Smart Water Leak Shut-off Valve

Design Document

Team 11

Client/Advisers

Cheng Huang

Team Members/Roles

Alex Murry

Andrew Fehr

Augusto Savaris

John Michael King

Kangcheng Xu

Natalia Almeida

Tyler Denning

sdmay22-11@iastate.edu,

http://sdmay22-11.sd.ece.iastate.edu/

Executive Summary

Development Standards & Practices Used

- IEEE 802.11
- IEEE 1625-2008
- National Electric Safety Code C2-2007
- IEEE/ANSI 315-1975

Summary of Requirements

- Mobile application will provide authenticated access to control of shutoff device settings as well as a visualization of water flow data
- Mobile application will have notifications when a shutoff event or other relevant events occur
- The server will maintain user data in a database for request by the mobile application as well as use by the machine learning process
- The server will perform machine learning analysis of the collected data and update the shutoff device
- Shutoff device will run a Machine Learning model that classifies the live data patterns as abnormal or not and shuts the valve when an leak is detected
- Shutoff device will have a motor capable of turning the existing main shutoff valve
- Shutoff device will be able to be set up without any technical experience or plumbing required
- Shutoff device will use a sensor external to the water main in order to detect the flow in the pipe
- Cost will be less than $200 for the customer
- Project should be scoped appropriately in order to be completed during senior design (cost, time, resources)

Applicable Courses from Iowa State University Curriculum

EE 230, EE 330, CprE 288, CprE 430, EE 475, EE 321, EE 224, EE 324, ComS 309, DS 201

New Skills/Knowledge acquired that was not taught in courses

- Using RaspberryPi
- Setting up and using an ADC
- Bash
- Rapid prototyping and testing

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1 Team

1.1 Team Members

Alex Murry
Andrew Fehr
Augusto Savaris
John Michael King
Kangcheng Xu
Natalia Almeida
Tyler Denning

1.2 Required Skill Sets for Your Project

There are many skill sets required for the successful implementation of this project. Embedded programming skills are needed for the Raspberry Pi to be able to process data and transfer data to the server. It will also be necessary to program the server to correctly store, interpret and output the data to the mobile application. Mobile app development skills are needed in order to create an app that functions as desired and is user friendly. Machine learning skills are needed so that the system can learn what a leak looks like and become more and more accurate over time. Skills regarding electronic devices and circuits are necessary when connecting components to the Raspberry Pi and ensuring the correct inputs and outputs are generated. Knowledge regarding sensors and motors is also important as the sensors must be accurate and must generate usable data. The valve motor must also be controllable remotely through electrical signals which is a core aspect of the project.

1.3 Skill Sets covered by the Team

Embedded programming: Alex

Mobile application development: John

Machine learning: Augusto

Electronic devices and circuits: Andrew

System Sensors: Natalia

Motors and Valves: Tyler, Kangcheng

1.4 Project Management Style Adopted by the team

The team has adopted the Agile leadership style.

1.5 Initial Project Management Roles

Team Organization: Andrew
Client Interaction: Natalia
Testing Hardware: Natalia, Tyler, Andrew, Kangcheng
Testing Software: John, Augusto, Alex

2 Introduction

2.1 Problem Statement

According to Home Advisor, the average cost for homeowners to pay for water damage in 2019 is $2,582, depending on the actual damage. Recently, there are smart leak shutoff valves on the market that allow homeowners to remotely monitor and control the water shutoff valve. However, the prices of such products are typically above $500, which is outside the comfortable price range that most homeowners would consider having one installed. In this project, students will develop a low-cost smart water leak shutoff valve, which has similar functionality but reduces the cost below $200.

2.2 Requirements & Constraints

- **Requirements from prompt**

The device should able to 1) measure the water flow through the water line, 2) connect to the internet such that the user can monitor the water flow in real-time and control the water valve, 3) other smart functions, e.g., send alerts when excessive water leak is found when the home owner is away or asleep during the night, 4) identify abnormal water usage by learning the patterns of different household appliances and user habits (optional).

- **Requirements derived from assignment and limitations**

Will = Required
Should = Not Required

Software Requirements

Mobile Application

- Will perform authentication (with username and password) of users to access their device(s).
- Will display a graph view of historic water usage (up to 1 year of data).
- Should retrieve the water usage data from the service's server and send user shutoff requests to the server.
- Will allow the user to manually tell the valve to close in the app. It will then remain closed until the user manually allows it to open again.
- Will have user settable sensitivity of the automatic shutoff functionality (low, medium, high for example).
- Will send push notifications if abnormal water usage is detected and/or if the valve is automatically shut.

Server

- Will store water usage data, user credentials, and associated devices in a SQL table.
- Will be always waiting for a connection to be initiated by mobile applications and/or RaspberryPIs.
- Will authenticate the mobile app and RaspberryPi devices using username and password credentials.
- Should provide water usage data associated with a user to the mobile app on request.
- Will accept and store water usage data from a connected RaspberryPi.
- Should be available at a public address on the internet for devices to connect to. (This is the intended functionality but will likely not be implemented during the prototyping stages and instead will be run as a local server on the LAN in order to simplify the development process).
- Will store preprocessed usage data that will be used for Machine Learning
- Should perform machine learning analysis of the stored data when the device is in the pattern building mode and update the model on the associated shutoff device.

RaspberryPi

- Should average water flow data over 10 second intervals and send to the server along with a timestamp.
- Will run a Machine Learning model that classifies the live data patterns as abnormal or not
- Should close water main when loss of power has occurred and backup power is reduced to a critical level.
- Will control the shutoff device.
- Will collect the sensor data from the ADC to be processed.

Hardware Requirements

- Will be able to be installed without plumbing
- Will detect water flow
- Should have Wifi module or bluetooth are going to be used as communication between the hardware and software
- Will have a mechanism for closing the main water supply
    - Will be a Motor that mounts to, and operates existing main shutoff valve

User/Customer Focused Requirements

- Will Cost less than $200 for the customer
- Will be Installable by general population with no plumbing required
- Will not pose any significant risk to life or limb of Customer

Research and Development Constraints

- Will ost under $500 to design, build, test and all other functions of R/D
- Restricted to ~2000 work hours

- 2 Semesters

2.3 Engineering Standards

- 2020 -IEEE 802.11- IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks--Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

The Raspberry Pi communication over wireless ethernet, governed by this IEEE standard. All protocols, power restrictions, and best practices are explained in this document.

- IEEE 1625-2008 - IEEE Standard for Rechargeable Batteries for Multi-Cell Mobile Computing Devices

Residential power outages do occur and there is a correlation between incidents that cause leaks and power outages. There is a possibility we will build our system resistant to power outages. This would require a battery backup.

- National Electric Safety Code C2-2007

There are inherent safety concerns when working with any electrical components. These codes specify best practices for safely handling electrical components.

- IEEE/ANSI 315-1975 - IEEE Standard for Graphic Symbols for Electrical and Electronics Diagrams

We will document all designs we make following a standard for easier interpretation by any future parties that will use our documentation.

2.4 Intended Users and Uses

- Any home/property owners
  - Emphasis on warm weather climates where pipes are not insulated and are vulnerable to freezing
- App allows easy shut off for non-emergencies as well
  - Leaving on vacations
  - Maintenance
- Can track water usage throughout day and find out usage patterns
- “Use Cases”
  - Normal Operation Scenario

Enable homeowners to remotely actuate main water shutoff and view water usage patterns from the app. Allow homeowners to select preferences for power failure mode, leak detection sensitivity, and notification settings.

- Standard leak Scenario

During home renovations a water pipe running to a washing machine is sheared. Our solution must detect the leak, close the water main, and notify the homeowner of a leak.

- Slow leak Scenario

Corrosion causes a slow leak to start in the water pipes. Our solution must detect the leak, close the water main and notify the homeowner of a leak.

3 Project Plan

3.1 Project Management/Tracking Procedures

We will use the waterfall + agile management style. This is because the scope of our project is not large enough to justify a completely agile management style. In addition, since we do have hard deadlines for the completion of different aspects of our project we will be able to create a project plan in the waterfall style which aligns with the 491 & 492 course requirements/assignments. Then on a week to week basis we will be able to use an agile style by having weekly sprints and regular check-ins with the client to verify the progress of the project.

We will use GitLab to track software development and progress.

We will document hardware testing and datasheets in google docs

3.2 Task Decomposition

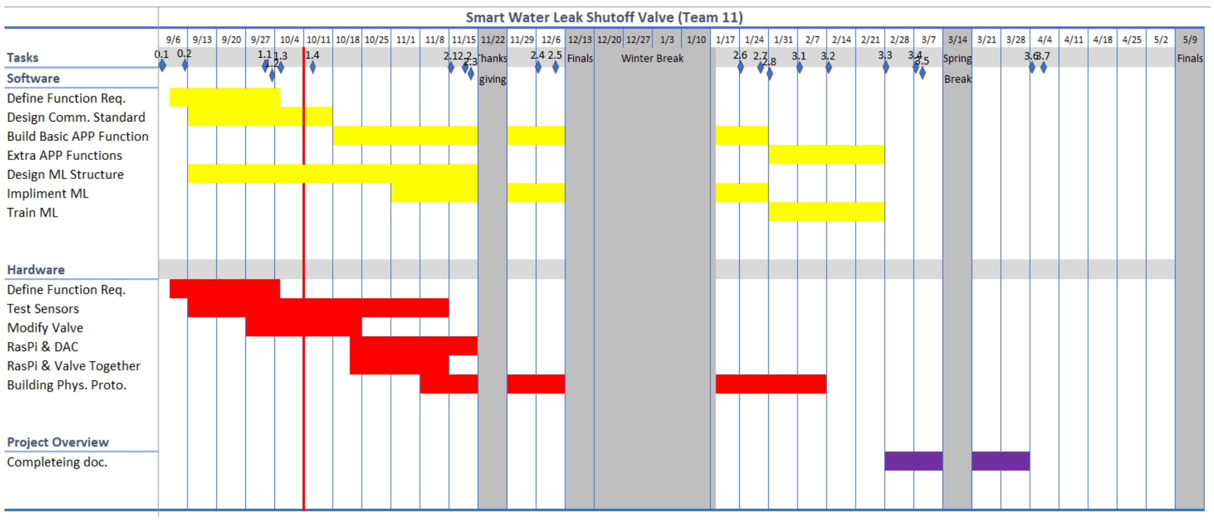
- Android app development
  - Login/security implementation
  - Create line graph based on input data
  - Define, connect with, and communicate with server for data and shut off notification
  - Creation of potential notifications for specific criteria from sensor information
- Water leak detection system using Machine Learning
  - After the sensor hardware is defined, analyze data format and choose appropriate ML model
  - Gather, clean, and preprocess data to perform training
  - Train ML model and determine feasibility of solution
  - Implement ML pipeline to run on the server:

        - ML pipeline will, for each user, gather data and perform training automatically
        - After defined training period to learn specific user water usage patterns, the trained ML model will be deployed for real-time inferences
- Finding hardware for detecting water flow
    - Test both Sensor types (Microphone and vibration)
    - Research and test other possible sensor types
- Finding hardware for turning off the main water line
    - Purchase and test existing motor valves
    - Modify to connect to MCU
- Connect sensors to MCU
- Connect wifi module to MCU to connect with App
- Backend/database development
    - Define and maintain connection with PI
    - Store data with user information in database
    - Communicate with application to inform user of leak

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

- Phase 0 (Organization and Project Management)
    - 0.1 Assigned Groups
    - 0.2 Project Kick off Meeting
- Phase 1 (Independent component design and fundamental software)
    - 1.1 Find sensor able to detect water flow to an accuracy of High, Medium, Low
    - 1.2 Open and Close water from digital input and detect valve position
    - 1.3 Define structure for transmitting and receiving data from remote servers
    - 1.4 Design structure of the machine learning algorithm
- Phase 2 (Connecting components and build software fundamental)
    - 2.1 Using testing, define the flow in volume over time with an accuracy of 75%
    - 2.2 Read and save data from sensor on raspberry pi
    - 2.3 Use Raspberry pi to control the Valve
    - 2.4 Build App capable of reading flow data from the remote server
    - 2.5 Send flow data from Raspberry Pi to remote server
    - 2.6 Add login functionality to App
    - 2.7 Notifications within App
    - 2.8 Program the machine learning algorithm
- Phase 3 (Training machine learning and Cleaning User interface)
    - 3.1 Adding Valve Close and Open command to App
    - 3.2 Build stand alone prototype
    - 3.3 Feed data into training algorithm and tune to detect leak scenarios
    - 3.4 Head to tail test
    - 3.5 Requirements Review
    - 3.6 Finalise Documentation
    - 3.7 Present to Sponsor

3.4 Project Timeline/Schedule



3.5 Risks And Risk Management/Mitigation

Risk	Estimated Probability	Mitigation Plan
Exterior pipe sensors unable to detect a leak	High	Restructure project around interior pipe (flow) sensors (which need plumbing)
Server hosting untranslatable from local hosting	Low	Restructure backend code to function with server (complete re-write of the parts that do not work)
Collected data is not correlated with leak detection	Low	Normalize collected data to emphasize even slight changes
Servo incapable of closing valve	Low	Spect a servo with more force
Internet transmitted data gets lost frequently	Low	Induce timeout for requests, resending if need arises
Machine Learning algorithm too complex to work for many concurrent users	Low	Select simpler ML model with decreased accuracy but less needed computation for inference
Leak damages RaspberryPI before it can shut off valve	Low	Shutoff water flow to the main line if not signal it's lost with MCU. Move RaspberryPi to safer location and reset system

Data gets deleted on application-side	Low	Create feature to re-send data from database
Hacking of user's personal info, turning off user's water main	Low	Increase security technique
Valve shutoff too slow to prevent major leak from causing significant damage	Low	Restructure detection thresholds to be more conservative and test for speed often
Sponsor changes requirements midway into project	Medium	Look for sensors that give the same type of output, so the software doesn't need to be adjusted
Test water main unable to be obtained [plumbing solution] (i.e. how do we verify flow sensors)	Low	Talk to professor to how to proceed

3.6 Personnel Effort Requirements

Task	Total person-hours	Justification
Researching & testing sensors	64 hours	32 hours of research divided by 4 people 32 hours of testing divided by 4 people
Designing communication protocols & SW structure	10 hours	This step is already largely completed and mostly involves discussion between members to clarify intent of design.
Building mobile application	96 hours	None of our members are highly experienced in mobile app design so much of the time will be spent in that stage of the process. The reason it is not longer is the app will be fairly simple with only two-three screens and only a few points of interaction for this initial design.
Building server	72 hours	Some of our members have experience setting up servers and SQL databases. So the biggest time consumption here will be in writing the scripts that will communicate with the RaspberryPI and mobile app as well and ensuring the server is set up securely.
Writing RaspberryPI software	48 hours	The logic for the RaspberryPI will be relatively straight forward since its functionality is

		simple. The largest time consumption will be in testing as well as getting the machine learning logic communicating clearly with the HW drivers so the shutoff decisions can be made accurately.
Water Leak Detection System	130 hours	analyze data & choose model: 10h; data processing & model training: 30h; ML pipeline: 90h
Valve Testing and Wiring	2 hours	

3.7 Other Resource Requirements

- House with standard plumbing to test water flow detection system

4 Design

4.1 Design Context

4.1.1 Broader Context

Describe the broader context in which your design problem is situated. What communities are you designing for? What communities are affected by your design? What societal needs does your project address?

List relevant considerations related to your project in each of the following areas:

Area	Description	Examples
Public health, safety, and welfare	How does your project affect the general well-being of various stakeholder groups? These groups may be direct users or may be indirectly affected (e.g., solution is implemented in their communities)	Increasing/reducing exposure to pollutants and other harmful substances, increasing/reducing safety risks, increasing/reducing job opportunities
Global, cultural, and social	How well does your project reflect the values, practices, and aims of the cultural groups it affects? Groups may include but are not limited to specific communities, nations, professions, workplaces, and ethnic cultures.	Development or operation of the solution would violate a profession's code of ethics, implementation of the solution would require an undesired change in community practices
Environmental	What environmental impact might your project have? This can include indirect effects, such as deforestation or unsustainable practices related to materials manufacture or procurement.	Increasing/decreasing energy usage from nonrenewable sources, increasing/decreasing usage/production of non-recyclable materials

Economic	What economic impact might your project have? This can include the financial viability of your product within your team or company, cost to consumers, or broader economic effects on communities, markets, nations, and other groups.	Product needs to remain affordable for target users, product creates or diminishes opportunities for economic advancement, high development cost creates risk for organization

4.1.2 User Needs

Property owners need a way to prevent leaks from causing increased water bills and water damage because they are often harmful to their property and/or costly.

Property owners also need a way to remotely shut off their water so that they can prevent unwanted water usage and have peace of mind when away from their property.

Property owners need a cheaper alternative to the leak prevention options currently on the market so that none are excluded by financial means

Property owners also need a way to view their water usage over time so that they can learn their own usage patterns and be able to conserve when needed.

4.1.3 Prior Work/Solutions

During our first meeting with our faculty advisor/client, he mentioned that there already exist available solutions in the market but that they are expensive (above $500, and usually in the range $800-$1000). That's why one of the main motivations for our project is to develop a working system that costs under $200. Another shortcoming from previous work is that most of the available products require plumbing to install the sensor to detect water flow. We are testing microphones and vibration sensors that can be mounted outside the pipes for easier installation. Needing plumbing to install the system increases the overall cost and nuisance for the user. For example, this link (https://www.amazon.com/Moen-900-002-4-Inch-Smart-Shutoff/dp/B07W9LV16S/ref=asc_df_B07W9LV16S/?tag=&linkCode=df0&hvadid=385182617423&hvpos=&hvnetw=g&hvrand=8883935064914519972&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=1015640&hvtargid=pla-822871258308&ref=&adgrpid=73789135650&th=1) shows an existing product that costs more than our threshold of $200 and requires plumbing. However, one advantage of a product that requires plumbing in comparison to ours is that they will likely be more sensitive to leaks and have a higher leak detection accuracy.

Since we are basing our project on vibration sensors that measure the water flow from outside of the pipe, a research paper that is providing us with technical background is this one: https://www.ijert.org/research/contactless-running-water-flow-detection-and-water-flow-measurement-system-IJERTV7IS040272.pdf. The researchers designed a system that detects water flow using a vibration sensor and show how the signal amplitude behaves for four relevant scenarios: no water flow, small water flow, medium water flow, high water flow.

4.1.4 Technical Complexity

Our solution is sufficiently complex. It contains three subsystems, the RaspberryPI controlled hardware device, the server which manages and processes the user data and the mobile app which displays the data to a user along with some other minor functions. The physical device itself contains multiple components including the sensor hardware, the ADC, the mounting hardware, RaspberryPI software, etc. The project also has some unique constraints that make it different from current solutions that exist. One is that the solution we are trying to create will be able to mount externally to the water main instead of having to be plumbed into the pipe. This would make it significantly easier and cheaper for a user to set up themselves. There is another company with a similar technique but they use a sensor that attaches to the water meter of a house which may not always be accessible while our solution the user would place the sensor directly on the water pipe. Another is the price of the device needs to be less than $200 while the current solutions available cost upwards of $700-$800.

4.2 Design Exploration

4.2.1 Design Decisions

Key Decisions:

- Selecting the MCU (Raspberry Pi, Aurdino, Tivia C)
- Water Sensor (Microphone, Piezoelectric, Waterflow Sensor)
- Water Shutoff Valve (Solenoid, Motor Valve)
- Type of Machine Learning Used - we started testing with Recurrent Neural Networks, as they usually perform well for time-series data. But we quickly realized the data was too noise and the RNN was not performing well, so we switched the data preprocessing to only give the model the signal's statistical properties. Thus, we are using a Decision Tree Classifier, which gracefully captures nonlinearity without many training samples.
- App development Platforms(Android studio, Visual Studio, Qt)

4.2.2 Ideation

A key component of our project is detecting the flow within a pipe. As a team we brainstormed possible solutions without any criticism then we went back through them to inspire any other ideas. After that we discussed the feasibility of the ideas and determined which were worth pursuing. There are several different ways we initially brainstormed for detecting water flow in a pipe. We discussed using a water flow sensor that is installed into the pipe. We also discussed using a microphone on the exterior or the pipe to hear the flow inside of it. Another possibility is that we use a vibration sensor to detect the pipe shaking as the water flow increases. Option 4 is that we detect the frequency of the pipe at two locations and use this data to calculate the water flow. Finally we thought about using an assortment of pressure, temperature and hall effect sensors to detect flow.

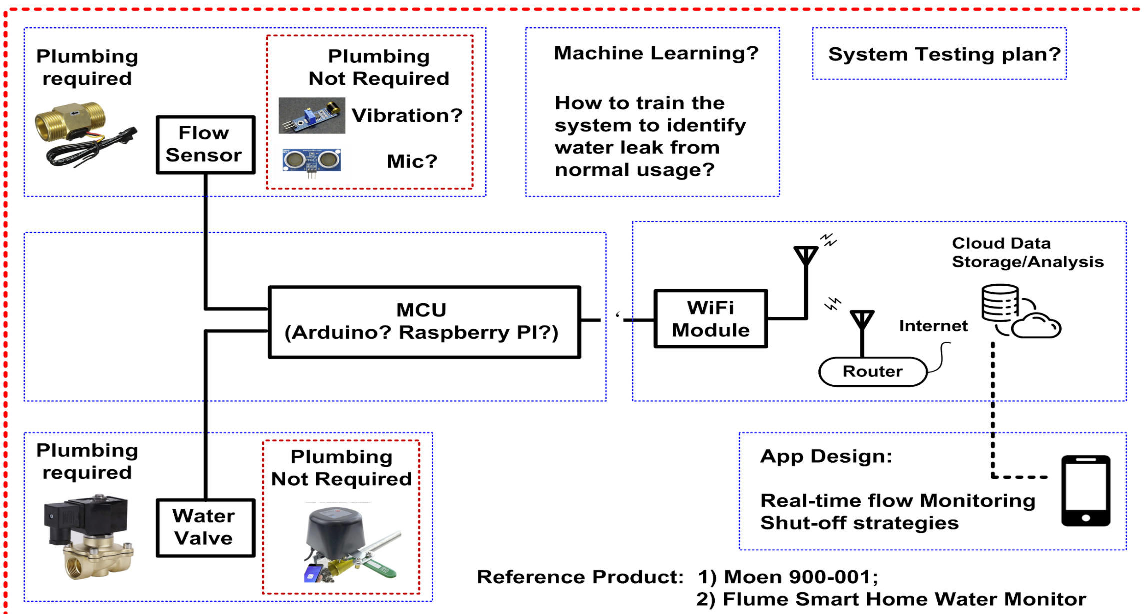
4.2.3 Decision-Making and Trade-Off

We discussed potential solutions amongst the group and with our client. The options chosen were selected mostly based on the cost to implement with preference being given to solutions that did not require plumbing. It also had to be taken into consideration that the setup of the device is meant to be done by any user and in a variety of potential settings so the system must be small, and simple to correctly set up without electrical knowledge.

4.3 Proposed Design

Our design consists of an external vibration sensor monitoring water flow through the water main. The sensor sends data to an ADC and then to a Raspberry Pi. The Raspberry Pi is responsible for sending data to the server via its wifi module as well as for controlling the motor that turns the water valve. The data is then stored in the cloud until it is accessed from a mobile device where the user can look at real time data as well as data over time. The user can also turn the water main on and off at their pleasure from the app.

4.3.1 Design Visual and Description



The design right now would use the two "plumbing not required" options on the left side of the diagram meaning that we will detect water flow externally through a vibration sensor, and when the valve needs to be shut a motor on the outside of the pipe will be turned on and will be able to close/open the valve depending on the user's need. Both the sensor and motor will be connected to an MCU (we have elected to use raspberry pi since the diagram was initially made). The raspberry pi has a wifi module on it which will be able to connect to a server to store the collected data (most likely hosted on one of our laptops for this project). The cloud can then be accessed by a mobile device and interfaced through an app that we will design. The app will allow real time flow monitoring as stated in the lower right of the image along with shutoff capabilities for any time the user wants. When the system detects a leak and automatically shuts off the user will get a notification from the app so that they are aware of the shutoff and they will be able to turn the water back on from the app if it is a false alarm.

4.3.2 Functionality

Use Cases

- Normal Operation Scenario

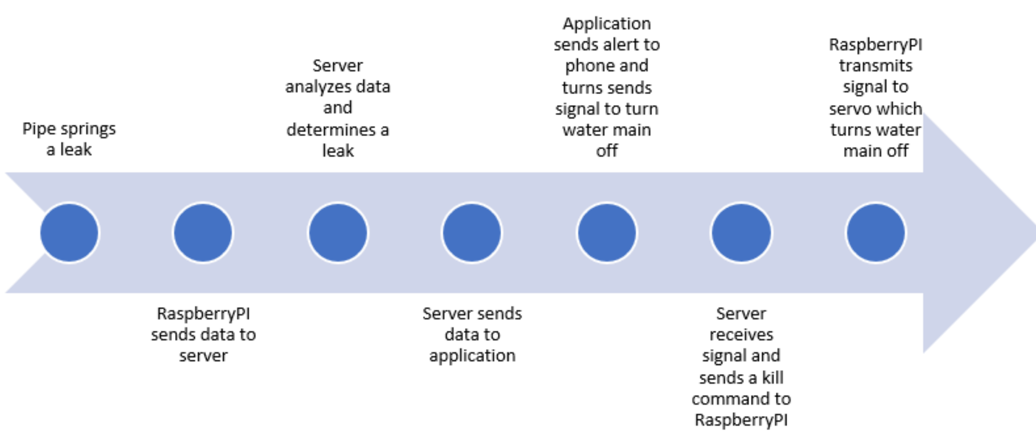
Users can remotely control the main water shutoff and view water usage patterns from the app. Users can select preferences for power failure mode, leak detection sensitivity, and notification settings.

- Fast leak Scenario

During home renovations a water pipe running to a washing machine is ruptured. The Vibration sensor detects the increased water flow and the machine learning algorithm identifies it as a leak. This sends a signal to the valve telling it to close and pushes a notification to the user's phone.

- Slow leak Scenario

Corrosion causes a slow leak to start in the water pipes. The Vibration sensor detects the increased water flow and the machine learning algorithm identifies it as a leak. This sends a signal to the valve telling it to close and pushes a notification to the user's phone.



The current design satisfies all of the requirements both functional and non-functional. We hope this trend continues when we move into implementation and actually connect the entire system together.

4.3.3 Areas of Concern and Development

One current area of concern is the accuracy of the system when using a vibration sensor as opposed to an internal sensor. We have been unsuccessful in being able to consistently pull good and usable data that we know is not simply noise. The detection will hopefully become better as we increase our knowledge and implementation of machine learning but it is hard to quantify that improvement. At the moment we will continue to work on that as well as look for potentially better sensors, but we want to stay with the external design. There is also some concern because none of our team members have a ton of experience doing mobile app design or development but there is no particular solution to this beyond learning the necessary skills and working together to get the simple app we need to build. After that the last concern is simply interconnecting the different pieces and hoping that they all work together coherently. The solution to that though is to plan ahead while we work now. We have and will continue to think before we do so that we can build the different systems to work together and not just independently. This means lots of different things but can be as simple as making sure that outputs and inputs of the different systems are in the form they need to be to be interpreted correctly at the next stage and so forth, it simply requires planning.

4.4 Technology Considerations

Highlight the strengths, weaknesses, and trade-offs made in technology available.

Discuss possible solutions and design alternatives

The biggest consideration/trade-off in the entire design up to this point has been whether or not to go from an external sensor to an internal sensor. The decision comes down to trading lower cost (lack of plumber needed to install) for lower accuracy (external sensor). The external method allows the device to be cheaper and easy to install by the user, while the internal method allows for very good leak detection accuracy. We have accepted the trade-off of the external method but we are hoping to minimize the accuracy loss.

It is a strength of our design to use machine learning instead of having designated thresholds because of the wide range of potential use scenarios and environments. This will allow the device to adapt to its surroundings and make accurate decisions based on the data it receives without relying on pre-made thresholds to define what is a leak and what is not.

4.5 Design Analysis

So far, we have spent the majority of the semester trying to find an external sensor capable of accurately detecting water flow through pipes. We have looked into a microphone which did not work as well and a few different vibration sensors, one of which shows promise. In these tests we attached the sensors to the water main and used an arduino (eventually a Raspberry Pi after it came in) to read in the data and then we looked at both the raw data and a graph of the data trying to distinguish usable patterns. Over the course of the semester as we got better sensors and our machine learning knowledge improved we were able to come across a promising sensor able to detect a leak of about 0.83 gallons/hour and above.

We also ordered a motor for closing the valve and confirmed that it can open and close the valve on the water main. The motor was modified so that it was controllable via electrical signal from the Raspberry Pi and this functionality was tested and confirmed.

As for the software side of the project, the application has been designed and the critical components are now present. All the main buttons and radio selections have been made and can be checked by the Android Application. In addition, the charting api has been fully integrated with the application, complete with dummy data capable of being displayed on the chart. In addition, the dummy data can be changed with a button press, indicating that the data can be updated while the application is running (important as the api documentation stated that it the api could not be used for real time graphing, but it seems the frequency of updates in the requirements is slow enough to make this a non-issue).

Overall, we have not finished and implemented the entire system so it is hard to say if it will all work just yet but we have made good progress this semester and have a strong plan moving forward into next semester. We should be able to hit the ground running and finish the rest of the implementation and then move on to testing and debugging the system as a whole.

4.6 Design Plan

The design meets the normal or steady state case. The device will sit on the pipe tracking the water flow. It sends this data to the app for the user to view. In this state it is a passive object that will sit ready to act. It is not a hazard in any way and is ready to toggle the valve if the user requests it through the app.

In the second use case there is a leak. The pizo-electric sensor will continue to measure the water flow within the pipe. The raspberry pi running the machine learning algorithm would detect this as an anomalous water flow. This will trigger the raspberry pi to execute a command to the water valve telling it to close. It will simultaneously send a notification to the app to notify the user that a water leak has been detected.

This design completely meets the functional requirements possessed by the advisor/client.

5 Testing

5.1 Unit Testing

The various sensors we are using are being tested using graph data to see if they can do what is required of them. To test the sensors, the sensors shall output the data to the Raspberry PI to visualize if leak detection is possible.

Also, we shall be testing components at the unit level as development progresses, such as verifying the chart api works with arbitrary data points, verifying the server correctly stores arbitrary simulated data, and verifying the Raspberry PI collects the data from the sensors as intended.

For the hardware aspecte, an important unit to test is the motor which turns the valve that turns off the water. An existing device has been modified such that the motor may be controlled electronically. The main concern is that the motor will attempt to draw too much current from the raspberry pi. During initial tests with a power supply and a DMM we saw that the motor will draw several amps of current if this is not regulated which is not acceptable. We added resistors to limit the current and were able to test again and confirm the lower current, which allowed a test with an MCU afterward.

Another unit to be tested is the sensor used to detect water flow. The tests for this unit are very important because we must see how the sensor output varies when water is being used in different amounts in order to characterize normal usage and leaks. To do this we started with simply using an arduino to interface with the sensor and then using putty to observe the data. At times we also used Excel to create a graph of the data. The Arduino will switch to a raspberry pi once our unit is set up to interface with the sensor.

5.2 Interface Testing

For the software, the primary interface that will need to be tested is using http protocol to connect the Raspberry Pi, Server, and Phone App together in order to share information and commands. The testing will be performed by testing the protocol with a tool such as Postman as well as verifying the various components connect successfully and share the data they are meant to while doing integration and system testing. There should not be too many concerns with the protocol as http is already very well defined.

As for the hardware, we have an interface from the water flow in the pipe to the sensor. We are testing this interface by physically attaching several sensors to a pipe and collecting the values from the sensors on a data acquisition tool (arduino). We can then go back and verify that the water flow information is detected by the sensor. Another interface we have is between the motor and the water valve. This was easy to test by simply hooking up the motor to the valve and visually observing the valve actuating. We also had an interface between the motor and the raspberry pi.

5.3 Integration Testing

One of the critical integrations relevant to our project is how the raspberry pi, server, and app are connected together. We'll need to test the connection between each of these major components. For the connection between the raspberry pi and the server, we'll need to test if the real-time requirement (uploading the data every 10 seconds) is being met, we'll need to ensure that the data is being transferred completely. Additionally, we'll need to test if the app can pull data from the server in real-time and if the pulled data is correct.

We have two critical integration paths for the hardware. We need to send a signal from the controller that causes the valve to close and we need to get information about the water flow into the controller. To test both of these critical paths we will need to set up portions of the prototype. The first is the signal going from the pipe through the sensor, through the ADC and finally detecting it with the raspberry pi. For this path we need the raspberry pi, the ADC, the sensor and the main water pipe. For the second test of the other integration path we only need the raspberry pi and modified water valve.

5.4 System Testing

System testing will be done by simulating a leak and verifying that each step works as expected. We will simulate multiple types of leaks using usage data previously collected and learned. We will know that the system works as expected when the system properly shuts off the water main upon a leak simulation and that the system does not shut off the water main when the water is used "normally." Also, ensuring that the app interaction correctly manipulates the greater system will be performed.

5.5 Regression Testing

We will run the main leak simulations once more. The critical features are that the system can detect the simulated leaks and turn off the water main, as well as the application can turn off the water main remotely as well.

5.6 Acceptance Testing

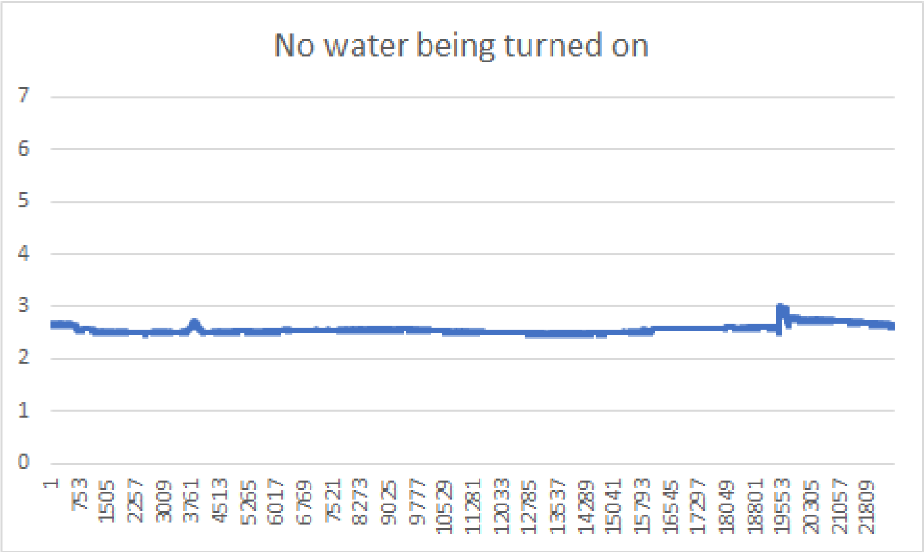
We will show the data of simulated leaks and demonstrate that the leak simulations are representative of environments in the real world. Included in the definition will be time for the system to notice the leak and take action. We will show Professor Cheng the finished prototype either physically or from a video after it passes our internal acceptance check which will include a review of design requirements.

5.7 Security Testing (if applicable)

N/A

5.8 Results

From our initial sensor tests, we collected voltage data output which is shown below:

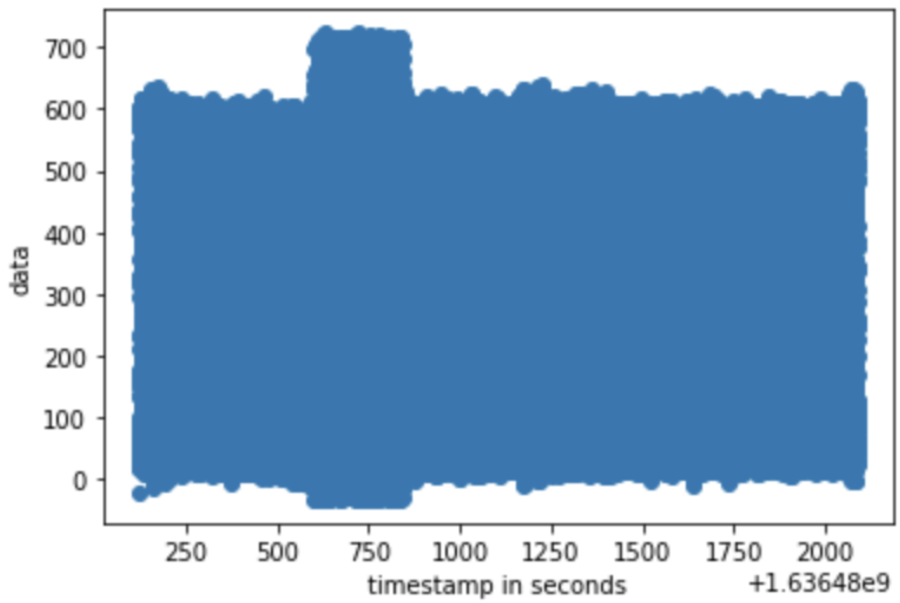


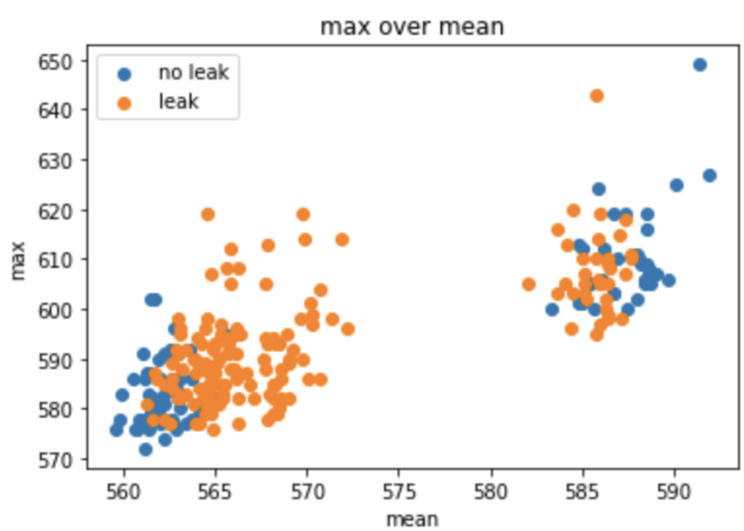
This graph shows the baseline of the data, meaning that it was collected when there was no water flowing. This allows us to understand what data patterns correspond to each situation, and eventually we can use these patterns to recognize leaks or high-usage situations.

Microphone setup -

The original setup seemed to be insufficient, but as tests and research progressed, the machine learning algorithm was able to use the sensor to detect a leak.

Next we decided to use a pizo-electric sensor to detect the water flow in the pipe. The setup was very similar but we hoped that the sensor would enable us to detect the flow more accurately. The pizo-electric sensor is essentially a film that generates an electric signal when it is vibrated, compressed or bent. We theorized that this would be sensitive enough to detect the vibrations in the pipe caused by the moving water. The only way to know for sure was to run the tests.





The first graph is one example of the water being turned on for and off for a portion of the time. The second is a more realistic collection of means pulled from the data while simulating a leak and no leak - each point in the graph represents the (max, mean) values for a period of 30 seconds from the raw data . The data comes from two different tests which explains the two pockets of data. This indicates that machine learning would not be able to distinguish between a leak and no leak due to the limited signal that is easily hidden by noise. Ideally, we would want to see two clusters that represented the two different scenarios, instead of the two different tests. Since the tests were performed in the exact same conditions and the properties of the signal were not maintained, we are likely just observing noise rather than meaningful data.

6 Implementation

Our plan is to implement our solution by building a full prototype. We have the raspberry pi to valve interface, waterflow to data interface, and data to machine learning interfaces all complete and tested. We need to complete the data to the app interface and tie all the components together. We have also considered making a demonstration model that can be displayed on campus. This would involve making a simulated house plumbing system as well that can be displayed at the school.

7 Professionalism

This discussion is with respect to the paper titled " Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012

7.1 Areas of Responsibility

Area of Responsibility	**Definition**	**NSPE Canon**	**IEEE Canon**
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence	Perform services only in areas of their competence. Avoid deceptive acts	Maintain and improve technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations.
Financial Responsibility	Deliver products and services of realizable value and at reasonable cost	Act for each employer or client as faithful agents or trustees	Reject bribery in all forms
Communication Honesty	Report work truthfully, without deception, and understandable to stakeholders	Issue public statements only in an objective and truthful manner. Avoid deceptive acts.	Be honest and realistic in stating claims or estimates based on available data.
Health, Safety, Well-Being	Minimize risks to safety, health, and well-being of stakeholders	Hold paramount the safety, health, and welfare of the public	Accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that

			might endanger the public or the environment
Property Ownership	Respect property, ideas, and information of clients and others	Act for each employer or client as faithful agents or trustees	Avoid injuring others, their property, reputation, or employment by false or malicious action
Sustainability	Protect environment and natural resources locally and globally		(Covered in the health and safety section)
Social Responsibility	Produce products and services that benefit society and communities	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession	Treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression

Descriptions:

Work Competence: The IEEE code states similarly to the NSPE code that one should not perform tasks that they are not qualified for/knowledgeable about, but the IEEE code states that engineers should be striving at all times to improve their technical knowledge.

Financial Responsibility: The codes differ here as the NSPE focuses more on reporting true information, we believe this is in reference to information that could affect stock pricing. The IEEE code focuses on direct monetary dilemmas with the engineer regarding bribery.

Communication Honesty: The NSPE code says to issue only true statements and not word them in a way that is deceptive. The IEEE code says the same but to also stick to claims based on data.

Health, Safety, Well-Being: Both codes say to protect the health, safety, and well-being of the public at all costs, but the IEEE code specifies disclosing any factors that could affect those things or the environment as well as actively working in their best interest.

Property Ownership: Both codes essentially say to be a good person and trusted advisor to everyone, but the IEEE code goes farther specifying not diminishing anything about others whether it is work related or merely their actual property or reputation.

Sustainability: Apparently the NSPE code uses the definition of sustainability as their official stance. The IEEE code does talk about actively working to protect the environment but that statement was used for the health and safety section, but it definitely applies here as well.

Social Responsibility: The NSPE code states to respect each other in general for the betterment of the profession. The IEEE code goes into detail about specific things that should not be discriminated against listing several examples.

7.2 Project Specific Professional Responsibility Areas

Work Competence is important to this project because there is a time constraint. Therefore, the team must acknowledge who can do certain tasks successfully and who may not be able to do them at the same level. This ensures that tasks are completed as correctly as possible. However, it is also an opportunity for others to learn and improve their own skills. It is also necessary that if no one knows how to do something we must collectively work together to improve our knowledge. The team is performing at a high level in this regard as members are very honest about what they can and cannot do.

Financial Responsibility applies to the project since the goal of this project is bringing down the cost of the product making it accessible to everyone. Reaseasing and buying parts that are reasonable for the end goal of the project.The team is performing high in this area since it is the core of the project.

Communication Honesty is important to the team because not all members can work at the same time or are working on the same tasks, therefore, we must be honest with each other about progress made and results gathered so that the project is functional in the end for the consumer. The team is performing at a high level in this regard as no one is afraid to admit any issues at weekly meetings and others offer help when needed.

Health, Safety, Well-Being applies to the project since we are managing electrical components, different sensors and measuring devices. We always need to be careful and take the necessary precautions and use protective equipment. The team has a high level of following the safety guidelines.

Property Ownership applies to the team in that we have spent money on physical items for the project and it is our responsibility to make sure the items are not broken or misused throughout the testing and building phases. This also applies to the idea that we are acting as advisors to each other in the best interest as stated in the NSPE code. The team is performing at a high level in this regard as no one is being harmed and the items we have purchased are being properly cared for.

Sustainability is covered by this project since by competing it will be increasing/decreasing energy usage from nonrenewable sources, increasing/decreasing usage/production of non-recyclable materials. The team performing in the are it's medium since by doing the project we are already accomplishing this.

Social Responsibility is important to our group on multiple levels. For starters, our group is made up of a wide range of demographics, so it is important to not operate on any level of discrimination. The product itself is also meant for all to use, so it is important that we do not discriminate against any potential customers through our design. The group is easily complying to this standard at a high level.

7.3 Most Applicable Professional Responsibility Area

The responsibility area that we feel is most relevant to our project is work competence. We have demonstrated responsibility in this from the start as in our first meetings we took down a list of skills that each member brings to the table and initially divided tasks based off of that. As an example, the EE's of the group are handling a lot of the hardware side of the project because their skills are more applicable. The CEs and SE are working on the software side of their project because their skills apply best to that. After the initial decisions members have been able to further divide tasks within those initial groups as well as crossover hardware to software and vice versa when necessary. Being able to divide work based on competency has really allowed us to hit the ground running and start making useful progress very early on. Our project in essence has involved a lot of testing from the beginning because we need to figure out what technology will work for our purpose and what does not so we can have a plan ready for spring semester. Given the nature of our project and our group's approach to it, we will be in great shape for 492 thanks to this progress.

8 Closing Material

8.1 Discussion

We have a design that meets all of the base requirements but implementation will pose new challenges. Our team has already encountered and overcome issues stemming from the physical challenge of detecting the volume of water flowing through a pipe from the outside of the pipe. Our design is at least capable of the minimum requirements stated in the problem. We expect more trouble shooting and design modifications to see that the final project still meets the requirements but nothing substantial

8.2 Conclusion

This semester we designed a system for detecting leaks within plumbing systems. We built prototypes and tested key components of the system. This verified our design and will enable us to start full prototyping next semester. We will also refine our design, improving accuracy, reducing cost and streamline efficiencies. The next step we need to take is to assemble the components we have into a working model. This will be done early next semester.

8.3 References

Prajakta, Miss, et al. Contactless Running Water Flow Detection and Water Flow Measurement System.

8.4 Appendices

ADS111x Manual

Pizo-Electric Film Sensor Datasheet

Valve Purchase link

8.4.1 Team Contract

Team Name
sdmay22-11

Team Members

1) Alex Murray
2) John Michael King
3) Tyler Denning
4) Augusto Savaris
5) Andrew Fehr
6) Natalia Almeida
7)Kangcheng Xu

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:
   Mondays 4:30-5pm F2F
2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):
   Discord and e-mail will be the team's communication channels.
3. Decision-making policy (e.g., consensus, majority vote):
   Majority vote shall be used as the primary decision making policy.
4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):
   The team shall use a rotation for notes using discord

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
   The meeting policy is focused on not missing 2 meetings in row, and to communicate that you will not be attending before the meeting begins.
2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
   If the deadline is not going to be met, communicate with the team to get help otherwise full responsibility will be assumed onto the team members indicated to work on the task.
3. Expected level of communication with other team members:
   Trouble should immediately result in communication to the immediately involved parties, and a Discord message shall be sent in situations where it affects the whole team.
4. Expected level of commitment to team decisions and tasks:

Each team member is expected to complete their sections on time, with the exception given in cases where the member(s) notify the team of trouble in advance.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):

    Team Organization: Andrew
    Client interaction: Natalia
    Testing Hardware: Natalia, Tyler, Andrew, Kangcheng
    Testing Software: John, Augusto, Alex

2. Strategies for supporting and guiding the work of all team members:

    The team shall endeavor to allocate specific parts of the project to the team members' strengths and shall also closely examine if the time and effort is fairly divided amongst team members.

3. Strategies for recognizing the contributions of all team members:

    The team shall ensure that acknowledgement is given to who performed the task when discussing with clientele as well as ensuring that team members have the opportunity to discuss their own successes.

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

    1) Alex Murray - Experience with embedded systems
    2) John Michael King - App-making experience, data science, comfortable with software testing
    3) Tyler Denning - Experience in Industrial Automation
    4) Augusto Savaris - Experience with machine learning and backend development
    5) Andrew Fehr- Experience with circuit design, soldering, plumbing (relevant to our project)
    6) Natalia Almeida- Experience with sensors, circuit design, automation controls devices.
    7) Kangcheng Xu- experience with the circuit design，embedded system and physical background for fluid.

2. Strategies for encouraging and support contributions and ideas from all team members:

    The team shall engage in positive affirmation when someone makes progress; encouragement shall be given to a team member struggling but still giving a good effort. Encouragement shall be awarded to all new ideas shared in concept even if they will not be implemented. Use of the brainstorming strategy, Rapid Ideation, will also be performed (writing down ideas before discussing as a group).

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)

If a person has an issue with one other in particular they should go directly to that person with their problem and also make the team aware of the issue. If an issue involves more than two people then it should be brought up at a team meeting. If the problem persists the TA/client professor may be asked for input on the matter.

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
    - Design Document capable of guiding a third party on building the project
        - Define Communication Protocols
        - Electrical Schematic
    - Data Collection in Progress
2. Strategies for planning and assigning individual and team work:

    By skills and what the team member feels comfortable doing.
3. Strategies for keeping on task:

    Team members shall give updates periodically.

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?

    The team shall have a strike system where two strikes result in the TA being informed, while the third strike shall be considered more serious.
2. What will your team do if the infractions continue?

    We shall get the TA involved.

****

a) I participated in formulating the standards, roles, and procedures as stated in this contract.

b) I understand that I am obligated to abide by these terms and conditions.

c) I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.

1) Natalia Almeida DATE: 09/14/2021
2) Alex Murray DATE: 09/14/2021
3) John Michael King DATE: 09/14/2021
4) Tyler Denning DATE: 09/14/2021
5) Andrew Fehr DATE: 09/14/2021
6) Augusto Savaris DATE: 09/14/21
7) Kangcheng Xu DATE: 09/14/2021