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An Embedded Smart System for Water Monitoring and Leakage Detection of Storage Tanks

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Abstract

Many people worldwide are suffering from a shortage and lack of water quantity. As a result, it draws a lot of interest from scientists who are trying to tackle this issue. One of the proposed solutions is to monitor the water quantity by monitoring the water inside the storage tanks and reservoirs. This paper purposes an embedded smart tank system that can communicate with the user and control the pump remotely. Moreover, this smart tank is provided with a leakage detection sub-system that warns the user about wasted water in case of leakage. This tank is designed to save water by closing the pump in case of finding any leakage or the tank being filled up. The suggested system can adapt to the volume of the tank, making it a standalone embedded system that can be utilized for many types of tanks. This flexibility makes the system particularly adaptable. The proposed system consists of a microcontroller, ultrasonic sensor, flowmeters, a GSM module, a water pump, a solenoid valve, and two flow meter sensors. The ultrasonic sensor is used for detecting the water level and flowmeters are used to determine the inward and outward flow rates. The GSM module is designed to connect the user and the tank. It also receives commanding SMS from the user to manually control the system as an interrupt. The testing of the designed prototype clarifies that the system operates well, and the process is done properly. The sensitivity analysis test yielded 1.65%, 2.2%, and 4.15% deviation from the simulation values for the input flowmeter sensor, output flowmeter sensor, and ultrasonic sensor, respectively.

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Keywords: Water monitoring, Leakage detection, GSM, Smart tanks, Embedded systems, Ultrasonic sensors, Flowmeters.

1. INTRODUCTION

Fresh water supply is vital for all aspects of life. Hence, it is SDG6 of the UN2030 Agenda to ensure universal availability and sustainable management of water [1]. Regardless, there are still about 2.2 billion people worldwide who have no access to safe drinking water [2]. Egypt's water security situation is not better: it was reported in 2020 that almost 25% of Egyptian villages and 4% of cities have no connection to water pipelines. So that citizens have to dig and build the pumps themselves [3]. Besides, the increasing Egyptian population density and disintegrating water pipe networks caused water loss of up to 27.9% in FY2020-21, equivalent to 3,069 billion cubic meters [4]. This amount, if saved, can serve fresh potable water to 43 million more inhabitants [5]. This research aims to mitigate these losses and effectively automate water monitoring and control in a water supply network.

Water storage facilities are elemental to any sizable supply system as shown in Fig. (1). They can be found at the distribution system's source (the treatment plant), near the end of the transport line, or any other advantageous site, usually at higher elevations. These reservoirs (or tanks) ensure constant water production under variable supply and supply firefighting and emergencies. The tank capacity covers 20-50% of the maximum daily consumption of a certain area; higher percentages can be obtained with additional safety requirements. Storage tanks may be constructed as underground, ground-level, or elevated surfaces (water towers). The prototype is addressed to the ground-level model, shown in Fig. (2), yet the solution applies to all sorts of water tanks [6]. The water tank industry is affordable, scalable, and profitable: the size of the world market for water tanks was estimated at $3,686 million in 2019 and is anticipated to increase to $4,736 million by 2027 [7].

Embedded systems are a pivotal technology for process automation. It comprises microprocessor-based hardware and software designed to perform a dedicated function. Tank fluid monitoring solutions have already

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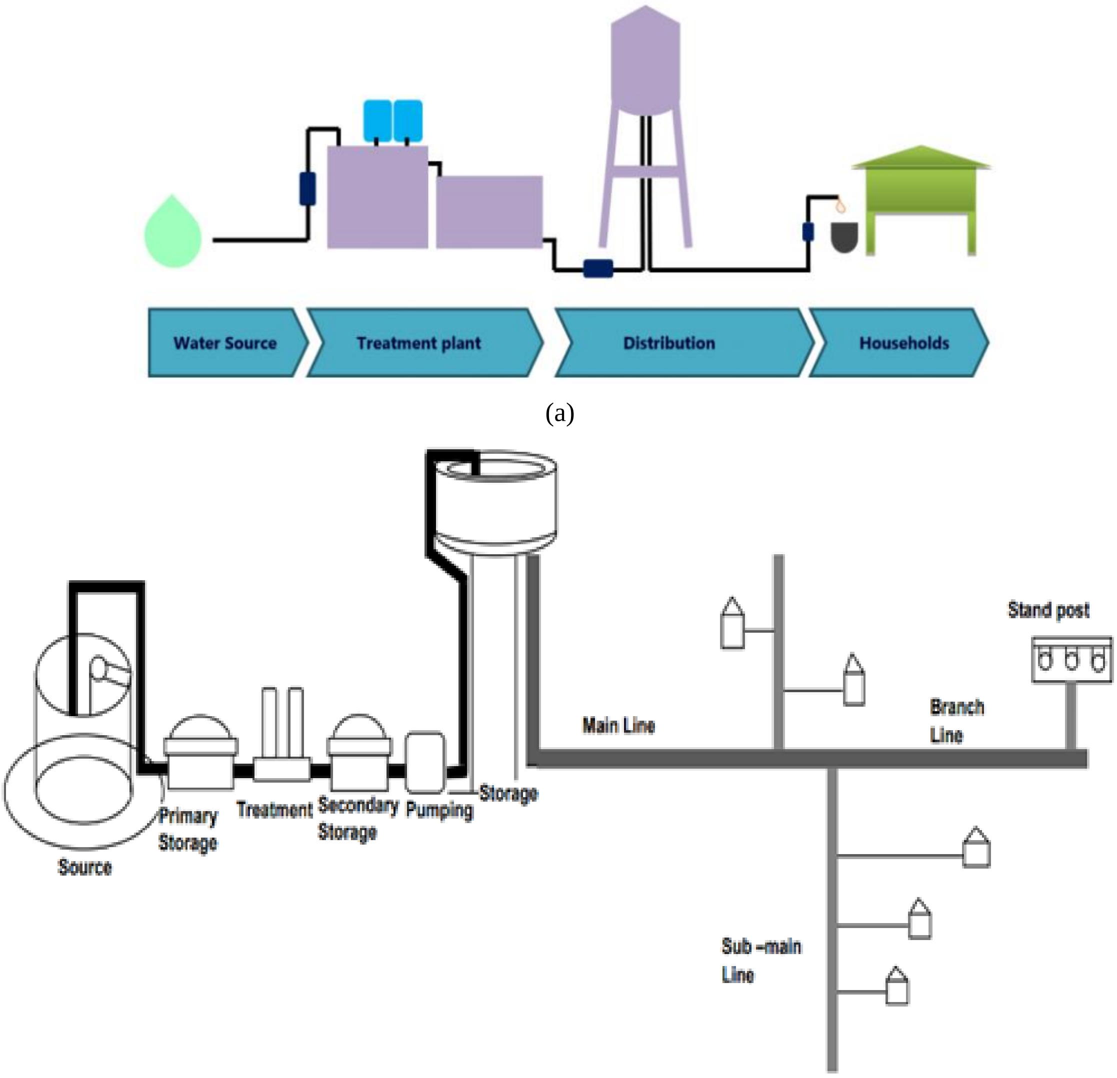
implemented embedded standalone technology. Prior solutions used microcontrollers to receive readings from different sensors (ultrasonic, pressure, temperature, etc.) and send control signals to the actuators (pumps, valves, motors, etc.) and another wireless signal to the user interface (SMS, mobile application, web application).



(b)

Fig. 1 (a) Water storage facilities. (b) A freshwater supply network for households [3].

Fig. 2 Ground-level municipal potable water storage tanks [7].

The microcontrollers may communicate wired or wirelessly depending on the elevation of the tank from the pumping system. However, such systems operate in a single mode and do not *consider* interruptible water supply or tank leakage cases. Additionally, they require professional supervision during installation.

Unlike the existing systems, the proposed one continuously measures the water level and flow rate and controls the pumps in three modes: normal operation, outage, and leakage. Outage and leakage modes interrupt the normal operation mode to indicate cases of outage from the water source and leakage in the tank, respectively. The user is updated about the water level, pump status, and switching between modes at all times. The user is also provided control by the mobile phone to override the automatic operation as needed. The practical constraints considered in the system design are cost-effectiveness, measurement accuracy, and real-time operation.

The rest of the paper is organized as follows. Section 2 is dedicated to a literature review of the recently published work. Section 3 discusses the methodology adopted in the system construction and operation, sensors, relay module, and interface. Section 4 discusses the obtained results and discussions. Finally, Section 5, concludes the paper and investigates possible future work improvements.

2. LITERATURE REVIEW

Daadoo and Daraghmi [8] proposed a paper concerning overhead tanks' water level monitoring, auto refill, and water leakage detection at urban buildings. The hardware consists of a microcontroller, distance gauge, ultrasonic sensor, GSM module for wireless communication with the system, and a solenoid valve. The water leak detection system is based on fixing multiple water sensors, each for the main supply pipe. If leakage occurs, the sensor-corresponding pipe is shut off through the solenoid valve. In their system, a mobile application was developed for data visualization, notifications, and refilling processes.

Kumar et al. [9] introduced multiple connected tanks' water level monitoring with an auto refill and leakage detection by developing an IoT standalone with a user interrupts micro-grid system. The microcontroller received water level information from an ultrasonic sensor. For data visualization, a mobile application was developed along with ThingSpeak IoT private cloud services that were fed by a GSM shield. In contrast, the user can also command the pump via the GSM Module. The system detects the water level, and if beyond the threshold, it initiates the auto-refill process. Bernoulli's principle-based algorithm was developed to detect water leakage and the corresponding area. However, the hardware functionality and cost-effectiveness are arguable.

Dissanayake and Wickramarachchi [10] introduced a tank water level monitoring and auto refill system. The main microcontroller is interfaced with an ultrasonic sensor for the detection of the water level inside the tank. Wireless communication is established with a local Wi-Fi router subscribed to the microcontroller. The data is stored with the aid of Google Firebase and visualized in the Fusion-Chart package. The water volume computation equation developed is a handful in self-calibration. The equation can be utilized for circular and other tanks structure with some modification. The water leakage problem is not considered in their system.

Natividad and Palaoag [11] aimed for a low-cost and efficient system based on IoT to improve communities' water distribution. The system focuses on water level detection, tank auto-refill, pipe leakage, and burst prevention. It consists of a control room and a client site device. On the client side, the main controller is Arduino Uno connected with a GSM SIM800 modem for data reporting [12]. An ultrasonic sensor is used for water level measurement, and an analog pressure sensor is fixed to each pipe for burst and leakage prevention. Whenever a pipe pressure is above the threshold, the flow is diverted to other pipes.

Nikeeta et al. [13] developed an IoT system to reduce wasting water in residential buildings. The system addressed tank water monitoring, auto refill, and leakage control. Metallic layers of water sensors were used to gauge the water level and data was sent to a cloud server. Two flow meters were installed on the pipe to measure the difference between the flow readings, so the system alerts the end user if there is a significant difference (a leakage). The system cost is relatively high. The microcontroller used was Raspberry Pi which is costly and replaceable by NodeMCU. Water sensors resolution is not sufficient, subject to corrosion, and only discrete levels can be measured.

Asif et al. [14] proposed an IoT-based solution for household water network monitoring. The system focuses on gauging four parameters: water level, water leakage, tank auto-refill, and water turbidity. An ultrasonic sensor is implemented to measure the water level. To detect the leakage, a water flowmeter sensor was installed at each water distribution branch controlled by a NodeMCU. Water turbidity was monitored by a system of LED and LDR. Water leakage and consumption rely on machine learning and sensor data fusion. An IoT platform is used (ThingSpeak) for end-user access.

Adjardjah et al. [15] proposed dual-mode water level monitoring and tank refill. It is based on a microcontroller interfaced with an ultrasonic sensor for gauging water levels, a GSM module for wireless communication purposes, and an LCD screen for data visualization. In the automatic mode, the system is responsible for measuring the level, controlling the pump for an auto-refill, and notifications to the user's phone. In the manual mode, the user takes control of the system by sending an SMS to the GSM module that then transfers the data to the microcontroller. The system showed great results, but water leakage is not considered.

Pawaskar et al. [16] A GSM, a website, and a mobile application-based hybrid solution are introduced for water level monitoring in tanks. The main microcontroller is Atmel89C51, an 8-bit MCU. The water level is measured at three discrete levels by fixing three magnetic float sensors on different levels in the tank. A GSM modem supplemented with the mobile application is used in data transmission and visualization and water pump control. Although magnetic float sensors are good anti-corrosion and biofilm devices, they provide poor resolution.

Gupta et al. [17] proposed a water monitoring and consumption control IoT-based system in residential areas. The area is divided into blocks with each occupied by a NodeMCU controller and an ultrasonic sensor to gauge the water level in each tank. The NodeMCU is used for sharing data with the SQL server that consists of several databases for data visualization and analysis. The data is not processed in the microcontroller but in the server. The system is robust, although it lacks water leakage and outage detection.

Charles et al. [18] proposed a system for monitoring water levels in large area tanks based on IoT technology supplemented with LABVIEW software. The system consists of a control center and a client site. On the client site, the used controller is a NodeMCU that is connected to an ultrasonic sensor to gauge the water level and provide an auto-refill option. After fetching the data, the NodeMCU transmits it to the Google Cloud server with the help of the Wi-Fi module in the controller. On the control center, a (NI DAQ (USB2009)) National instrument data acquisition card is programmed using LABVIEW. The NI DAQ is used to control the solenoid valves and water pumps. The main problem is hardware redundancy as the valves and pumps could be controlled using the NodeMCU.

3. METHODOLOGY

3.1. System Construction

Figure (3) illustrates the proposed system block diagram. It is constructed with Arduino UNO as the main microcontroller taking its power from a power module. This microcontroller receives input data from ultrasonic sensors and flowmeter sensors. The ultrasonic sensor is mounted inside the tank on the top to determine the water level. A flowmeter is put through the tank input pipe and the other one is put through the tank output pipe. Both are put after the pumps to accurately detect the water flow inside and outside the tank. Based on the received data from sensors, the Arduino generates output signals to either the GSM module or the relays, or both. If the process is normal, the Arduino generates nothing. The GSM module is connected to the Arduino through a level shifter to change the value of logic 1 from 5V to 3.3V and vice versa. Moreover, it is also used to send some instructions from the user to the Arduino. The circuits of pumps are connected with relays to control the operation of pumps.

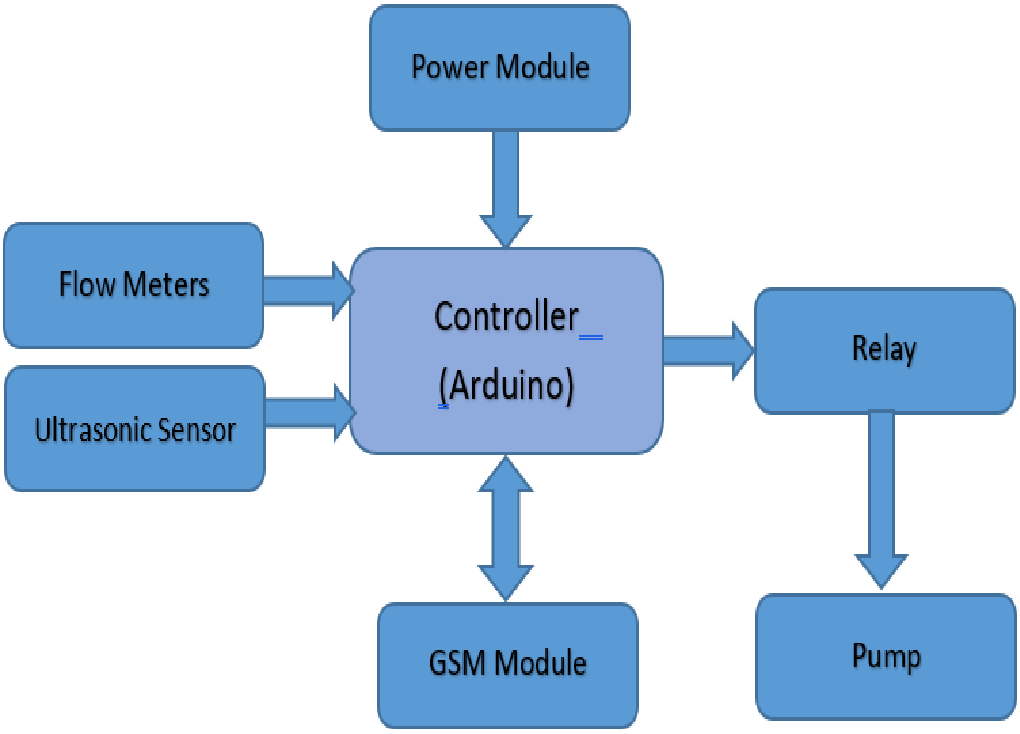


Fig. 3 System block diagram.

3.2. System Operation

The system operation is categorized into three main states or modes: Normal, Leakage, and Outage. Figure (4) illustrates the flowchart of the operation process. Software is developed and adopted auto-calibration to calculate the area of the tank and use it during the operation. The detection of the mode of operation is based on the following equation

$$\boldsymbol{V_i = V_o + V_s} \qquad (1)$$

Where $\boldsymbol{V_i}$ represents the input volume to the tank that is calculated by the flow rate each time through the input pipe, $\boldsymbol{V_o}$ is the output volume to the tank which is calculated by the flow rate in a given time through the output pipe. In addition, $\boldsymbol{V_s}$ is the stored volume inside the tank which is calculated by the change in water level using the constant cross-sectional area of the tank The process is started by initializing two important threshold values used throughout the entire algorithm. These are ε1 which determines the outage state and the other is ε2 for determining the leakage state. ε1 is determined according to the specifications of the water provider and pump. While ε2 is a numerical value determined by the accuracy of used sensors.

After that, the system takes its inputs from the sensors' readings. If the value of the input flowmeter is less than the first threshold (ε1), the system will go to the outage mode and consequently will turn off the input pump and send a message to alert the user about the water outage. While the value of the input flowmeter is above the threshold, the program goes to the next step and calculates the input volume to the tank which is calculated by the flow rate in a given time through the input pipe and the output volume to the tank which is calculated by the flow rate in a given time through the output pipe. The stored volume inside the tank is calculated by the change in water level using the constant cross-sectional area of the tank. Then, the difference between the input volume with the summation of output and stored volumes is calculated and checked using the second threshold (ε2). If the difference is greater than ε2, the system will go to the leakage state and consequently will turn off the input pump and send a message to alert the user of water leakage. However, if the difference is less than the threshold, the system continues its normal operation and returns to take the sensors' readings again. Figure (5) illustrates the prototype components and their respective models.

3.3. Relay Module

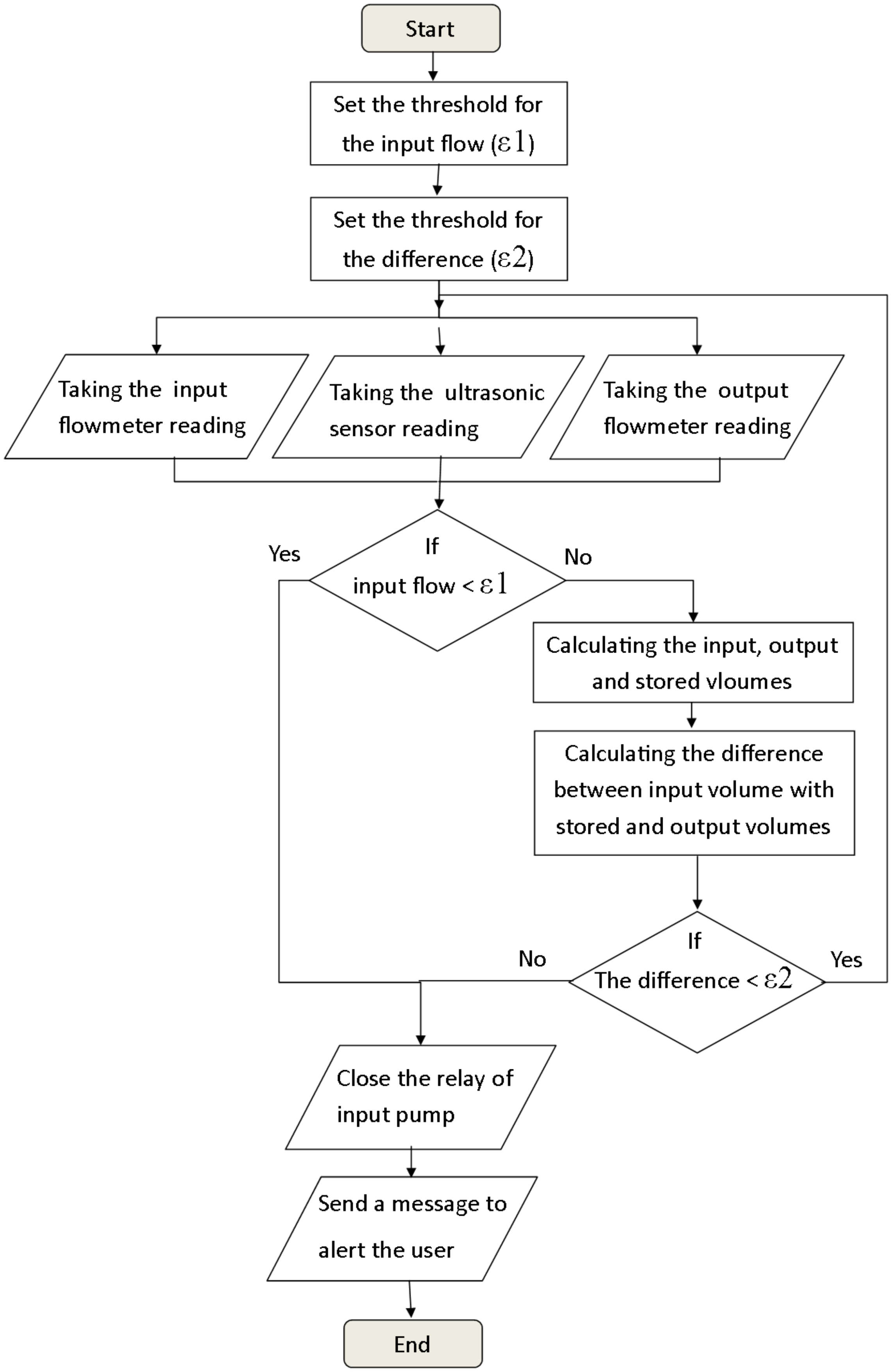
An electromechanical switch based on the principle of electromagnetic induction. An electrical signal induces a magnetic field around an electromagnet made from copper windings around an iron core. Then, the electromagnet attracts the relay contacts to open/close the circuit. For a relay module, to open or close contact switches, DC is used to energize the relay coil. A coil and two contacts, such as normally open (NO) and normally closed (NC), are often found in a single channel 5V relay module (NC).

3.4. Sensors

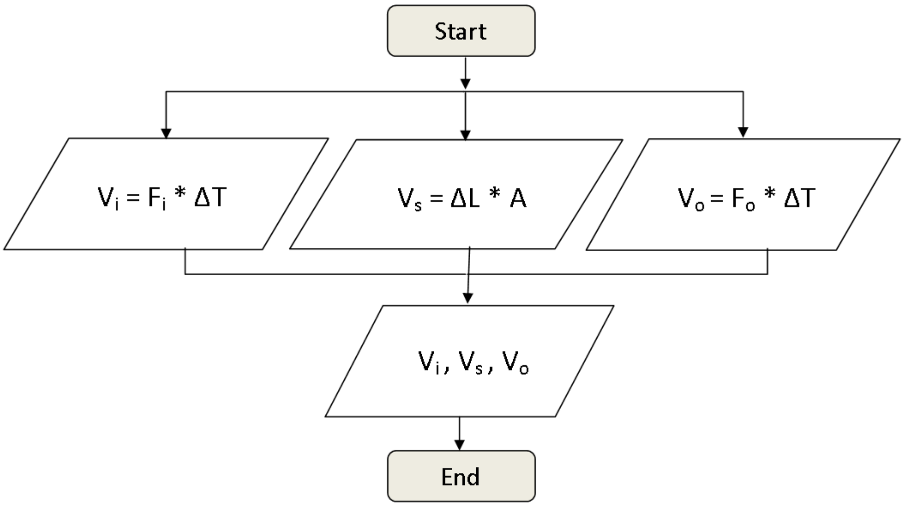
The proposed system operates relying on two sensors: one for gauging the water level in a tank and the other to measure the water flow on both tank inlet and outlet ports. To measure the water level, an (HC-SR04) ultrasonic distance sensor is used. The module consists of three parts: an ultrasound transmitter, an ultrasound receiver, and a control circuit. It has four pins: power (V_{CC}) and ground (GND) for powering the module, trigger (Trig), and receiver (Echo) responsible for transmitting the ultrasound waves and receiving them, respectively. This non-contact measurement module measures effectively in a range from 2 cm to 4 meters with an accuracy of up to 3 mm, an operating frequency of 40 kHz, and a measuring angle of 15 degrees. The measuring process starts by setting the trig pin to logic level 1 for 10 microseconds leading to transmit a 40 kHz eight pulses ultrasonic burst. The eight pulses are dedicated to allowing the receiver to differentiate the transmitted signals from the ambient noise in the same band. After a successful transmission, the echo pin is pulled high to sense the echo signal. After 38 milliseconds with no reflected pulses, the echo pin is set low indicating there is no water in the tank. Otherwise, the echo pin is set low after reception generating 150 microseconds to 25 milliseconds pulse according to the waiting time interval. Finally, the pulse is fed to the $D = S \times T$ equation to calculate the water level, setting the speed of sound as 343 m/s [19-20].

Regarding leakage detection (YF-S401) water flow meter is implemented. The function of the sensor is to measure the rate of water flowing through it. The sensor consists of three parts: a turbine wheel with magnets, a hall effect sensor, and a plastic body. It has three pins: power (VCC) and ground (GND) for powering the module and an analog signal output (OUT). It has the capability of measuring the flow ranging from 0.3 to 6 L/min with a maximum water pressure of 0.8 MPa and an accuracy of ±5%. The best performance is achieved when the unit is vertically installed or with no more than a 5-degree tilt. The measuring process starts when the water flows into the inlet driving the wheel to rotate. The sensor is based on the hall effect which implies that measuring a voltage perpendicular to a current path that flows in a conductor introduced to a perpendicular magnetic field is applied.

When the wheel with magnets rotates it triggers the hall effect sensor that outputs square waves. By counting the number of pulses of each rotation the flow can be measured.



(a)



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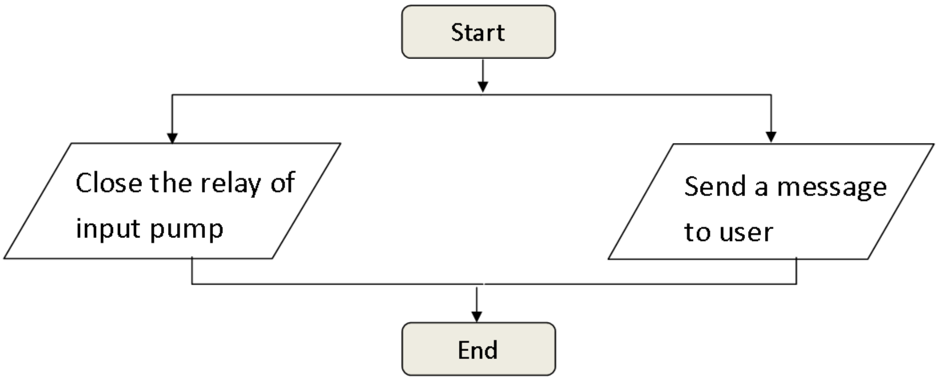

(c)

Fig. 4 (a) System Flowchart, (b) Normal Mode Flowchart, and (c) Outage and Leakage Modes Flowchart.

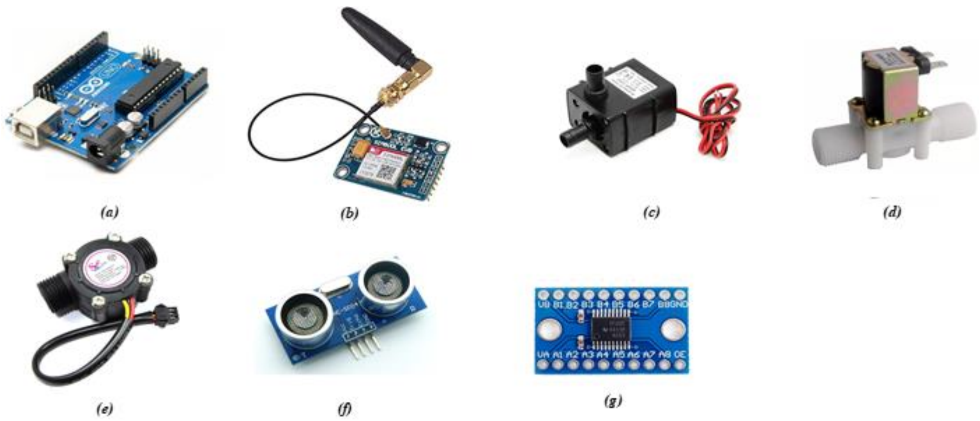

Fig. 5 Prototype components and their respective models (a) Arduino Uno R3 Microcontroller, (b) SIM800L V2 5V Wireless GSM GPRS Module, (c) AD20P-1230C Ultra-Quiet DC 12V 3M 240L/H Brushless Submersible Water Pump, (d) 12V Electric Solenoid Valve 90 Magnetic N/C Water Air Inlet Flow Switch, (e) YF-S201 Water Flow Measurement Sensor with 1-30 Liter/min Flow Rate, (f) HC-SR04 Ultrasonic Sensor, (g) 3.3V to 5V 4 Channels IIC I2C Logic Level Converter Bi-Directional Shifter Module.

3.5. User Interface

Many options can provide good user interfaces experiences such as Wi-Fi modules, XBee modules, LoRa modules, GSM modules, and many other options. Each option has advantages and disadvantages, but while choosing the solution that will be implemented the coverage and electricity were considered. Some modules require Wi-Fi implicitly or explicitly to operate. Wi-Fi has some drawbacks. A Wi-Fi router is exposed to misconfiguration problems in many settings such as transmitting channel, frequency, interference in a router crowded places, DNS servers, and power cut-off problems. Any of these disadvantages can affect the system performance in leakage critical mood. Another perspective is that the user may be in a situation in which there is no available Wi-Fi access for any reason.

The choice is to implement a GSM module that can be used for both IoT and cellular communication. The GSM module allows the microcontroller to send and receive both SMS and calls. The microcontroller communicates with the module with attention (AT) commands that are used to control (MODEMs) modulator-demodulator. The GSM module requires an active SIM card to subscribe to the network. It behaves like a phone by connecting to the highest power (BTS) Base Transceiver Station. In the system the GSM module is used to send notifications to the user including the tank is empty, leakage detected, the tank is filling, and no water coming from the source vis SMS. The system also can receive commands from the user as interrupts through SMS: Start or stop the pump, measure water level, and measure the flow.

4. PROPOSED SYSTEM ASSESSMENT

The following criteria need to be assessed to ensure the system's feasibility and efficiency. Each system component is priced commercially for the 2023 online market in Egypt. They were all available at online commercial stores at the given prices. Table 1 enlists the prototype components whether for the hydraulic or embedded system. The overall embedded prototype cost needs to be calculated and anticipated for the scaled-up community tanks. The cost of a rural village storage tank depends on its size. The ratio between the hydraulic prototype and the embedded prototype gives a rough estimation of the cost of a sizable storage tank embedded system.

TABLE 1 COMPONENTS COSTS.

Subsystem	Component	Price (USD)
Embedded subsystem	Arduino Uno R3	13.78
	HC-SR04 Ultrasonic Sensor	1.65
	SIM800L V2.0 GSM Module	12.86
	Water Vacuum Pump	8.46
	Water Flow Sensor (YF-S201)	4.04
	Solenoid valve	8.27
	Total of Embedded subsystem prototype	48.71
Hydraulic subsystem	Total of hydraulic tank prototype	$21,600

The system is powered by two trials of 12V DC and 5V DC which makes the power consumption nihilistic. Additionally, the sensors and actuators must be power-compatible so as not to overpower or burn in scaled-up, larger tanks. Sensitivity analysis has been carried out to measure the change in desired output to the change in the input of the system. In the case of sensors, sensitivity analysis is therefore a plotting of the value of the sensors concerning time (actual curve) and comparing it to the same plot from the simulation (theoretical curve). If the maximum deviation between a sensor's actual and theoretical curves was greater than 5%, the sensors do not measure accurately. The sensitivity analysis test yielded 1.65%, 2.2%, and 4.15% deviation from the simulation values for the input flowmeter sensor, output flowmeter sensor, and ultrasonic sensor, respectively.

The specific software tool deployed for the simulation and the implementation of the proposed system is Proteus. It is a simulation and design tool developed by lab center electronics [21]-[22]. Proteus is a very useful tool as it ensures that the circuit design and the code is working properly before beginning physical implementation. It has an extensive collection of libraries; however, it doesn't come with an inbuilt Arduino library, so it is installed first using the steps outlined in [23]. Single pole single throw switch was employed to represent float switches sensing low, medium, and full water levels. Algorithms that explain the sequence of operations and steps for the design were written thus enabling the diagrammatical representation of the flow of process through the flowchart shown in Fig. 4, from which codes were written and compiled on Arduino IDE. All variables were declared to represent inputs and outputs for the system.

The program code was written for the system and its operation. Investigation of the proposed system simulation shows that: it acts as a closed-feedback control system. Since the actual water flow is turbulent, the flowmeter sensor readings are averaged for five readings taken every second, for a five-second delay. Given the relay status, the ultrasonic sensor readings derive the input and output flow. So, the ultrasonic sensor can replace either of the flowmeter sensors and vice versa. A similar method introduced in [24] has been adopted for this purpose system as shown in Figure 6. In this figure, the microcontroller is the heart of this system, as all the control signals pass through and are processed. The LCD was interfaced with the microcontroller to display the system status as it operates. The microcontroller then processes the data received and uses it to control the tank and the pump based on the written flow or control algorithm described in Figure 4.

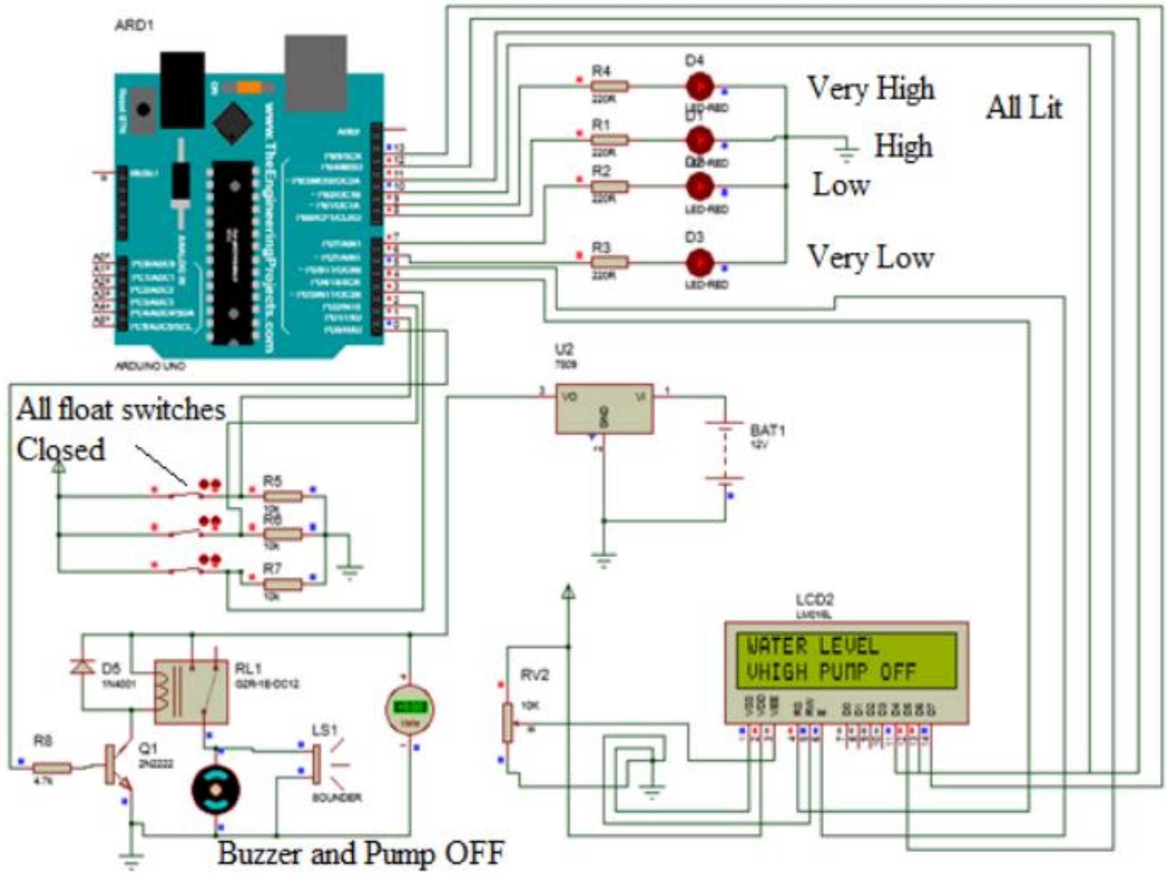

Fig. 6 Simulation in proteus environment.

5. RESULTS AND DISCUSSION

The proposed system consists of a microcontroller, a GSM module, an ultrasonic sensor, a water pump, a solenoid valve, and two flow meter sensors. The used controller is Arduino Uno R3 which uses ATmega328P, an 8-bit microcontroller. The water level in the tank is measured via the ultrasonic sensor that sends a burst of ultrasound pulses and receives them to calculate the distance. A pump is used to pull the water from the reservoir up to the tank and a solenoid valve is used to control the water flowing out of the tank for usage. Two flowmeters are used, one on the inlet and the other on the outlet both after the pumps. The inlet sensor is used for the self-calibration mode that adapts the systems to work with any tank geometry. This is done with the help of the measured flow rate and time calculated to fill the tank using the ultrasonic and the controller.

The outlet flow sensor is used in leakage detection mode. If the ultrasonic detects a lowering of the water level with no flow in the outlet sensor indicates a leakage situation. A GSM module is used to send the states of the tank and urgent notification for the subscribed user in the form of SMS including leakage detected, the water level is under the threshold, and the tank is empty. The GSM module also receives commanding SMS from the user to manually control the system as an interrupt.

After constructing the proposed prototype, the system is tested, based on the chosen design requirements, and results are collected. The obtained results illustrated that the system works well in addition to being applicable in real life. The system only uses a microcontroller, GSM module, and dedicated sensors. All these components use a small amount of power. The microcontroller unit is the most consuming part; however, it only uses a 5V DC. Therefore, the overall system has low power consumption, and this again makes the system applicable. The practical measurements of the sensors are compared to simulated ones to determine the accuracy of the sensors. Table (2) illustrates this check.

TABLE 2 MEASURING THE ACCURACY OF THE SENSORS.

Sensors	Measured reading	Simulated reading	Error (%)
Input Flowmeter	3.46	3.39	2.06
Output Flowmeter	4.52	4.48	1.18
Ultrasonic	0.43	0.49	-1.77

Investigation of the proposed system flowchart illustrated in Figure (4) shows that: it acts as a closed-feedback control system. Since the actual water flow is turbulent (variable), the flowmeter sensor readings are averaged for five readings taken every second, for a total delay of five seconds. Given the relay status, the ultrasonic sensor readings derive the input and output flow. So, the ultrasonic sensor can replace either of the flowmeter sensors and vice versa. Nevertheless, they are used together to confirm each other's readings, so the system is more accurate and robust to dysfunctions. For example, if a sensor is down or reading wrong due to aging or environmental factors, the whole system won't behave wrong or ultimately shut down; due to the added-sensor feedback. This by far limits regular maintenance to critical times only.

The power trails of the system were connected correctly since the multi-meter readings at the input and output terminals of components matched greatly with the simulation results. The leakage mode is treated as an interrupt at either the normal operation or outage modes. For a leakage during an operating mode other than the discharging (i.e. outlet water pump is closed), the overall latency of a system in the leakage mode was 9 seconds and 7 seconds for the 0.7 mm-radius and 2 mm-radius hole tests, respectively. During a discharge process, however, the latency increased by the amount of time to reach the minimum threshold water level according to the following equation.

$$\text{Total Delay } (D'_{tot}) = \frac{(L_x - L_{min}).A}{\dot{V}_{out}} + D_{tot} \quad (2)$$

where L_x, the initial water level before discharging, L_{min} the minimum threshold water level, A the base area of the tank, $\dot{V}_{out}$ the volumetric flowrate measured by the flowmeter sensor, and D_{tot} the non-discharging delay.

The developed system is compared with previously published work concerning its ability to tank level monitoring, leakage detection, adopted hardware, and the usage of mobile applications. Table (3) illustrates a comparison between the proposed system and seven recently published similar systems [8]-[11] and [13]-[15]. From this table, the proposed design is superior to others concerning the added features such as:

- monitoring the water inside the storage tanks and reservoirs,
- communicating with the user and controlling the pump remotely,
- designed to save water by closing the pump in case of finding any leakage or the tank being filled up,
- determining the inward and outward flow rates,
- the sensitivity analysis test yielded acceptable deviation from the simulation values for the input flowmeter sensor, output flowmeter sensor, and ultrasonic sensor, it is cost-effective.

The numerical comparison between the systems is not possible due to the lack of published data for all of them.

TABLE 3 PERFORMANCE COMPARISON BETWEEN THE PROPOSED DESIGN AND PREVIOUSLY PUBLISHED WORK.

Reference	Level Monitoring	Leakage Detection	Hardware Adopted	Mobile Application	More Features and Limitations
Daadoo et.al [8], 2017	✓	✓	microcontroller, distance gauge, ultrasonic sensor, GSM module, and a solenoid valve.	✓	-
Kumar et al. [9], 2019	✓	✓	Microcontroller, ultrasonic sensor, GSM module, ThingSpeak IoT private cloud services.	✓	Used for connected tanks, the hardware functionality, and cost-effectiveness are arguable
Dissanayake and Wickramarachchi [10], 2019	✓	x	microcontroller, ultrasonic sensor, a local Wi-Fi router, and a solenoid valve.	x	The auto refill system, Google Firebase for data storage, and visualized in the Fusion-Chart package.
Natividad and Palaoag [11], 2019	✓	✓	Arduino Uno, GSM SIM800 modem, ultrasonic sensor, analog pressure sensor	x*	Tank auto-refill, pipe leakage, whenever a pipe pressure is above the threshold, the flow is diverted to other pipes.
Nikeeta et al. [13], 2020	✓	✓	Raspberry Pi (replaceable by NodeMCU), Metallic layers of water sensors, 2 flow meters	x*	Auto refill, data is sent to a cloud server, The system cost is relatively high since Raspberry Pi is used,

					Water sensors resolution is not sufficient, subject to corrosion, and only discrete levels can be measured.
Asif et al. [14], 2020	✓	✓	IoT ThingSpeak platform, ultrasonic sensor, water flowmeter sensor, NodeMCU water distributor, LED, and LDR water turbidity monitored.	✓	Household water network monitoring, the tank is auto-refilled, and the water consumption relies on machine learning and sensor data fusion.
Adjardjah et al. [15], 2022	✓	x	Microcontroller, ultrasonic sensor, GSM module, and LCD screen	✓	Tank auto-refill, Operates in automatic and manual modes.
The Proposed System	✓	✓	Microcontroller, ultrasonic sensor, flowmeters, a GSM module, a water pump, a solenoid valve, and two flow meter sensors	✓	Monitoring the water inside the storage tanks and reservoirs, it can communicate with the user and control the pump remotely, designed to save water by closing the pump in case of finding any leakage or the tank being filled up, it determines the inward and outward flow rates, The sensitivity analysis test yielded acceptable deviation from the simulation values for the input flowmeter sensor, output flowmeter sensor, and ultrasonic sensor, it is cost-effective.

* It is not mentioned clearly that a mobile application is included.

6. CONCLUSIONS

This paper addressed the water shortage and waste problem by designing and implementing a smart flexible water monitoring and leakage detection system that can be used with several types of water tanks. If the system is deployed on a large scale, it will facilitate more efficient leakage detection, water waste reduction, and water resources management. The sensitivity analysis test yielded 1.65%, 2.2%, and 4.15% deviation from the simulation values for the input flowmeter sensor, output flowmeter sensor, and ultrasonic sensor, respectively.

The overall cost of the embedded prototype was $48.71 compared to the hydraulic tank prototype, which was $21,600 as indicated in [9]. So, the proposed embedded solution is considered cost-efficient even when scaled up. This finding is very important because it makes the system applicable to a large number and types of tanks. Also, it allows the system to be used for domestic usage or commercial usage. Finally, the system succeeded in reducing the wastage of water and conserving it to use in daily life. If the system is deployed on a large scale, it will facilitate more efficient leakage detection, water waste reduction, and water resources management.

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