Insights into Irrigation from Internet of Things Perspective

Abstract:

Temecula Valley is turning into high tech hub for winegrowers in Southern California, as it is looking into technology and collaboration to improve the irrigation efficiency. Independent growers and winemakers have come together to serve the best tasting wine and to find mutually beneficial cooperation to conserve water use. In this paper, we will discuss some of the challenges that growers face and technology they are exploring to address these issues. Their observations suggest 20% water savings, enhanced analytics and automation. We will demonstrate tools and technologies that can drive innovation and revolutionize agriculture by (1) providing insight into the farm in real time, (2) analytics of water usage, and (3) irrigation automation. We will also cover a case study on a novel and inexpensive soil moisture sensors called Vinduino Sensors and Stations.

Introduction

Internet of Things was the next logical steps after proliferation of Internet and mobile devices. As devices that support internet connectivity shrinked in size and power demands new market opportunities and possibilities are a reality. Fueled by Internet's social success, (Facebook, Google …) engineers believe that Internet can also bridge small engineering systems into larger far more advanced or "smart" solutions.

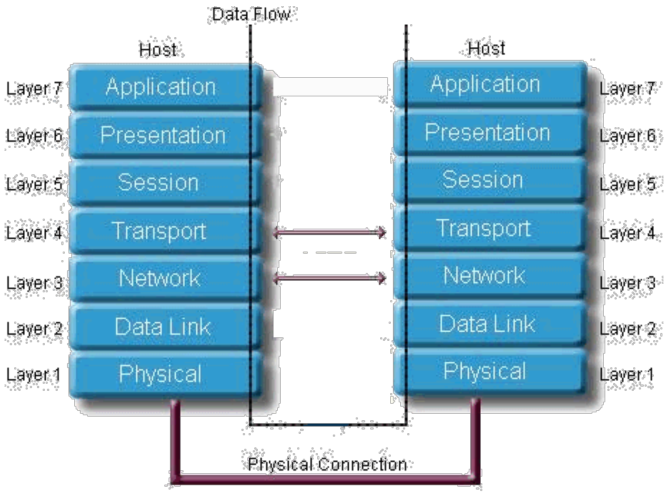
From this perspective, one of the worlds oldest engineering systems, irrigation systems, can really benefit from the Internet connectivity. When we look at the first engineered irrigation system in Babylon, we see how the moisture content was used as a feedback to determine how much to irrigate. Now, few thousand years later, we have an interent connected world where we can get that feedback everywhere, even on a flight to our favorite, Irrigation Conference. This is the goal, and the desire of the modern world, where decisions are made from far away.

The distance between two machines, machine and a human, or 2 humans is no longer a central problem. We know exactly, which technology to use for communicating plurality modes of information. Thus, the century old bottleneck of communication is no longer there and we can truly communicate information beyond mountains and fields of sight. That's why Internet of Things is the next driver behind agriculture.

In this context, we shall identify challenges for IoT proliferation in Agricultural practice of irrigation and as well as opportunities offered, as well as the most important components of any IoT system first. These essentials can be grouped into 3 areas: communication, computation and usability.

IoT - Communication:

Internet as we like to think about it is the magical tool that connects devices in a way that you can access information from anywhere. The way it works is just briliant. Everything is organized in layers of abstraction, which utilizing rigorous scientific methodologies. Basic transmission of modulated signals is used to transfer bits of data from point A to B. This layer is called the physical layer (Figure 1). On top of this layer, is the data link layer. Each data is communicated independantly and in isolation in the physical layer. This is the layer that actually transmits information. The layer above is the Network layer. In this layer, information exchange is handled between the nodes on the same small network. However, its in the Transport layer, that one of most important decisions was made, which allows devices to be far closer to each other. It is the hierarchy that allows connection of different small networks to other networks by special Internet Protocol Addressing, a unifying mechanism that allows to make few hopes between devices as depicted in Figure 2. As we move up in the ladder of these communication layers as depicted in the Figure 1, information exchange is used for cohesian and unification of systems into an entity called Internet.



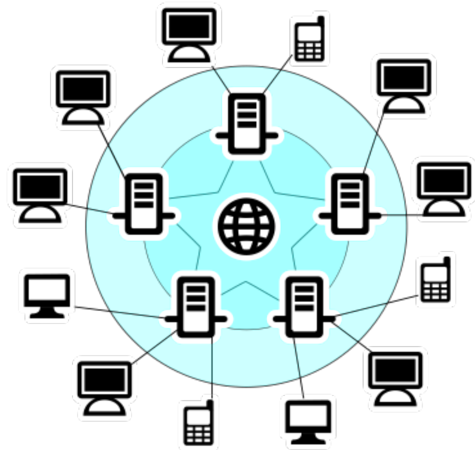


Figure 1: Internet Layers (Nolan)

Figure 2: Internet Model (Pixobay)

In the design of Internet, every to machines is connected to routers, or so caled base stations. These base stations than route, hance the name, pockets of information to next station while effectively routing the shortest path between any 2 devices. This allows having short latencies and elastic throughput. It is important to note that once devices are connected to internet via any base station, they are connected to each other. Thus, Internet of Things simplifies the interdevice communication, given that these devices can connect to any base station.

Originally, Internet was designed to be a wired network, where wires were the hard carriers of signal, but over time it grew into mix of wired and wireless communicaiton systems. Wireless communication is one of the key components in our vision for the Internet of Things for Agriculture as large distance in fields allow require robust communication mechanisms.

Network Structures – Local and Wide Area Networks

Network architecture for networks differs due to their physical connectivity range and type. Local connection thru wired ethernet create a different type of network than wifi connections. However, when we are thinking about agriculture and using sensors and actuators that are connected to one another ranges can exceed few hundred meters. Therefore, the conventional use cases are impractical and longer range solutions beyond WiFi need to be used if we wish not to complicate with labor intensive network modifications.

Technologies	Frequency Band	Data Rate	Trans. Range	Energy Cons.
Wifi	5-60GHz	1Mb-1Gb/s	20-100m	High
WiMAX	2-66GHz	1Mb-1Gb/s	<50Km	Medium
LR-WPAN	868/915 MHz, 2.4 GHz	40-250Kb/s	10-20m	Low
2G	865 MHz	50-100kb/s	Cellular area	Medium
3G	865MHz	200kb/s	Cellular area	Medium
4G	2.4GHz	0.1-1Gb/s	Cellular area	Medium
BlueTooth	2.4GHz	1-24Mb/s	8-10m	Medium
LoRa	868MHz/900MHz	0.3-50Kb/s	<30km	Very Low

Table 1: Comparison of popular communication technologies (Ray 2016)

Wifi and Bluetooth, which are the two dominant wireles communication protocols use 2.4Ghz band and can support devices up to 100m in unabstracted view. However, in practice this number is far lower considering that quality of communication efficiency tends to get lower causing multiply retransmissions, delays, and higher energy costs. Energy is an important metric particularly for wireless sensor networks, which need to harvest their own energy as wiring them adds manual labor and complicates use. For this reason, lower frequency bands such as 400-900MHz have been proposed for use as they tend to offer a practical alternative for applications such as agriculture. One such new technology is known as LORA. In Figure 3, LORA based Wide Area Network architecture demonstrates an application where a gateway is used as an intermidiatory between the local wide area network and overhauling Internet servers.

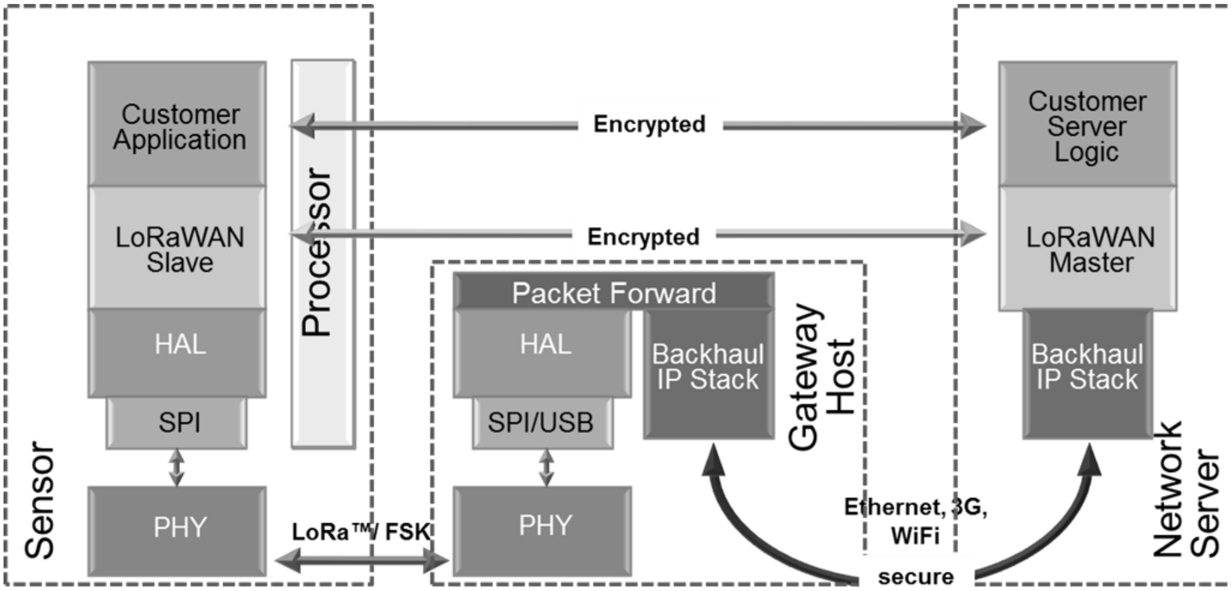


Figure 3: LORAWAN Structure (LoRa 2017)

IoT - Computing

Although, semiconductor industry has yielded plurality computing device, it also created a very complex set of computing devices with parameters that's not easy to use to differentiate. Currently there are many devices ready for use in IoT setting, see Table 2, however, many of these are not meant for industrial and extreme condition use, although they may well be much more powerfull than those in Apollo missions.

Table 2: Comparison of popular IoT Platforms (Ray 2016)

Platform	CPU	Operating Voltage	Clock (MhZ)	Bus Width
Arduino Uno	ATMega328P	5V	16	8
Arduino Yun	ATmega32u4,	5V, 3V	16,400	8
Intel Galileo Gen 2	SoC X1000	5V	400	32
Intel Edison	SoC X1000	3.3V	100	32
Beagle Bone Black	Sitara AM3358BZCZ100	3.3V	1024	32
Electric Imp 003	ARM Cortex M4F	3.3V	320	32
Raspberry Pi B+	BCM2835	5V	700	32
ARM LPC1768	ARM Cortex M3	5V	96	32

Cloud Platforms

What is cloud? Cloud is the general term used for abstraction of computing architecture into a service that includes a bit more than just computation and storage of information. It's a service provided to users for providing continues and uninterrupted service no matter the scale of the operation in a flexible and scalable manner. Cloud platforms, such as Dropbox offer file storage, while others such as Google Compute Engine offer computational resources. Depending how they charge their users, and what kind of costumer service they provide whether it's a technical expert 24/7 on duty or some of the hardware is located on site of the user, so called hybrid cloud service, there will be lots of choices for the costumers. That's why IoT will always have some sort of cloud service associated as it is just too easy to to integrate these two technologies together and get something more out of it, which is peace of mind that your data, your service is reliable and works all the time.

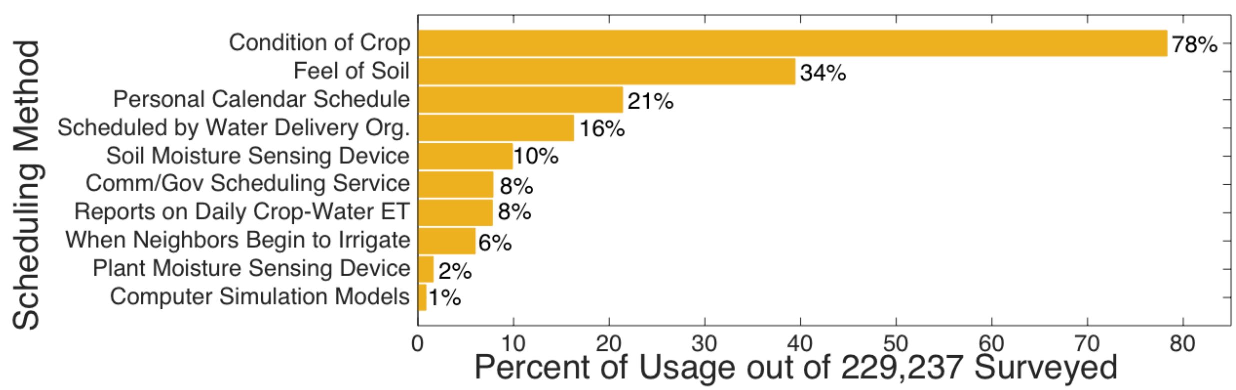
Table 3: Comparison of popular Cloud services for IoT (Ray 2016)

Cloud Platform	R.T. Data	Visual.	Cloud Type	Analytics	Cost
Xively (https://xively.com/)	Yes	Yes	Public	No	Free
ThingSpeak (https://thingspeak.com/)	Yes	Yes	Public	Yes	Free
Plotly (https://plot.ly/)	Yes	Yes	Public	Yes	Free
Carriots (https://www.carriots.com/)	Yes	Yes	Private	No	Pay per use
Exosite (https://exosite.com/)	Yes	Yes	Hybrid	Yes	Pay per use
GroveStreams (https://grovestreams.com/)	Yes	Yes	Private	Yes	Limited
ThingWorx (www:thingworx.com/)	Yes	Yes	Private	Yes	Pay per use
Nimbits (www.nimbits.com/)	Yes	Yes	Hybrid	No	Free
Connecterra (www.Connecterra.io/)	Yes	Yes	Private	Yes	Pay per use
Axeda (www.axeda.com)	Yes	Yes	Private	Yes	Pay per use
Yaler (https://yaler.net)	Yes	Yes	Private	Yes	Pay per use
AMEE (www.amee.com)	Yes	Yes	Private	Yes	Pay per use
Aekessa (www.arkessa.com)	Yes	Yes	Private	Yes	Pay per use
Paraimpu (https://www.paraimpu.com/)	Yes	Yes	Hybrid	Yes	Limited
Phytech (http://www.phytech.com/)	Yes	Yes	Private	Yes	Pay per use
Cayane (www.mydevices.com)	Yes	Yes	Private	No	Mixed
EVineyard (www.evineyard.com)	Yes	Yes	Private	No	Mixed
WeatherUnderground (https://www.wunderground.com)	Yes	Yes	Private	No	Mixed

IoT - Usability – Why now? and How?

Fresh Water is the critical resource for humans, yet, its far more important for life on our planet. Worldwide, roughly 70% of fresh water is used for irrigation, and over 90% in least-developed countries (UN 2015). According to the 2005 US Census Data, total fresh water use in the United States was 355 billion gallons per day (Census 2013). That is over 1000 gallons per day per capita. Out of all fresh water usage in the United States, Irrigation utilizes 38% of all fresh water in the United States, which is often wasteful and highly inefficient (Hsiao 2007). Between 2008 and 2013 total fresh water used for irrigation in farms rose by at least 22% (Maupin 2010). The problem is further exacerbated with extreme climate events such as droughts, which cause environmental disasters. For example, due to drought California implemented a first-ever mandatory water reduction (CNN 2015). Yet, data shows that situation may worsen in 2030 with worldwide 40% fresh water deficit (UN 2012). That said, irrigation control is still largely done by quasi-rational techniques such as feel of soil or condition of crop, respectively, with 78% and 34% popularity among 232K surveyed by US Geological Survey (Maupin 2010).

Figure 4: USGS Irrigation Survey (USGS 2015)



Irrigation systems are cyber-physical systems, because they are composed of man-made systems: irrigation networks and their controllers, and physical world: soil, atmosphere and plants. In cyber-physical systems, all elements involved in the overall picture must be carefully weighted. Moreover, the complete solution for an irrigation system must incorporate every step from design and development to deployment. In other words, there should be means to make design decisions a priori, use the known to engineer tailored or standardized solutions, and finally, recalibrate system settings during or after the final stages of installation on the farm.

Global deficit of fresh water poses challenges just like energy, however, it has not been addressed with the same intellectual investment. Hence, to address water deficit demands with the same level of emphasis as other main stream domains, we have designed set of experiments which will try to examine irrigation scheduling practices and offer new insight to irrigation science. Specifically, our main objectives are in examining relationships between optimal scheduling techniques and yield of crops with respect to state of the art and conventional irrigation techniques and proposed irrigation methodologies.

Irrigation Background

We can write the soil moisture as a differential equation and use commonly used simulation tools to simulate this ordinary differential equation relationship (ODE):

$$\frac{\partial m}{\partial t} = \mathrm{P} - \mathrm{E_T} - \mathrm{R} \quad (1)$$

or

$$\frac{\partial m}{\partial t} = \mathrm{P} - \mathrm{E_T} - \mathrm{R} + \mathrm{I} \quad (2)$$

where m is soil water content, t is time, P is precipitation, E_T is evapotranspiration, R is total surface runoff, and I is the irrigation.

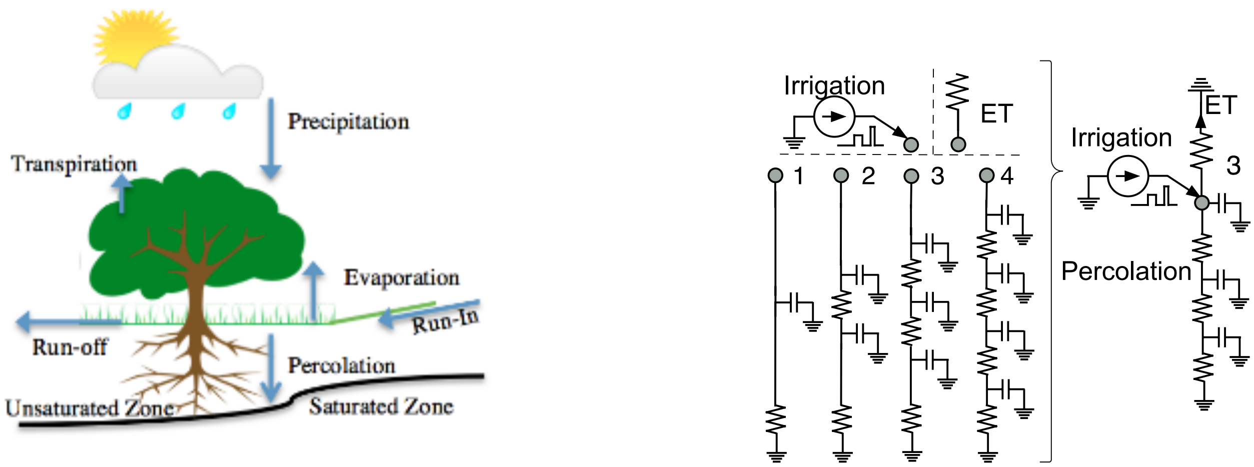


Figure 5: Basic Hydrologic Processes in Irrigation (left) and Equivalent Circuit Model (right) (Hovhannisyan 2016)

Thus, using the analogy of hydroelectric phenomena, we were able to model the soil water percolation as a circuit. The idea of incorporating all the stakeholders in one loop was the main driver for this contribution. On the right is the graphical representation of the model and modeling strategy.

These are the reasons why its important to bringing in hindsight expensive technologies to agricultural proctice. One way to bring IoT into agriculture is the maker community. In the following case study, where we will talk about a maker community in Temecula, CA where not just sensor and weather stations are made for fun, but for reducing community water usage by 5-10% and saving the water district $10mil. Whether they will succeed or fail, only time and math can say, but they won't give up until they do!

Case Study: Temecula Valley

The traditional irrigation practice for vineyards is a weekly good long soak. However, long irrigation drains deep in the soil, whereas short irrigation achieves majority of irrigated water staying at higher levels. Thus, irrigating once a week, and replacing the weekly amount of water in one irrigation cycle, applies more water than what can be used in one or two days. The surplus of water will drain deeper and eventually become out of reach of the active roots. Unlike popular belief, even for plants with long roots, like grapevines, most of the actual update of water takes place at shallow soil levels (up to 4 feet). Together with the draining water fertilizers also wash away, thus, reducing fertilizer efficiency and polluting aquifer. By irrigating more frequently, like every day, there is more granular dosage of irrigation water, closely following the (daily) evapotranspiration needs. The main goal is to supply the precise amount of water needed and have it delivered only to the soil layers with the active root system, where the plant uptakes it. The expereiments took place in Van der Lee Vineyard as well as other local Vineyards (Figure 7).

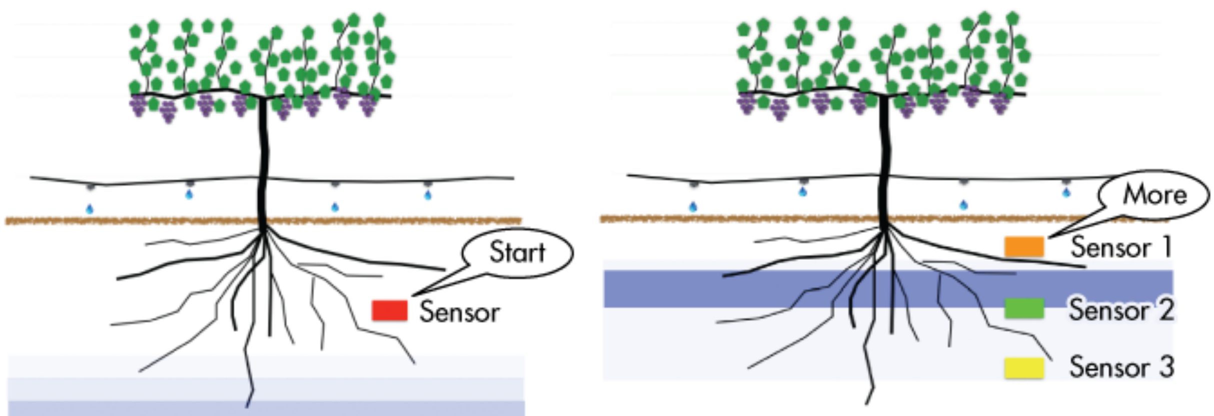


Figure 6: Comparison of single (left) and multi-sensor stations (right)

Figure 7: Van Der Lee Vineyard

We used multiple sensors within the active root zone to monitor the available water to the plants. By placing a soil-moisture below the root zone, we can detect percolation reaching that level (Figure 6: left). Looking at the soil model circuit in Figure 5 we can see that starting from the ground level and moving down, a time-varying signal goes through successive stages of low-pass filters. This is reflected in Figure 6, which were obtained using SPICE simulation of the soil water transport model in Figure 5 which shows that water moisture level becomes more stable at lower soil layers and for the daily irrigation schedule. This behavior predicted in SPICE simulation was verified by actual measurements at different soil levels shown in Figure 9. The moisture levels at deeper and shallower levels track reasonably well, and the deeper sensor moisture levels looks like the moisture level at the shallower level but attenuated and passed through a low-pass filter. The variations in the water levels over the days is due to the different levels of evapotranspiration due to temperature changes within and between days of the experiments. Although, these changes were not captured in the SPICE simulations, they could be easily accommodated into the SPICE models by varying the R value in the ET circuit model based on the daily weather forecast.

Figure 8: SPICE Simulation at different depths.

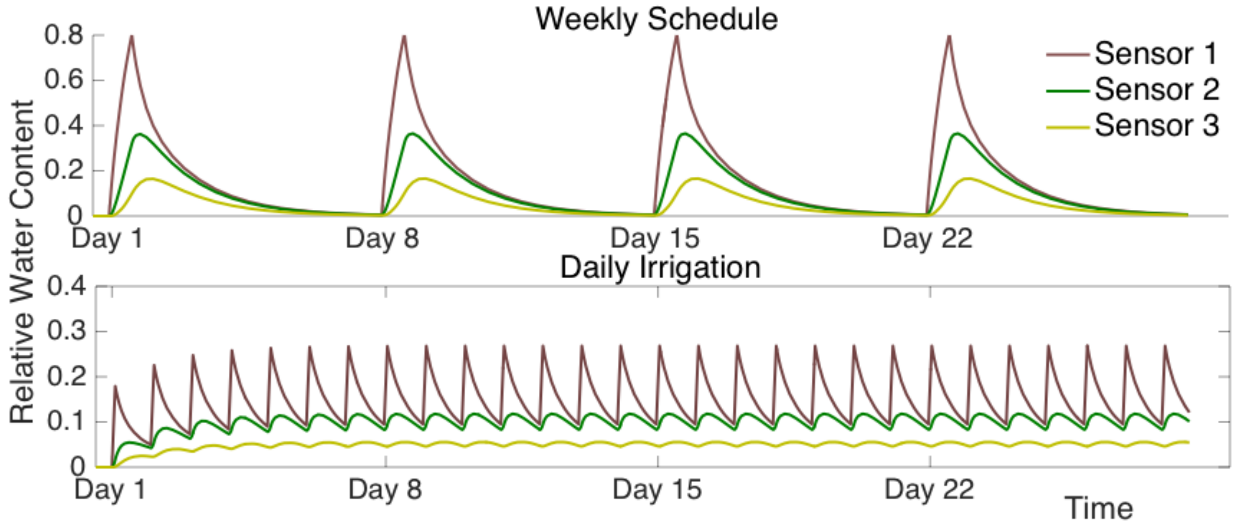
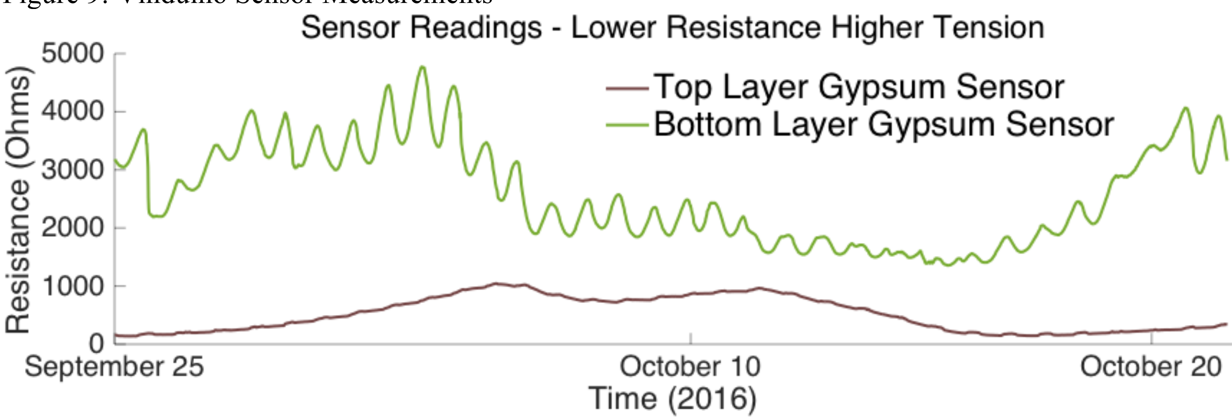


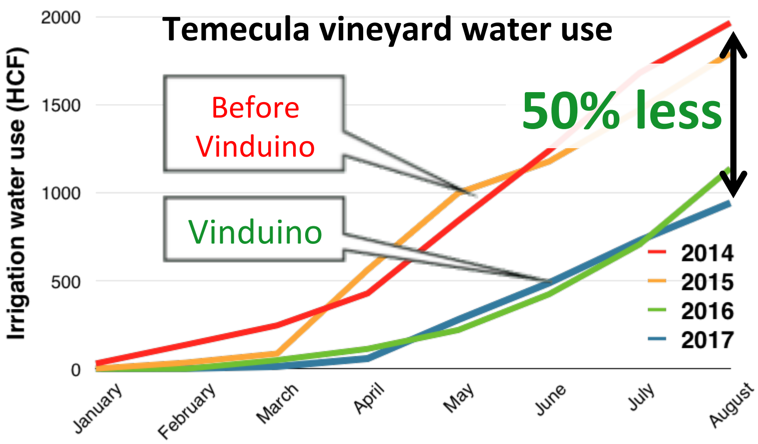
Figure 9: Vinduino Sensor Measurements



Conclusion and Future of IoT in Irrigation

In conclusion, we can see that IoT has potential not to just improve efficiency of irrigaiton saving of around 50% for a given period year to year (Figure 10), but also to bring together people and excitement to this very important area, where there is still so much to be learned.

Figure 10: Comparison of Water usage in 100 cu. Ft/month.



Future of IoT in Irrigation

Technologies where IoT can be used are:

- Smart Meters: Bidirectional meters for water producers and consumers. Similar to Smart grid for electricity, some farmers might be able to sell water to the water network and their neighbores and use the biderectional metering for that purpose in which case they would be able to utilize IoT metering to be able to get their readings real time without human in the loop. Otherwise, using meters fr internal site-specific metering for irigation zones and division of agricultural (priority) vs other commercial use cases, for flexibile policies from water district which may prioritize day times for normalizing pressure and rates for use cases.
- Irrigation Removte Controlled Self-Sufficient IoT Valves
  - Micro irrigation valves for per site irrigation. IBM has demonstrated in the Galo Vinery that distributed control systems can save signiicant water over traditional single controller.
  - Remote controlled valves for main lines will support emergency shut off conditions that will allow reducing water loss due to busted pipes and animals chewing on tubes.
  - Valves for zones in site specific irrigaiton could control flow as well as pressure and irrigaiton schedule for most efficient water use cases.
- Leak Detection - Major problem for automated tools.
  - Using pressure sensor with valves seems to be possible. In fac we have demonstrated in our lab that we can model water flow and use the model for flow characterization, so nothing gets lost.
  - Using sonic sensors for detection of vibrations across pipes and in areas of breakage.
  - Using flow data and Artificial Intelligence to track the flow areas and leaks.

Infrastructure Upgrades

- Pipes and Tubes that integrate sensors, can the pipe have the leak detector embedded?
- Valve controllers with internal power generation mechanisms – flow, solar and etc.
- Weather stations – that integrate into one national service.
- Base stations – that allow integration of all parts and components by provide wide area networks.

In the future, these technologies will be avilable and our initial in lab findings suggest that can very well be in market now or in near future.

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