# CMPE181
# Final Project Report
# Smart Irrigation System

## Group 10

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# 1. Idea

## 1.1 Problem Statement

Agricultural watering is becoming more challenging. Global warming is generating climate fluctuations that have changed the rain and dry seasons around the world (USDA Sustainable Agriculture Research and Extension). Additionally, different soils require different care, which can be challenging for some farmers to do so. For large scale agriculture, there can be a lack of the ability to accurately measure the adequate irrigation, causing an inadequate watering that can lead to the soil being over or underwatered. Therefore, the crop yield can be affected causing loss of potential income, and water waste.

## 1.2 User Scenarios

To address the issue we propose an IoT smart irrigation system that monitors soil moisture and will automatically water the fields if the moisture drops under a specific threshold. The user has full control of the system via a mobile device that allows him to observe and control the device from anywhere, provided that there's a network connection, and use Bluetooth connection when close to the device for offline control.

Potential users include local farmers that grow different types of crops and may live remotely, urban landscape managers to conserve parks and fields green throughout the year with the changing weather, and large agricultural companies that need to monitor several fields at the same time and yield as much crops as possible.

## 1.3 Envisioned Device Kit

We envision a device that will constantly measure the soil moisture level, alert when it's under a certain threshold, and allow for automated watering. All using state of the art technology, like precise sensors and motors, and using essential protocols for network and device communications to ensure user privacy and security. The device could help users learn from trends, maximize efficient water usage, and even prevent wildfires caused by dry soil.

# 2. Work Developed

## 2.1. Communications

### 2.1.1. Description & Analysis

Communication layers are essential in the elaboration of any IoT device, in our case, they ensure a smooth interaction between the device and the user. For our device, we incorporated the ThingSpeak platform that allows us to have a robust communication layer. The application layer uses the HTTPS Protocol through the ThingSpeak platform to be able to securely transport data over the internet when using the connection mode. In the transport layer, ThingSpeak employs the TCP Protocol, and is also compatible with MQTT protocols if desired,  to transfer data between device and user in a reliable manner. In the Network Layer, we utilize IPv4 through ThinkSpeak to be able to address and route data that is being shared. At the physical and link layer, the device primarily uses the Wi-Fi module for connectivity to home routers.

Now, in addition to the Wi-Fi, the device would include Bluetooth connectivity to be able to provide user interaction when there is a close connection and no internet connection available. This way, the device ensures connection and operation in scenarios where Wi-Fi connectivity might be unavailable or unreliable like it is in remote agricultural fields.

### 2.1.2. Key findings

- Integrating ThingSpeak allowed for streamlined data visualization and remote monitoring.
- Including both Wi-Fi and Bluetooth allows for the device to be useful both in online and offline environments.
- One improvement that could be done is to explore other protocols to optimize resource usage and support deployments on a larger scale in an adequate manner.

## 2.2. Adoption of Cloud/Fog/Hybrid Computing

### 2.2.1. Description & analysis

ThingSpeak is a cloud-based analytics platform service that processes and stores data collected from our sensors. The use of the Wi-Fi module enables connectivity between the sensors and the cloud platform. The device is then able to present real-time data to the user through mobile devices and/or web interfaces. Including a Bluetooth feature adds an additional layer of flexibility by enabling local data access and device without relying on internet connection.

Adopting a hybrid approach with fog and cloud computing brings computational capabilities in a faster way, enabling faster response times and reducing the reliance on external networks. This would look like deploying localized servers close to the agricultural fields to process data from multiple sensors in real-time. The hybrid approach along with the Bluetooth connectivity allows for a more optimized device that could have a better performance for the user.

### 2.2.2. Key findings

- Cloud Computing allows for real-time data gathering and access which is good for scalability.
- Fog computing reduces the latency in transporting the information between application and the user as well as reducing network traffic.
- Hybrid approach is the best approach for large scale solution because it provides a more robust model in which local fog nodes can be included closer to the systems locations for faster data processing, and enhance the responsiveness of the device.

## 2.3. Privacy and Security

### 2.3.1. Description & analysis

While Wi-Fi data transmission via ThingSpeak, which utilizes the Transmission Control Protocol (TCP) for connectivity, can be encrypted using their built-in protocols like the Hypertext Transfer Protocol Secure (HTTPS) or the Message Queuing Telemetry Transport (MQTT) protocol, Bluetooth data transmission needs to also be secured to prevent any data leakage or unauthorized access. Therefore, the adoption of the Secure Simple Pairing (SSP) protocol for Bluetooth ensures that only authorized users can connect to the device. All data layers need to include these authentication features to ensure that data transmission is only seen and done by authorized and authenticated users. Additionally, security measures such as firewalls, secure gateways, and end-to-end encryption should allow for the application to ensure the protection of data from any potential attacks.

### 2.3.2. Key findings

- ThinkSpeak provides some baseline protocols like TCP for connectivity and HTTPS and MQTT for data transmission.
- For Bluetooth connections, the Secure Simple Pairing (SSP) protocol will be utilized so that only authorized users can connect to the device via Bluetooth.

- Basically, multi-factor authentication and encryption will be utilized for the two types of connections that our device can establish: Wi-Fi and Bluetooth.

## 2.4. Robustness and Reliability

### 2.4.1. Description & analysis

To ensure long-term reliability, the system uses corrosive resistant moisture sensors to withstand the harsh elements, minimizing the need for frequent maintenance and replacement. Currently, our device is designed to be error-tolerant, capable of handling minor disruptions without compromising the overall functionality. What this means is that if for example, a sensor temporarily fails, the system is able to continue to work independently. At a larger scale, the system would indicate to the user of a sensor fault and resort to a backup sensor in close proximity.

A robustness technique that can be employed is having a watchdog timer on each MCU that resets the system in the case of long periods of inactivity due to system hangs. Likewise, in the event of multiple faulty sensors in the same zone, an alert from the system will be sent to notify the user and stop the system from collecting data from the soil and stop watering where the faulty sensors are located. For additional connectivity, Bluetooth is integrated; If no network is available users can rely on Bluetooth connection as a redundant backup. These features allow the device to continue monitoring the soil for a long period of time without needing replacement while also providing reliability without the need for constant maintenance.

### 2.4.2. Key findings

- Hardware material selection needs to be key in the building of the device to be able to guarantee a long-lasting device that is robust and reliable. Therefore, we will utilize corrosive resistant soil moisture sensors.
- Redundancy is needed to guarantee reliability and handle disruptions. It can be done by having multiple sensors per zone to maintain system integrity. When a sensor stops working, another sensor in the same zone can be turned on and take its place.
- A restartable IOT solution will be implemented, where watchdog timers will check whether a sensor has transmitted

data in a certain amount of time. If not, troubleshooting steps will take place, and the sensor will be restarted if needed.
- Single point of failure must be considered at both software and hardware levels, corrosive resistant sensors and watchdog timers are great for fail-safe techniques for our system.

## 2.5. Algorithms

### 2.5.1. Description & analysis

IoT algorithms in the system are designed to manage data efficiently and accurately. Sensors will collect data from the outside world, then we will be able to access secure and reliable data that is processed through communication and cloud protocols from what was discussed in 2.1 and 2.2. After the readings from the sensor has been processed in real-time and is ready for data storage and retrieval to ThingSpeak, it will be able to process the readings into data in Thingspeak so that the system can decide to do an action such as water the plant if it is low on soil moisture, or to notify users if there is a faulty sensor within the system. With multiple sensors within a large system, APIs, which ThingSpeak provides, makes it possible to have all sensors communicate with each other and have any additional sensors added to other zones of a larger agricultural landscape when needed.

Implementation of Machine Learning (ML) can enhance and optimize algorithms for the device. ML could help analyze historical data to share trends and identify patterns of soil health and deterioration or insufficient water usage with the user having access to this data to make more informed decisions. The predictive models could optimize the irrigation schedules to be able to both conserve water while also improving crop yield. All this is incredibly relevant with weather forecasting being in constant change thanks to climate change and global warming.

### 2.5.2. Key findings

- ThinkSpeak is a good start for data management, but to enhance the system further and provide even more complex features, advanced algorithms need to be implemented into the system.
- Machine Learning could be key in enhancing features that provide historic data analysis and provide insights that the user could find helpful. From this we can set customizable settings

for specific plants and soil for ML algorithms to learn and predict when to water not only based on current soil moisture level but before the plants soil becomes dry in the first place.

## 2.6. Interaction between the IoT devices within the solution and with the users

### 2.6.1. Description & analysis

Users can access the ThingSpeak system interface with an internet connection to monitor soil moisture levels and manage irrigation schedules remotely. Users can access historical data for the whole system or each individual sensor to be able to see historical trends and make evaluations on the soil moisture behavior and learn from it.

When near the device and offline, the user could connect to the device via Bluetooth to directly access the data of the sensors to control irrigation settings through the system application. This allows for easy Human Device Interaction (HDI) as users who want to view data through their devices via ThingSpeak are able to if they are near the microcontroller. The location of the sensors would be in key regions of the field and would be easy to install. Protection and warning labeling would be provided to ensure that the system does not get damaged. These labeling would be for each sensor to easily identify each one for service.

Future developments of the system for Cross-device interaction (XDI) can include the inclusion of smart home and device compatibility so users can access the system, notifications, and its data through them. The ThingSpeak API makes it easy to add additional devices if the user desires to, allowing for easy implementation of XDI. ThingSpeak is compatible with other smart home systems such as Amazon Alexa, Google Assistant, and Apple Siri.

### 2.6.2. Key findings

- Dedicated application for the system enhances the user experience and the accessibility to the sensor information.
- There is opportunity for integration for other smart devices and also other systems to improve the performance of the system in different environments and even with existing irrigation systems.

- Alerts and feedback notification for the users are key in the usability of the device for both access to the system data and overall care of the system.

## 2.7. Evaluation

The current proof of concept represents a significant step toward achieving the full realized vision of a smart IoT irrigation system for agricultural fields. The proof of concept is able to accurately perform the key function of our device, which is to detect the moisture of the soil and present it to the user, as well as sending alerts whenever the soil moisture is under the threshold. Having this operational, means that the concept can be further developed to achieve its fullest potential. However, there is further work and improvement pending, that for the time constraint we could not dive deeper into.

The integration of dual communication methods, Bluetooth and Wi-Fi, permits for adaptability and usability in different environments and situations. The Wi-Fi connectivity through ThingSpeak enables the user connectivity and access to the data, as well as Bluetooth providing an additional reliable backup for the user to access the data when internet is not available.

Using durable and resistant materials for the hardware and enclosures allows the device to withstand agricultural duty wear and tear. An error-tolerant design ensures that the system can withstand minor failures without it affecting the whole functionality of the system as whole.

As a whole, the device allowed us to learn that there is an importance on having redundancy on a device for the user to be able to have access to it despite not having an internet connection, hence why we included Bluetooth in our concept. Furthermore, we believe that the design for the system and application needs to be user friendly such that the device is intuitive and easy to use.

Furthermore, as we encountered problems with the motor pump for our proof of concept, we realized the importance of constant testing, not only for software but also for hardware, to ensure that the device works seamlessly and as expected through every stage of the development and design.

Overall, the development of the concept and the proof of concept provides a solid foundation for the further work on the IoT Smart Irrigation device. While there were challenges, they provided us with valuable insights that can guide the future research and design of the concept, and allow us to explore and see the theoretical concepts in action.

### 2.8. Recommendations & Future Work

We believe that there is opportunity to keep developing the concept further by deepening and keep researching in certain areas. For the proof of concept the initial idea included the motor integration for the self-irrigation system but due to technical challenges with the hardware set up and time constraints, this could not be fully realized.

There is a need to fully develop mobile and desktop applications that can interact with the system to be able to have the full functionality of an IoT device that can be accessed remotely.

Researching more robust protocols to protect and encrypt the data that is being shared specifically through Bluetooth, is necessary to be able to enhance the robustness of the device and prevent any attacks that could compromise the user and system information.

While the system shows promise for scalability, there is a need to keep developing features like real-time error reporting, advanced data analytics, and even enhance the device with further Machine Learning capabilities that can make the device even more appealing and useful for the user.

## 3. Project Management

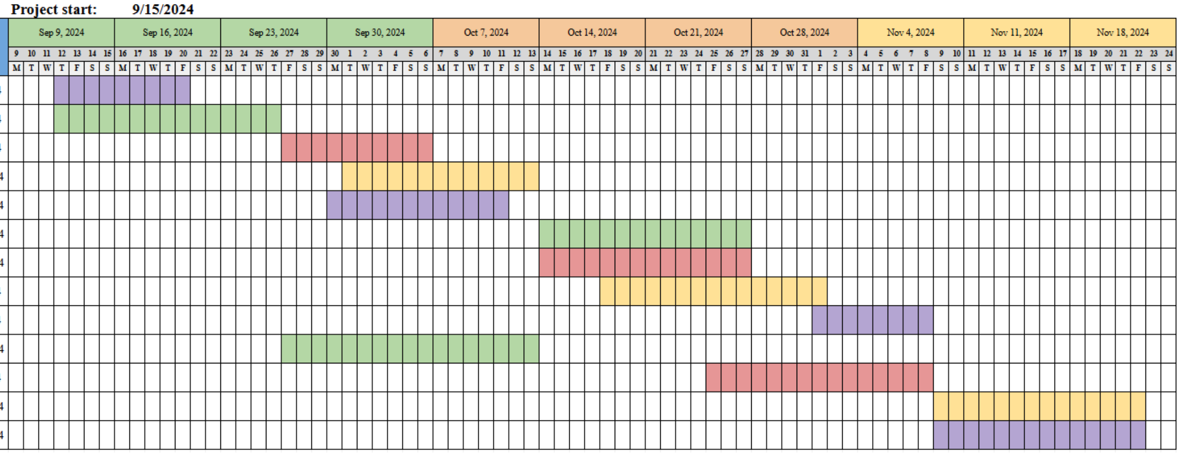
### 3.1. Final Schedule & Task distribution

**CMPE 181 Project**

**Group 10**

**Project start: 9/15/2024**

| TASK | PROGRESS | START | END |
|---|---|---|---|
| Project Initial Report | 100% | 9/12/2024 | 9/20/2024 |
| Design | 100% | 9/12/2024 | 9/26/2024 |
| Communications | 100% | 9/27/2024 | 10/6/2024 |
| Cloud/Fog | 100% | 10/1/2024 | 11/13/2024 |
| Midterm Presentation | 100% | 9/30/2024 | 10/11/2024 |
| Privacy | 100% | 10/14/2024 | 10/27/2024 |
| Secruity | 100% | 10/14/2024 | 10/27/2024 |
| Case Study Presentation | 100% | 10/18/2024 | 11/1/2024 |
| Robustness and Reliability | 100% | 11/1/2024 | 11/8/2024 |
| Algorithms | 100% | 9/27/2024 | 10/13/2024 |
| Interactions | 100% | 11/1/2024 | 11/8/2024 |
| Report | 100% | 11/9/2024 | 11/22/2024 |
| Final Presentation | 100% | 11/9/2024 | 11/22/2024 |




The tasks were evenly divided, where everyone contributed in some part to everything regarding the 6 criteria points for the project. We had continuous meetings and were in constant contact with each other to support one another and accomplish the final objective.

## 3.2. Challenges

The main challenge we had faced was the difficulty of working on and with the picobricks board. We had initially wanted to have a working water pump through the motor on the picobricks board that would be automated to water the soil when the sensor had a low enough threshold to water it. However the motor driver IC was having I2C communication issues with the board and the picobricks library, hence unable to make the automated water pump to work. This was not such a huge deal as the prototype was simply a proof of concept, but working on the picobricks board and getting to code to run smoothly also took a while to be completed.

## 3.3 Learning Outcomes

Throughout the semester we had learned 6 major topic points that are crucial to the development of IoT system design. As we began to develop our prototype we had to readjust our mindset to a larger scale as our prototype was simply just a proof of concept. As we dug deeper into what our project would potentially become through class discussions, lectures, and individual research it had become more and more clear how important these 6 points were and why as engineers it is important to consider each one of them. Through individual research, project building and the case study, we've learned to utilize different applications such as APIs and other software, as well as think about other concepts that we could use if we ultimately had unlimited funding for an IoT project. It was interesting to play around and tune the picobricks board, and each one of us in Group 10 are grateful that our professor was able to grant us the opportunity to borrow the picoboard for our proof of concept.

# References

USDA Sustainable Agriculture Research and Extension. (2021, July 9). *CH 17. Managing Water: Irrigation and Drainage - SARE*. SARE. https://www.sare.org/publications/building-soils-for-better-crops/managing-water/