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Flood Prevention System

Project Report

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Abstract

Flooding in modern homes can create thousands of dollars in property damage and endless headaches for homeowners. The inclusion of large appliances that use huge amounts of water into this scenario is a recipe for disaster. In the event a large appliance like a dishwasher or washing machine becomes faulty, the damages to the surrounding home could be extremely costly. The purpose of the flood prevention system developed over the course of this report was designed, tested, and built in order to limit or eliminate these types of damages.

By creating a system that can detect flood water on the floor near appliances, monitor for sub-freezing temperatures and recognize abnormal humidity levels, this project was designed to try and prevent large amounts of flood damage inside homes. To achieve this, 3 sensors were deployed at two major appliances: a dishwasher and a washing machine. To detect thin layers of water on the floor, the Optomax Digital Liquid Level Sensor was chosen for its enclosed design. This sensor uses infrared to determine if its tip is submerged in water, acting as a single-poll/single-throw switch, whether the tip is submerged in water acts as flipping a switch, changing the output from a high to a low. To measure temperature and humidity, the AM2315 - Encased I2C Temperature/Humidity Sensor was chosen to fulfill both purposes. This sensor uses an I2C buss with the microcontroller to relay the current temperature and humidity level to the microcontroller.

Detecting flooding, while important, is only one facet of this project. Once flooding is detected, this system is required to shutoff water to a faulty appliance, or in the case of freezing temperatures, shutoff water to the entire home. This is accomplished by four high torque servo motors, DS3218s, which drive the opening and closing of shutoff valves located at both appliances and the main water pipe entering the home. These servo motors serve an important role, to shutoff water before too much damage has been caused.

Controlling these components are ESP8266 microcontrollers chosen for their low price and Wi-Fi capabilities. These microcontrollers have three main functions, reading sensor data, controlling the high torque servo motors, and communicating wirelessly with the monitoring hub/user interface, a Raspberry Pi 4. The Raspberry Pi 4 is the brains of the operation. Its role is to collect temperature and humidity information from the microcontroller, notify the homeowner of flooding or abnormal sensor readings, and allow the user manual control over the servo motor powered shutoff valves.

These devices, the sensors, the servo motors, and the microcontrollers were tested to ensure that they can meet or exceed the requirements of this project. The infrared water sensor was connected to a simple bread board circuit, then its tip was slowly dipped into a thin layer of water in a Tupperware container. The microcontroller was able to read the exact moment when the very tip of the sensor broke the surface tension of the water. The AM2315 temperature/humidity sensor was compared to similar sensor used to measure temperature and humidity inside cigar humidors. The AM2315 proved to be very accurate in freezing, normal and hot temperatures, as well as high, medium, and low humidity. The torque required to close the valve with the most pressure on it, the main water valve, and the DS3218s were tested to be sure that they could actually apply that torque, and more. A printed circuit board was designed and tested in order to provide a connection to all sensors and servo motors. Unfortunately,

during the testing of the printed circuit board, an issue with the LM1084 regulator was found. The LM1084 is unable to dissipate the power required from the circuit when more than just the servo motor is attached. This means that in order for the system to function correctly and be implemented in the future, a separate power source is needed in order to properly power the servo motors so that the temperature and humidity sensor have enough power to operate on the PCB.

The original plan when programming this system was to have all three microcontrollers at all three locations communicate with the Raspberry Pi user hub; however, it was deemed while programming that a more practical method was to program each microcontroller to host its own internal webpage which can be accessed by both the Raspberry Pi and any device connected to the local area network. This change allows for a more robust user interface, as the system can even be accessed beyond the local area network, if the home router is configured in such a way. The rest of the programming is relatively straight forward, only requiring the microcontrollers to read high/low logic on the water sensor, as well as, temperature and humidity date over an I2C buss from the AM2315 sensor.

The physical build of the project was made by rendering 3-dimensional images and then printing them in PLA plastic with an Ender-3 3D printer. This allowed for sturdy housing to be built around the printed circuit board, with the base plate that holds the PCB and water sensor just high enough off of the ground so that the tip of the water sensor is lined up perfectly with the floor. Also included in the physical build were mounts to securely attach the high-torque servo motors to the shutoff valves, so that they can be adequately motorized.

Overall, this project was mostly a success. The Flood Prevention System was able to detect water and control servo motors to immediately shutoff water. The biggest setback being the power consumption of the high-torque servo motors combined with the failure of the voltage regulator to provide a steady five volts at the required current to run both a servo motor as well as the I2C bus. In future revisions, this can be avoided by power the servo motors separately, which dramatically reduces the power need to run the sensors on the printed circuit board. By changing the user interface to a web-based system, the system gained better access from the user, without losing the ability for the Raspberry Pi to control the system. In totality, the system need minor revisions before it can be fully implemented into a home.

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1.0 Introduction

The modern home includes several appliances that consume large amounts of water, and when those appliances are faulty, they can cause huge amounts of damage to their surroundings. Dishwashers, washing machines and other appliances that use water can cause large scaling flooding if they become unreliable or damaged. The ability to quickly shut off water to either the entire house or to individual appliances could potentially save thousands of dollars in damages.

1.1 Purpose

The purpose of this project was to create a system that could quickly shut off water to individual appliances or an entire house should flooding be detected. This system would be part automated and part user controlled; automatically shutting off water at key locations if flooding is detected, but also at the control of an end user should they choose to turn water on or off. In this specific design the system should be able to detect flooding at the dishwasher and washing machine, while being able to control shutoff valves at both appliances as well as the main water pipe entering the home.

1.2 Scope

For the purpose of this project, the scope of the flood prevention system is limited to detection of flooding at two locations, a washing machine, and a dishwasher. The system is designed to be able to turn on and off the water at three locations, the main water pipe, a dishwasher, and a washing machine. Other locations in this home are currently not included in this project, and should flooding occur in other areas of the home, it would be up to the user to find that flooding on their own and shut off the water manually through the user interface if required.

1.3 Outline

The remaining sections of this report will thoroughly discuss how the project was designed, tested, programmed, and built. The design of this project will be laid out in detail, including overall design, component choices, circuit design and a printed circuit board schematic. Test results of each component, as well as the printed circuit board will also be discussed and documented. The programming of this project will be explained and explored. Finally, the physical design and build of this project will be provided, including 3d models. All of this material will be covered in the sections of this report.

2.0 Design

This section will layout the overall design of the project. This includes the components used, the selection process behind why each component was chosen, as well as other components that were considered. This section will include a basic flow chart of the overall design (figure 1), a detailed schematic (figure 4), and the layout for the printed circuit board (figure 5).

2.1 Overall Design

The basic layout for this project can be found in the flow chart located in figure 1. The main user interface is a touchscreen connected to a Raspberry Pi. This Raspberry Pi is connected by Wi-Fi to three microcontrollers, each at a location where there is a shutoff valve to be controlled. These shutoff valves are controlled by high torque servo motors which are controlled by the microcontrollers. This allows each microcontroller to stop and start water flow as needed. At the individual appliances (dishwasher and washing machine), there will be several sensors installed in order to detect possible flooding. Each appliance has an infrared switch which is actuated by contract with water. When correctly aligned with the floor these switches should be able to detect thin layers of water along the floor. Temperature sensors are also deployed at each appliance; in order to detect if temperatures dip below freezing. In the even temperatures are below freezing the system will shutoff water at the main valve to avoid pipes freezing and bursting. The final sensors will detect humidity. This measure is more of a safety net to catch flooding that the infrared switches may miss. The ability to detect humidity and therefor abnormally high humidity levels can help detect flooding that might not be reaching the infrared switch.

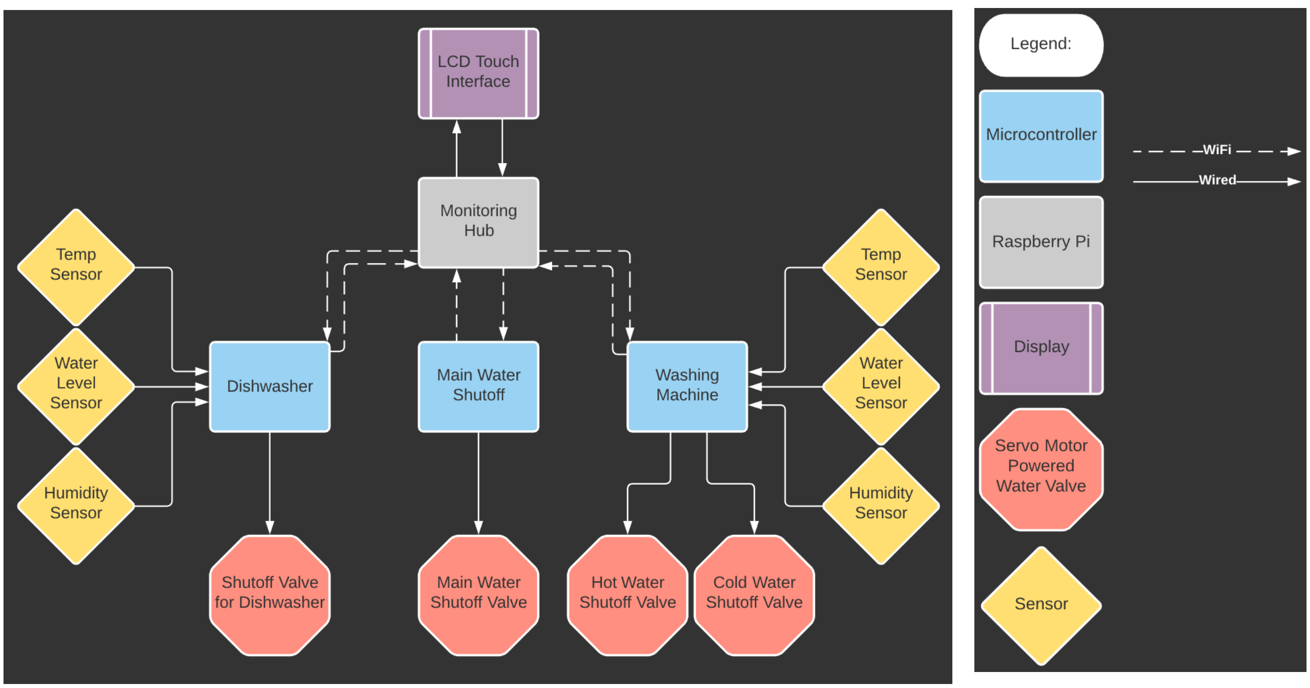


Figure 1 Basic Flow Chart

2.2 Component Choices

Components for this project were selected based off of ability to meet design requirements as well as immediate availability. The user interface is built off of a Raspberry Pi 4 primarily because it was already purchased one for another other course work this semester. As for the microcontrollers, several were considered, including the Arduino Nano IOT, ESP32, and the ESP8266 (as seen in table 1). These microcontrollers were chosen for consideration because they all include built in Wi-Fi, as well as a compact size that could be suitable for smaller printed circuit board design. With most of the heavy computing power being done by the Raspberry Pi, the microcontrollers only needed to be able to actuate servo motors, as well as read data from sensors. For this reason, the ESP8266 was chosen for its lower price, availability form the project sponsor David McMillan, and its ability to meet the basic requirements of the project.

	Arduino Nano IOT	ESP32	ESP8266
Clock Speed	46MHz	240MHz	80MHz
Flash memory	256KB	32MB	4MB
Wi-Fi compatibility	Yes	Yes	Yes
Price	$35.38	$13.99	$5.00

Table 1 Microcontrollers Considered

2.2.1 Servo Motors

The servo motors of this project were chosen based off the ability to actuate a ball valve for a water pipe that may have immense pressure within it. In order to measure this requirement, a torque wrench was used on the main water valve to determine the torque necessary to close such a valve. This torque measured out to be roughly 14kg/cm. In order to maintain modularity and keep similar specifications throughout the project, DS3218 servo motors where chosen because of their high torque specifications (20kg/cm) as well as their relative affordability compared to other high torque servo motors.

2.2.2 Water Sensors

To detect thin layers of water on the floor, the Optomax Digital Liquid Level Sensor was chosen for its enclosed design. This sensor uses infrared to determine if its tip is submerged in water, with the sensor is encased in a cylinder as shown in figure 2. Other water level sensor would expose electronic components to water if the water level got high enough. The threaded design allows for this sensor to be threaded into to the case for electronic components, keeping the electrical parts away from potential flood water.

Figure 2 Optomax Digital Liquid Level Sensor [1]

2.2.3 Temperature and Humidity Sensor

There are a lot of sensors that can detect both humidity and temperature. For this use case, a sensor that could be exposed to the air outside the electronics enclosure was necessary; however, this sensor needs to be exposed to an environment that may contain water. For these reasons, the AM2315 - Encased I2C Temperature/Humidity Sensor (figure 3) from Adafruit was chosen. The AM2315 is a good quality temperature and humidity sensor that has enough accuracy to detect freezing temperature as well as drastic changes in humidity. Its enclosed design makes it ideal for exposure to a busy home environment.

Figure 3 AM2315 - Encased I2C Temperature/Humidity Sensor [2]

2.2.4 Miscellaneous components

The rest of the electrical components were chosen on the basis of how to supply enough current and voltage to the overall circuit while maintaining modularity and price constraints. The largest current draw in the overall circuit are the high torque servo motors. According to their data sheet, the DS3218 servo motors draw approximately 1.8 amps at full stall torque. To be able to provide that current, as well as enough current for the rest of the components, a PJ-102A barrel jack and LM1084IT 5-volt regulator were chosen for their ability to handle up to 5.0 amps. The LM1084IT requires two 10µF capacitors for its desired operation.

2.3 Circuit Design

To maintain modularity and relative simplicity, one universal circuit design was deployed across all three locations. The circuit, located in figure 4, is a simplistic way to connect all possible sensors and servo motors to the ESP8266 microcontrollers. J1 and J2 are strips of header pins which will serve as the connection the ESP8266. J3 is the PJ-102A barrel jack which will take in 12 volts and 5 amps from the power cord. The LM1084IT 5-volt regulator should take the 12 volts from the barrel jack and provide the circuit with a steady 5 volts. The remaining components are to be attached to the terminal blocks J4-J7. The AM2315 temperature and humidity sensor requires an I2C connection to the microcontroller, which is connected at terminal J4. Resistors R1 & R2 act as pullup resistors for the I2C bus. The terminal block J5 is used to connect to the Optomax Digital Liquid Level Sensor, as the sensor acts as basic single poll single throw switch, in this design we are providing it 3.3 volts and measuring the logic level of switch. J6 & J7 are terminals for connecting the servo motors. Two servo motor terminals are needed only at the washing machine, as it uses hot and cold water, however all boards are designed to include both terminal blocks because of the singular universal design.

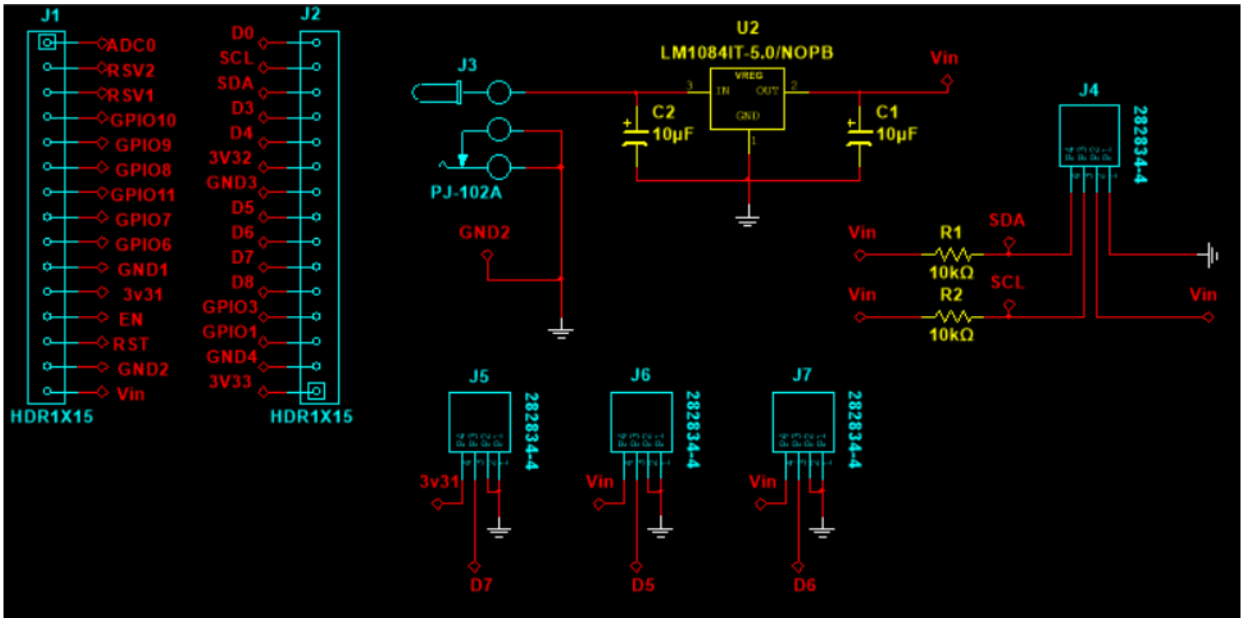


Figure 4 Circuit Schematic

2.4 Printed Circuit Board Design

The printed circuit board design is relatively simple and compact. The PCB is 2x2.5 inches with holes for #2 screws in each corner for standoffs. The headers for the ESP8266 microcontroller are measure to be the exact distance from the edge of the PCB so that the microcontroller edge will line up with the edge of the PCB. The barrel jack and 5-volt regulator are located at the bottom of the board, with minimal space between them to keep power traces as short as possible. The terminal blocks for the servo motors are also located near the voltage regular as they also require significant power traces. The terminal blocks for the sensors are easily accessible along the right edge of the PCB in the left-over space.

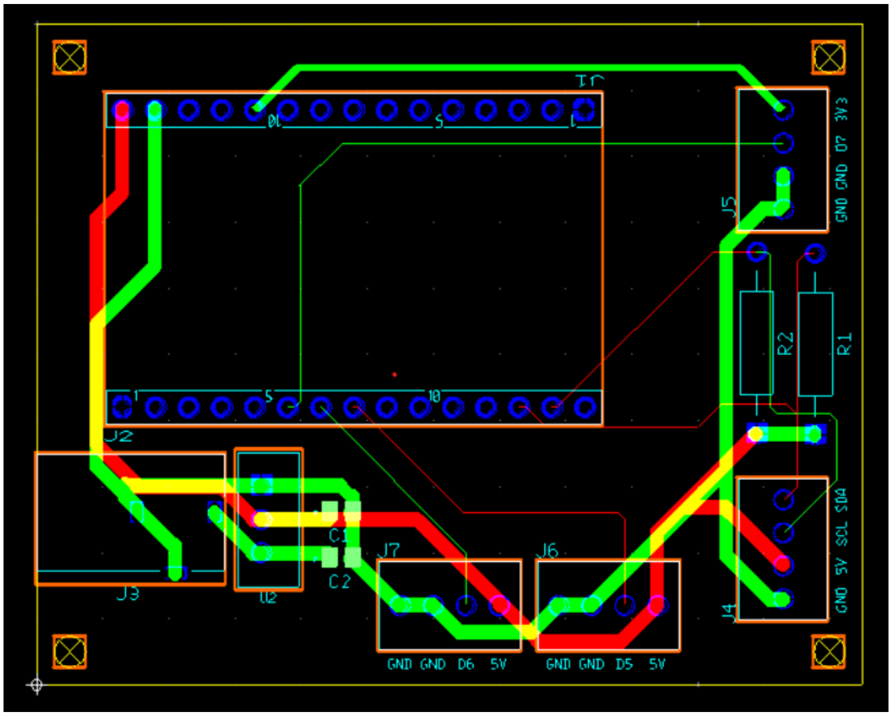


Figure 5 Printed Circuit Board Schematic

3.0 Testing & Results

This section contains the methods behind testing each of the components involved in this project, as well as the results of those tests. Calibration and adjustments made after these tests will also be included in this section. Printed circuit board tests and changes will also be covered.

3.1 Component tests

To verify the correct functionality and operation of the sensors, each sensor was tested in small individual bread board circuits. The first sensor tested was the Optomax Digital Liquid Level Sensor, as it is the most critical sensor in terms of flood detection. In order to correctly detect flooding this liquid level sensor needs to accurately detect thin layers water on a hard and flat surface. To test this, a simple circuit was made by connecting the Optomax Digital Liquid Level Sensor to a breadboard and wiring it to one of the ESP8266 microcontrollers. Firmware was written for the ESP8266 that simply read the logic value of a digital input and output the result to a serial communications terminal on a PC. Next the sensor was slowly dipped into a Tupperware container with a thin layer of water. At the very moment the tip of the Optomax Digital Liquid Level Sensor breaks the surface tension of the water, the ESP8266 microcontroller recognized a change from a logic high to a low on the digital pin connected to the sensor. This was deemed a successful test as even the smallest amount of water was able to be detected.

The next component tested was the AM2315 - Encased I2C Temperature/Humidity Sensor. For the AM2315 to be considered functioning correctly it needs to be able to correctly read temperature and humidity with minimal margin for error. As with the digital liquid level sensor, a simple breadboard circuit was used to connect the AM2315 with an ESP8266 microcontroller. For a reference point for both temperature and humidity, results were compared to a temperature/humidity sensor used to monitor the air inside a cigar humidor. A simple program was written and uploaded to the ESP8266 that measured both the temperature and humidity every 30 seconds and printed the results on a serial communications terminal on a PC. To test the sensor in both high and low temperatures and humidity, the AM2315 and humidor sensor were placed in three unique locations. For normal temperature and humidity, both sensors were placed on a computer desk which is at room temperature. For high temperatures and humidity, the sensors were placed inside a cigar humidor which is kept at approximately 30°C and 67% humidity. For low temperature and humidity, the sensors were placed inside a freezer, which provided below zero temperature and low humidity. The results are located in table 1 below. Overall, the AM2315 sensor provided temperatures and humidity levels close to those provided from a humidor sensor that has been correctly calibrated. This test was considered a success.

Location:	AM2315 Temperature	AM2315 Humidity	Humidor Sensor Temperature	Humidor Sensor Humidity
Computer Desk	26.4°C	22.56%	27°C	24%
Humidor	31.04°C	68.32%	30°C	67%
Freezer	-8°C	5.43%	-7°C	5%

Table 2 AM2315 Test Results

The last major component to be tested was the DS3218 servo motors. This project requires that the servo motors be able to actuate a ball valve to shut off water flow. Of the 4 water valves that will be controlled by the servo motors, the main water pipe to the home has the most pressure and therefore requires the most torque to actuate. A torque wrench was used to measure the torque required to actuate this valve. The torque wrench measured a maximum torque of 14kg/cm in order to operate the main water shutoff valve. This is well within the specification of the DS3218, but in order to verify the DS3218 can operate as needed, they were hooked up to a breadboard circuit powered by an ESP8266 microcontroller. The DS3218 motors where then attached to the very same torque wrench used to measure the torque on the main water valve. With the torque wrench in a fixed position the DS3218 servo motors were able to twist the torque wrench completely while the torque wrench was set for 19 kg/cm. This result verifies that the DS3218 servo motors should be sufficient for this project.

3.2 PCB testing

After the printed circuit boards were ordered and received, components were soldered in and the board was tested. All the applicable sensors and servo motors were connected to the boards and power was added to through the barrel jack. Unfortunately, all components didn’t behave as expected when they were running at the same time. Once the temperature and humidity sensors were running at the same time as the high-torque servo motors, the LM1084 voltage regulator became overwhelmed by the large current draw of the servo motors and overheating occurred. When this occurred, the deadline for presenting was too soon to make major board revisions and change components, so during the presentation the voltage for the servo motors was provided by a DC power supply, and the signal and a common ground was provided from the printed circuit board.

4.0 Programming

This section focuses on the programming involved in the overall operation of this project. With three different microcontrollers at three different locations all communicating wirelessly with a Raspberry Pi, the programming part of this project is complex and requires several different versions of code. The main format of the code, as seen in figure 6, is to set up each microcontroller as its own webpage, which can be access from a web browser by any device on the same network. The Raspberry Pi hub will use a browser with each webpage open in a different tab, to allow for user control.

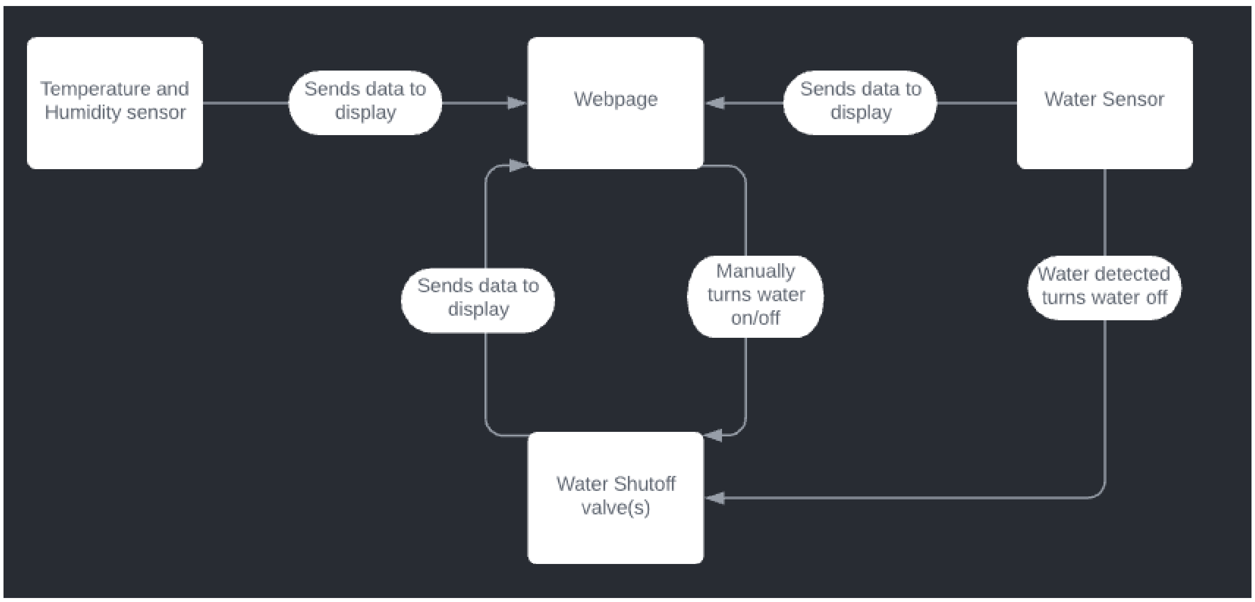


Figure 6 Program Flow Chart

4.1 Main Water Valve Microcontroller

The most simple program in this project is the firmware loaded onto the ESP8266 microcontroller located at the main water shutoff valve. This microcontroller does not have sensors to monitor, so its only purpose is to display a webpage that tells the end user whether or not water is on or off and allow them to control whether the water is on or off. The ESP8266 will have 2 pre-set pulse width modulation (PWM) signals to send to a single DS3218 servo motor. One PWM signal will open, and the other will close the valve located on the main water pipe.

4.2 Microcontrollers at Appliances

The firmware on the ESP8266 microcontrollers located at major appliances will be monitoring their sensors as well as hosting a webpage that can be accessed from the Raspberry Pi. The ESP8266's will have 2 preset pulse width modulation (PWM) signals, one for an open water valve, the other for a closed water valve. The microcontrollers will close the valve when water is detected by the Optomax Digital Liquid Level Sensor, as that will indicate that water has reached the floor below the appliance. The valve will also be closed if the microcontroller receives that command from the Raspberry Pi. In addition to opening and closing the valve, the ESP8266s will also be tracking the temperature and humidity recorded by the AM2315 sensor, and reporting that data back to the Raspberry Pi. As stated earlier, there will be one of these circuits at the dishwasher and another at the washing machine. Both circuits will be almost the same, the only difference being that the circuit at the washing machine has to control two valves, one for hot and one for cold water.

5.0 Physical Build

This section outlines the physical design of this project. This includes the enclosures of the microcontrollers and PCBs, and the servo motor powered shutoff valves. The majority of these parts were 3D printed in PLA plastic on an Ender 3 printer. This allowed for custom 3D models to be manufactured at home over long periods of time. This section will go through each design and how the design meets the overall need of the project

5.1 PCB and Water Sensor Housing

The main housing for the PCB and water sensor is designed to protect the circuitry from damage and lift the water so only the tip is in contact with the floor. As shown in figure 7, the house is a rectangular box on stilts with an opening on one side. There is a track on the inside of the box which allows for the base plate, which will hold the PCB and water sensor, to slide into and stay elevated off the ground. The stilts are measured to be the exact right height, so that when the base plate is resting on the track, the tip of the water sensor will be just above the ground. The slit in the top is designed so that an end plate can be slid down to close off the enclosure, with holes for the power connector and a CAT5e cable that connects to the shutoff valves.

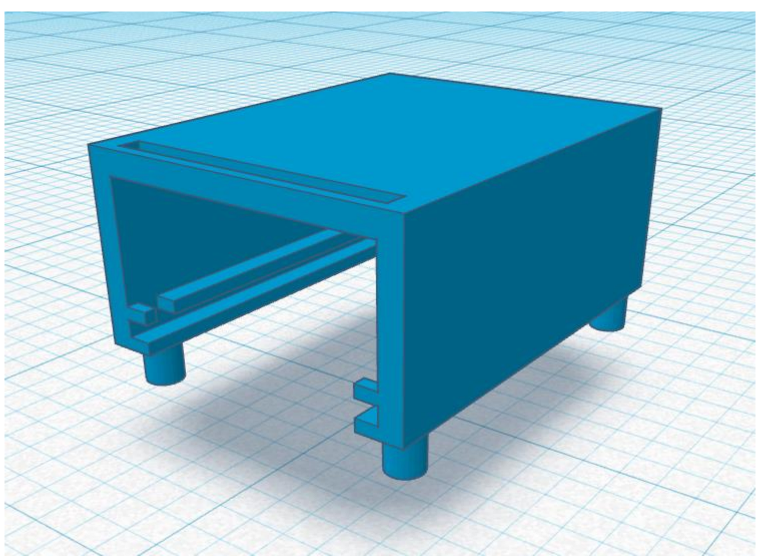


Figure 7 PCB and Water Sensor Housing

5.2 Base Plate

The base plate for the enclosure is designed to hold the PCB and provide a whole which the Optomax Digital Liquid sensor can be mounted to. As shown in figure 8, the base plate is an eighth of an inch thick, which slide into the track on the inside of the housing, with enough room so that the water level sensor can just touch the ground. The hole through the baseplate it large enough that the water level sensor can fit through and be fastened to the board with a nut. The stilts sticking up from the board are for holding the PCB, as they measure to be the exact size to fit the holes in the PCB. With this design the barrel jack, the PJ-102A, will be mounted on the edge of the pate, so it can stick out the open face of the housing, and accessed through a hole in the end plate.

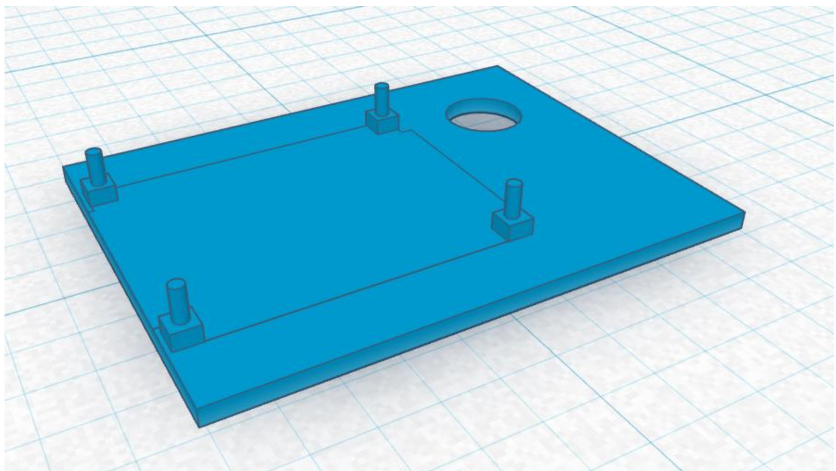


Figure 8 Base Plate

5.3 End Plate

The end plate closes off the housing, leaving a hole big enough that the wires running to the temperature and humidity sensor, as well as the servo motors can leave the enclosure. Figure 9 shows the fairly basic end plate, which is just a quarter of an inch thick, with a window in it just large enough for the inputs and outputs. It's the exact right size to close of the housing and protect the PCB.

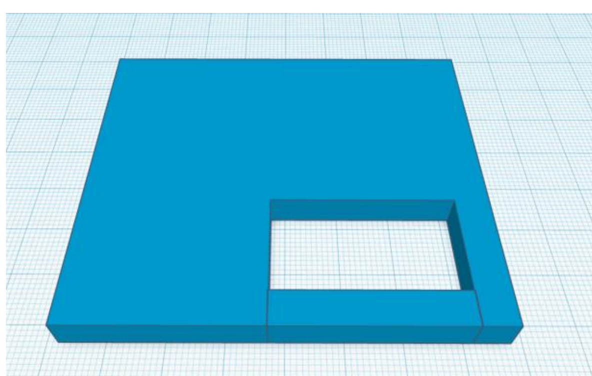


Figure 9 End Plate

5.4 Pipe Fitting

Finally, the last piece of the design is a pipe fitting which mounts the high-torque servo motor onto the shutoff valve. Figure 10 shows the two pieces required, with the orange object which goes around the square base of the servo motor, and the blue object which goes around the water valve. The holes on the top and bottom are for three-inch screws to hold the two pieces together. The bottom screw holes have an extension on them to provide enough clearance fore the valve to turn without hitting the bottom screws. Once together, three layers of heat shrink tubing was used to bind the valve to the arm of the servo motor.

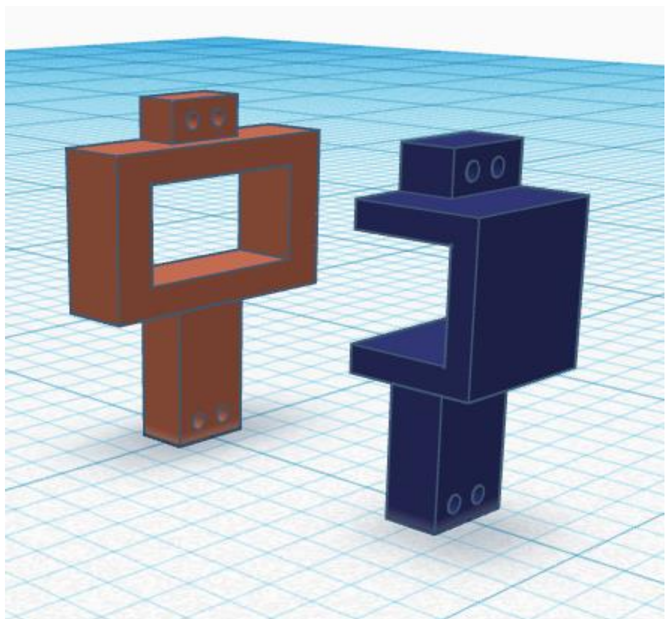


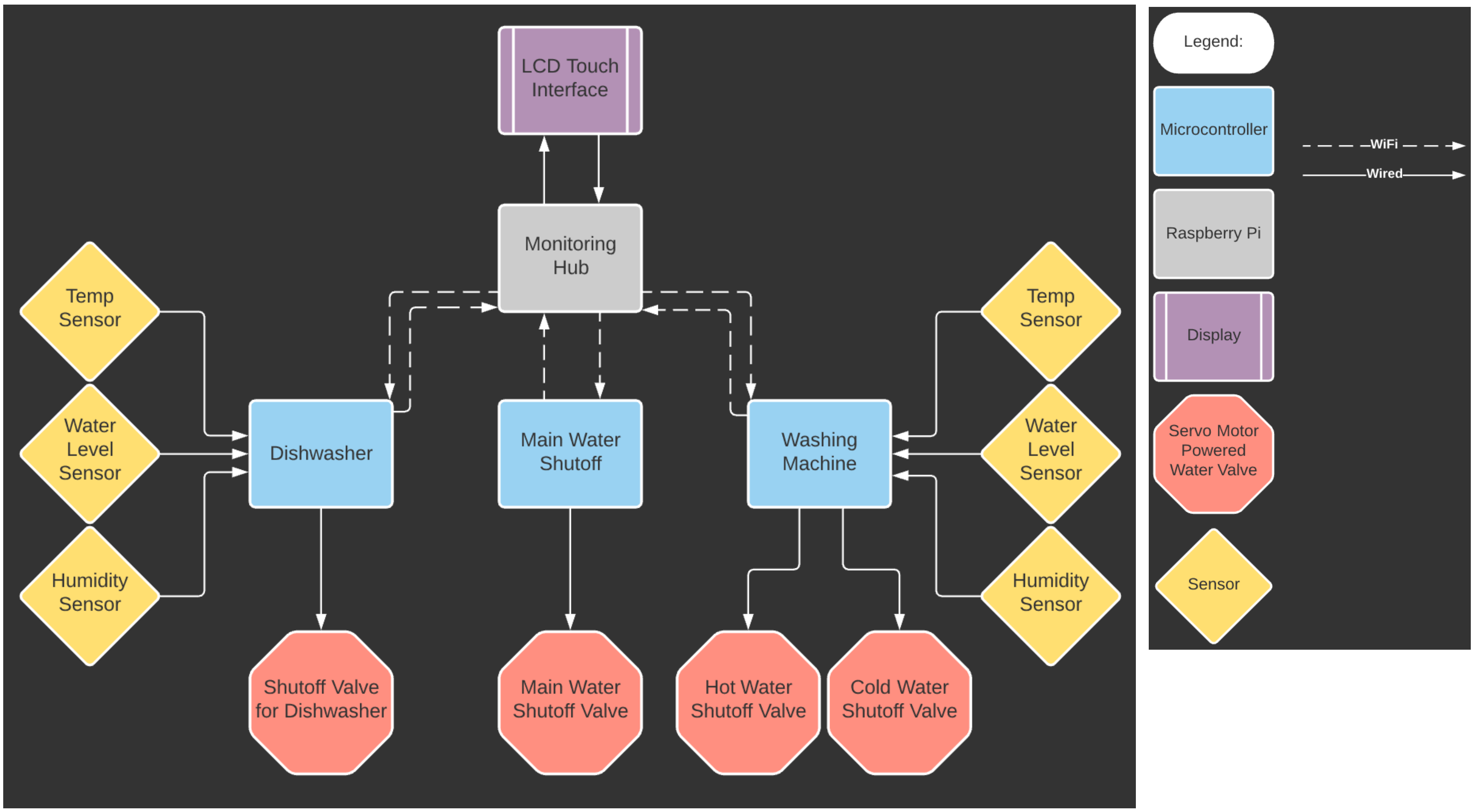
Figure 10 Pipe Fitting

6.0 Conclusion

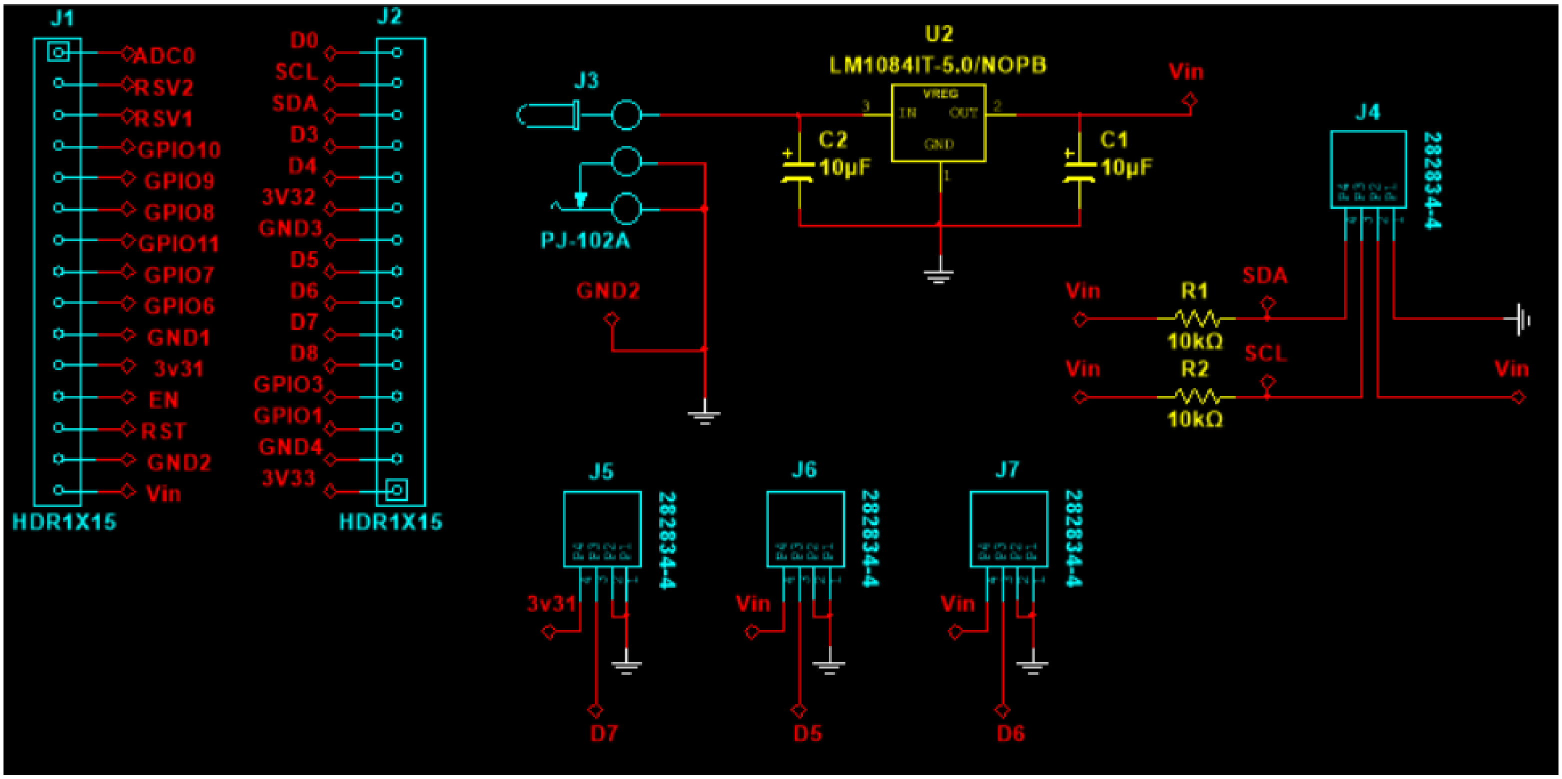
This project was commissioned in order to create a system that could prevent flooding from faulty appliances that use large amounts of water. This was achieved by designing a system that uses a variety of sensors to detect flooding, and motorizing shutoff valves that prevent flooding from getting out of hand. Through the course of implementation, each element of this system was thoroughly tested to make sure that the system as a whole can perform as desired. Unfortunately, it was at this stage where it was discovered that the LM1084 voltage regulator is unable to dissipate enough heat to remain functional when the servo motors are powered from the printed circuit board. In a future revision, it is the recommendation of this report that the servo motors receive power from their own power source, and only maintain a connection with the PCB though signal and a common ground. The system was originally designed in a way where the only way to control each of the microcontrollers would have been through the monitoring hub. While the monitoring hub is still able to achieve that functionality, a more robust solution was to program each microcontroller to manage it’s own webpage, so that the microcontrollers could be controlled from anywhere within the local area network, or with proper setup of router settings, even outside the network. By designing custom 3D models and then 3D printing them in PLA plastic, adequate housing and fittings were made to protect important components and the servo motors were able to be mounted to the shutoff valves. Overall, this project was mostly a success, by providing a way for flood water to be detected and water to be immediately shutoff; however, more work is need to be completed, such as a better power system for the high torque servo motors, in order to fully implement this project in a home.

APPENDIX:

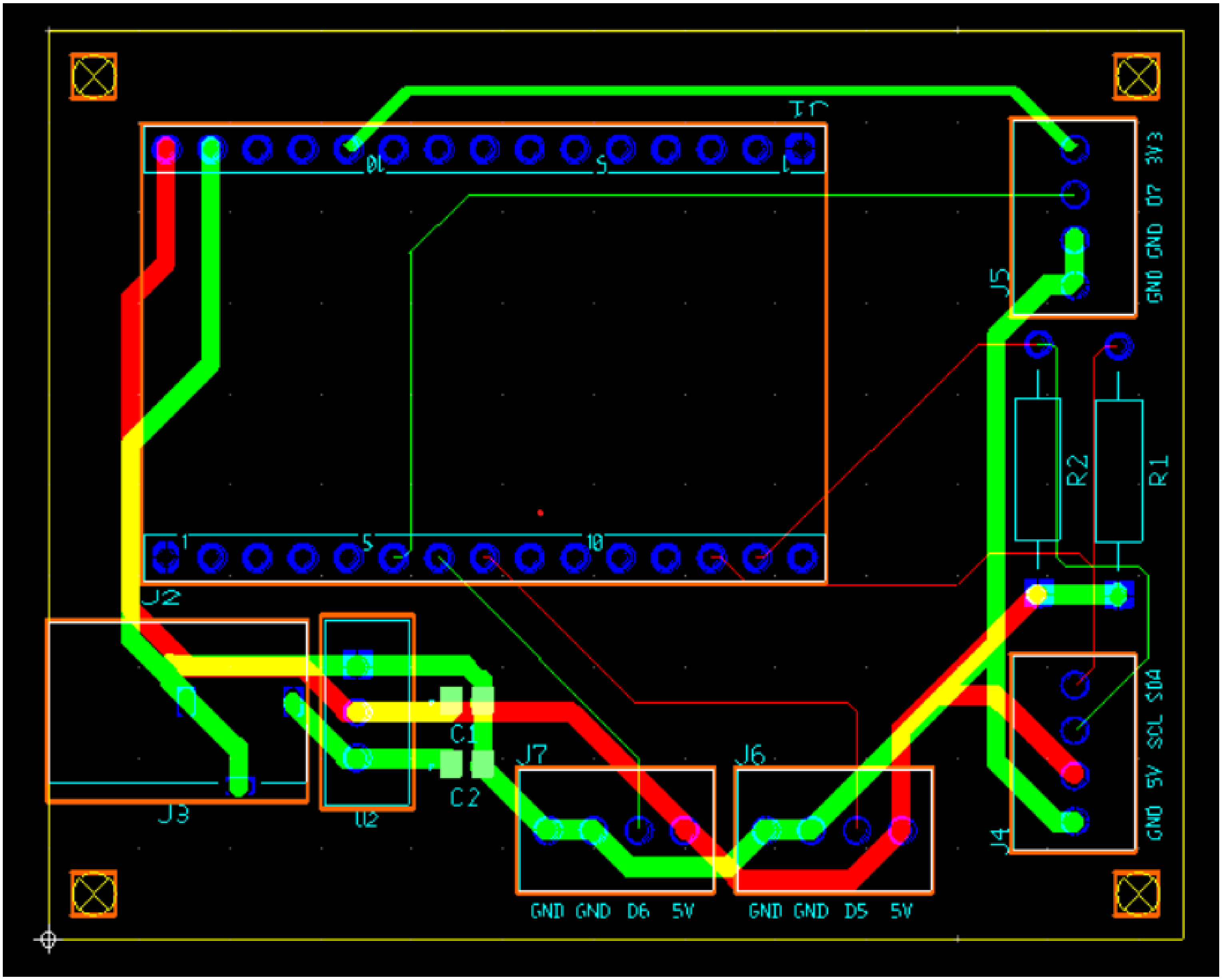
Appendix A: Flow Chart



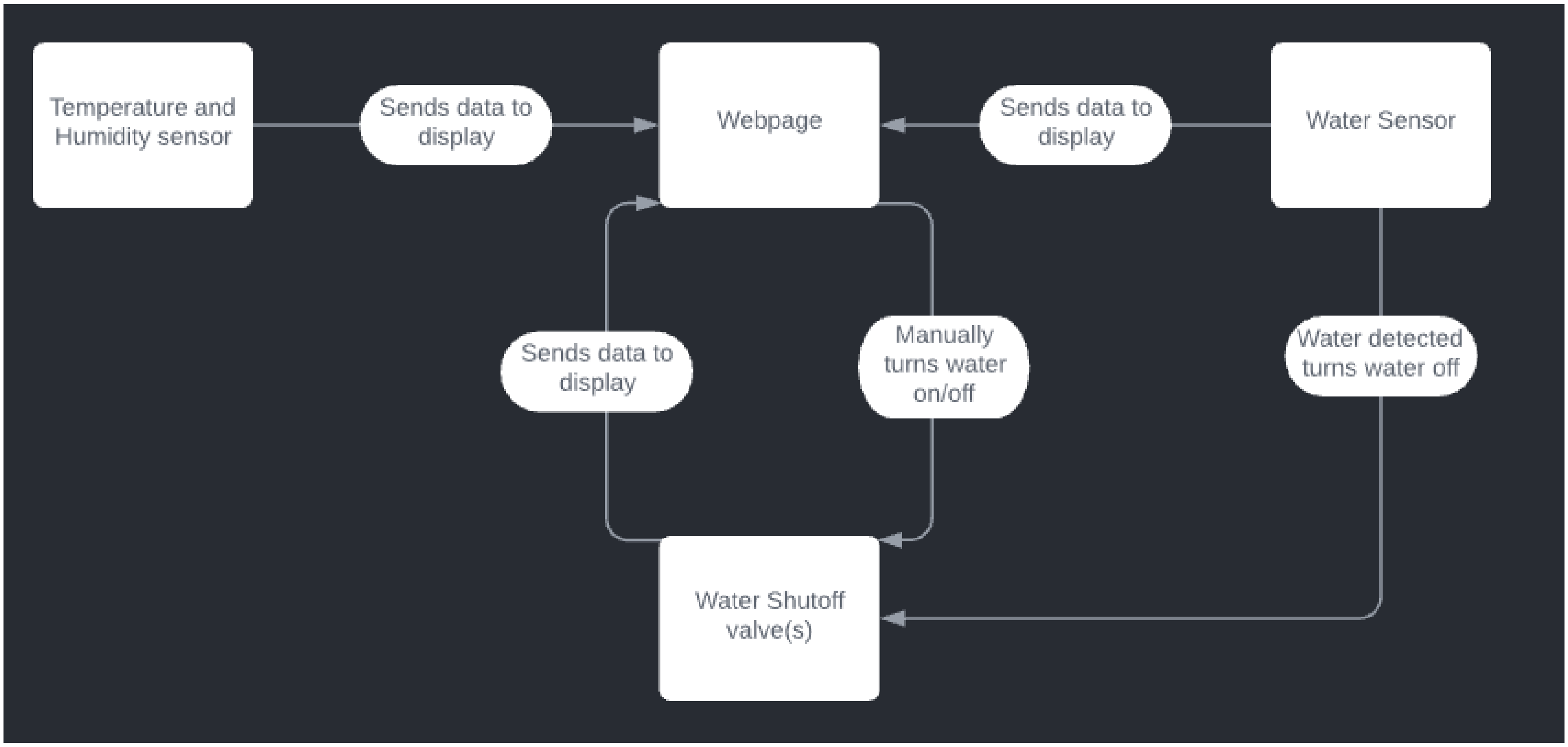
Appendix B: Circuit Schematic



Appendix C: PCB Schematic



Appendix D: Program Flow Chart



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