa modules equipped with Semtech's SX1276 [20] RFM95/96 radio transceivers. These modules are currently built into the Whisper Node micro controllers and are designed to give full LoRa capabilities to small micro-controllers such as Arduino type boards [?]. Messages are sent with the use of the Radiohead library, a readily available library that supports multiple different radio modules, including the RFM95/96 LoRa module [16].

Since the module also has the ability to enter sleep mode, when a node does not have to collect, send, or receive data, it can also power down the radio along with the micro-controller which allows for even more energy efficiency.

VI. Evaluation

The SU prototype was tested with seven different sized water tanks at the Red Thistle Ranch in Livermore, California. The tanks were of different heights and diameters and each had different water levels. The prototype was then evaluated for both accuracy and energy efficiency.

A. Accuracy

The SUs are extremely accurate as verified via both a mechanical tape measure and a laser distance meter [21]. The angle of the ultrasonic sensor is of utmost importance as well as the clarity of the surrounding, as either can interfere with sound wave propagation and/or reflection. For this purpose, it is highly recommend that an SU is installed as close to the center of a tank as possible if the water tank is very narrow, and around one meter away from the sides of the tank, otherwise. The tank heights examined ranged from 8.5 to 12 feet. We examined the tanks while empty and at varying levels of fullness as the valves to each were opened and they were allowed to fill up to their designated limits. All measurements were verified against a tape measure as well as a laser distance meter for accuracy.

B. Energy Usage

The Whisper Node can be powered through the VBAT or VIN pins. The VBAT pin's input ranges from 0.9v to 3.3V which is routed through a step-up regulator to provide the 3.3V that the board uses. However no protection against polarity in the form of an internal diode for instance, is provide on the VBAT pin. Hence higher voltages are to be avoided for powering the Whisper node through the VBAT pin. In contrast the VIN pin can take 3.4v to 6v and is connected to a LDO MCP1700 regulator to drop the voltage to a usable amount. To conserve energy when the SU is not needed, the Whisper Node's ATMEGA328P chip is placed into power down mode [18]. The Whisper Node has several on-board components that draw excess power. These components are the SPI Flash and RFM95/96 Radio Module. To decrease power, these components are powered down. In addition, the brown-out detector (BOD) and analog to digital converter (ADC) were pragmatically disabled. The Low Power library provided by RocketScream is utilized to put the ATMEGA328P chip to sleep [17]. A timer on the on-board RTC can generate an interrupt to wake the board from this low power state after a designated amount of time. When a Whisper Node with an on board RTC is in sleep mode and has an input voltage of 3.3V through its VBAT pin, it has a power consumption of around 9.6 μA according to its data sheet [11]. The same setup, however, results in different energy consumption if the Whisper Node has an input voltage of 5V through its VIN pin instead. The data sheet does not include energy readings for this scenario. Table I shows the power measurements of an SU in different states as powered by an adjustable bench power supply of 5V. As the data in table I shows the power consumption thus is more than when the board is powered by 3.3V but is still very efficient. It is important to note that operating the ultrasonic sensor at voltages lower than 5V resulted in inaccurate or inconsistent readings thus necessitating the usage of 5V to power the SUs.

TABLE I
POWER CONSUMPTION USING 5V INPUT

Mode	Power
Sleep (Watchdog)	14.7 μA
Sleep (RTC)	2.2 μA
Idle	8.46 mA
Sensing	53.17 mA
Transmitting	75.32 mA
Receiving	60.26 mA

VII. Work in Progress

HA SU prototypes have demonstrated their successful operation and thus have affirmed their promise as a viable competitor in the irrigation landscape. The current work in progress and next steps include custom PCB design, 3D printed casing, wireless update capabilities, and the completion of the implementation of HA's communication subsystem.

A. Custom Circuit Board

The current SU prototypes are composed of off the shelf PCB boards and soldered components. A next step in the design and implementation of the project is the streamlining and standardization of SU production. To this end, a printed PCB fabrication design is currently underway. A printed PCB will also substantially reduce the points of failure as well as soldering time.

B. 3D Printed Casing

Packaging plays an important role in any IoT system as it enables the customization of the installation, if not usage at all. As aforementioned, SUs require waterproof and weatherproof casings. We therefore plan to improve upon HA's design by 3-D printing our own unit encasement. Currently, several designs are under consideration by the team. Figure 4 shows an assembled and exploded 3D model of the leading design. This new design will improve the water proofing of our box due to its custom designed openings which limit the number

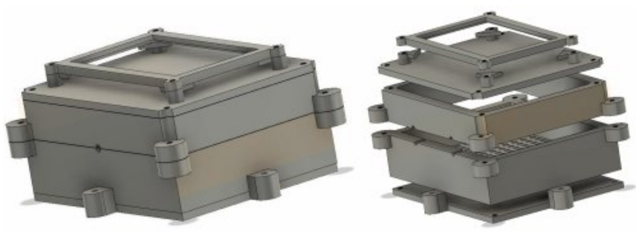

Fig. 4. Closed 3D-Printed SU encasing (left), and exploded 3D-Printed SU encasing (Right). The design includes six 3D-printed layers which fasten using 3D-printed screws and hold all of the components in place. The internal circuitry is protected from the environmental elements such as water and sunlight yet accessing the internals is easy due to the modular design.

of openings in the casing in comparison to the current junction box used in our prototypes. A sealant will be used to cover all junctions. Furthermore, the design includes a built in mesh which further simplifies the assembly process and reduces the number of components and screws.

C. Software Updates Once Deployed

Current SU designs require truck role. The SU casing lid must be removed and an FTDI chipped usb board or cable must be used to interact with the Whisper Node. As an alternative, wireless updating over WiFi and LoRa are under investigation. Preliminary results with WiFi band transceivers as well as LoRa push updates have shown promise. The implementation of wireless software updating is thus intimately tied with the communication sub-system's research and development currently underway.

D. Communication Sub-System Deployment

The second phase of HA's research and development centers around the system's communications subsystem. The research and development is centered around the creation of a new low energy packet switched routing protocol which will utilize LoRa technology as its data-link layer. The protocol, however, will be independent of LoRa, enabling HA to also utilize WiFi, the GSM network, and the LTE network, when the environmental or economic conditions dictate. The work takes advantage of low-power wireless communication modeling methodology delineated in [22] for modeling signal propagation, noise floor, system variations, and interference. The new contributions of HA's communications protocol is the subject of a future paper by the authors.

VIII. Conclusion

A myriad of different tank monitoring systems exist which use sonar, pressure, or radar signal sensors and each poses different strengths and weaknesses. A powerful solution often overlooked is one utilizing cheaper ultrasonic sensors coupled with low power wireless networking in the form of LoRa communication technology. HA's Sensing Units clearly demonstrate this point and present themselves as a cheaper, smaller, simpler, modular, smart, and sustainable solution for irrigation system monitoring automation.

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