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Enhancing Water Conservation Efforts with Smart Technology: The Role of Arduino-Based Water Level Management Systems

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***Abstract* - The development of an Automatic Overhead Storage Tank Water Level Management System using Arduino represents a significant advancement in water resource management. This system utilizes two ultrasonic sensors to monitor and manage the water levels in overhead storage tanks, ensuring efficient water usage and preventing overflow and dry-run scenarios. Initially, the system was simulated using Tinkercad, allowing for precise calibration and troubleshooting in a virtual environment. Following successful simulations, a functional prototype was constructed. The Arduino microcontroller processes data from the ultrasonic sensors to provide real-time water level information, which triggers appropriate responses such as activating or deactivating the water pump. This approach not only optimizes water conservation but also reduces manual monitoring efforts, providing a reliable and cost-effective solution for residential and commercial water management systems.**

***Keywords* - Water level management system; Water conservation; Arduino; Ultrasonic sensor**

I. INTRODUCTION

Water, an essential resource for daily human activities, plays a critical role in both residential and industrial contexts [1], [2]. Despite Earth's considerable water abundance, only 1% constitutes freshwater [3], with a staggering 70% of the freshwater trapped in polar ice caps and glaciers [4]. This disproportionate distribution underscores the necessity for efficient water management strategies. The confluence of escalating threats such as water pollution, climate change, and rising global demand intensifies the urgency for efficient water management [5]. The current issue is marked by multifaceted challenges like pollution, chemical contamination, and water leakage, collectively contributing to the depletion of pure water on a global scale, thereby looming a potential water scarcity threat [6]. About two billion people worldwide lack access to clean drinking water [7], with waterborne diseases disproportionately affecting underdeveloped nations [8]. The intricate interplay between climate change and freshwater supply further highlights the need for sustainable practices, prompting a paradigm shift towards the imperative use of renewable energy, given the interconnection between water and energy [9]. Given water's pivotal role in both residential and industrial spheres, effective water management stands as a backbone for sustainable development. In Ghana, the Ghana Water Company Limited shoulders the responsibility of water distribution but faces challenges such as exorbitant costs, accessibility issues, and unpredictable supply [10]. Faced with these impediments, Ghanaians resort to alternative sources like subterranean water access systems, necessitating technological interventions to address ensuing challenges [11]. The introduction of the overhead storage tank system, incorporating pumps and storage tanks, has significantly augmented water supply technology, particularly in elevated regions. However, the reliance on manual pump operation within this system introduces efficiency challenges. This manual operation gives rise to issues such as water wastage, increased electrical costs, and structural damage over time [12]. The inefficiencies arising from manual operation prompt the proposition of an automated system to streamline the management of overhead storage tanks. This study proposes a cost-effective solution, using Arduino microcontrollers and ultrasonic sensors. The proposed system seeks to:

- Design and implement a cost-effective Arduino-based system for monitoring water levels in overhead storage tanks.
- Reduce manual intervention in the operation of overhead tanks by introducing automated control.
- Minimize water wastage and associated structural damage caused by inefficient manual pump operation.

Through this technological intervention, the project seeks to address the existing drawbacks associated with traditional overhead storage tank systems and pave the way for a more sustainable and efficient water management system.

II. RELATED WORKS

[13] developed a smart system utilizing an Arduino UNO microcontroller, ultrasonic sensors, and a 16*2 LCD display

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to monitor water levels in tanks and control pumps. The system employs three ultrasonic sensors, two placed on the water tank (upper and lower levels) and one monitoring water flow from the sump tank to the upper tank. The Arduino processes signals from the sensors, instructing the pump control system to turn on or off based on water levels. The third sensor prevents the pump from running dry, safeguarding it from damage and conserving electricity. A 16*2 LCD display provides real-time information on the system, including status and water levels.

[14] introduced water level sensing system in their design project. The system includes a metal electrode probe water level sensor with voltage output, a JK flip-flop sequential circuit for digital logic processing, a relay-based driver to control the motor drive circuit, and a segment display unit for key parameter display. These water level sensors utilize conductivity for electricity transfer between fixed probe positions, enabling measurement at a chosen level. When water closes the circuit, the signal output triggers the storage tank system. Initially, the mechanism checks if the tank is full. The encoder, receiving a signal from the electrode probe, indicates the water level and outputs data to the segment display. This encoder output also acts as input for the sequential circuit controlling the motor pump drive circuit. Notably, sensor probe rusting may lead to inaccurate readings.

[15] designed a water tank monitoring system using Raspberry Pi, two sensors and an Android Application. One sensor is attached to a higher level of the tank, while the other is connected to a lower level of the tank. When the water level falls below a certain level, a notice is sent to the user's Android application, instructing them to use the app to switch on the pump. When the tank is full, the pump shuts down automatically. The Raspberry Pi automates the system, so the pump turns on automatically when the tank is empty and switches off automatically when the tank is filled. There is no dry pump run protection

[16] introduced a smart water management system that monitors water level, pH, and turbidity. The system employs solar power to generate energy for the water pump. Two ultrasonic sensors gauge the water level by sending sound waves through the tank and measuring their return time. When the first sensor indicates a low level, the Arduino signals the pump to turn on automatically; conversely, a high signal prompts the pump to turn off. Additionally, if the second sensor detects a low signal, the Arduino enforces an automatic pump shutdown. The system includes an android application for data monitoring, but lacks pump management functionality. The system lacks dry pump run protection and features a complex design implementation.

[17] proposed a solution for an independent water level controller with SMS notification. The system consists of two main parts: hardware and software. The hardware utilizes an Arduino UNO, ultrasonic sensors, and a relay circuit, while the software is implemented using LabVIEW programming. The Arduino UNO acts as a bridge between the software and hardware components. LabVIEW, a graphical programming language, is employed to program the microcontroller, utilizing a dataflow concept. Ultrasonic sensors detect the water level, and the signal is processed by the Arduino UNO through LabVIEW. When the water reaches a specific level, the output triggers the relay circuit. For SMS notifications, a Motorola c261 model SMS circuit is employed, providing a serial connection through a headset connector to operate the Global System for Mobile (GSM) system.

[18] proposed a water level regulation system employing accessible components like a laser sensor, Arduino, Relay, Motor, and Adafruit cloud. The laser sensor, positioned atop the tank, monitors water levels. Data is transmitted to the pump, enabling its operation, and simultaneously stored in the cloud via Node MCU connection. The Arduino UNO receives this data from the transmitter to manage pump activation and deactivation. The motor starts when water levels dip below a set threshold, halting when it surpasses the maximum level. During mid-range water levels, control via the Adafruit cloud platform is possible. Given the 220V AC voltage, managed by the Arduino through a relay, the motor functions as a switch for AC devices. This setup addresses the Arduino's inability to regulate the 220V AC directly. Importantly, a drawback is highlighted — difficulty in assessing water levels in the absence of an internet connection.

In their study, [19] proposed a smart system using accessible components like Arduino, an ultrasonic sensor, an LCD, a buzzer, and a Bluetooth module to keep track of liquid levels in a container. The ultrasonic sensor, placed atop the container, operates within a range of 3mm to 400cm. It sends a signal to the liquid surface, calculates the level based on the echo return, and relays this information to the Arduino. The liquid level is then displayed on the LCD, and a buzzer alerts the user if it goes beyond the desired range. The data is transmitted via Bluetooth to a smartphone, allowing users to monitor the liquid level through a dedicated app.

[20] suggested a wireless water level management system for tanks. The system incorporates water level sensors, a Bluetooth module, an ATMEGA 328 controller, an LCD display, and a buzzer. The water level sensors relay tank data to the ATMEGA 328 controller, which processes and displays the information on a 16*2 LCD panel. Simultaneously, the data is transmitted to the user's smartphone through Bluetooth. A buzzer alerts the user about the water presence. The system categorizes the tank into four stages: initial (10%), 40%, 80%, and 100% water levels. The LCD provides real-time updates on the water level, pump status, and buzzer status at each stage. When the tank reaches full capacity, the pump is automatically turned off, and the buzzer signals completion. Both the LCD and Bluetooth transmit this information to the user.

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III. METHODOLOGY

A. Working Principle

The design consists of two ultrasonic sensors, a power source, an ATmega328 (the chip for Arduino Uno microcontroller), a pump, a relay, jumper wires, a printed circuit board (PCB), two tanks of different sizes, and an LCD display.

The Arduino gathers information from sensor 1, monitoring the water level in the overhead tank, while sensor 2 reports the reserve tank's water level to the Arduino. If the water level in the overhead tank falls below a certain point, sensor 1 signals the Arduino to activate the pump automatically, filling the tank. Before starting the pump, sensor 2 verifies if the reserve tank has enough water. If the overhead tank is empty, and the reserve tank is very low or empty, the Arduino prevents the pump from turning on, ensuring a "dry pump run protection" that conserves energy and protects the pump. When the overhead tank is full, sensor 1 alerts the Arduino to turn off the pump. The system's LCD display shows the water level and pump status. The circuit is assembled on a printed circuit board, and the system includes calibration settings for the pump speed and tank depth within the ultrasonic sensor's range. This configuration enhances efficiency and prevents unnecessary energy consumption or pump damage. The working principle is presented as a flowchart in figure 1 below.

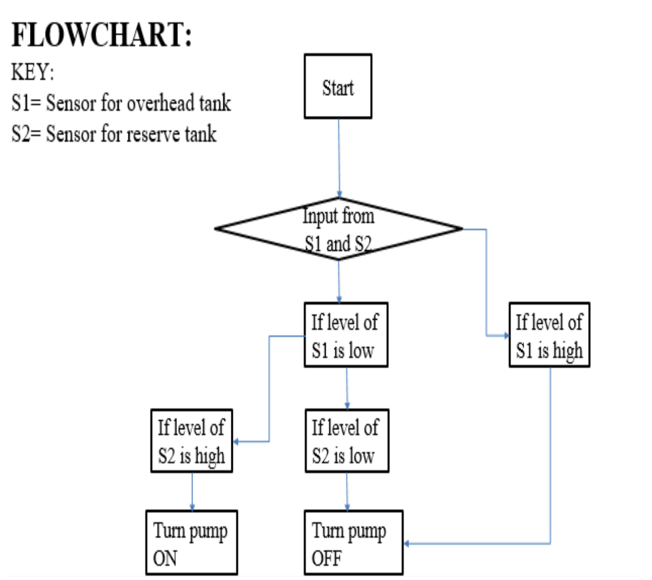

Figure 1. Flowchart of Automatic Overhead Storage Tank Water Level Management System.

B. Hardware Components

The hardware components included in the design include: Arduino Uno microcontroller, Ultrasonic sensors, Power supply, Pump, LCD, Jumper wires, and Printed Circuit Board.

The Arduino Uno board was chosen for this project mostly because to its low cost and ease of programming with the Arduino computer software. This board is also ideal for project planning. DIP (Dual-Inline-Package), ATmega328 microprocessor, power jack, USB connection, ISP header, and RST (Reset) button make up the Arduino Uno board. The operational voltage is 5 volts, while the input voltage should be between 7 and 12 volts. The input voltage range is from 6 to 20 volts. There are 14 digital input and output pins on the Arduino Uno. Six of the digital pins on this board are for PWM (Pulse Width Modulation). There are additionally six analog input pins on the board. Each input/output pin has a DC current of 20mA, and the 3.3V pin has a DC current of 50mA. The board features 32kB of flash memory and 0.5kB of RAM for the boot loader. It has a 2kB static random-access memory and a 1kB EEPROM (Electrically Erasable Programmable Read Only Memory). The EEPROM allows the user to frequently delete and reprogram stored data. The CLK operates at a frequency of 16MHZ. LEDs are incorporated into the Arduino Uno. The size of the board is 6.86cm x 5.34cm, and it weighs 25g. ltrasonic distance sensors can detect the distance between an object and the sensor without touching it. Ultrasound waves are used by the ultrasonic sensor to identify things and calculate distance. Ultrasonic waves have frequencies that are beyond the range of human hearing. A transmitter converts electrical impulses into ultrasonic sound pulses that are emitted by the sensor, while a receiver absorbs reflected waves reflected by an object and provides an output pulse whose width may be used to measure the pulse's distance. The distance between the object and the sensor is determined by the total time taken by ultrasonic waves to travel from the sensor's transmitter to the object and back to the receiver. Because speed is equal to the distance traveled divided by the time taken, distance is calculated by converting speed into time. The sensor gives the time taken and the speed of ultrasonic waves in the air is 340 m/s. Mathematically, the distance is expressed:

$$Distance = \frac{Time\ x\ Speed\ of\ Sound}{2} \quad (1)$$

A power supply adapter which can produce 12V DC for the pump is used. Below 12V, the pump cannot run to siphon the water from the underground tank to the overhead tank. The pump action of the prototype project is represented by a motor. When the water level in the tank falls below the desired level, the Arduino sends a signal to the motor, which turns it on and keeps it running, simulating the pump siphoning water into the tank. The motor stops running when the tank is full, thanks to a command from the Arduino microcontroller.

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It should be noted that driving the motor straight from the Arduino board pins will cause harm to the board. The type of motor selected for this project is the DC Motor. This DC motor was selected based on its lowest cost, efficiency and its speed. The LCD is used to display the output of the Arduino to the user. It helps the user to get a fair idea of how the system is operating and which processes are ongoing in the system. The user will be notified of the status of the system, mainly water level in the overhead tank and the reserve tank. Some of the information that can be displayed on the LCD are: overhead tank empty, overhead tank full, reserve tank empty, motor running, etc. The 16*2 LCD was selected because it is relatively cheaper and simple to program and control.

B. System Design and Implementation

The system planning and design involve using simulation tools or software, specifically the TinkerCad program, to simulate the expected outcomes. TinkerCad is a free and user-friendly web-based 3D modeling program widely accessed by beginners due to its simplicity. This program, accessible to anyone with an internet connection, is utilized by various individuals, including children, educators, and enthusiasts, to bring ideas to life through 3D printing, laser cutting, or building blocks. The simulation model and schematic diagram for the automatic overhead storage tank water system were created using TinkerCad as shown in figures 2 and 3 below.

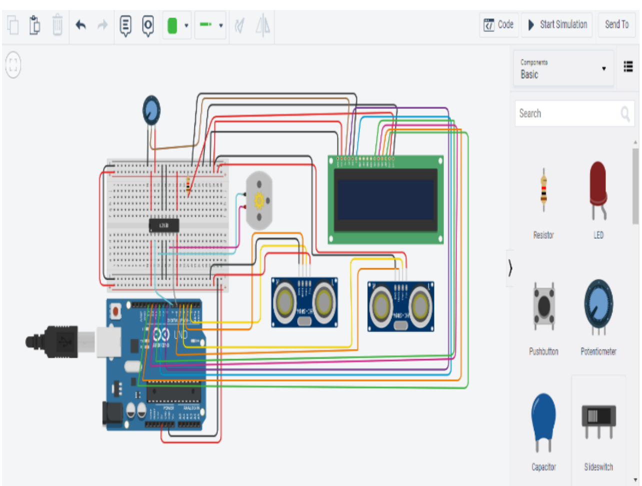

Figure. 2 Design model of the Automatic Overhead Storage Tank Water Level Management System

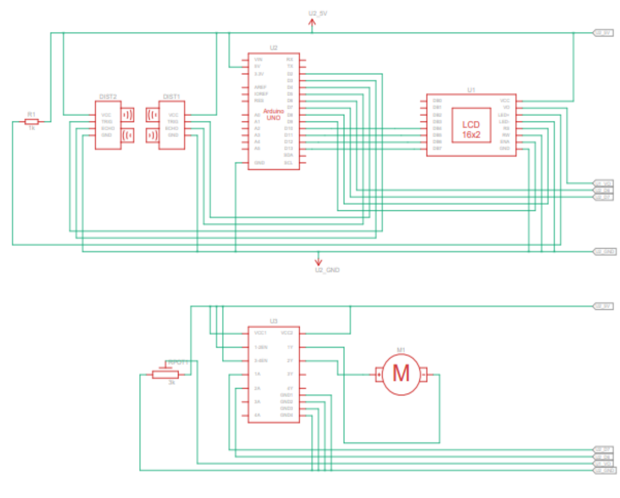

Figure 3. Schematic diagram for the Automatic Overhead Storage Tank Water Level Management System

The system's design and schematic diagram were created on TinkerCad by writing lines of code in C++. Users write the code to make the system operate as desired. The codes on TinkerCad are compatible with Arduino boards, allowing for easy transfer to control the automatic overhead storage tank water level management system. The simulation helps us understand how the automatic overhead storage tank water level management system will work, outlining the system's step-by-step operation. The principles and codes from the simulation are then used to build the prototype of the automatic overhead storage tank water level management system.

IV. SIMULATION RESULTS, ANALYSES AND SYSTEM PROTOTYPE

The results of this experiment were derived from three main steps, focusing on the water levels in both the overhead and reserve (underground) tanks. The study observed how the system automatically responds to changes in these levels. The three key stages include:

- When both the overhead tank and the reserve tank are full.
- When the overhead tank is empty and the reserve tank is full.
- When both the overhead and reserve tanks are empty (Dry pump run protection).

The ultrasonic sensor in this project operates within a range of 4cm to 400cm. The code is adjustable to suit tank heights within this range, with the experimental simulation considering a tank of approximately 300cm height. Tanks with a height equal to or less than 400cm are suitable for the project. To prevent the overhead tank from being completely empty, the system activates the pump automatically when the water level drops to around 200cm or lower. This precaution is taken to address potential emergencies, ensuring water availability even

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during pump faults or power outages. Conversely, when the water level reaches 25cm or less, the system considers the tank full and automatically switches off the pump. Additionally, a dry pump run protection feature is integrated. In situations where water levels are low in both tanks, the system turns off the pump to prevent dry running, safeguarding the pump from damage and minimizing electricity costs. The results and findings are given in the table 1 below.

Table 1. Summary of the automatic water level management system

Condition	Overhead tank water level	Reserve/Underground tank water level	LCD Display	Motor status
1. Both overhead and reserve tanks are full.	<= 25cm	<= 25cm	Water tank full	Motor turned OFF.
2. Overhead tank empty and reserve tank full.	>= 200cm	<= 25cm	Low water level	Motor turned ON.
3. Both overhead tank and reserve tank are empty.	>= 200cm	>= 200cm	Dry protection	Motor turned OFF.

Below are the figures from the Tinker cad simulation software to understand perfectly well the principle of operation of the Automatic Overhead Storage Tank Water Level Management System.

Case 1: Water level in both the overhead and underground tanks are high.

Overhead tank high(<=25cm)

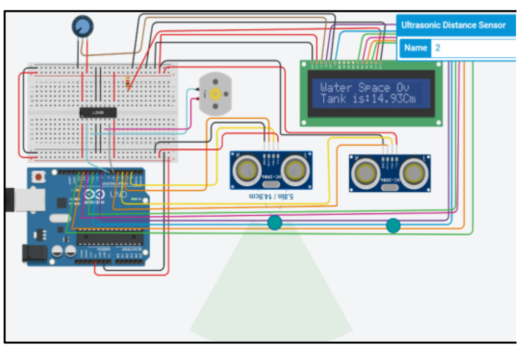

Figure 4. Water level in overhead tank high

Underground tank high(<=25cm)

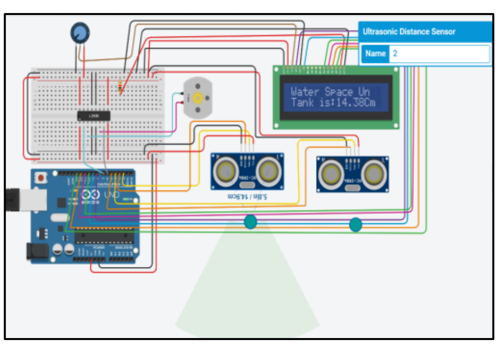

Figure 5. Water level in underground tank high

Motor Status

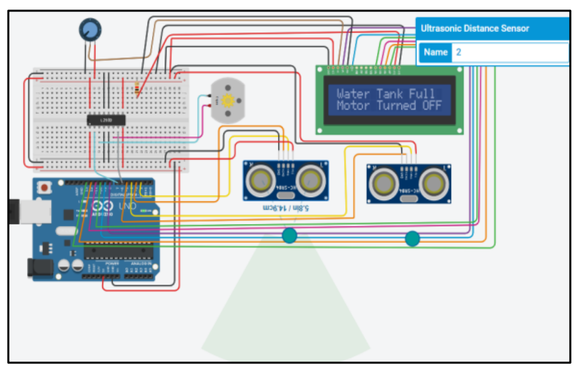

Figure 6. Motor status OFF

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Case 2: Water level in the overhead tank low and underground tank high.

Overhead tank low (>=200cm)

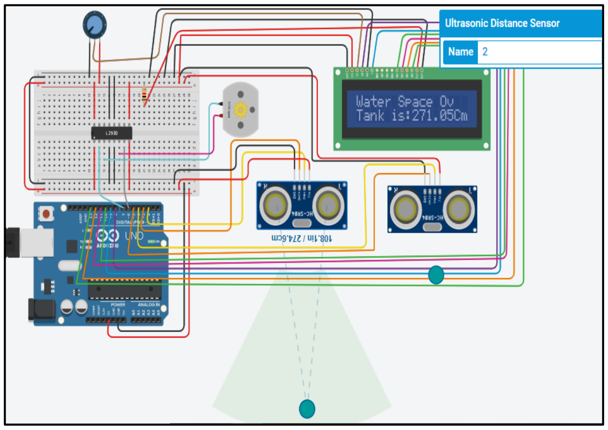

Figure 7. Water level in overhead tank low

Underground tank high

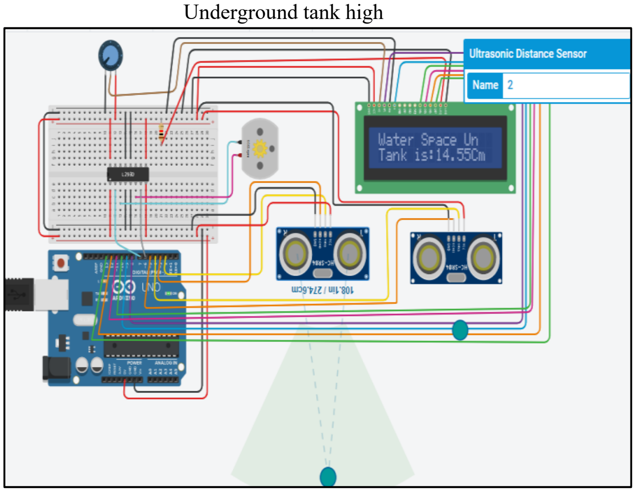

Figure 8. Water level in underground tank high

Motor Status

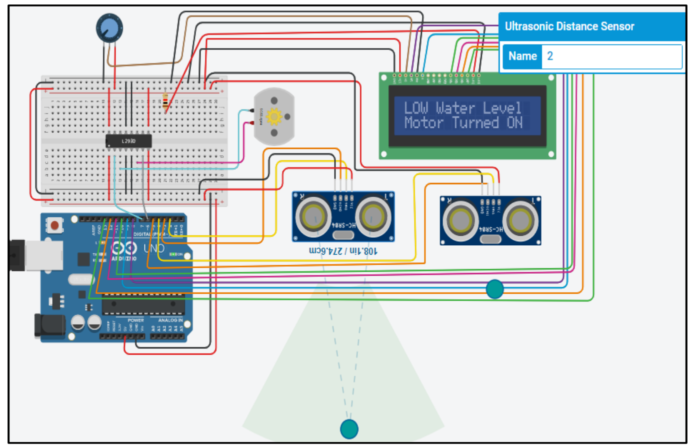

Figure 9. Motor status of ON

Overhead tank low (>=200cm)

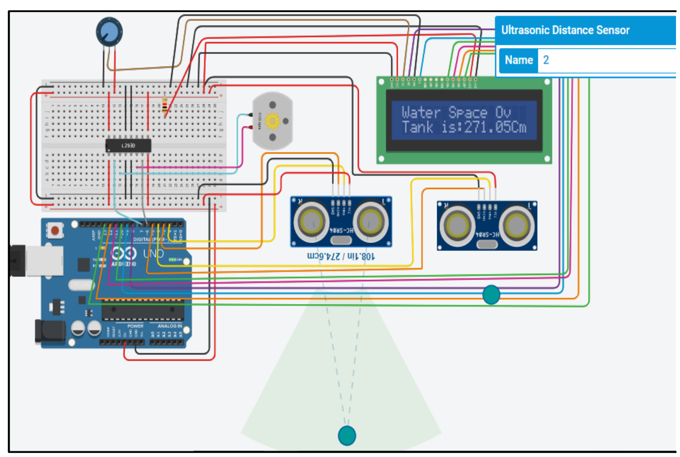

Figure 10. Water level in overhead tank low

Case 3: Water level in both the overhead and underground tanks are low.

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Underground tank low(>=200cm)

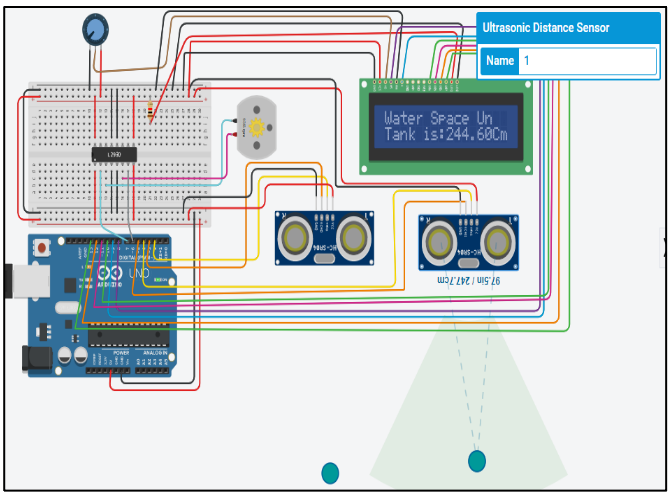

Figure 11. Water level in underground tank low

Motor Status

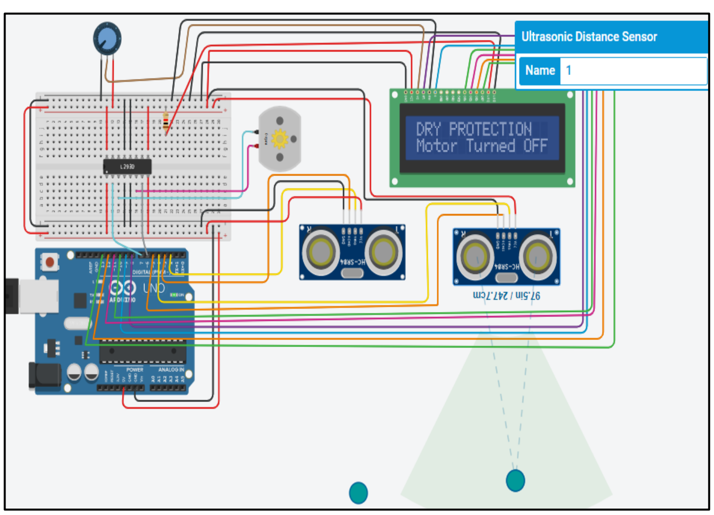

Figure 12. Motor status OFF

VI. CONCLUSION

The rapid population and technological progress underscores the need for responsible use of natural resources, particularly water. The suggested system, along with an assessment of various technological approaches, marks the initial stride toward safeguarding water and promoting its efficient utilization. Employing an Arduino microcontroller, the automated water pump control system emerges as a cost-effective and easily maintainable solution. The experimental model, aligned with the circuit schematic, yielded anticipated results. The pump activates when the overhead tank reaches a specified low level, preventing dry running and extending the pump's lifespan. In addition, the pump deactivates when the tank is full, curbing unnecessary power consumption. The autonomous operation of the microcontroller ensures seamless pump functioning without human intervention. This proposed design

V. SYSTEM PROTOTYPE

Figure 13 below shows the system prototype of the automatic storage tank water level management system.

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