DESIGNING A SMART WATER LEVEL DETECTION SYSTEM FOR AUTOMATED PUMP REGULATION

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Abstract. This research outlines the creation of a microcontroller-based, non-intrusive system for automated water level monitoring using HC-SR04 Ultrasonic sensors and an ATMEGA328P microcontroller. This system employs sound wave reflection to measure water depth in tanks by calculating the Time of Flight (TOF) of ultrasonic waves. The data processed by the microcontroller is displayed on an LCD and controls the water pump via a relay-based output interface. The design is proven reliable through experiments and is versatile enough to monitor other fluids like diesel and hazardous chemicals.

Keywords: Automatic Pump Control, HC-SR04 Ultrasonic Sensors ,Liquid Crystal Display (LCD), Microcontroller-based Water Level Monitoring, Sound Wave Reflection Technology, Non-intrusive Fluid Management, Time of Flight (TOF) Analysis, ATMEGA328P Microcontroller, Relay Output Interface Circuits, Fluid Volume and Level Monitoring

NASOSNI AVTOMATIK BOSHQARISH UCHUN SUV SATHINI ANIQLASHNING AQLLI TIZIMINI ISHLAB CHIQISH

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Annotatsiya.Ushbu tadqiqotda HC-SR04 ultratovushli datchiklar va ATMEGA328P mikrokontrolleridan foydalangan holda avtomatlashtirilgan suv darajasini kuzatish uchun mikroprocessor asosidagi, no-intruziv tizim yaratish bayon etilgan. Ushbu tizim ultratovush to‘lqinlarining qaytishi asosida tanklardagi suv chuqurligini o‘lchash uchun ulatovush to‘lqinlari uchish vaqtini (TOF) hisoblaydi. Mikrokontroller tomonidan ishlov berilgan ma’lumotlar LCD ekranda ko‘rsatiladi va relay asosidagi chiqish interfeysi orqali suv nasosini boshqaradi. Dizayn eksperimentlar orqali ishonchli ekanligi isbotlangan va boshqa suyuqliklarni, masalan, dizel va xavfli kimyoviy moddalarning monitoringini amalga oshirish uchun ham mos ekanligi ko‘rsatilgan.

Kalit so‘zlar: Avtomatik nasos nazorati, HC-SR04 ultratovush datchiklari, Suyuq kristalli displey (LCD), Mikrokontroller asosida suv darajasini kuzatish, Ultratovush to‘lqinlarining qaytishi texnologiyasi, No-intruziv suyuqlik boshqaruvi, Ulatovush to‘lqinlari uchish vaqtini (TOF) tahlili, ATMEGA328P

mikrokontroller, Relay chiqish interfeysi davrlari, Suyuqlik hajmi va darajasini kuzatish.

Introduction

Water is an indispensable resource for all forms of life. It originates from several principal natural sources, including rainfall, springs, rivers, and subterranean aquifers. Additional sources such as boreholes and fountains are derived from these primary natural reserves. Water is crucial across various sectors—agricultural, transportation, fishing, and industrial—along with its usage in domestic and recreational activities[1]. To facilitate these applications, water is often pumped from its natural sources into storage units like overhead and underground tanks. This pumping process, however, consumes significant amounts of electricity, necessitating rigorous monitoring to prevent the wasteful expenditure of both energy and water. In many industrial and domestic settings, considerable volumes of water and electricity are squandered, particularly during storage. A common issue in both homes and industries is the late notification of tanks reaching capacity, often only recognized when overflow occurs, which leads to substantial water loss and electrical waste. Addressing this issue is critical in optimizing water and power usage in various domestic, industrial, and governmental water pumping systems.

Numerous strategies have been implemented to address the issue of water and energy waste, involving both mechanical means like ball gates and electronic circuitry, which are often intrusive. Many electronic solutions cited in the literature rely on methods such as dielectric capacitive sensing or metal conducting probes that make direct contact with water at specific intervals, as illustrated in Figure 1[2]. Direct contact with water introduces several complications. Firstly, electrical interaction with water facilitates current transfer between metal contacts through the water, leading to its decomposition into other chemical elements via electrolysis, which alters the water's properties and renders it unsuitable for consumption[3]. Secondly, metals in direct contact with water are prone to corrosion, which diminishes the system's efficiency[4]. Thirdly, to achieve higher resolution and precision, a substantial number of probes are required, making the system significantly intrusive and invasive. Consequently, there is a pressing need to develop a non-intrusive, accurate method for monitoring water levels in reservoirs and intelligently controlling water pumps to minimize waste of both water and electricity.

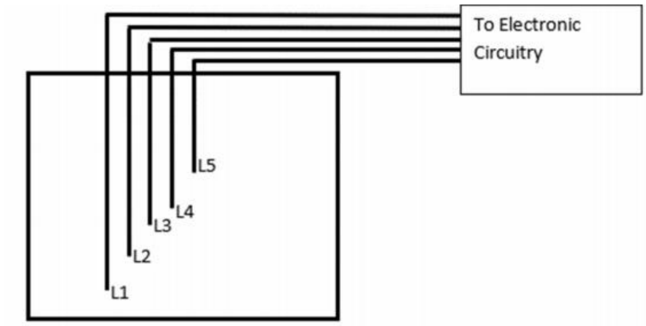

Fig 1. Instrusive water level detection system

Literature review

Various techniques for detecting liquid levels are discussed in the literature, encompassing methods such as the intrusive probe, capacitive sensing, fiber optics, and infrared technologies. A recent study introduced level detection using an ultrasonic sensor[4], although it did not account for system dynamics and inputs, which may lead to instability. Research detailed in [5] employed copper sensors at specific tank levels to measure water level through the electrical conductivity of water and copper contacts, comparing these measurements against a reference voltage. Further research[7] explored a liquid level sensor using ultrasonic lamb wave technology, observing the characteristics of acoustic lamb waves in steel plates, though system non-linearity made it impractical. An innovative approach using Chipless RFID technology was proposed by the author of [8], utilizing high-quality factor resonators on a flexible laminate without needing sensitive materials, with detection limits depending on the distance between the tag and reader antenna. The study in [9] employed a transistor switching method controlled by a 555 timer to regulate output based on water level and dirt content signals, using a relay to activate the pump only under specific conditions. Conversely, an invasive optical fiber technique for detecting liquids below freezing point involved a multiplexed array of point probes, though it was limited by the need to manage large temperature gradients in liquid vapor[10].

Another study developed a water level controller using metal contacts based on water conductivity, requiring full immersion in the water for measurement, which introduces high intrusiveness and unreliability due to potential corrosion from water-metal contact. This system focused only on detecting maximum and minimum levels, ignoring intermediate water levels, which could limit its practical application[10].

The system introduced here offers a highly efficient, non-intrusive, and contactless method for measuring water levels within a reservoir using an ultrasonic transceiver sensor. This ultrasonic sensor simplifies distance measurement from a target object, boasting high accuracy and a fine resolution of 3mm within its operational range. It operates by emitting ultrasonic pulses in the form of a frequency square wave from the transmitter. The echo produced by the target is captured by the receiver module, which then generates a signal waveform. The duration of this waveform is directly proportional to the distance between the sensor and the object, enabling precise and reliable water level detection.

Methodology

The methodology implemented for the hardware development of this system follows a top-down design approach. Initially, the process began with the assembly and testing of the sensors, ensuring their functionality and accuracy. Subsequently, the focus shifted to developing the control system that interprets the sensor data and manages the system operations. This phase was followed by setting up the output interfaces, which involved connecting the various output devices such as displays or actuators. Finally, the last step involved integrating the final output elements that interact directly with the user or other systems. Figure 3.1 below illustrates the block diagram of the top-down design method, providing a visual representation of each developmental stage and their sequential progression.

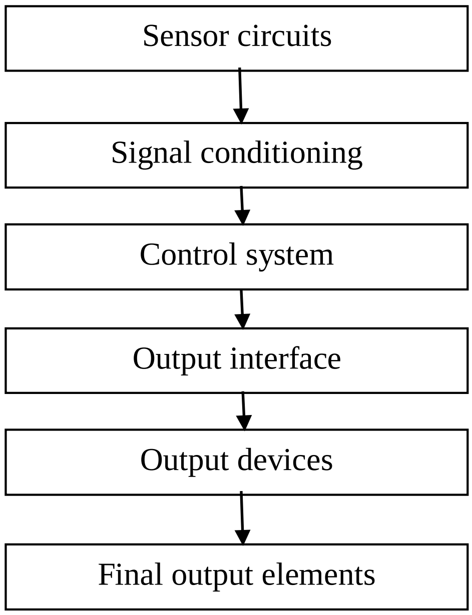

Fig 2. The block diagram for top down design approach

The system utilizes an ultrasonic transceiver module to detect the water level. Signals from this sensor are relayed to the microcontroller for accurate interpretation. This data is then used to calculate the water volume in the reservoir, which is subsequently displayed on the LCD. The core of the control system is the ATMEGA328P microcontroller, along with all necessary components to configure it for optimal functionality. The output interfaces include circuits that convert digital signals from the microcontroller into corresponding analog signals for devices requiring analog inputs, and they provide digital outputs for devices that operate digitally.

The final output components are crucial for executing actions in the real world based on the control system's decisions. In this proposed system, the key final output element consists of relays that switch the water pump ON or OFF as required. Additionally, the software development approach employs pseudo-codes and flowcharts for program design, ensuring that the control system's intended actions are clearly outlined and implemented effectively. This methodical software approach oversees the overall operation of the system, ensuring efficient and reliable functionality.

The successful operation of the hardware relies heavily on the accompanying software that drives it. The sequence of operations designed to resolve a problem or achieve a specific result is often referred to as a control algorithm or pseudo codes. These sequences form the backbone of the control system's actions. A commonly utilized method for illustrating these action sequences is through the use of flowcharts. Alternatively, pseudo coding can be employed, which involves constructing English-like descriptions of the steps the controller is expected to execute. These descriptions serve as the foundational guide for writing the necessary Arduino program codes to manage the system's operations.

A program is essentially a structured sequence of machine-readable instructions, which can be created using either high-level or low-level programming languages. These instructions are compiled and then uploaded to the microcontroller using an Arduino Uno board. Figure 3.2 in the documentation illustrates the control algorithm in the form of pseudo codes, while Figure 3.3 displays the control flowcharts that detail the operational sequence of the system, ensuring a comprehensive understanding of the programming and operational logic integral to the system's functionality.

This sequence forms a loop where the system continually monitors and adjusts the operation of the water pump based on the water level, ensuring efficient management of water resources and power usage. This algorithm can be translated into pseudo code or a programming language like C/C++ for implementation in an Arduino environment, facilitating the control of the hardware setup through the microcontroller.

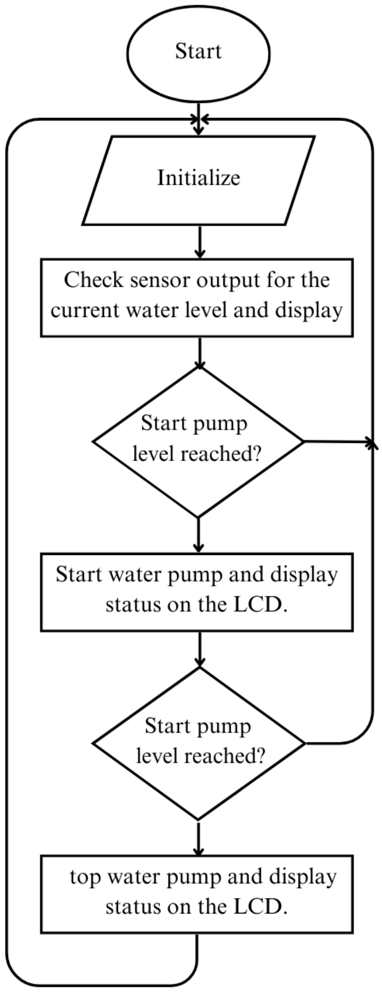

Fig 3. Flow chart

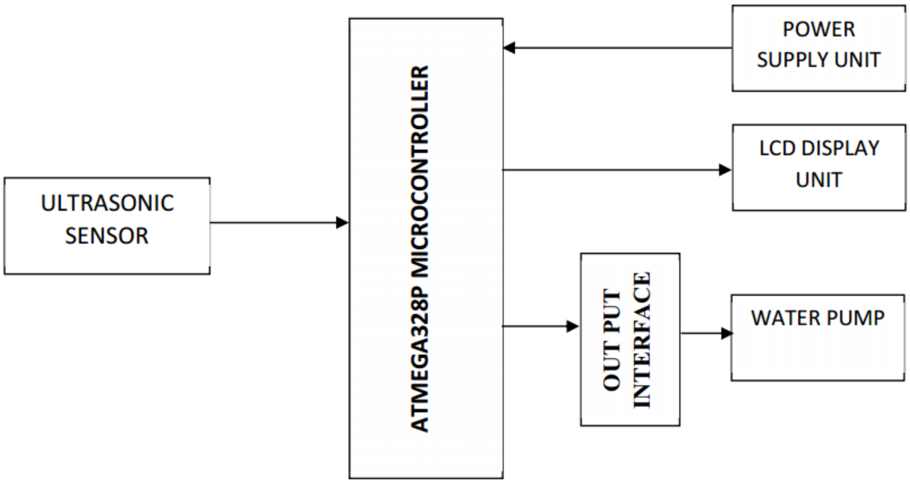

Fig 4. Block Diagram Overview

The block diagram of the proposed system is designed to provide a clear visual overview of the functional components and their interconnections.

Together, these components form an integrated system that effectively monitors and controls the water level in a reservoir, optimizing the use of resources and ensuring operational efficiency.

The intelligent water level monitor designed in this study represents an effective, non-intrusive, and contactless method for assessing water levels in a reservoir using an ultrasonic transceiver sensor. This sensor facilitates convenient measurement of distances from a target, boasting high accuracy within its operational range and offering a fine resolution of 3mm. The process involves the sensor emitting ultrasonic pulses shaped like frequency square waves through its transmitter. These pulses are then reflected back from the target, with the echoes captured by the sensor's receiver module. This receiver generates a signal waveform whose duration is proportional to the distance of the object from the sensor.

The ATMEGA328P microcontroller is integral to this setup, as it interprets the signals received from the receiver and calculates the distance based on these inputs. For this specific application, the HC-SR04 ultrasonic range finder was employed. This device regularly transmits short, high-frequency sonic pulses that travel through the air at sound speed. The ultrasonic waves, like all waves, exhibit the phenomenon of reflection—where a wavefront changes direction at the boundary between two different media, reflecting back to its origin. When these transmitted waves hit an obstacle, such as the water surface in a container, they undergo specular reflection. This reflected wave then bounces back to the sensor receiver, as depicted in Figure 3.5, allowing for precise measurement of the water level. This technology not only ensures accuracy but also avoids any direct contact with the water, maintaining the purity and integrity of the reservoir contents.

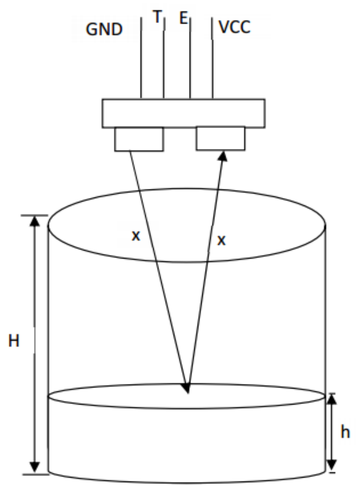

Fig 5. The Setup of the Intelligent water level monitor

The method for determining the water level in a container involves measuring the distance between the sensor and the liquid surface, which reflects the ultrasonic waves emitted by the sensor. As the liquid level decreases, the distance to the sensor increases correspondingly. Crucially, this distance is not measured by the intensity of the sound but by the total travel time of the ultrasonic waves.

To calculate the distance (x) between the sensor and the liquid level, consider the travel time (t) of the waves from the sensor to the liquid surface and back to the sensor. The total travel time, or time of flight, for the ultrasonic burst is represented as 2x. The speed (v) of the sound wave can be expressed by the formula:

$$v = \frac{2x}{t} \quad (1)$$

From this, the distance x can be determined:

$$x = \frac{v \cdot t}{2} \quad (2)$$

Given that the speed of sound in air (v) is approximately 340 m/s, or 34000 cm/s, the formula for instantaneous distance becomes:

$$x = \frac{34000cm/s \cdot t}{2} = 17000cm/s \cdot t \quad (3)$$

Thus, equation (3) allows for the calculation of the distance x, in centimeters, from the sensor to an object or surface based on the wave's time of flight.

In terms of the application to a cylindrical water tank where the height (H) of the tank and the radius (r) are known, the maximum volume (Vmax) the tank can hold is derived from the formula for the volume of a cylinder:

$$V_{max} = \pi r^2 H \quad (4)$$

As the water level changes, the current volume (Vi) of the water can be instantaneously calculated based on the current water level (hi), which varies over time from the bottom (h0) to the maximum height (H):

$$V_i = \pi r^2 h_i \quad (5)$$

This equation (5) serves as a straightforward model to convert the detected water level into volume, facilitating real-time display of this information on an LCD. This setup allows for continuous monitoring and efficient management of water resources within the reservoir, providing critical data in an easily interpretable format for users and automated systems alike.

To ensure the functionality and correctness of the software codes, the programming was initially tested using Proteus ISIS software—a comprehensive electronics simulation tool capable of emulating microcontroller circuits. This step allowed for pre-implementation verification of the program in a controlled environment, identifying and addressing any potential issues. After successful simulation, the program was then executed on the actual hardware. The software performed effectively in both the simulated environment and on the physical hardware, confirming the reliability and accuracy of the programming across different testing platforms. This dual-phase testing approach helped in optimizing the software for real-world application.

The results from the testing of the system's hardware sub-systems are summarized in Table 3.0. The tests conducted and the corresponding results are detailed as follows, ensuring a comprehensive understanding of the system’s performance and reliability:

S/N	Test plan	Expected test result	Actual test result
1	Continuity test on the Vero board	There should be no bridging.	There was no bridging.
2	Power supply voltage 5Vdc at 1A	5.00V at 1A	4.95V at 1A
3	Smoke Sensor Test	Voltage output when smoke is detected.	There was voltage output when smoke was detected
4	Output relay response	Reliable	Reliable
5	Feedback speed	Very Fast	Fairly fast
6	Controller Output port	High= 5V at 10mA	High=4.95V at 10mA

The results indicate that the system performed well across various tests:

- Continuity Test on the Vero Board: The absence of any bridging confirmed the proper assembly and connection integrity of the circuit on the Vero board.

- Power Supply Voltage: The slight variance from 5.00V to 4.95V is within an acceptable range, indicating stable power delivery.

- Smoke Sensor Test: The sensor correctly responded to the presence of smoke, validating its functional reliability in detecting environmental changes.

- Output Relay Response: The relay consistently performed as expected, showing its reliability in real-world applications.

- Feedback Speed: Although the feedback speed was slightly slower than expected ("Fairly fast" versus "Very Fast"), it remained effective for the system's needs.

- Controller Output Port: The minor variation in voltage at the controller output port is again within acceptable limits, ensuring proper functioning of connected devices.

Overall, the test results support the system's readiness for practical deployment, with minor deviations that do not impact the fundamental operation and safety.

The additional tests conducted on the hardware subsystem encompassed a series of meticulous checks to validate the integrity and functionality of the entire system. Here’s a breakdown of each step undertaken and the outcomes observed:

(a) Continuity Test:

- Purpose: To confirm the absence of short circuits and open circuits in the system.

- Procedure: After wiring the system, a continuity test was conducted using a multimeter.

- Outcome: The test confirmed that all connections were correctly made without any shorts or open circuits, ensuring the electrical safety and functional reliability of the hardware.

(b) Power Supply Verification:

- Purpose: To verify that the necessary voltage levels were supplied accurately at different points of the hardware without the integrated circuits (ICs) installed.

- Procedure: The system was powered up, and voltage levels were measured at various critical points to ensure proper distribution and availability.

- Outcome: The test confirmed that all required voltage levels were correctly supplied, indicating that the power supply subsystem was functioning as designed.

(c) Output Interface Testing:

- Purpose: To check the output interface's functionality when supplied with the required voltage level.

- Procedure: The output interface was manually supplied with its requisite voltage level.

- Outcome: The interface operated perfectly under these conditions, confirming its capability to handle operational voltages and perform its intended functions.

(d) Control System Validation:

- Purpose: To test the control unit's functionality and its interaction with other system components.

- Procedure: A test program was run using the control unit, involving various operations that required interactions with different units of the system.

- Outcome: All units responded perfectly to the control commands during individual tests, confirming that the control system was properly integrated and functional.

Final System Integration and Testing:

- Purpose: To ensure that all subsystems worked harmoniously when assembled together.

- Procedure: After successful individual tests, all components were integrated, and the whole system was powered up for a comprehensive operational test.

- Outcome: The system functioned flawlessly in this fully assembled state, demonstrating the successful integration of all hardware components and the overall reliability of the system.

These tests are critical for ensuring that each component of the hardware subsystem not only performs its individual function correctly but also interacts appropriately with other components in the system. The successful outcomes of these tests indicate a high degree of readiness for practical deployment and operational reliability.

Conclusion

The integration of the intelligent water level monitor and automatic pump control system into existing manually operated water pumping systems across domestic, industrial, and official settings is imperative. This addition is not just a step towards modernization but a necessary evolution for enhancing system efficiency and sustainability. By automating the water level monitoring and pump operation, substantial savings can be achieved in terms of water, electricity, and financial expenditures.

This system not only conserves resources but also significantly improves the operational efficiency of water supply systems in homes, offices, and industrial facilities. Automated control reduces the risk of human error and the inefficiency of manual monitoring, ensuring that water pumps operate only when necessary. This tailored operation prevents the pumps from running continuously, thereby minimizing wear and tear and extending the lifespan of the equipment.

Moreover, the intelligent system contributes to environmental sustainability by reducing unnecessary water and energy usage, aligning with global efforts to promote more eco-friendly technologies. In summary, the adoption of this intelligent water level monitor and automatic pump control system represents a critical advancement in water management technology, promising enhanced performance, cost-effectiveness, and reliability for various applications.

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