SMART PET WATER FOUNTAIN

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Abstract

The smart pet water fountain is designed to help pet owners to better ensure the health conditions of the small pets and accommodate the water supply when he/she needs to leave home for several days. In addition to common functions that pet water fountains on the market share, this product features displaying real-time water quality result, automatic draining polluted water system and auto-refilling water from general water supply to maintain sufficient amount of freshwater in the fountain tank. The sensor unit keeps monitoring water temperature, pH-value, and water conductivity to provide timely water quality evaluation.

Contents

1. Introduction 1
1.1 Background 1
1.2 Objective 1
2 Design 3
2.1 Sensor Unit 3
2.1.1 Temperature Sensor 3
2.1.2 pH-Value Sensor 4
2.1.3 Conductivity Sensor 4
2.1.4 Liquid Level Sensor 4
2.2 Display Unit 4
2.2.1 LCD Screen 4
2.2.2 LED Indicators 5
2.3 Power Supply Unit 5
2.3.1 110 V---15 V AC-DC Converter 5
2.3.2 15 V---5 V Voltage Regulator 5
2.3.3 5 V---3.3 V Voltage Regulator 5
2.3.4 13.5 V 9-pack battery pack 6
2.4 Mechanical Unit 6
2.4.1 Fountain Pump 6
2.4.2 Supply Pump 7
2.4.3 Solenoid Valve 7
2.5 Control Unit 7
2.5.1 Software Control Unit 8
2.5.2 Mechanical Unit Control 8
3. Design Verification 9
3.1 Sensor Unit 9
3.2 Display Unit 9
3.2.1 LCD Screen 9
3.3 Power Supply Unit 10

3.3.1 110 V---15 V AC-DC Converter 10
3.3.2 15 V---5 V Voltage Regulator 10
3.3.3 5 V---3.3 V Voltage Regulator 10
3.4 Mechanical Unit 10
3.4.1 Fountain Pump 10
3.4.2 Supply Pump 11
3.4.3 Solenoid Valve 11
3.5 Control Unit 11
4. Costs 12
4.1 Parts 12
4.2 Labor 13
5. Conclusion 14
5.1 Accomplishments 14
5.2 Uncertainties 14
5.2.1 PCB 14
5.2.2 Liquid-level Sensor 14
5.3 Ethical considerations 14
5.3.1 IEEE Code of Ethics I-1 14
5.3.2 IEEE Code of Ethics II 15
5.3.3 IEEE Code of Ethics I-6 15
5.4 Future work 15
References 16

1. Introduction
We designed a smart pet water fountain that helps pet owners to keep track on fountain water quality. Specially, the product aims pet owners who are likely to leave home for several days. Automatically replacing polluted water and refilling water when running out functions ensure fresh water supply for pets when owners are away from home.

1.1 Background
Today, more people around the world have pets than ever before. According to American Pet Products Association's survey in 2020, 67% of U.S. households own a pet which is about 84.9 million homes. This proportion has increased by 20% in thirty years [1]. The breakdown of the pet types shows that cats and dogs are the most popular animals and contribute about 80% of all pets. Same trend of raising cats and dogs happens all over the world. On average, one in three households own a dog globally and about a quarter of households worldwide own a cat [2]. Both cats and dogs prefer flowing water. [3] A source of fresh clean running water can encourage pets to drink. Drinking a certain amount of water daily plays an important role in long-term health for pets, especially cats. As a result, a pet water fountain is essential to most households having cats or dogs as pets. However, owners cannot ensure the water quality when they are away from home for several days. It is likely that pets finished all remaining water in the pet water fountain, or water was polluted somehow by the pet. These can cause the pet to be unwilling to drink water from the fountain.

There have been many pet water fountain products on the market [4], while most of them have only filtration as an extra function besides providing running water [5]. Also, the size of the pet water fountains limits the capacity of the water source, so that most pet water fountains cannot store enough water for multiple pets to drink in several days. We planned to solve the drawbacks and add additional features on water quality to create a smart pet water fountain for customers.

1.2 Objective
Our goal is to design a smart pet water fountain that can monitor the water quality and automatically replace water when polluted (not healthy) or running out. We will use sensors to measure the water quality. Common water quality measurement factors include temperature, pH-value, conductance, turbidity, and hardness [6]. Considering the pollution at home can only affect limited factors, we choose temperature, pH-value, and conductance as the three properties used for evaluating water quality in our smart pet water fountain. These data will be collected, calculated, and conveyed to the user in terms of "Good", "Average" and "Bad" on the display screen. The pet water fountain is also designed to self-filter the water every time water is pumped through the submersible water pump.

In detail, we set up three high-level requirements for the product:

- Able to drain the polluted water and replace it with fresh water. Specifically, the polluted water will be drained by a motor-controlled valve to the "polluted water temporary storage tank" part. After completing the draining process, fresh water will be pumped from the general water supply. The pump should be able to drain the water in 20 to 30 seconds.

- The fountain must accurately monitor the water quality (water temperature, pH value, conductivity). The sensors will be calibrated to an overall accuracy of 5% for all of the sensors.
- Water quality index should be displayed on the screen. The readings from the three sensors related to the water quality (water temperature sensor, conductivity sensor and pH-value sensor) will be taken every minute. And the overall water quality index (good, average, poor) will be updated and displayed in the same timely manner.

2 Design

To ensure the health of small pets while our customers are away from home, water quality is a critical point. The water quality monitor system embedded in the smart pet water fountain is the highlight of this project. Water quality will be determined according to three major factors: temperature, PH-value, and conductivity. The results will then be demonstrated with three levels: poor, average, and good. When the water quality is determined to be poor, then the polluted water will be drained, and freshwater will be pumped into the freshwater tank. This leads to the second highlight of this project: the automatic water replacement mechanism. Whenever water level is detected to be under the lower limit, supply water pump will start working to pump water from source. Figure 1 below is the block diagram of our project.

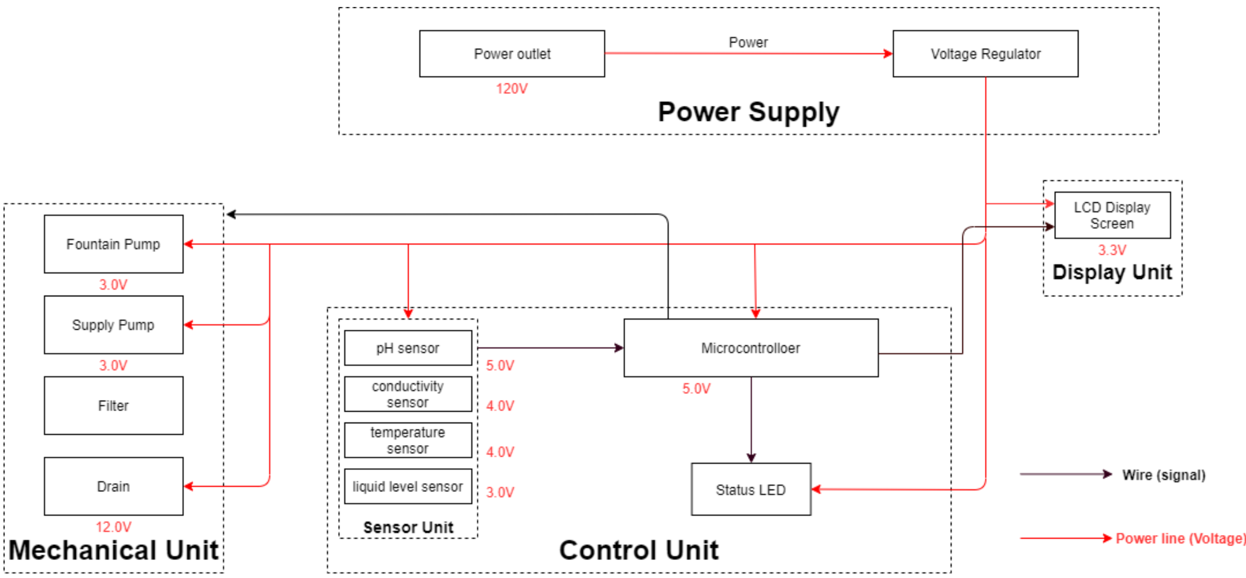

Figure 1 Block Diagram

2.1 Sensor Unit

This block contains four sensors: temperature sensor, pH-value sensor, conductivity sensor, and liquid level sensor. For the PH-value sensor, temperature sensor and conductivity sensor, values will be retrieved and calculated to determine the overall water quality level. The liquid level sensor will be used to determine the amount of fresh water left in the water tank.

2.1.1 Temperature Sensor

Temperature is to be measured as one important parameter in monitoring the water quality. We used a temperature sensor to keep track of the temperature. A water-proof temperature sensor is chosen for the design. The part number from Sparkfun is: DS18B20 [7]. This temperature sensor is compatible with a relatively wide range of power supply from 3.0 V to 5.5 V. The measured temperature ranges from -55 to +125 degree Celsius. Between -10 to + 85 degree Celsius, the accuracy is up to +-0.5 degree Celsius. This sensor can fulfill all requirements needed for this project. There are three major requirements for the temperature sensor:

1. The accuracy of the Temperature sensor should be within +- 0.5 degree Celsius.

2. Should be able to work along with other sensors(blocks) which share the same power unit. The input voltage will be between 3.0 V to 5.5 V at all times and the sensor should be working under these conditions.
3. The frequency of at least1 reading every 10 seconds is expected when the pet water fountain is fully functional.

2.1.2 pH-Value Sensor

pH-Value Sensor is the second parameter used to determine the water quality. A pH-Value Sensor is used to measure the pH values and report the results. This pH-sensor [8] works with 5 V voltage, which is also compatible with the temperature sensor. It can measure the pH value from 0 to 14 with an accuracy of +- 0.1 at the temperature of 25 degree Celsius. There are two requirements for the pH-Value Sensor:

1. The pH-sensor should be able to measure pH-values from 0-14. In addition, accurate measurement for solutions with pH-value between 5.0 to 8.5 needs to be achieved. Most daily use water has pH-value sitting in this range so an accuracy up to +-0.3 is sought for.
2. The pH-value claims a less than or equal to one minute response time. When the pet water fountain is working fully functional, pH-values are expected to be reported every minute.

2.1.3 Conductivity Sensor

Conductivity sensor is also part of the water quality assessment. The input voltage is from 3.0 V to 5.0 V. The error is small, +-5% F.S. The measurement value ranges from 0 to 20 ms/cm which is enough for water quality monitoring [9]. Similar to the that of pH-Value Sensor, two requirements are to be met by the conductivity sensor:

1. The measurement range is expected to be accurate within 5% range from 0 to 10 ms/cm.
2. A rate of 1 reading per minute is expected for this sensor.

2.1.4 Liquid Level Sensor

The liquid-level sensor, though never shipped by the vendor, is initially designed to measure the remaining amount of water in the fountain tank [10]. The range of measurement of the sensor is 0 to 9 inches. The resistance of the sensor changes based on the water level around it. Detailed parameters and design information are missing since the sensor never arrives for testing. There are two requirements designed for the sensor:

1. Achieve a detection threshold of one inch.
2. Limit the overall measurement error to 1%.

2.2 Display Unit

The display unit consists of two parts, the LED indicators, and the LCD screen.

2.2.1 LCD Screen

The LCD screen [11] is used to display the readings from the sensors in a real-time manner through Serial protocol. As described in the sensor part, the water quality and remaining water quantity will be displayed. The LCD screen unit is controlled by an Arduino Uno board, separated from the main control unit board, for communication stability. Two signals are generated by the control unit to indicate the water quality to be good or average. The only requirement for the screen is to display water quality level in the format of ‘Water Quality: Good/Average/Poor’ and update the information once every minute.

2.2.2 LED Indicators

The LED indicators contain three LEDs, one for average water quality indication, one for pump function indication, and one for valve function indication. Since an average water quality is not considered as harmful to pets, the average water quality indicator is used to inform the owner about the current condition, leaving the owner to decide whether the water should be replaced. Two function indicators are designed to notify the user and simplify customer services for problem diagnostics. The LEDs are powered through the digital output pins of the main Arduino board.

2.3 Power Supply Unit

There are a total of 4 components in the power supply unit. One 110 V---15 V ACDC converter, one 15 V---5 V voltage regulator, one 5 V---3.3 V voltage regulator and a 13.5 V 9-pack AA battery pack. Figure 2 on page 6 is the PCB circuit design of the power supply unit, including the two regulators. The AC-DC converter is connected to the board using wires.

2.3.1 110 V---15 V AC-DC Converter

To utilize the wall plug to provide a stable and usable voltage, this converter is needed. The 110 V---15 V AC-DC converter [12] should be able to convert the AC wall plug power to DC power compatible with parts we plan to use in the design. Two other voltage regulators (DC---DC) are also used to further convert 15V to compatible voltages. There are two requirements for the 110 V---15 V AD-DC converter.

1. It should be able to convert wall-plug ~110 V voltage to a stable 15 V DC power.
2. The Voltage output should be stable in a long period of time. The acceptable error is within +-1%.

2.3.2 15 V---5 V Voltage Regulator

The 15 V---5 V voltage regulator [13] is used to power parts including the Arduino, conductivity sensor and pH-Value sensor. It is expected to provide a stable 5 V output voltage with an error of +-1%. There are also two requirements for this voltage regulator:

1. It should be able to take in the 15 V DC mentioned in part 2.3.1 and convert to a stable 5 V DC.
2. The Voltage output should be stable in a long period of time. The acceptable error is within +-1%.

2.3.3 5 V---3.3 V Voltage Regulator

The 5 V---3.3 V voltage regulator [14] is used to power the LCD screen, 2 submersible water Pumps and the Liquid-Level Sensor. The requirements for this voltage regulator would be similar to that of 2.3.2. There are two requirements for this voltage regulator:

1. It should be able to take in the 5 V DC mentioned in part 3.3.2 and convert to a stable 3.3 V DC.
2. The voltage output should be stable in a long period of time. The acceptable error is within +-1%.

2.3.4 13.5 V 9-pack battery pack

This 13.5 battery pack is used to power the solenoid valve through the control of using a power relay. When using the relay, a separate power supply for the solenoid is needed and this 13.5 V battery pack is the solution. There are two requirements for this battery pack:

1. The actual voltage output of the battery pack should be able to safely activate the solenoid value.
2. It should be able to work for a long time period. As it only needs to provide instant voltages which activates the solenoid valve every time the relay control opens or closes, it is expected to be able to work continuously for over half a year's time.

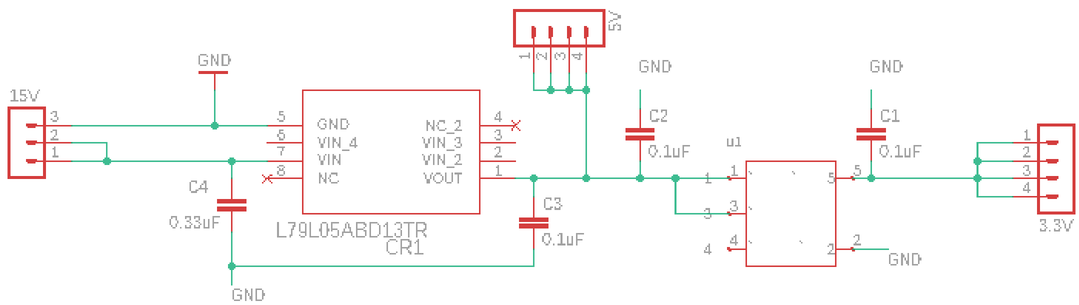

Figure 2 Power Unit Circuit Design

2.4 Mechanical Unit

There are a total of 3 mechanical parts involved in this project. Two submersible water pumps were used, and one solenoid valve was used. The two submersible water pumps served for different purposes and therefore are named fountain pump and supply pump. The fountain pump is used to create the actual 'fountain' like water stream that enables pets to drink water from the fountain. The supply pump is used as a freshwater supplementing system that activates after water quality is detected to be 'poor'. Figure 3 below shows the PCB design of the mechanical unit. This PCB contains three circuits: one for the liquid level sensor in the sensor unit which has been discussed in section 2.1.4, one for the supply pump, and one for the solenoid valve.

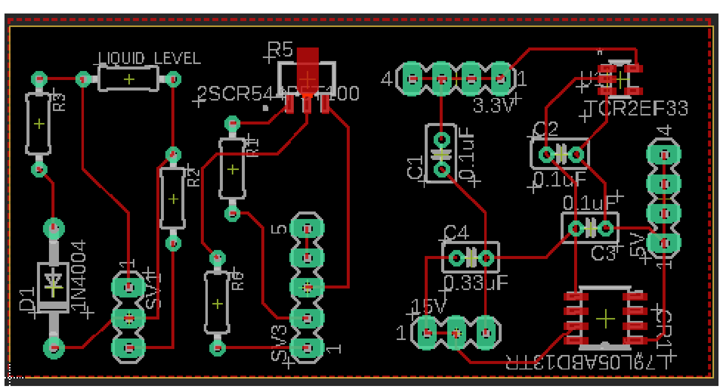

Figure 3 Mechanical Unit PCB Design

2.4.1 Fountain Pump

This pump [15] is relatively easy to implement, and its purpose is to create a water stream. There are two requirements for this pump:

1. It should be able to work in a non-stop continuous manner for extra-long periods of time (months long) because the fountain is kept on when the smart pet water fountain is plugged in.
2. It should be able to maintain a stable water stream from the freshwater tank when the applied voltage to it is maintained.

2.4.2 Supply Pump

The supply pump is used to add freshwater from other containers. It is implemented in a control circuit to work according to instructions sent by the control logic. There are two requirements specifically for the pump:

1. Should be able to work steadily with a wide variety of voltages: 1.5 V to 4.0 V
2. A 3.0 V to 3.5 V voltage input is desired and thus when those voltages are applied to the pump, it should be strong enough to transport water from any angle to the freshwater tank.

2.4.3 Solenoid Valve

The solenoid valve [16] is used to drain the water that is detected to be of 'poor' quality. The solenoid valve is activated when a voltage that is greater than its threshold activation voltage is applied. It remains closed for the rest of the time. It is operated, as described in the power supply unit, by the control of a relay. It has three requirements:

1. When the activation voltage supplied by the 13.5 V battery pack is applied, it should respond promptly and remain open until the voltage supplied is shut.
2. When the valve is on, the water should be able to flow freely.
3. When no voltage is applied, the valve should be able to be sealed and no water is expected to leak from the freshwater tank.

2.5 Control Unit

The control unit includes two parts: software control unit and mechanical control unit. Figure 4 is the PCB design for the software control unit which will be discussed in section 2.5.1 below.

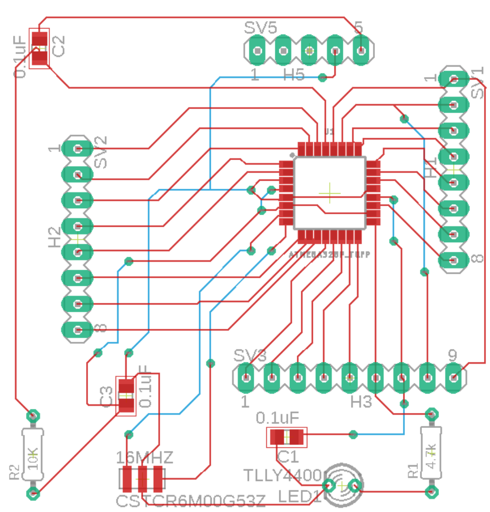

Figure 4 Control Unit Microcontroller PCB Design

2.5.1 Software Control Unit

The control unit is implemented on an Arduino Uno. The analog input pins are used to receive the voltage output from the sensors. Control signals for mechanical and display units are read from the digital output pins. Control software is loaded onto the ATMega328P microcontroller on the Arduino board.

Determining the water quality in the fountain tank is one of the most important designs in the project. Based on research concerning pets' drinking water quality, a criterion based on the temperature, pH, and conductivity is designed to serve as the water quality algorithm.

Table 1 Water Quality Level Ranging

	Poor	**Average**	**Good**
Temperature (°C)	Temp < 5 or Temp > 30	5 < Temp < 30	15 < Temp < 25
pH-Value	pH < 6.5 or pH > 8.5	6.5 < pH < 7 or 8 <pH < 8.5	7 < pH < 8
Conductivity (mS/cm)	Cond > 1ms/cm	Cond < 1ms/cm	Cond < 0.5ms/cm

2.5.2 Mechanical Unit Control

The fountain pump for pet water supply is designed to operate all the time when the system is powered. For poor water quality, valve control signal is first held high for 10s, lighting the corresponding LED, to fully drain the water in the fountain tank, and then set low to close the valve. Then the supply pump control signal is held high for 10s to deliver fresh water into the fountain pump.

3. Design Verification

3.1 Sensor Unit

Table 2 Sensor Unit Verifications

Sensors	Verifications
Temperature Sensor	The accuracy of the temperature sensor is verified through comparison with a commercial grade temperature sensor based on measurement of 3 tanks of water with various temperatures.
	Various input voltages (3.0 V, 3.5 V, 4.0 V, 4.5 V, 5.0 V and 5.5 V) will be tested using power supply and test the working conditions for the sensor.
	Readings of the sensor should be acquired every 10s for 2 minutes. The overall deviation between the sensor reading and standard measurement should be no more than 2 degree Celsius. Outliers should be reported to check sensor stability.
pH Sensor	The accuracy of the pH sensor is verified through comparison with a lab grade pH sensor based on measurements of 3 solutions with standard pH values.
	Readings of the sensor should be acquired every 30 s for 5 minutes. The overall deviation between the sensor reading and standard measurement should be no more than 1. Outliers should be reported to check sensor stability.
Conductivity Sensor	The accuracy of the conductivity sensor is verified through comparison with a lab grade conductivity sensor based on measurements of 2 solutions with standard conductivity values.
	Readings of the sensor should be acquired every 5 s for 2 minutes. The overall deviation between the sensor reading and standard measurement should be no more than 0.5 ms/cm. Outliers should be reported to check sensor stability.

Table 3 below shows the sensor unit verification data. Temperature sensor achieved an average accuracy of over 95%. Conductivity sensor has an average accuracy close to 95%. The pH-value sensor however has an average accuracy of only approximately 85%. Since the error is more significant at extreme pH-values which is hard to achieve in daily life, we think this average accuracy level for water pH-value is acceptable.

Table 3 Sensors Verifications Data

Sensor Type	Sensor Value 1	True Value 1	Sensor Value 2	True Value 2	Sensor Value 3	True Value 2	Average Accuracy
pH-Value	7.13	7.30	1.72	2.49	8.16	8.50	~85%
Conductivity	0.34	0.37	0.15	0.14	0.87	0.85	~94.07%
Temperature	23.5	23.6	25.2	25.4	23.7	23.5	~99.31%

3.2 Display Unit

3.2.1 LCD Screen

Table 4 LCD Screen Verifications

Verifications	Results
1. Correctly connect the LCD screen to the Arduino board. Wire the LCD Arduino board with the control unit Arduino board.	The LCD displays appropriate information as programmed on

2. Program both Arduino board with pre-written code. 3. The screen should display the same water quality level as set (change through the three levels in sequence). Detailed control logic mentioned in 3.5.	Arduino.

3.3 Power Supply Unit

3.3.1 110 V---15 V AC-DC Converter

Table 5 110 V---15 V AC-DC Converter Verifications

Verifications	Results
1. Connect the AC---DC converter to the wall plug and connect the multimeter to the voltage output. 2. The voltage output should be stable at around 15 V and it was tested for a long period time to test for its stability.	Expected voltage: 15 V +-1% Actual result (multiple tests with long periods): An average of 14.99 V.

3.3.2 15 V---5 V Voltage Regulator

Table 6 15 V---5 V Voltage Regulator Verifications

Verifications	Results
1. Connect the input voltage pins to the 15 V power supply source. 2. Measure the output voltage multiple times with long periods of time. 3. Connect the input voltage pins to the output pins of the 110 V---15 V converter instead of 15 V power supply source. 4. Measure the output voltage again multiple times with long periods of time.	Expected Voltage: 5 V +-1% Actual results (multiple tests with long periods): An average of 4.98 V

3.3.3 5 V---3.3 V Voltage Regulator

Table 7 5 V---3.3 V Voltage Regulator Verifications

Verifications	Results
1. Connect the input voltage pins to the 15 V power supply source. 2. Measure the output voltage multiple times with long periods of time. 3. Connect the input voltage pins to the output pins of the 110 V---15 V converter instead of 15 V power supply source. 4. Measure the output voltage again multiple times with long periods of time.	Expected Voltage: 3.3 V +-1% with appropriate control voltage. Actual results (multiple tests with long periods): An average of 3.31 V

3.4 Mechanical Unit

3.4.1 Fountain Pump

Table 8 Fountain Pump Verifications

Verifications	Results
1. Test the pump with voltages in the range between 2.0 V to 3.0V and observe the direction and the strength of the fountain created. 2. Locate the pump in the freshwater tank. Fix it in place and make sure the voltage supplied makes the fountain stream stay in the tank.	The pump is able to pump water out in the freshwater tank continuously.

3.4.2 Supply Pump

Table 9 Supply Pump Verifications

<table>
<tr><th>Verifications</th><th colspan="2">Results</th></tr>
<tr><td rowspan="3">1. Test with the BJT NPN transistor circuit and appropriate resistors. The voltages at base and collector were set, measured, and recorded.
2. Choose the optimal resistors and the optimal collector voltage to make the voltage across the pump be between 3.0 V to 3.5 V.</td><td>Emitter</td><td>Ground</td></tr>
<tr><td>Collector</td><td>15 V Vcc, pump in series connected with a 1000 Ohm resistor.</td></tr>
<tr><td>Base</td><td>Base works as the control pin, Vcc applied is from the logic output from Arduino, measured to be around 4.98 V. Pump connected in series with a 100 Ohm resistor.</td></tr>
</table>

3.4.3 Solenoid Valve

Table 10 Solenoid Valve Verifications

Verification	Results
1. Test with 13 V with +-10% error and observe the exact range of voltages that can activate the solenoid valve. 2. Using paper cups to test the flow rate when valve is open. 3. Test in control relay circuit which includes the 13.5 V battery voltage supply.	Expected Voltages: 13 V +-10% Actual results: 13.0 V to 13.5 V works the best.

3.5 Control Unit

Table 11 Control Unit Verifications

Parts	Verifications
Arduino Uno	Power the Arduino with 5 V DC power supply, the Operation LED should light on. Test the integrity of the program loaded on the microcontroller by controlling the system.
Good Water Quality Check	Put all 3 sensors into liquid with "Good" quality condition. All three indication LEDs should not light up. The fountain pump should keep operating. The valve should stay close, and the supply pump should not operate. The LCD screen should display the message "Water Quality: Good".
Average Water Quality Check	Put all 3 sensors into liquid with "Average" quality condition. The "Average Water Condition" LED should light up. The fountain pump should keep operating. The valve should stay close, and the supply pump should not operate. The LCD screen should display the message "Water Quality: Average".
Poor Water Quality Check	Put all 3 sensors into liquid with "Poor" quality condition. The fountain pump should keep operating. The valve operation LED should first light up for 10s, with the valve opening at the same time. Once the valve is closed, the supply pump LED should light up for 10s, with the supply pump operating at the same time. The LCD screen should display the message "Water Quality: Poor".

4. Costs

4.1 Parts

The following table lists all parts costs spent for the project, including both parts that have and have not been used as well as parts used for verifications. All prices are unit price that do not include tax.

Table 12 Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
NPN 80V 2.5A MEDIUM POWER TRANSI	Rohm Semiconductor	0.54	0.27192	0.54
CERAMIC RES 6.0000MHZ 15PF SMD	Murata Electronics	0.27	0.14368	0.27
Submersible 3V DC Water Pump - Vertical Type	Adafruit Industries	1.95	1.56	1.95
Liquid-In-Glass Laboratory Thermometer	SP Scienceware	15.25	/	15.25
Digital PH Meter	Embryant	12.99	/	12.99
Temperature Sensor - Waterproof (DS18B20)	Dallas Semiconductor	11.95	/	11.95
SparkFun 20x4 SerLCD - RGB Backlight (Qwiic)	SparkFun Electronics	24.95	/	24.95
ATmega328 - TQFP	Atmel	4.25	/	4.25
SOLENOID VALVE ONEWAY FREE HANG	SparkFun Electronics	7.95	/	7.95
IC REG LINEAR -5V 100MA 8SO	STMicroelectronics	0.47	0.14501	0.47
IC REG LINEAR 3.3V 200MA SMV	Toshiba Semiconductor and Storage	0.34	0.07314	0.34
Liquid Level Sensor - 8"	Milone Technologies	39.95	/	39.95
TUBING PVC 8MM ID X 1 METER	Adafruit Industries	1.50	/	1.50
AC/DC CONVERTER 15V 45W	XP Power	31.93	/	31.93
18 AWG 3 Conductor 3-Prong Power Cord	Middleway	8.99	/	8.99
GTSE Vinyl Electrical Tape, 3/4 in x 66 ft	Vinyl	3.99	/	3.99
40 Pin 2.54mm Male and Female Pin Headers	DEPEPE	4.99	/	4.99
AA Battery Holder Bundle	LAMPVPATH	6.99	/	6.99
Analog pH Sensor / Meter Pro Kit for Arduino	DFRobot	56.90	/	56.90
Analog Electrical Conductivity Sensor /Meter	DFRobot	69.90	/	69.90

Loctite Clear Silicone Waterproof Sealant	Loctite	9.14	/	9.14
Brita Longlast UltraMax Water Filter Dispenser	Brita	32.99	/	27.99
Total				**343.18**

The total cost above includes almost everything we purchased for our project. Some parts cannot be purchased in volume because the amount we need is only a few. If the smart pet water fountain can be manufactured, total price for producing one water fountain would largely decrease.

4.2 Labor

The estimated hour labor cost for our group is $30/hour, 10 hours/week for three people on average through the 8 weeks. So the total labor cost is:

$$3 * (\$30/\text{hr}) * (10\text{hr/week}) * 8(\text{weeks}) * 2.5 = \$18{,}000 \quad (1)$$

5. Conclusion

5.1 Accomplishments

For this project, our group managed to get three sensors working: pH-Value sensor, conductivity sensor and the water temperature sensor achieving an overall accuracy of approximately 92.7%. The goal was 95% accuracy but 92.7% was reasonable and astonishing. The integrated control logic and circuit was well built. Both control software and hardware were working cooperatively to correctly control the order of activation and the activation of various parts including pumps and the solenoid valve. The power supply system for the whole water fountain was stable and reliable. The converter and regulators can provide sufficient and stable power for maintaining the whole system for an extended period of time. The LCD was successfully implemented and can show the user real-time water quality information according to the readings from the sensors. Although there were a lot of accidental instances we faced and encountered, this project is very successful as a whole.

5.2 Uncertainties

5.2.1 PCB

The PCB for this project is only partially working. Because of the university Gmail system malfunction between members of the team and the TA, the email was sent out but was never received. Thus we did not receive a PCB on round 2 PCB order. The PCB round 3 experienced severe delay and only got to our hands on the Monday of the demo week while our demo slot was scheduled on Wednesday. Even worse is the fact that because of the demo schedules, labs were mostly closed on Monday and Tuesday on that week. During this limited time, we only got the PCB partially working (1 of the 3 circuits designed on the PCB). This is something unforeseeable and we should be aware of the fact that there are always unexpected things happening and we should get ready.

5.2.2 Liquid-level Sensor

Another part that did not work was the liquid-level sensor. We finished designing and testing the circuit, but the actual part was never shipped out from Sparkfun. Over a month before the demo date that the sensor was ordered, and it was never shipped out although they promised multiple times that they would ship it soon. We would like to add this sensor to our project so that it can be complete, and the functions can work more smoothly.

5.3 Ethical considerations

5.3.1 IEEE Code of Ethics I-1

Quoted from IEEE Code of Ethics [11]: “To hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment.”

We will carefully choose the materials used to build the container. Non-toxic are sure to be used. We will prefer using reusable materials. In addition, the users can choose to buy reusable bottles of water for the freshwater supply for the pet water fountain. Those universal water bottles are safe and reusable. A special connector will be designed, and the universal connection is planned. After the water in the bottle is used up, this reusable bottle can be recycled and reused. This is the most environmentally friendly solution and complies with the IEEE Code of Ethics #I-1. It not only improves the practicality, convenience, and reduces the future cost when using the pet water fountain.

5.3.2 IEEE Code of Ethics II

Quoted from IEEE Code of Ethics: “II. To treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others.”

As mentioned in the previous section, the mechanical unit involves electronic components that are physically placed in the water tank. The consequence can be serious if the leak-proofing is not performed properly. To maintain a safe, convenient using experience, we will be responsible for testing and ensuring all containers meet the demand. These actions must be taken to ensure the safety of using the pet water fountain and protect the others.

5.3.3 IEEE Code of Ethics I-6

Quoted from IEEE Code of Ethics: “to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations.”

All team members involved in the development of the pet water fountain have completed “Laboratory Safety training” and have gained required and necessary knowledge in dealing with emergency situations. In case of accidents, proper reaction will be made to ensure the safety of people and property to the largest extent.

5.4 Future work

The design is currently implemented on breadboard, which makes the system relatively messy and hard to debug. Implementing the system on PCBs would be a good starting point for future work. The project is mainly composed of water and electricity. Thus, better strategies should be applied to prevent contact between these two. The commercial level sensors used in this project have a relatively larger scale compared to the fountain framework. To improve the performance of the product, smaller but more precise sensors can be integrated into the system. A user-friendly interface that indicates the meaning of LED indicators should be considered if the design of the project is improved and finalized. At last, the product should be tested on pets in real life to check out its performance.

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