SU 2.0: A Marketable Low-Power Wireless Sensing Unit for Hydration Automation

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***Abstract*—The status of crops, water tanks, and various other components of modern agricultural irrigation systems can be sensed and valves and pumps can automatically be actuated to ensure the distribution of adequate water to all parts of the system. In previous work, we have discussed the design and implementation of low cost, small factor, and sustainable Sensing Units (SUs) which use ultrasonic sensors to measure the available empty space in a water tank and communicate the water levels to the Actuating Unit (AU) they are assigned to, so that the AU can operate the valves and/or pumps necessary to send the exact amount of water needed to restore the tanks' designated water levels. There, we indicated that a future step is the redesign of the circuitry in order to shrink the overall size of the SU, increase its energy efficiency, and enable the addition of new environmental sensors such a temperature sensors that can warn the users or take automated action when the freezing of the water in the tanks is predicted and/or sensed. Also, in previous work we have discussed the design and 3D Printing of a water proofed, cost effective, and environmentally friendly custom encasement for the SUs and indicated that a next step is to redesign the internals of the SU casing in order to allow for the addition of new components while reducing the size of the casing as an effort to reduce the amount of material used and hence enhance the system while further reducing the SUs' cost. This paper is to report on the success of all these steps and more which collectively enable the production of a marketable smart agricultural environment monitoring SU for irrigation automation.**

Keywords–3D Printing; Agricultural Internet of Things (IoT); Hydration Automation; Irrigation System; Sensing Units.

I. INTRODUCTION

Outdoor Internet of Things (IoT) systems such as agricultural automation systems require robust, compact, and reliable nodes combined with algorithms that automate tasks and allow these systems to operate well in the harsh environments they are deployed in. Specifically, irrigation automation equipment such as the Hydration Automation (HA) Sensing Units (SU) [1] is often exposed to environmental elements such as direct sunlight, humidity, extreme temperatures, and temperature fluctuations. To create a viable system, HA combined modular and compact circuitry inside of a custom, 3D printed capsule [2] that wirelessly communicated with the system's actuators through a robust communication subsystem utilizing a custom in-house routing protocol called ÂB [3], which is specifically developed and fine tuned. The original HA system, and its SUs specifically, proved to be successful. However, the system had room for improvement. By upgrading to more efficient components, creating a compact and modular design, and crafting a custom 3D printed shell, the SU was upgraded into a much more powerful IoT hardware system; and by packaging this hardware with an advanced software and custom networking protocol, HA was adapted to be a much more capable and widely applicable IoT solution.

The rest of this paper is structured as follows: Section II delineates the hardware changes and circuitry updates in SU 2.0 and Section III details the updates to the system's communications subsystem. Section IV details the 3D printed casing upgrades and includes waterproofing test results. Section V provides an update on the cost of the units due to the hardware and casing upgrades. Sections VII and VI delineate the work in progress and future steps in the evolution of the SUs, respectively. And finally Section VIII provides some concluding remarks.

II. HARDWARE CHANGES & IMPROVEMENTS

As with nearly all IoT devices, size, capability, and power are major constraints. The hardware changes made to the SU 2.0 bring the HA system closer to these ideals. These hardware changes included redesigning hardware to be more compact, adding a new sensor to increase capabilities of the SU, and re-configuring the architecture of the system to reduce power usage.

A. Compact Layout

To accommodate narrow and tight spaces, the SU 2.0 was redesigned using a multi-layer, compact approach that minimizes its mounting surface footprint.

The components of the SU include a Wisen Whisper Node [4] board with an on-board LoRa (Long Range) communication module [5], a JSN-SR04t Ultrasonic Sensor [6], a temperature sensor [7], a voltage regulator, a TP4056 battery charge controller [8], a 5W lithium battery pack, and a 5V 100 mAh solar panel. To design the structure of the unit, the components were divided into three groups:

1. *Components that are not upgradeable by the user and are unlikely to need periodic replacement.* These components include the base PCB (Printed Circuit Board), the charge controller, the step-up voltage regulator, the temperature sensor, and the solar panel connector. All of these have long lifespans which exceed the lifespan of the SU. Hence, these components are all directly soldered to the base PCB board.
2. *Components that do not need periodic replacement, but that the user may wish to upgrade.* These components include the ultrasonic sensor and the Whisper Node micro controller which includes a built-in LoRa communications radio and Real Time Clock (RTC) for

managing the micro controller's, and as an extension, the entire SU's sleep cycles.

3. *Components that need periodic replacement.* The only component in this category is the battery, which has a minimum lifespan of 2-3 years.

Grouping the components in this manner allowed the SU 2.0 to be designed using multiple layers, with the non-serviceable components on the bottom and the components requiring periodic replacement on the top.

Since there are no user-replaceable or serviceable components on the charge controller or temperature sensor, they were soldered directly to the prototype board, creating the first layer. The Whisper Node board has software that can be replaced, serviced, or upgraded by the user, but performing this upgrade requires removing the board from the SU housing and connecting it to a computer using a special FTDI enabled USB to TTL Serial adapter. To accommodate software upgrades, the Whisper Node board is mounted on the prototype board using a set of female to male pin headers to allow for easy removal without the need to desolder. The pin headers raise the height of the Whisper Node enough to fit it directly over the battery charge controller and temperature sensor, minimizing space and creating the second layer. The ultrasonic sensor is also mounted on the second layer of the board using a set of female to male pin headers to allow for easy removal and replacement. This allows the user to perform upgrades on the SU 2.0, such as replacing the current sensor with a more powerful sensor or one better suited for liquids other than water.

The first two layers of the unit were then placed into the custom 3D Printed capsule. A 3D printed divider board was then inserted on top of the first two layers of the device and screwed down to the capsule for secure mounting. The battery was then placed on top of this divider board, creating the third and final layer. This separation allows the user to easily replace the battery without risking damage to any of the first or second layer components. The SU is then enclosed by the lid of the 3D printed capsule. The capsule lid includes a solar panel holding bracket which securely mounts a solar panel that provides power to the entire device and recharges the battery during the day. Using this layout, a more compact SU was designed and produced.

B. *Energy Efficiency*

A serious challenge for designing IoT devices is to ensure all components are compatible with each other. One such compatibility issue in the SUs is the operating voltage of the components. Most components in the SU allow for a range of input voltages except for two components which only operate at immutable voltages: the ultrasonic sensor and the battery. The lithium battery used in the SU has a nominal voltage of 3.6 volts, but the ultrasonic sensor only operates at 5 volts, creating a need for a step-up voltage regulator (a.k.a. a boost converter). The usage of the ultrasonic sensor with 3.6v was considered and thoroughly tested. However, it was observed that the range of the ultrasonic sensor was drastically reduced to well below the requirements needed by the system. Therefore in SU 1.0, a boost converter was installed directly after the battery, essentially boosting the battery output voltage to 5v for the entire system. This worked because the Whisper Node's nominal voltage range is between 3.3v and 5v. However, as both the documentation of the Whisper Node and energy usage testing by the authors show, the Whisper Node operates less efficiently when it is powered with 5v instead of 3.3v. This, in turn, led to an approximately 15% decrease in overall system efficiency as everything was powered through the boost converter. A 15% loss did not seem significant initially because a more powerful (and hence physically larger) solar panel was installed. This however, became a problem for the SU 2.0 design because the size of the device is reduced dramatically, and thus the original solar panel is bigger than the whole device. This problem was addressed via a specific redesign of the solar panel brackets on top of the casing, as will be discussed in Section IV.

The solution explained above did not however, address the fact that, over time, the 15% increase of energy usage can reduce the battery's lifespan by hours or even days. To solve this issue, a more compact and efficient step-up voltage regulator is used to feed the ultrasonic sensor alone, rather than the entire SU. Thus, the original voltage booster is eliminated from the design, as can be seen in the SU's updated circuit diagram depicted in Figure 1.

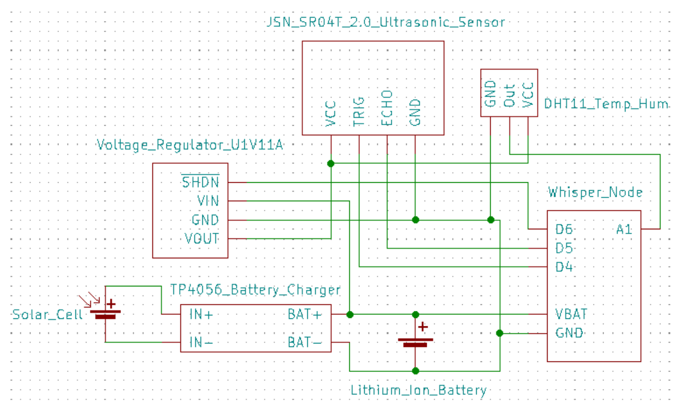


Figure 1. HA SU 2.0 Schematic.

In SU 2.0, the battery is connected directly to the Whisper Node board, which is capable of running at the battery's nominal 3.6v. This allows for the board to operate without any inefficiencies. For the brief periods of time when the ultrasonic measurements need to be taken, the Whisper Node sets a pin to HIGH, activating the step-up voltage regulator which boosts the voltage provided by the pin to the Ultrasonic Sensor to 5v, allowing a measurement to be taken. After the measurement, the Whisper Node pin is set to LOW, disabling the step-up voltage regulator and thus the ultra sonic sensor in order to conserve power.

Through the changes to the location of components in the SU system, SU 2.0 operates 15% more efficiently than SU 1.0. Thorough before and after testing was performed on the HA power system through multi-week field tests. While the original HA SUs worked well when they had access to sunlight, in situations where the solar panel did not have access to sunlight (due to winter storms, a branch falling on top of panel, etc.) the system would quickly drain in less than a week. Due to the efficiency improvements made, SU 2.0 was able to last well over a week, even with no access to solar power.

C. Temperature Sensor

The HA system must be usable even when located in environments where frigid temperatures result in the possibility of water tanks freezing. Previously, HA had methods of detecting anomalies, such as alerting a user about the possibility of a leak when it detected an unexpected drop in a tank's water level reading coming from its SU. This error detection system was reactive and not proactive; meaning it could detect problems such as a tank level dropping after cold temperatures had caused the tank to freeze and burst, but could not predict such failures due to weather related events in advance and enable preventative measures. To enable the SU to predict weather related issues, a HiLetgo DHT11 Temperature and Humidity Sensor module [7] was added to the SUs in order to provide more sensing capabilities regarding weather and climate. By analyzing data from the temperature sensor, the SU's algorithm can recommend actions to the user in advance. For example, if the SU notices the temperature dropping below a threshold, it can notify the user to drain the tanks to a lower level before the tanks freeze and burst. This can also be automated if actuation capabilities are directly added to each tank's output valve. However, this is beyond the designed capabilities of a sensing only unit such as the HA system's current SUs; and thus, beyond the scope of this paper, except for a brief description in Section VII below. Future direct communications between SUs and local tank level AUs, or the addition of such local actuation capability to current SUs is under consideration and research by the HA research and development team.

III. COMMUNICATION

SU 2.0 uses the custom ÂB communication protocol [3] to communicate with other nodes in the network, such as Relay Units (RUs) and the base station. ÂB is a protocol designed from the ground up for IoT devices which takes advantage of the devices' sleep cycles in order to reduce the overall energy usage of the system as a whole. ÂB's original design is to provide network layer support (a.k.a. routing) to IoT systems that utilize Semtech's LoRa [9] as their Link layer fOSI model's combined Data Link and Physical layers) communication protocol. However, ÂB is built in a modular and medium access independent manner as to allow for its utilization with any existing Link layer protocol. For instance, current efforts are under way by an international team from Santa Clara University's EPIC laboratory in the United States and researchers from the Universiti Teknologi MARA in Malaysia to utilize ÂB as the Network layer protocol for a water quality testing system under joint research and development which uses the Zigbee protocol [10] at its Link layer.

IV. CAPSULE CHANGES & IMPROVEMENTS

The first SU design in [1] utilized an off the shelf IP65 junction box [11], which is shown in Figure 2 on the right. However, this design was not manageable long term as the junction box is created with a very differed purpose in mind. Junction boxes are installed within walls and hence out of the elements for the most part. They have basic weatherproofing to protect against a water leak in the wall, but are not designed to withstand storms, intense daily sunlight, or other environmental abuse present on a farm or ranch. Hence, a

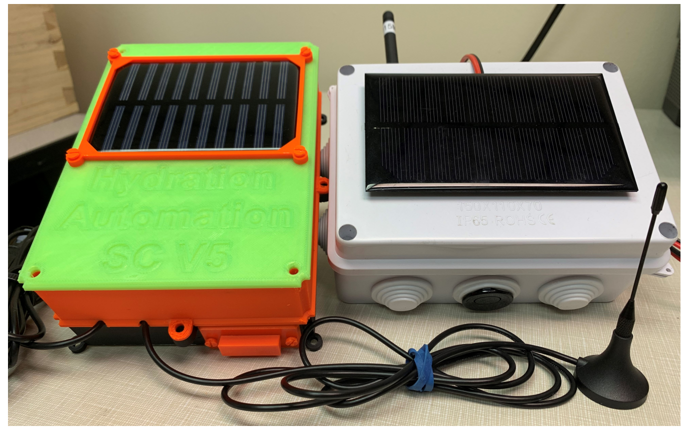


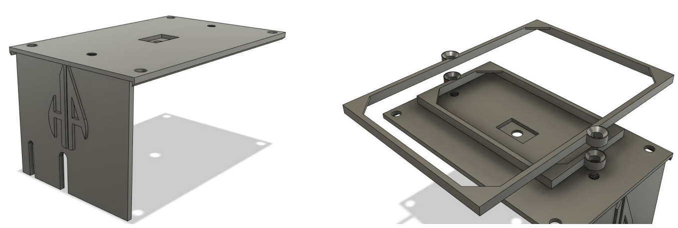
Figure 2. 3D printed capsule on left and original pre-fabricated capsule on right.

custom 3D printed SU casing was developed [2], which is depicted in Figure 2 on the left.

Even though this capsule was far more waterproof, sustainable, and cost effective, it still was very large. As the SU 2.0's circuitry was shrunk in size, so arose the need to shrink its custom casing. The SU's latest capsule is thus much smaller and even more waterproof than the previous model. These alterations have majorly simplified the capsule, which has in turn increased the waterproofing and ease of use of the system

A. Slide-In Front Wall

In the previous design, the capsule had middle and bottom sections which met at the level of the cables in order to completely seal the entry point and not force the cables to bend. The third generation capsule was designed with a slide in wall depicted in Figure 3a attached to the top section so that the middle section could be removed completely, while still enabling the cables exiting the box to be surrounded all around.



(a) (b)

Figure 3. (a) Display of the top section's slide-in front wall. (b) Solar panel is placed between mounting part and top lid to secure it.

B. Solar Panel Mounting

The second generation SU capsule was constrained in its size by the 70 x 100mm solar panel mounted on its lid. In order to reduce the size of the capsule further without changing the solar panels, the mounting system shown in Figure 3b is designed to mount screws along the shortest cross-section of the panel instead of at the corners. This mounting system has thus enabled the mounting of any solar panel with a cross-sectional size of 70mm or less, as shown in Figure 4. Ideally though, as visible in Figure 4b, the capsule uses smaller 36 x 68mm solar panels akin in size to the panels used in the Relay Unit (RU) capsules delineated in [2].

(a) (b)

Figure 4. (a) SU enclosure with bigger solar panel mounted. (b) SU enclosure with smaller solar panel mounted.

C. Battery Separator

The first generation capsule simply housed everything (including the battery) in one compartment [1]. The second generation casing used a 3D printed grid to separate the battery compartment from the circuitry and a custom 3D printed drawer in order to provide easy access for battery replacement [2]. The third generation capsule replaces the mesh and drawer with a specialized battery separator that houses the battery above the hardware, as can be seen in Figure 5. Curved ridges near the edges of the battery separator firmly secure the battery and make it easier for the user as the battery is situated at the top of the capsule and can be easily clicked in and out of its holder once the lid is removed. The battery separator slides into two indents along the side and back walls in order to keep it straight. In addition, a raised screw hole near the front of the capsule enables the locking of the separator in place, which also secures the PCB and hardware beneath it.

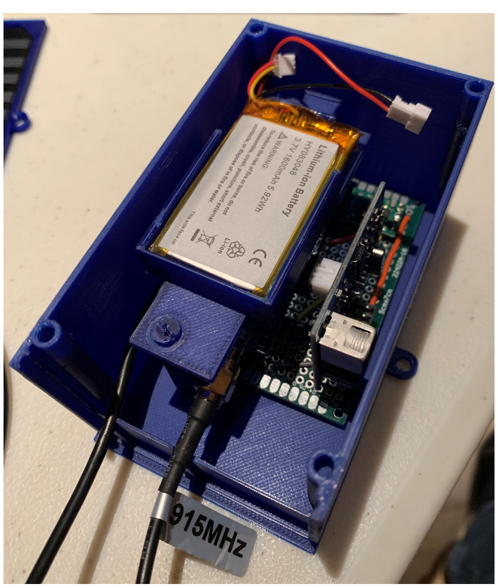


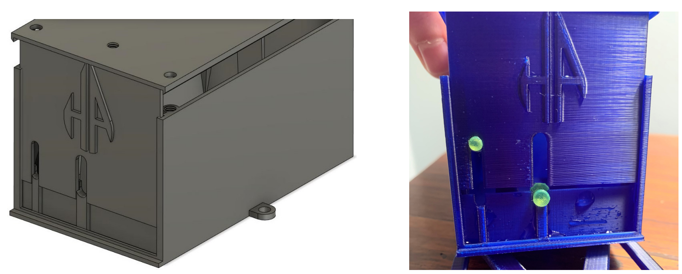
Figure 5. Battery separator situated above circuitry.

D. Waterproofing

The SU capsules are intended for long-term use outdoors. Thus, ensuring the waterproofing of the system is one of the biggest constraints for the SU's casing. With this in mind, Polyethylene Terephthalate Glycol (PETG) filament was used in all parts, because it has been proven to be resistant to harsh environmental elements such as rain, prolonged exposure to sunlight, and even acidic conditions [12].

Many of the choices made when designing the third generation SU capsule were in order to maximize its impermeability. Similar to the previous generation of SU capsules, the newest design utilizes exterior overhangs to cover the joints between the top and bottom sections. This ensures that the largest opening in the capsule is more resistant to moisture.

Adding the slide-in front wall, however, required new techniques for waterproofing the opening. Similar overhangs to the ones used on the top were added to the sides and the bottom - where the slide-in wall connects. The cable openings for the cables exiting the unit are thus not located at the bottom of the slide-in wall, but rather designed to meet with the bottom of the capsule at an elevated level so that the cables are surrounded fully on both the top and bottom, as shown in Figure 6. A protective wall was added behind the slide-in wall to ensure an even higher level of protection against any water attempting to enter the unit from the cable opening, as also shown in Figure 6.



(a) (b)

Figure 6. (a) A secondary interior wall and external overhangs overlap with attaching sections to prevent water from being introduced. (b) Opening capsule shows moisture behind slide-in wall having been stopped by the protective wall.

E. Waterproofing Results

When the capsules are used in the real world, they will either be affixed to the top or side of water tanks or placed in a raised position, so they will not be exposed to any puddling. Therefore, when testing the SU capsules in the lab, a mounting frame was designed that holds the capsule vertically off of the ground. In order to simulate the existence of exiting cables from the unit during water testing, 3D printed cable hole stoppers were slid into each of the cable holes, as can be seen in Figure 6b. The capsule was then exposed to a shower of water at varying strengths and for varying duration of time before being inspected for leaks. Figure 7a shows a capsule right after water testing. Upon slowly removing the top section from the bottom, moisture was discovered between the slide-in front wall and the protective wall behind it, as can be seen in Figures 6b and 7b. However, no water was able to enter the capsule or interact with the circuitry, as is also seen in Figure

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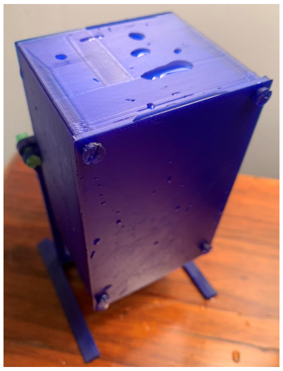
7b. This proves the accurate functioning of the overhangs and interior protective wall in protecting the circuitry from moisture.



(a)

(b)

Figure 7. (a) Wet capsule mounted on vertical frame. (b) Interior overview after water testing.

V. Cost Analysis

The cost of developing an SU comes down to the 3D printed casing and hardware (circuitry) used inside.

A. Hardware

The SU is produced with off the shelf components in order to ensure low cost and ease of repair. This is especially important for systems used in rural areas or developing couturiers where repair of the system via the replacement of off the shelf components is more feasible than enduring long shipping times at high cost. Table I shows the cost breakdown of each hardware component with the total price of the hardware coming to $61.98. As the hardware is off the shelf, the prices will fluctuate and thus bring the total price lower or higher at times.

TABLE I. DEVICE HARDWARE COST

Part	Price
Antenna	$5.35
Battery	$7.00
PCB	$0.10
RTC	$7.63
SMA female edge connector	$1.22
Solar Panel	$1.00
Standoff Header Pins	$0.25
Temp. and Hum. Sensor	$2.10
Ultrasonic Sensor	$3.71
Wires and connectors	$0.50
Whisper Node	$26.27
Total	$55.13

B. Casing

The parts for the third generation SU casing are all printed using Prusament PETG [13], which is manufactured to have a precision of 0.02mm, while most filaments on the market have a precision of 0.05mm. All the capsule's main sections are printed at a resolution of 0.15mm in order to save time. However, the screws and screw holes are printed at a resolution of 0.05mm, so that their threading will be at the highest quality possible.

As shown in Table II, the cost of manufacturing the capsule is between $2.27 and $2.87 depending on whether the vertical mount is included with the capsule or not. This is a massive improvement over the previous capsule's manufacturing cost of $9.36, which is 75.75% less. Also, the original ABS (Acrylonitrile butadiene styrene) IP65 junction box [11] used for encasing the circuitry in the very first SU was purchased for $11.99, with a shipping cost ranging from $5.98 to $19.99 depending on the seller. Therefore, even for the lowest shipping cost, 3D printing the latest capsule is 87.37% cheaper than the prefabricated ABS box used in the original SU.

In addition to the direct reduction in manufacturing costs, the reduction in 3D printing time is also significant. The last SU capsule took 34 hours and 19 minutes to print, while the SU 2.0 capsule only takes 10 hours and 27 minutes. This adds up to a 69.55% reduction in print time.

TABLE II. CAPSULE PARTS' SPECIFICATIONS

Part	Mass (g)	Time (h,m)	Cost (P/A)
Battery Separator	5.87	42m	0.18
Body	45.89	5h, 40m	1.38
FH 5x3.5 m4 Nut (2)	0.16	13m	0.01
FH L8 m4 Screw (7)	0.84	49m	0.03
FH L12 m4 Screw (2)	0.32	18m	0.01
Lid and slid-in wall	19.56	2h, 49m	0.59
Solar Frame (36x68mm)	2.39	19m	0.07
Solar Frame (69x99mm)	3.56	27m	0.11
Vertical Mount	19.55	3h, 54m	0.59
Total with Vert. Mount	95.75	14h, 52m	2.97
Total without Vert. Mount	75.72	10h, 27m	2.38

VI. Work in Progress

A. Further Casing Upgrades

1) Magnetic Connectors: 3D printing small screws is time consuming because they each need to be printed one by one. They are not printed together in order to prevent PETG strings between the screws that result from the hot print head moving from screw to screw as it builds layers onto all of them one by one before moving to the next layer on all of them. Also, the screws do not have a long life expectancy if they are removed and replaced more than several times. This is due to the nature of additive manufacturing and the direction in which the screws need to be built in. Since the screws are 3D printed vertically, their tensile strength is weaker in that direction. As a result, after multiple usages or if they are removed too forcefully, they can snap and thus leave behind multiple layers of their threading within the screw hole. Therefore, to sunset the practice of using 3D printed screws, magnets are being explored for connecting different sections of the capsule. Currently, 4x3mm and 5x1mm magnets are being embedded into the same locations where the screw holes were. This further reduces the print time of the system and eliminates the screw holes on the top section which provides even better waterproofing by limiting the number of possible entry points for moisture even though these screw holes do not lead into the circuitry chamber to begin with.

2) Addition of Gaskets: To guarantee waterproofing in situations where the SU may accidentally be submerged by sitting in a puddle or being drooped into the tank during installation or maintenance, gasket material and designs are

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under consideration by the research and development team. The gaskets may be 3D printed using Flexible ThermoPlastic Polyurethane (TPU) Filament which is known for its flexibility yet durability and resistance to even oils, greases, and a variety of solvents [14]. These properties make TPU a great candidate for 3D printing gaskets.

B. Remote bootloader over LoRa

Since the SUs are installed in remote rural locations, it is not the easiest task to manually reset one in case of a software glitch nor to update the firmware on them all when updates are available. Therefore, a remote option for rebooting the micro-controller firmware is essential for agricultural and aquacultural applications to reduce the amount of truck roll necessary. Furthermore, since SUs only contain LoRa connectivity through ÂB, a custom bootloader over LoRa that utilizes ÂB packages is needed and thus under development.

C. WiFi

The SU 2.0 also includes the option to communicate over WiFi using ESP2866 [15] or ESP32 [16] modules. WiFi is used when the SU is close to a WiFi network, such as with a backyard or indoors water storage system. Having the WiFi capability allows for the SU to be more easily integrated into an existing network and negates the need for a base station in a network with only one node.

VII. Future Steps

A. Battery Charge Regulatory Policy

The SU's 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 [17]. More testing is still necessary to see how the SU's battery is effected in the long run.

B. Custom Printed Circuit Board (PCB)

In order to streamline and standardize the production of the SUs, a custom Printed Circuit Board (PCB) is necessary and well overdue. A custom PCB will substantially reduce the points of failure as well as soldering time.

C. Security

IoT devices are in need of security similar to all other internetworked devices. The security measures must protect the hardware, software, and communication channels.

1) Physical: Even though the SUs are not expensive devices, they can still be stolen or vandalized. To prevent the theft of the SU as a whole, it can be secured into place using tamper proof brackets and bolts. To prevent the circuitry from being vandalized or altered, tamper proof bolts and lid opening warning systems in the form of time stamped messages to the base station can be utilized, respectively. Also, tamper proof stickers can be added to the opening of the SU casing so any unauthorized access to the internals of the SU can be detected, at least after the fact.

2) Software: The SU tampering detection message to the base station can easily be used as a means for potential software tampering and can thus initiate a backup, bootloading, or even disabling of the node until it is checked and reconfigured. Furthermore, the SU can be programmed to not allow any direct connections, and hence updates, without proper authentication credentials.

3) Communication: All SUs must be preregistered with the base station prior to deployment into the field. If an SU is not registered, then its request for assignment to an AU is ignored by the base station; and hence, it will not be included in the RUs' responsibility table, as described in the ÂB protocol [3]. Furthermore, to protect the base station from being manually jeopardized to allow the malicious node onto the network, the usage of a blockchain for the storage of all registered network nodes is under consideration and research.

D. Potential Micro-controller changes

The current SU design utilizes a Wisen Whisper Node [4], which includes an on-board LoRa transceiver and an RTC chip. In order to further modularize the system, it would make sense to separate the RTC and communication radio from the microcontroller. This way, any update to the microcontroller would not effect the other components and vice versa. Furthermore, this would enable the easy replacement of the Link layer protocol in the SUs without the need for custom designs for each protocol's radio transceiver. The off the shelf component currently under consideration is the AdaFruit Feather, which comes in many forms such as the Feather M0 Basic Proto [18], Feather M0 adlogger [19], and Feather M0 LoRa [20] if it is decided to always include LoRa capability regardless of other Link protocol additions. A further benefit of the Feather product line is that it has an open source design; and thus, even if Adafruit stops the manufacturing of this product line, compatible replacements will be producible.

E. Proactive Temperature Sensing

By combining data from the temperature sensor with existing data captured by the system (such as water usage, time of use, solar panel power production, etc.), HA can monitor data trends and take action based on detected changes in order to automatically water crops or disperse water to livestock in the most efficient and effective way possible. For example, if the temperature sensor depicts a sudden drop in temperature for an extended period of time, it can reduce the daily watering rate of the crops, and thus save water. If the opposite occurs, HA can increase the rate of watering to ensure crops are not lost.

HA could also maintain a watering schedule which takes into account the ambient temperature in order to provide more water to livestock during the heat of the day, or to release water for plants during the coolest times of the day to ensure as much of the water is absorbed by the plants as possible and minimize its loss to evaporation. Or, more infrequently, HA could analyze and calculate how much to increase the water flow through the system during a heat wave or how much to reduce it by, when it is raining.

The system needs to be able to make the decisions mentioned above in real time as they can have real world impacts on the crops, livestock, and users. For example, when the software detects a rapid drop in temperature occurring over an extended period of time, it should open valves at the bottom of the tanks, allowing them to partially drain; as any delay or mistake can result in irreparable damage to the watering system and thus hardships for getting water to crops or livestock; or worse, their loss which will have serious real world consequences for the farmer. This sort of proactive sensing (and actuating) of HA, therefore requires a measure of automated decision making and a robust machine learning mechanism.

VIII. CONCLUSION

SU 2.0 has improved upon many limitations of the previous iteration such as energy efficiency and size, while offering new features such as improved waterproofing and the addition of temperature sensing. Through reducing the capsule's size, the 3D printing manufacturing time has also been reduced, enabling greater production capacity. The SU improvements reported in this paper have enabled the mass production, real world deployment, and utilization of small form factor, cost effective, and yet sustainable IoT SUs for Hydration Automation systems. Even though many more improvements and additions are under way or slated for future development in Sections VI and VII above, the SU's in their current state are Minimal Viable Products (MVPs) marketable and utilizable in the field today.

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