Avoid gardening disasters: test performance of drip emitters

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Abstract

One of the most common problems that residential gardeners face is the clogging of drip irrigation emitters, but clogged emitter testers are currently unavailable in the consumer marketplace. The device described in this paper uses an Arduino Uno R3, relay, 385 Miniature Micro DC Water Pump, eTape Liquid Level Sensor, an LCD screen, and button to determine if an emitter is functioning properly. Validation results show that the device will be able to successfully rate drip irrigation emitters' flow status and a path forward is described.

1.0 Introduction

Did you know the average American family uses 320 gallons of water per day? In drier climates, about 195 gallons of water are used in residential gardening alone. Nationwide, landscape irrigation accounts for one-third of all residential water use totaling 9 billion gallons per day (*WaterSense Outdoor*, 2017). Irrigation, the process of applying a controlled amount of water to crops in a field, plants in beds, and/or plants in pots (Richman 2021), is typically done with sprinklers, manually, or with drip emitters.

Drip irrigation, the most water-efficient method, can be difficult for residential gardeners to maintain. The most difficult problem drip irrigation systems face is emitter maintenance. Emitters control the distribution of water into the soil, but often clog from dirt, minerals, and rock. If clogged, emitters can't emit the set amount of water or can't emit water at all. The most common way to actively test these emitters for blockage is to completely remove, test by blowing through, and replace them if necessary. A hand-held device that could test blockage would be appealing to residential gardeners because it would save time, money, and improve their gardening experience.

1.1 Background

1.1 Irrigation

Irrigation is the process of transporting water from one location to another. Three common methods of residential irrigation are manual irrigation, sprinkler irrigation, and drip irrigation.

Figure 1: Drip Irrigation

Drip irrigation uses tubing to distribute water through emitters onto the ground or into plant beds or pots. Advantages include efficient water distribution, reduced runoff, minimized weed growth, and low cost. In a typical setup, water is distributed from the mainline valve and flows through drip piping. Attached to the drip piping are emitters that emit water at a specific flow rate (see *Figure 1*). The water flows through drip piping and is then applied directly to the root zone of a specific plant using an emitter.

1.2 Emitters and their Flow Rates

Emitters are a core component of a drip irrigation system because they control how fast water is distributed to the soil. The most common emitters emit 1 gallon per hour (Stryker, 2021). Depending on the garden size and layout, a home garden drip irrigation system can have up to 150 emitters.

While there are many different types of emitters used in residential gardening, a consistent disadvantage in every emitter is clogging. Clogging can be due to mineral build-up from water, dirt or an insect entering the system, or a failure of the emitter due to age, wear, weather, and/or environmental factors.

The type of emitters used in this study are tortuous-path emitters; they were chosen because they contain sharp turns and obstacles in their internal flow paths and were specifically mentioned in Stryker (2021) to be resistant to clogging. These emitters were also chosen because a home gardening system using tortuous path emitters was accessible for testing.

In a drip irrigation system, the flow rate of an emitter determines the amount of water that flows through an emitter over a period of time (Stryker, 2021). Common emitter flow rates are ½, 1, or 2 gallons per hour.

1.3 eTape Liquid Level Sensor

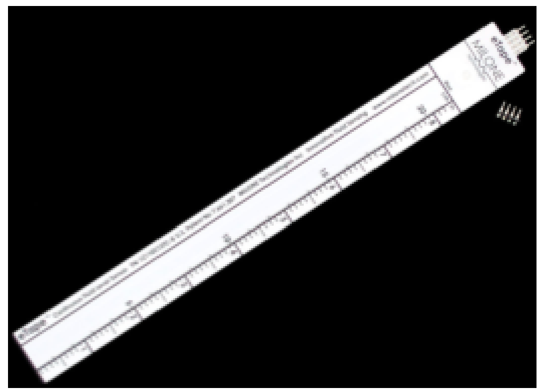


Figure 2: Image of eTape Liquid Level Sensor

An eTape Liquid Level Sensor, by Milone Technologies, is a device that when submerged in a liquid, experiences a change in resistance (ohms). The lower the liquid level, the higher the resistance and vice versa. The sensor envelope closes in the presence of liquid; a minimum 1-inch of substance is required to activate the device. The sensor outputs can be displayed as resistance or depth using calibration curves provided by the operating instructions (see *Appendices 8.1 and 8.2*). According to the operating manual, the accuracy of the device is ±15%. Known deficiencies include submerging the sensor above the maximum allowable level and bending or folding the sensor. In consulting with the manufacturer, they were unable to provide specifications for how the sensor would function in a dynamic environment with rapidly changing data.

1.2 Literary Review

A review of methods for leakage detection and location in water distribution systems published in the journal *Water Supply* in 2014 relates to this proposed project (Li et al., 2014). Bursts and leakages in water distribution systems have become both an environmental and economical issue that has seen attention in recent years. Methods of detecting bursts and leakages are split into two groups: hardware-based methods and software-based methods. The review consists of tables that compare different types of hardware methods, their individual detection rates, degree of leakage detection, and accuracy as well as their advantages and disadvantages. The review also discusses software methods, their inspection ranges, detectable leak sizes, precision, benefits, and defects.

The review results state that moving forward, the best devices to detect bursts and leakages in water distribution systems are devices that can combine hardware-based methods with software-based methods. This project's goal is to detect blockage in a drip irrigation emitter with a handheld device in a residential setting. Referencing Li et al. (2014), the decision to integrate software and hardware technologies for the best device functionality was made.

A subsequent paper was written about the uncertainty of the variation coefficient in drip irrigation emitters that provided a validation limit for the device (Zhao et al., 2014). A problem that occurred when experimenting with the tortuous path emitters was a varied flow rate. Due to manufacturing quality and efficiency, every emitter has a slightly varied flow rate. The paper evaluated industrial-sized emitters on a large scale in a controlled environment to determine an accurate variation coefficient. The conclusion of the study was that there was less than 5% variation between emitters. This sets the validation requirements for this device system. Any device using flow rate to determine emitter quality needs to differentiate at a larger level than 5% manufacturer variability to work accurately.

1.3 Problem Statement

Residential gardeners need a way to assess the blockage level of drip emitters so as to quickly identify which emitters are no longer functioning correctly. An automated device to conduct this assessment will reduce the time gardeners spend checking for problems, reduce damage to the drip irrigation system, and decrease the probability of flooded and dead plants. This project describes the design, testing, and validation of a prototype drip emitter performance test device.

2.0 Methods

2.1 Device Components

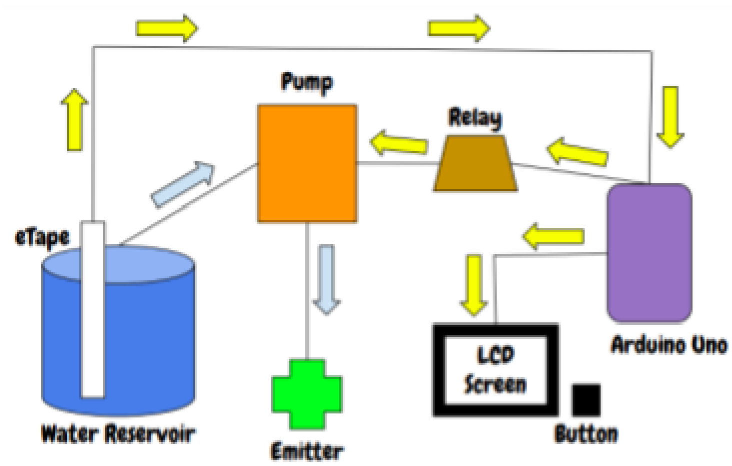


Figure 3: Sketch of Device Components

The device consists of an Arduino Uno R3, relay, 385 Miniature Micro DC Water Pump, eTape Liquid Level Sensor, an LCD screen, and a button. The water pump, controlled entirely by the relay, suctions and discharges water through a check valve that is opened and closed. The relay is a crucial component for device functionality as it allows the water pump to be controlled by the Arduino. The Arduino Uno controls the relay and water pump, receives and interprets data from the eTape Liquid Water Sensor as well as displays instructions and a pass/fail recommendation on the LCD screen. *Figure 3* is a sketch of the components as they appear in the device. Blue arrows indicate water flow and yellow arrows indicate electricity flow.

2.2 Device Design - Emitter Orientation and Variability

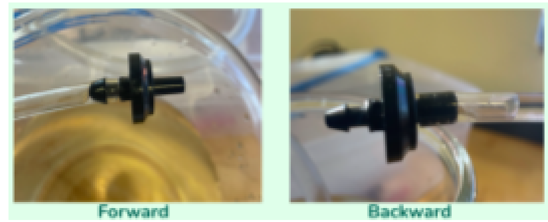


Figure 4: Tortuous Path Emitter Flowing Forward and Backward

To test a tortuous path emitter while it is installed in an irrigation system, water would need to be forced "backwards" through the emitter (the testing water reservoir is outside the actual drip irrigation system). Emitter orientation tests were conducted with two 1 gallon per hour emitters (in the forward and backward orientation) for 1 minute each with the output volume recorded and compared to the specification flow (1 GPH = 63 mL/min). Emitter variability tests were conducted to verify Zhao, 2014 for consumer emitters and determine precise guidelines for pass/fail. These tests were conducted by attaching each emitter in the backwards orientation for a one-minute test. Ten emitters were tested three times each.

2.3 Process Diagram and Device Terminology

The process diagram outlines how the device works and how the user is expected to interact with it. *Table 1* defines the device terminology used in the process diagram.

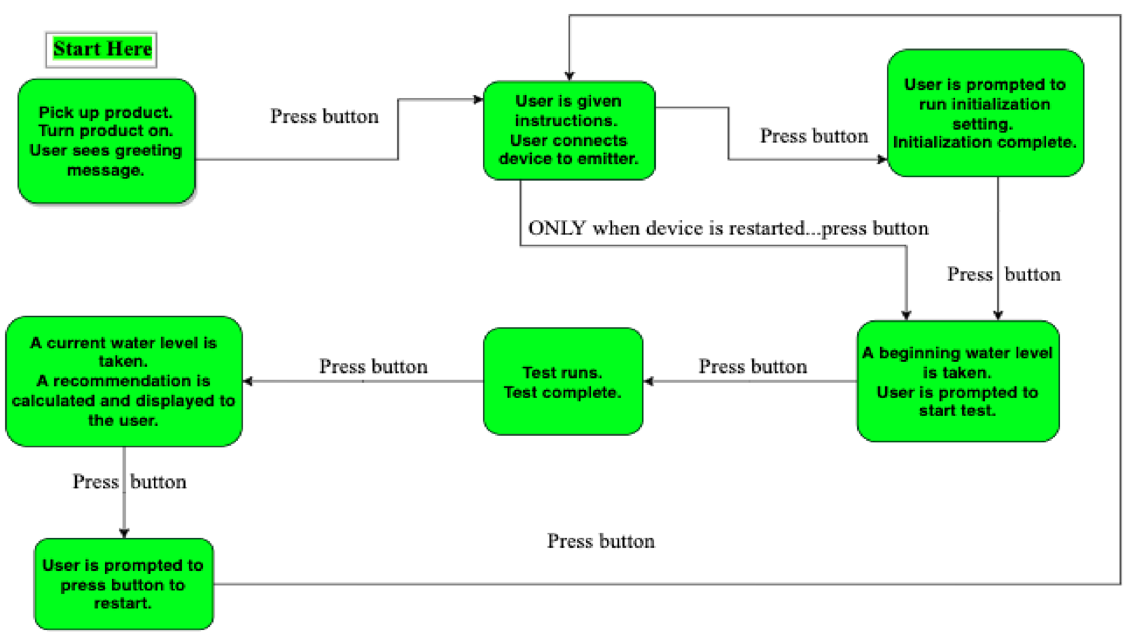


Table 1: Device Terminology

Terminology	**Explanation**
Initialization Setting	The initialization setting runs the motor on for 8 seconds and off for 2 seconds. Air bubbles inhibit the flow of water within the device tubing. This runs to eliminate the trapped air in the test line.
Beginning Water Level	The beginning water level is an average of 80 measurements over 8 seconds. The average method is used to prevent abnormally high or low measurements that might occur from a single measurement of sloshing water. This measurement is taken after the initialization setting and before the emitter test begins.
Current Water Level	The current water level is an average of 80 measurements over 8 seconds. The average method is used to prevent abnormally high or low measurements that might occur from a single measurement of sloshing water. This measurement is taken after the course of an emitter test.
Recommendation	A fully functioning 1 gallon per hour drip emitter will emit as follows: ___________. (between two numerical values) If the measured water level in the reservoir drops outside the defined range, a notice will be shown on the LCD screen.

2.4 Device Functionality: Desktop Prototype

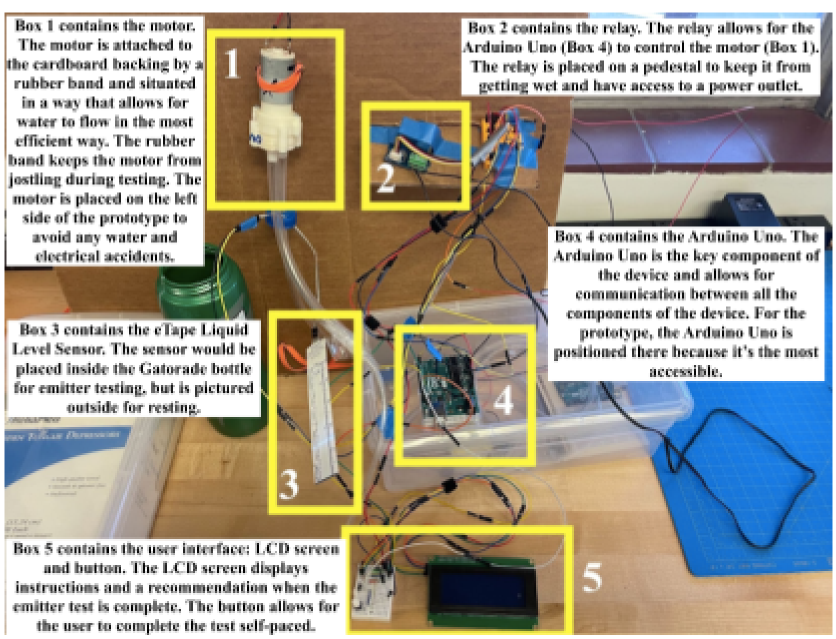


Figure 6: Captioned Image of Desktop Prototype

2.5 eTape Liquid Level Sensor Characterization

The eTape Liquid Level Sensor was used to measure the water level and its changes while the device was running. Depending on the reservoir used in the experiment, vibrations from the motor traveling via the silicone tubing can significantly disturb the water and affect the sensor's measurements. In order to determine the best setup for the components, the optimal duration for the test, and to provide the most accurate recommendation to the user, three tests were conducted using the eTape Liquid Level Sensor.

The first test was conducted by placing the eTape Liquid Level Sensor in a beaker and slowly siphoning the water out at a constant rate. The sensor gathered data by running a predetermined program. (see *Appendices 8.4*). The second test was conducted by placing the sensor and the tubing attached to the motor into a plastic 500 mL water bottle and attaching a 1 gallon per hour emitter to the output tube. The eTape Liquid Level Sensor gathers data by running a predetermined program (see *Appendices 8.5*). The third test was conducted by placing the sensor and tubing into a beaker and attaching a 1 GPH emitter to the output tube. This orientation allowed for ample space between the sensor and the tubing to reduce vibrations, allowed for better data collection, and helped inform a decision about the duration of the emitter test conducted by the device.

2.6 Usage Constraints

The device takes approximately 1 minute to complete 1 emitter test. In order to minimize water sloshing in the reservoir, the device must be static during testing and can not be moved until instructed to do so. The device must also be able to plug into an electrical outlet for power. Currently, the device can perform a pass/fail test with 1 gallon per hour emitters.

2.7 Validation

Since the device is designed for 1 GPH emitters, a ½ GPH emitter can be used to simulate a clogged emitter and a 2 GPH emitter to simulate a flooded emitter. Testing of 12 emitters (4 of each) was done to test whether the device could distinguish between good or bad (clogged or flooded). The test was done in a static laboratory environment.

3.0 Results

3.1 Emitter Orientation and Variability Data

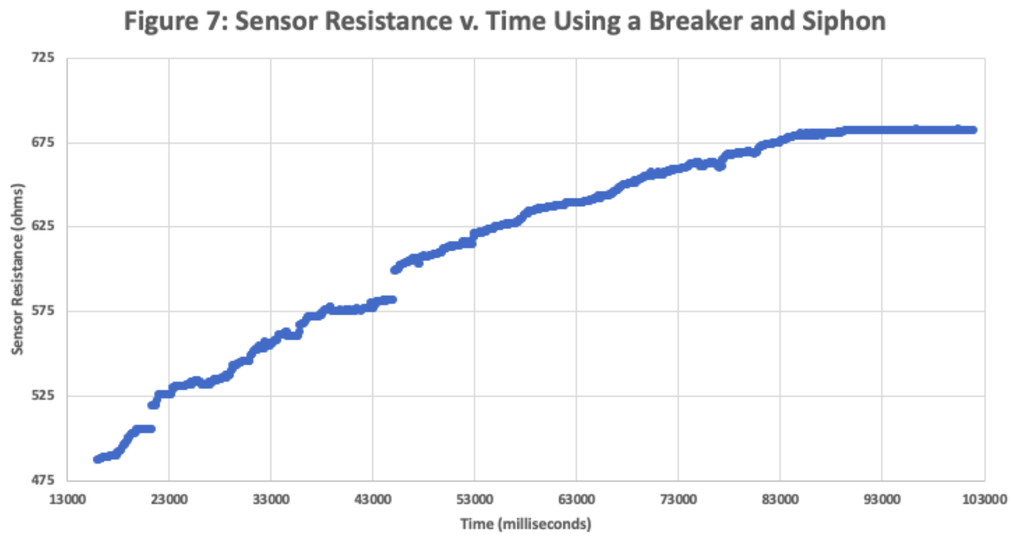
Table 2: Emitter Orientation and Flow Rate

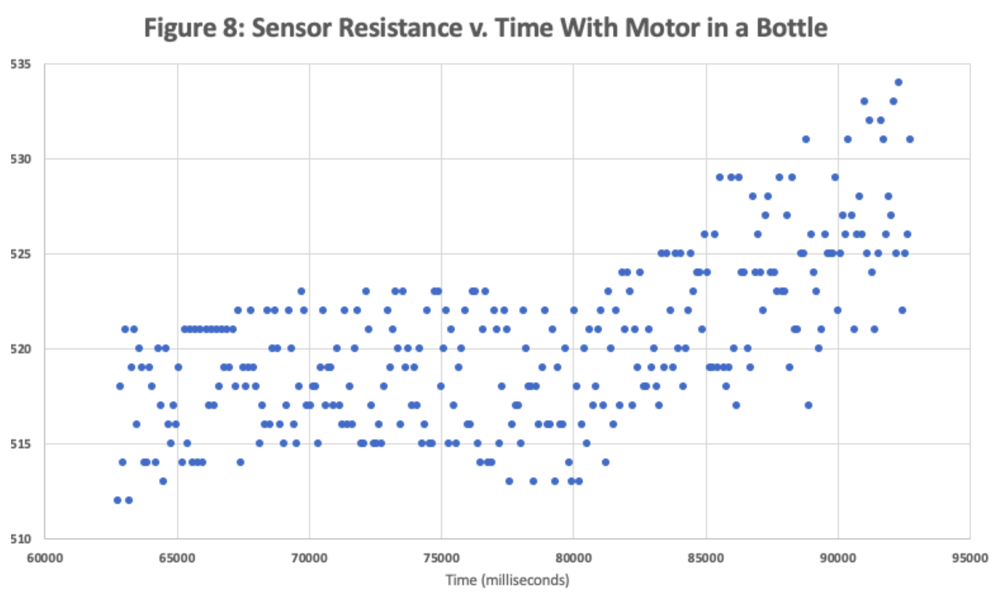
Emitter	Backwards Avg.	Forwards Avg.	Flow Backwards	Flow Forwards
1	62.2 mL/min	64.4 mL/min	0.986 GPH	1.021 GPH
2	62 mL/min	63 mL/min	0.983 GPH	0.999 GPH

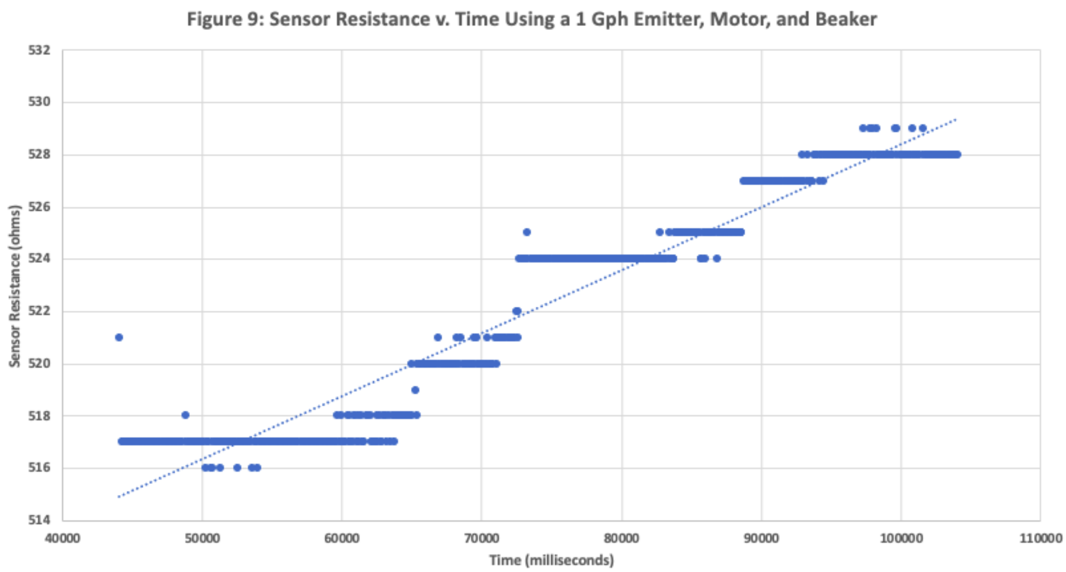
Table 3: Emitter Variability (Forward) and Corresponding Flow Rate

Emitter	Test 1 (mL/min)	Test 2 (mL/min)	Test 3 (mL/min)	Average GPH
1	55	55	55	0.872
2	65	65	65	1.030
3	50	50	50	0.793
4	47	46	46	0.729
5	56	56	56	0.888
6	61	60	60	0.951
7	64	64	64	1.014
8	53	53	53	0.840
9	50	50	50	0.793
10	65	64	64	1.014

3.2 Vibration vs. Isolation Readings







3.3 Validation Graph

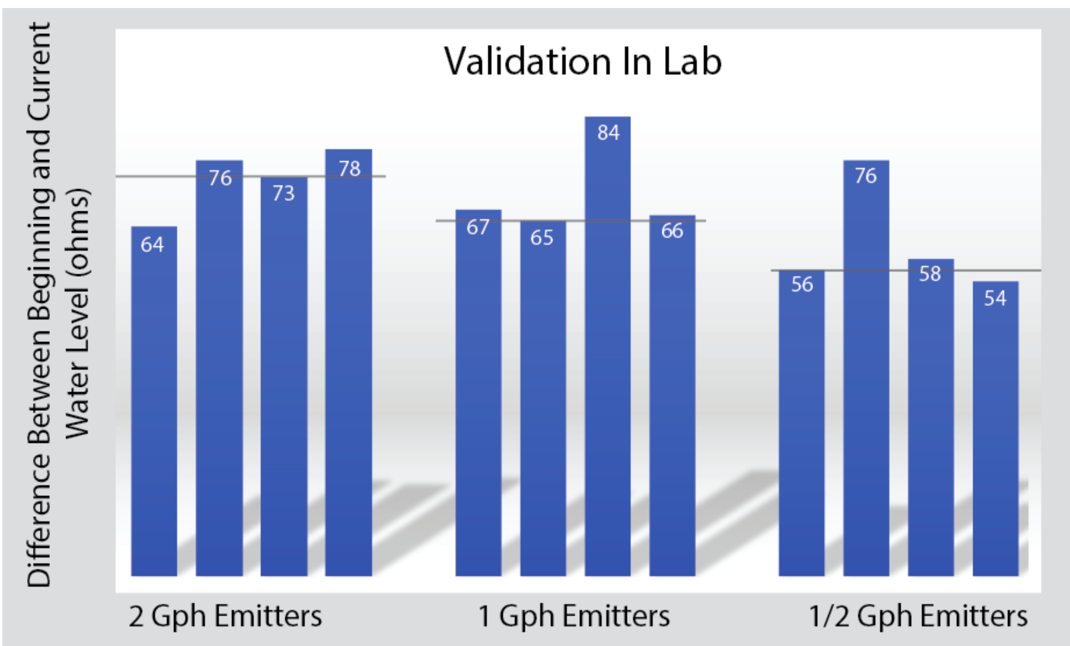


Figure 10: Graph of Validation in Lab with 2, 1, and ½ GPH emitters

4.0 Discussion

4.1 Emitter Orientation and Variability

Because the output forwards and backwards as well as flow rates forward and backwards for each emitter were close to identical, it was concluded that there was no significant difference in flow for emitters based on orientation that would affect the accuracy of the device.

4.2 Device Output

The device was run to test the accuracy of the equation and code used to measure the change in water level and corresponding resistance measured by the eTape sensor. A 1 GPH emitter was attached to the tube and the device ran for 30 seconds. The code used the eTape sensor to take readings at predetermined points while the device was functioning. The code output value was calculated by taking the absolute value of the average value of the water level taken at the beginning of the test minus the average value of the water level taken at the end of the test.

The output values from these tests range from 40.58 to 6.12 which provided a difference of 34.46. This difference was too unreliable for the device to guarantee an accurate reading and recommendation. Because a properly functioning emitter should consistently output the same amount of water, the code output value should not display as much variability as was expressed in the results of the test.

Therefore, the product can reliably pump a steady stream of water from a reservoir through a tube and through an unclogged emitter, but the recommendation displayed to the user utilizing the developed equation, code, and eTape sensor is not yet operational. Due to the inconsistencies from the data collected, a duration for running the device has not been set and testing with partially clogged emitters has not been conducted.

4.3 Vibration vs. Isolation

To determine the most accurate way to find the change in measured resistance (see *1.3 eTape Liquid Level Sensor* for a definition of resistance) to know how much water was expended during a test, tests were conducted to visualize the output from the eTape sensor. These tests were conducted by running the pump and eTape sensor in a variety of different containers, which allowed a visual representation of the eTape sensor outputs to be created.

While testing the product the vibrations caused by the motor were being transferred along the tube to the reservoir and were causing inaccurate and unstable readings by the eTape sensor. Therefore, the reservoir was redesigned to allow for adequate separation and isolation of the tube connected to the pump and the eTape sensor in order to inhibit the inconsistencies measured by the eTape sensor.

Figure 7 is a graph of the first test conducted (see *3.2 Vibration vs. Isolation Readings*). This test was performed to see if the typical eTape output (see *Appendices 8.2*) provided in the device specifications could be replicated and to determine the latency and response time of the eTape sensor as the water level underwent a dynamic change. This test confirmed that the eTape sensor could respond well to steady, continuous changes in water level that were not rapid.

Figure 8 is a graph of the second test conducted (see *3.2 Vibration vs. Isolation Readings*). This test was performed to see how the eTape sensor would perform in a potential reservoir. The graph shows the scattered and varied readings from the sensor during that test. These inaccurate readings were caused by the vibration from the motor that traveled through the silicone tubing and disturbed the reservoir.

Figure 9 is a graph of the third test conducted (see *3.2 Vibration vs. Isolation Readings*). This test was performed to collect information and inform a decision about how long the test duration should be to provide the most accurate reading and accurately provide a recommendation about the emitter being tested to the user.

4.4 Validation Interpretation

Four tests were conducted for each type of emitter chosen to simulate possible problems gardeners would encounter with their emitters. The three different types of emitters (2 GPH, 1 GPH, and ½ GPH) all showed distinct average changes in volume. The two outliers in the 1 GPH and ½ GPH categories can be attributed to the hypersensitivity of the eTape Liquid Level Sensor.

5.0 Conclusion

The device described in this paper was developed to fill a recognized need by home gardeners who use drip irrigation systems. The device uses an Arduino Uno R3, relay, 385 Miniature Micro DC Water Pump, eTape Liquid Level Sensor, an LCD screen, and a button to determine if an emitter is functioning properly. The device operates with the help of the user to force water through an emitter that is in line in a drip irrigation system to test the viability of the emitter and provide a recommendation to the user in regards to what should be done with the emitter. Problems with variable results from initial device testing and motor vibration were discussed, and the process for how the device provides a recommendation to the user is explained. The device proved during validation that it can function to distinguish between the different problems with emitters through a successful categorization of the simulated problem emitters. The device that is described in this paper requires more experimentation before it can be used as intended by a client in a home garden drip irrigation system.

5.1 Future Works

Testing with emitters in-line still needs to be conducted before the device can be used as intended by consumers. Issues with vibration and the arrangement of all components in a final reservoir still need to be developed. These steps would allow for a better validation of the device in the lab and test environments. Some future steps would be to develop a more compact device. Our device prototype is large and would not easily be carried around a residential garden. Simplifying the components and attaching all components on a single board would make this process easier. It would also be ideal to make the device handheld and battery powered. A further iteration of this device could be made to allow the user to test many types of emitters by selecting the target emitter from a device menu.

6.0 Acknowledgements

We would like to thank the Computer Science and Engineering department at Flintridge Sacred Heart Academy for their support and our advisor Mr. Ty Buxman as well as our external consultant Mr. Bruce Waggoner.

7.0 References

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Figure 1

eTape Continuous Fluid Level Sensor Operating Instructions and Application Notes. (n.d.). https://cdn-shop.adafruit.com/datasheets/eTapeApp.pdf

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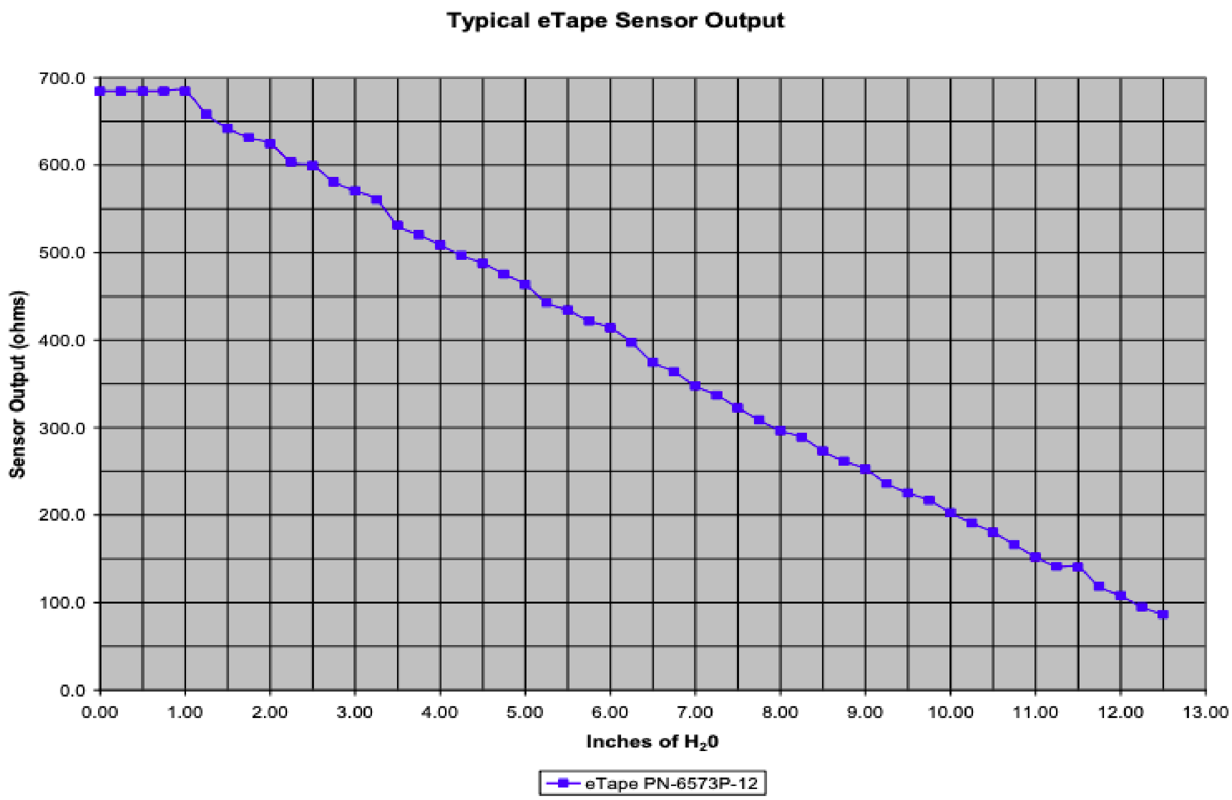
8.0 Appendices

8.1 eTape Continuous Fluid Level Sensor

1. *Operating Instructions and Application Notes*
2. *PN-12110215TC-X*

8.2 Typical eTape Sensor Output



8.3 eTape Liquid Level Sensor Code

Titled - HE_Water_Sensor

8.4 Emitter Test - Customer Display

Titled "All_H_ENG_2_CUSTOMER"

8.5 Emitter Test - Testing Display

All_H_ENG_TECH_EXTRA_DISPLAY