Scholars Journal of Engineering and Technology

OPEN ACCESS

Abbreviated Key Title: Sch J Eng Tech
ISSN 2347-9523 (Print) | ISSN 2321-435X (Online)
Journal homepage: https://saspublishers.com

Prototype Development of an SMS-Based Industrial Water Tank Level Monitoring and Control Parameters System

Otele Israel[1*], Beinmowei D. Egeun[2], C. J. Ezeofor[1]

[1]Department of Electrical Engineering, Faculty of Engineering, University of Port Harcourt, Rivers State, Nigeria
[2]Department of Agricultural and Environmental Engineering, Faculty of Engineering, Niger Delta University, Bayelsa State, Nigeria

DOI: 10.36347/sjet.2023.v11i09.004 | **Received:** 21.08.2023 | **Accepted:** 25.09.2023 | **Published:** 29.09.2023

***Corresponding author:** Otele Israel
Department of Electrical Engineering, Faculty of Engineering, University of Port Harcourt, Rivers State, Nigeria

Abstract **Original Research Article**

This study describes the creation of a prototype SMS-based fluid parameter monitoring system. Many water industry and oil servicing/plant maintenance companies use workers to measure and monitor fluid parameters such as flow rate, temperature, pressure, and level (taking periodic readings). The method is determined to be extremely difficult and severe, raising serious concerns. To address the aforementioned issue, it is proposed that a system be developed that would reduce the staff stress of manual monitoring of fluid parameters and notify the same to personnel for necessary action. The suggested system is made up of both hardware and software. The hardware section consists of four units: power supply, input, control, and output, all of which were created utilizing a top-down system design approach. The C programming language was used to write the software that controls the entire system. Following that, multiple units were constructed and tested. When the system is turned on, the sensors monitor various fluid (water) characteristics and provide signals to the microcontroller, which analyzes the parameters and sends them to a display unit and the employee's mobile phone for alert notification. The outcome is quite precise and accurate. A simulation of the system performance was also performed in PROTEUS. This proposed method is inexpensive and can be implemented in oil service organizations to provide faultless services in place of employees.

Keywords: Water Tank Level, Microcontroller, SMS Alert, C language, Automation, Fluid Mechanics

1. INTRODUCTION

The sustainability of accessible water supplies is currently a major issue in many parts of the world. This issue is caused by inefficient water allocation, inefficient use, and a lack of adequate and integrated water management. Water is widely used in agriculture, industry, and household consumption. As a result, water monitoring and effective use are potential limits for residential or office water management systems (Juh & Muh, 2015). The delivery of commodities or materials by a pipe is known as pipeline transport. The most recent numbers, from 2014, show a total of little less than 2,175,000 miles (3,500,000 km) of pipeline in 120 countries worldwide. The US had 65%, Russia had 8%, and Canada had 3%, accounting for 75% of all pipelines (cia,2014e). According to a worldwide survey conducted by the Pipeline and Gas Journal, 118,623 miles (190,905 km) of pipelines are planned or under construction. There are 88,976 miles (143,193 km) of planning and design and 29,647 miles (47,712 km) under construction at various levels. Pipelines transport liquids and gases, but they can also transport any chemically stable substance (Cepac, 2014).

One of the primary applications for UWSN is pipeline monitoring. An appropriate UWSN for pipeline monitoring should be simple to install on both existing and new pipelines. Measurements of the pipe's condition should also be non-invasive to the pipe in order to maintain the pipeline's structural integrity. This necessitates the creation of new technologies for assessing pipeline properties in order to monitor their structural integrity. Leaks in pipelines are detected and located using a variety of ways (Liu, 2012). Oil pipeline infrastructure has been repeatedly vandalized around the world over the years. One example is the oil pipeline infrastructure in Nigeria, where the NNPC authorities reported around 5,000 occurrences of oil pipeline damage between 1976 and 1996, with an additional 10.9 billion dollars lost between 2009 and 2011 (Okoli, 2013). As a result, the current study sought to create a system capable of measuring water level and parameters, as well as to construct system algorithms, program in C, and simulate the system using PROTEUS.

2. METHODOLOGY

System Design Methodology

The project consists of both hardware and software. The program is included in the software, whereas the circuit and its components are included in the hardware. The circuit is separated into four pieces, each of which performs a certain purpose. Figure 1 shows the block.

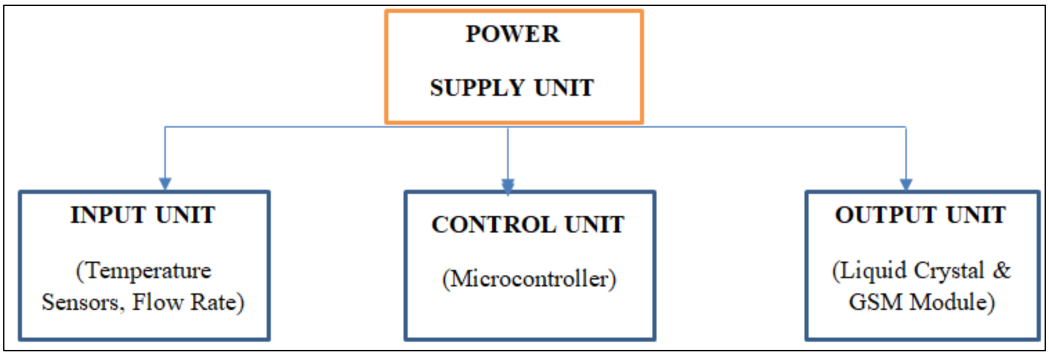

Figure 1: Block Diagram of Water Tank Level Monitoring System

Hardware Design Analysis and Power Supply Unit

The circuit diagram shown in Figure 3 shows the main diagram of the water Monitoring System. The circuit diagram will be explained below in detail in the various units which make up the system. The Power Supply Unit is made up of various components which include a transformer (Step-Down), TR_1: which converts the 220vac from PHCN to 5vac.

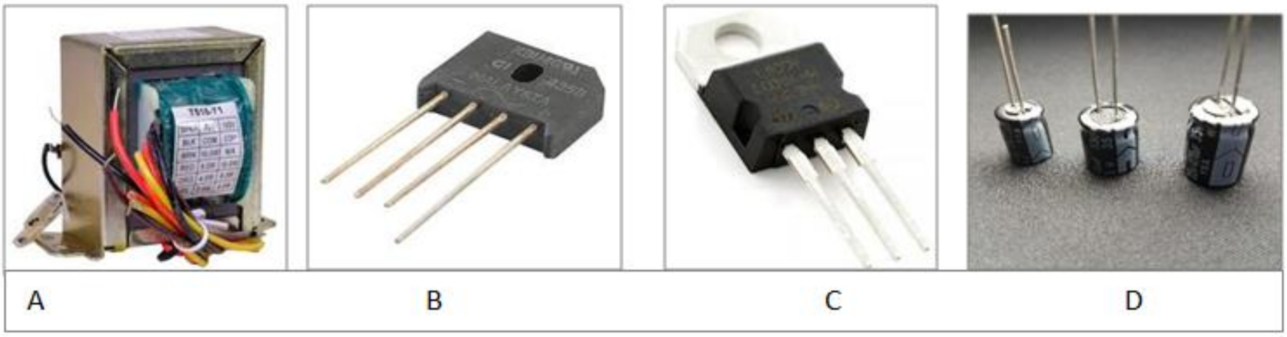

Figure 2: Transformer (A), Bridge rectifier (B), Voltage Regulator (C) and Filter Capacitor (D)

Bridge Rectifier, BR_1: *to convert the Alternating Current which moves in, varying directions periodically to a Direct Current, which moves in one direction. Voltage Regulators which are LM7805 (U_1 and U_2) and LM317 (U_3) generate a fixed output voltage of a preset magnitude that remains constant regardless of changes to its input voltage or load conditions.*

Limiting Resistor, R_L

The various components are connected in such a way that the step-down transformer (TR1) reduces the voltage supplied by PHCN (Power Holding Company of Nigeria) from 220 volts to 15 volts. The transformer must be capable of delivering the appropriate current. If the transformer is too tiny, the power supply's ability to sustain full output voltage at full output current is likely to be compromised, and if the transformer is too small, losses will skyrocket as full load is applied to the transformer. A bridge rectifier (BR1) converts the 15Vac to 15Vdc. The full wave bridge rectifier employs four diodes arranged in a bridge circuit to provide full wave rectification without the use of a center-tapped transformer; additionally, because two diodes (effectively in series) are conducting at any given time, the diodes require only half the reverse breakdown voltage, i.e. the 'Maximum Working Peak Reverse Voltage (VRWM)' capability of diodes used for half and conventional full wave rectification.

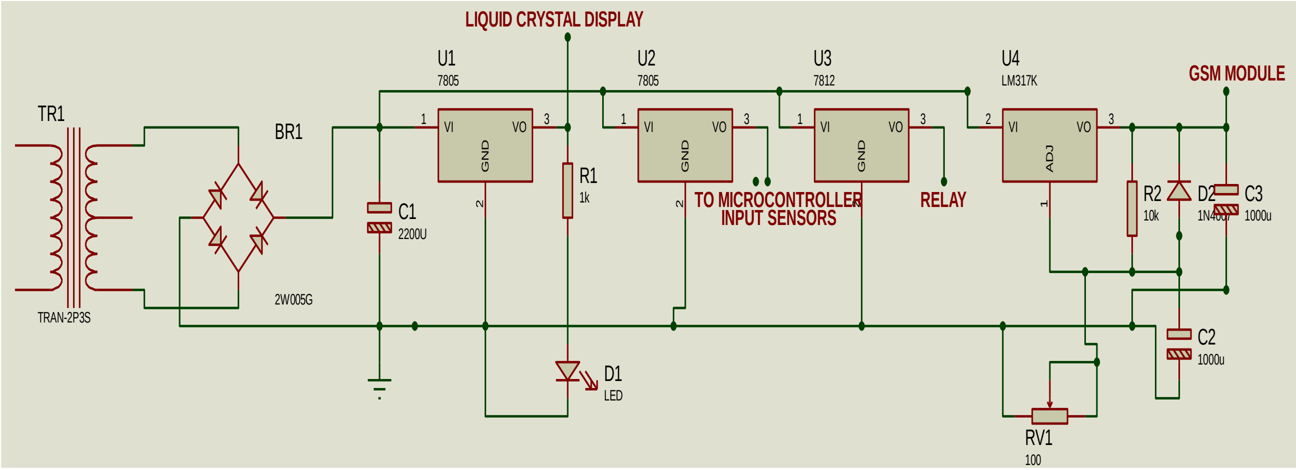

Figure 3: The complete circuit diagram of the power supply Unit

A bridge rectifier can be constructed using separate diodes or a combined bridge rectifier. The current paths on the input wave's positive and negative half cycles. On each half cycle, opposite pairs of diodes conduct, yet the current across the load remains polarized throughout. The DC voltage obtained is filtered by a filter capacitor (C1), which is used to filter out any AC ripples in the 15Vdc value. The voltage from the filter capacitor is an unregulated voltage, while the circuit requires 4.2 Vdc and 5 Vdc. This necessitates the use of three voltage regulators, 7805 (U1 and U2) and LM317 (U3), to provide consistent voltage; the 7805 (U1 and U2) would supply 5Vdc, while the LM317 (U3) would supply 4.2Vdc. To signal when power is flowing via the circuit, a light-emitting diode (d1) is employed as a power indicator.

Power Supply Calculation

The transformer used in the design is a $220V_{ac}$ to $15V_{ac}$ transformer with a current capacitor of 2000mA.

$$Supply\ Voltage\ to\ Transformer = 220V_{ac}$$
$$Step - Down\ Voltage\ fro\ Transformer = 15V_{ac}$$

The maximum voltage of the secondary side of the transformer can be calculated using eqn. 1.

$$V_m = \sqrt{2}V_{secondary} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

$$V_m = The\ maximum\ voltage\ from\ the\ secondary\ of\ the\ transformer$$
$$V_s = The\ voltage\ from\ the\ secondary\ of\ the\ transformer$$
$$V_m = \sqrt{2} \times 15 = 21.2\ volt$$
$$Maximum\ Peak\ Voltage\ , V_m = 21.2\ volt$$

The average DC voltage gotten is calculated from the formula below.

$$V_{dc} = 0.636V_m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

Where,

$$V_{dc} = Averaged\ DC\ voltage$$
$$V_m = Maximum\ Voltage\ of\ the\ Transformer$$

From equation 3.1, the maximum voltage is 21.2 volts.

$$V_{dc} = 0.636 \times 21.2 = 13.48\ volts$$

From the calculation,

$$Average\ DC\ Voltage\ , V_{dc} = 13.48\ volts$$

The bridge rectifier is used to rectify the voltage, and on Calculation the voltage gotten after the rectification by the bridge rectifier as shown in eqn. 3.3.

$$V_{dc} = V_m - 2(V_d) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

$$V_d = forward\ voltage\ drop\ across\ the\ silicon\ diodes$$
$$V_d = 0.7\ volts$$
$$V_{dc} = V_m - 2(0.7) = 21.2 - 1.4 = 19.8\ volt$$

The filter capacitor is then used to filter off the AC ripples in the DC voltage, thereby reducing the ripple to a minimal level.

$$Capacitor, C = 2200\mu f$$

The ripple voltage in the supply is gotten using eqn. 4.

$$V_r = \frac{I_o}{2fC} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

$where;\ frequency, f = 50Hz$
$I_o = regulator\ output\ current,$
$For\ C = 2200uf, I_o = 500mA$

$$V_r = \frac{0.5}{2 \times 50 \times 2200 \times 10^{-6}} = 2.27\ volts$$

From this the DC voltage after the filter capacitor is,

$$V_{dcc} = V_{dc} - V_r = 19.8 - 2.27 = 16.73\ volt$$

Three integrated chip voltage regulators are used to regulate the voltage from 16.73 volts to 5 voltsand 4.2 volts.

The light emitting diode is connected in series to the limiting resistor. The limiting resistor, R_L reduces the current that that flows through the diode to prevent high current from flowing through the light emitting diode.

Kirchhoff's Voltage rule shown in eqn. 3.5, is used to calculate the current through the diode

$$V = V_T + V_d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

$V_d = Voltage\ drop\ across\ light\ emitting\ diode$
$V_r = Voltage\ drop\ across\ the\ resistor$
$V = Total\ Voltage$

$$V_r = I \times R,$$
$$V_d = 2\ volt,$$
$$V = 5\ volts$$

Substituting this into the equation,

$$5 = I \times 1000 + 2$$
$$5 - 2 = I \times 1000$$
$$3 = I \times 1000$$
$$I = \frac{3}{1000} = 3\ mA$$

The current flowing through the light-emitting diode is 3mA. The voltage regulator (U_2) is used to supply the LCD and the microcontroller (Theraja, 2000).

Input Unit

The input unit includes: Water Proof Temperature Sensor, DS18B20, Water Level Sensor, HC-SR04, The Flow Rate Sensor: The type of flow rate sensor used and The GSM module is shown in figure 4.

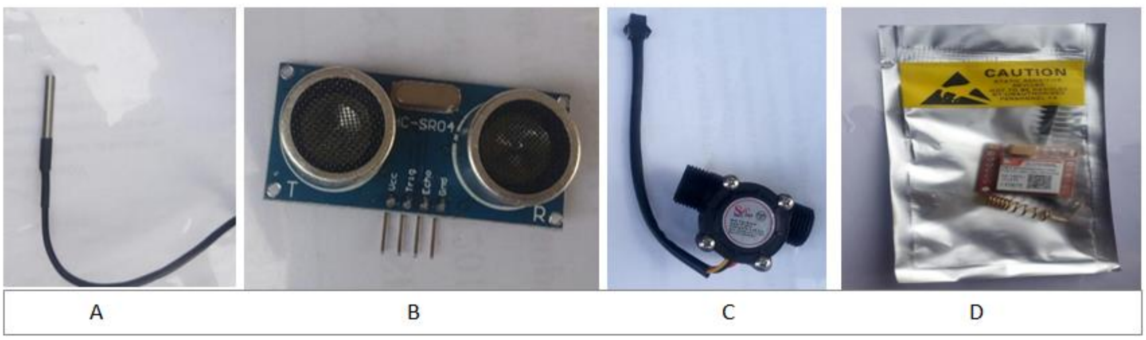

Figure 4: Water Proof Temperature Sensor (A), Ultrasonic Water Level Sensor (B), Flow Rate Sensor (C) and GSM Module (D) VBBKJ. The three sensors are used to convert the physical quantities they are sensing into electrical signal

The DS18B20 Water Proof Temperature Sensor was used as the temperature sensor. It was designed to measure the temperature of the fluid in the pipe. The sensor is a three-terminal device, with the red wire linked to the voltage regulator's 5 volts, the black wire to ground, and the yellow wire to the control unit. The water flow sensor measures the liters of water expanded in the system as water flows from the reservoir to the tank. The HC-SR04Ultrasonic Sensor is the water level sensor used. This is used to wirelessly measure the tank's water level. It has four terminals with the pins Vcc, Gnd, Echo, and Trigger. The Vcc and Gnd pin-outs are connected to the voltage regulator's 5V and Gnd pins, respectively. The trigger pin is used to send a sound out; this is initiated by sending a 10us signal from the control unit to the trigger terminal. The sound is reflected back from the water's surface. The water level is calculated by multiplying the duration of the high-level by the velocity (340ms(-1))/2, as stated in equation 5.

$$distance = duration\ of\ high\ level * \frac{velocity}{2}$$ …………………… eqn. 6

The duration of high level is at the echo terminal connected to the control unit. This signal is received by the control unit. The circuit diagram is shown in Figure 5.

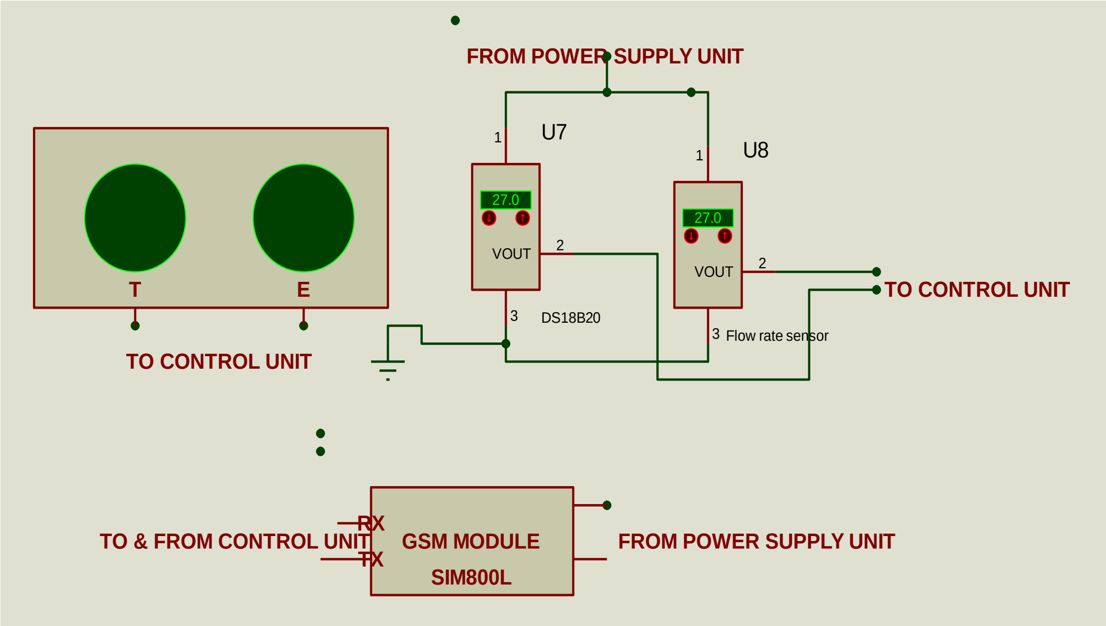

Figure 5: Circuit Diagram of Input Unit

The GSM module is used to receive message from the operator, and then the message is sent to the microcontroller to get the input sensors value to the operator. The RX and TX pins are connected to the microcontroller to send signals and receive signals from the control unit.

Control Unit

The control unit includes: The Microcontroller, ATMEGA328. The type of transformer used is in figure 6.

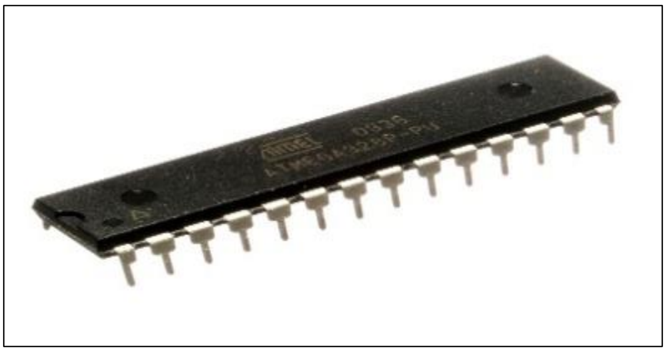

Figure 6: The Microcontroller, ATMEGA328.

The input unit, power supply unit, and output unit are all linked to the microcontroller. The ATMEGA328 microcontroller was utilized in this project. The embedded C-language is used to program the IC. Its output pins are linked to the input and output units. The temperature sensor is attached to the IC's analog pin. The analog voltage is transformed to a digital signal with a resolution of 1024 bits. Figure 7 depicts the circuit diagram.

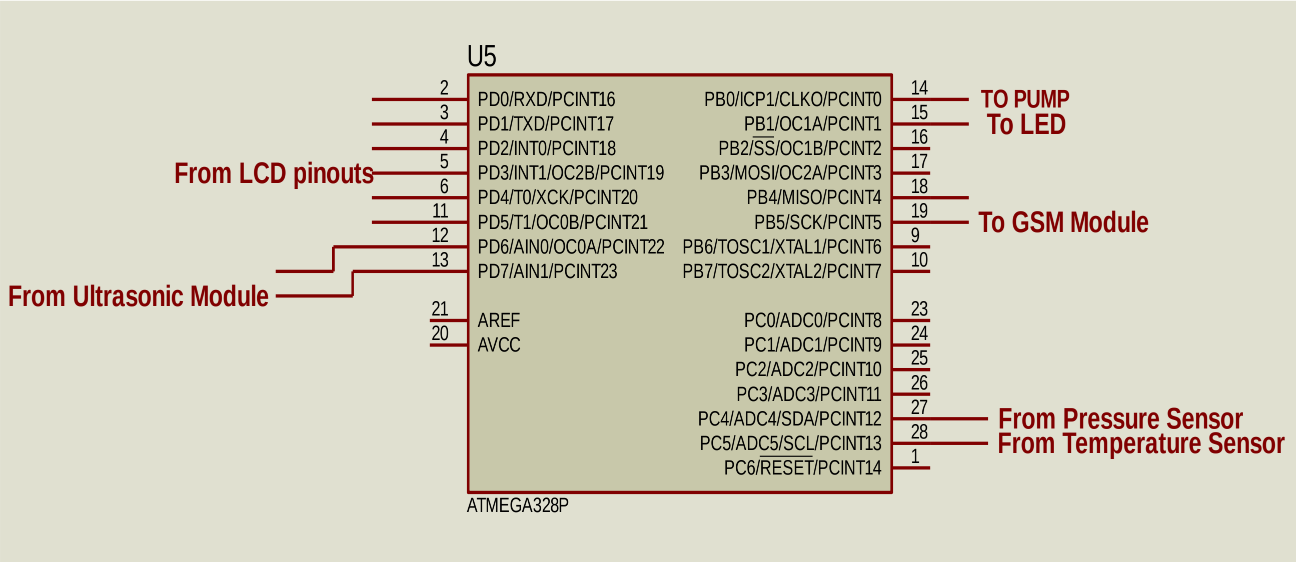

Figure 7: Shows the circuit connections of the control unit to the other unit. Pin 15 is connected to the light-emitting diode (D4) to indicate if the programming is working in the circuit. The resistor (R4) reduces the current that flows through the light-emitting diode (D4)

The GSM module is linked to the control unit's pins 18 and 19. The serial port on the microcontroller is used to communicate with the GSM module. The serial port has two terminals: transmission (Tx) and receiver (Rx). The baud rate of data transmission is 9600 bits per second. The GSM module and the microcontroller will interact at the same baud rate (9600 bps). It receives the signal from the input unit and transfers it to the output unit. The sensor signal is routed to the input for calibration. This is what the liquid crystal display looks like.

Figure 8: Liquid Crystal Display (A), Transistor (B), Relay (C), Variable Resistor (C) The Resistor R_3: limits the current entering transistor Q1, MTN SIM, Light Emitting Diode, D_4: indicates when the microcontroller is ready to function, Resistor, R_4: limits the current entering into LED D_4 and Variable Resistor (RV_2): for contrast and controlling the display of the liquid crystal

The GSM module is used to transmit SMS messages to the device's operator in order to display system parameters on the liquid crystal display. The microcontroller is linked to the pump via the transistor (Q1) and the relay (RL1). The resistor (R3) limits the current entering the transistor's base. The (Q1) limit the current flowing to the transistor's base, the collector is connected to one of the relay terminals, and the emitter is connected to ground. The GSM module is used to wirelessly transport data from the system to a telecommunication network, the SIM card used in the project is an MTN SIM, and the network utilized in the transmission is the MTN telecommunication network. The microcontroller may communicate with the GSM module by sending AT commands to it from the control unit. The serial communication utilized is a duplex protocol, and data can be sent and received by the GSM using the module's Rx and Tx terminals. The transfer baud rate between the microcontroller and the module is 9600.

The microcontroller is linked to the liquid crystal display. A nibble parallel communication is used between the microcontroller and the liquid crystal display. It transfers information or ASCII characters from the microcontroller to the liquid crystal display using four bits. The variable resistor (RV2) controls the contrast of the liquid crystal display by increasing or decreasing its resistance.

The light-emitting diode (D4) blinks twice to signal that the control unit's programming code is active. R4 is utilized to lower the current going through the light-emitting diode. The microcontroller is linked to the liquid crystal display. A nibble parallel communication is used between the microcontroller and the liquid crystal display. It transfers information or ASCII characters from the microcontroller to the liquid crystal display using four bits. The variable resistor (RV2) controls the contrast of the liquid crystal display by increasing or decreasing its resistance. The light-emitting diode (D4) blinks twice to signal that the control unit's programming code is active. R4 is utilized to lower the current going through the light-emitting diode.

Software Design

Choice of programming language

The intelligence of the controller is written in C language which is converted to the machine code which the controller understands.

System Algorithm and Flowchart

The working operation runs as follows:

Step 1: The system comes on

Step 2: The microcontroller and the timer is activated

Step 3: The size of the reservoir is read as 10L

Step 4: Initial time $T_i$as 1sand check T_f as 120s

Step 5: Check for the quantity of water in reservoir tank

i.) If the quantity of water is ≥5L proceeds to read time of operation

ii.) If not turns on pump

Step 6: Check if time of operation is equal to 120s,

i.) If yes, it reads parameter

ii.) If no, it keeps checking until the time of operation is 120s

Step 7: Transmit parameter to mobile phone

Step 8: Set time of operation to T_i= 1s, and goes back to read parameter at 120s.An eight-step listed above can be represented using the flow chart algorithm to represent the working and operation the system design is given on the next page.

Figure 9 shows the flow chart of the project work.

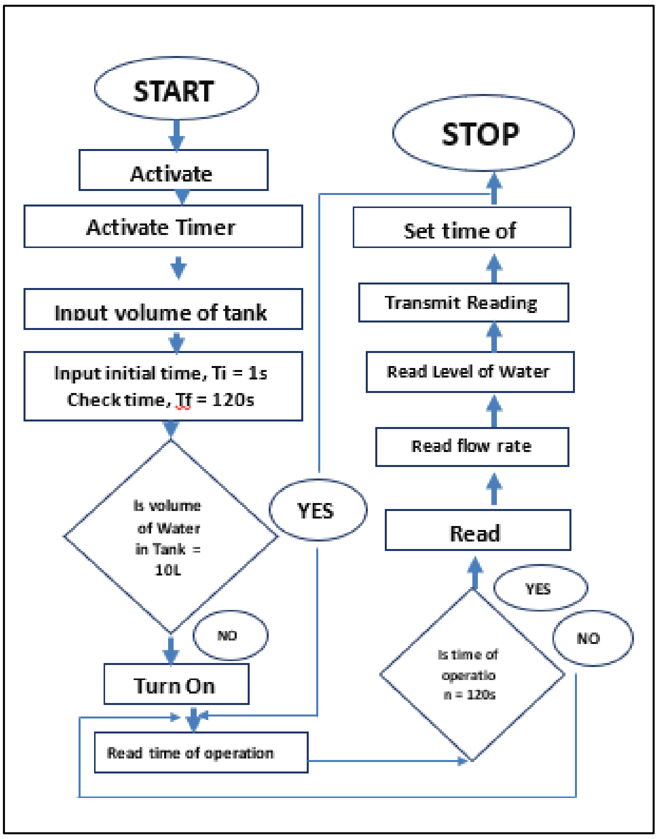

Figure 9: Flowchart Algorithm

System Operation and Circuit Diagram

The Power Supply Unit, Input Unit, Output Unit, and Control Unit are the four components of the project. Figure 10 depicts the circuit diagram for the entire circuit.

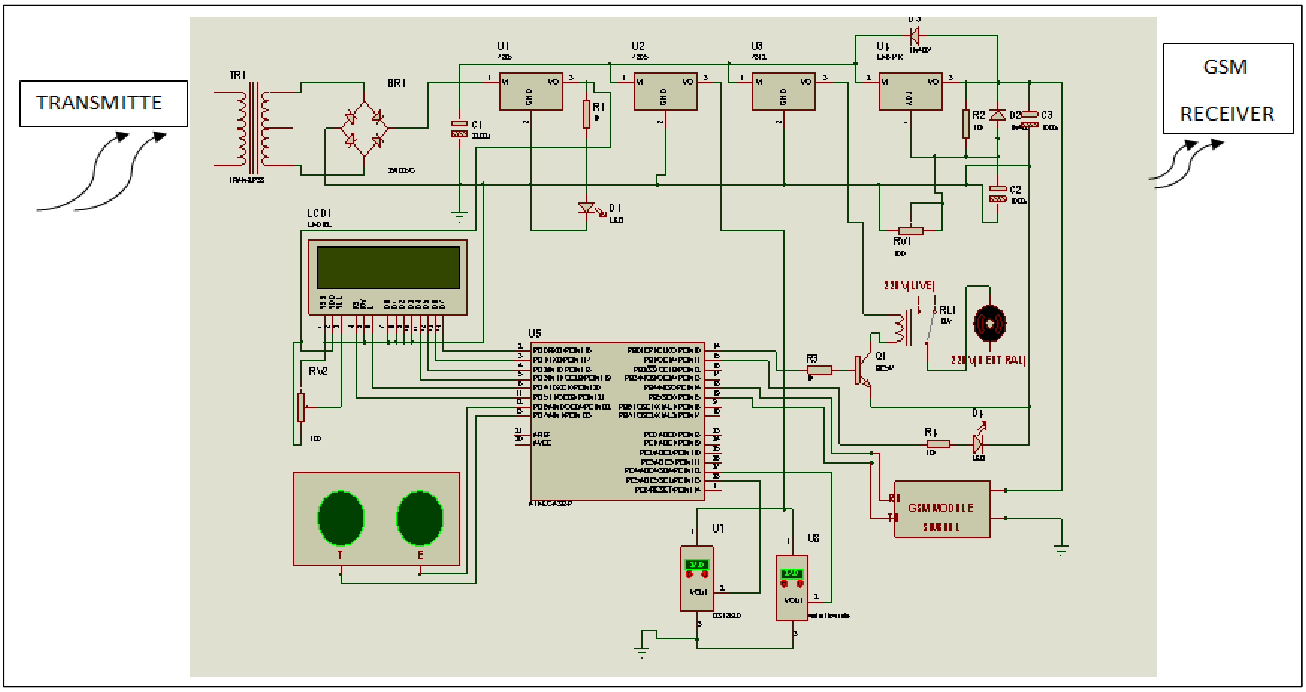

Figure 10: Circuit Diagram of water level monitoring.

RESULT AND DISCUSSION

Testing and Discussions

Testing is an essential stage in the development of any new product or the repair of an existing one. Tracing a flaw in a finished work is quite difficult, especially when the work to be tested is extremely complicated. There are two levels of testing for this project. There are two types of testing: pre-implementation testing and post-implementation testing.

Pre-Implementation Testing

It is carried out on the components before they are soldered to the Vero board. This is to ensure that each component is in good working condition before they are finally soldered to the board. The components used in this design are grouped into two; - Discrete components e.g. resistors, light emitting diodes, capacitors, and transistors, and Integrated circuit components. The discrete components are tested with a millimeter by switching the meter to the required value and range corresponding to each discrete component to check for continuity.

Post-Implementation Testing

Following the implementation of the circuit on a project board, the various portions of the entire system were checked to ensure that they were in good working order. The circuit was designed, and suitable calculations were performed to ensure the project's viability. Individual components were identified and purchased in markets. The circuit was built in stages, beginning with the power supply unit and progressing to the control unit, output unit, and display unit. The circuit was built with a soldering iron and soldering to attach the components to the Vero-board. The circuit was thoroughly tested using a digital multimeter to ensure the Vero board's continuity. After the required precautions were taken, the circuit was ready for testing. The purpose of the continuity test is to confirm that the circuit or components are properly connected together. This test was performed prior to powering up the circuit. After debugging the entire circuit, electricity was delivered to the circuit at the voltage reported in Table 1. At this point, visual troubleshooting was also performed to ensure that the components did not burn out. Following all of the above-mentioned tests and inspections, the project was finally certified and ready for packaging.

Table 1 Measurement and Results

Power output	Expected values	Measured values
LM7805 regulator	+ 5V	+ 5.02V
LM7805 regulator	+ 5V	+ 5.02V
LM317regulator	+ 4.2V	+ 4.20V
ATMEGA328		
Current	20mA	19.82mA
Voltage	+5V	+4.99V
Input Voltage PHCN	220Vac	211.00Vac

Testing of Prototype

For the system we designed, several tests were carried out. The test includes the volume control, the flow rate, and temperature measurements.

The Transmitter and Receiver Section

Table 2: Below shows the signal obtained from the ultrasonic sensor.

Ultrasonic sensor	Water	Action
The signal is sent out	Empty	Pump turns on
The signal is sent out	Full	Pump turns off

Construction of Circuit and Assembling of Components

The circuit was designed and analyzed, and the components were purchased from the market. The circuit was created on the PROTEUS version 7.8 environment. This was used to replicate some of the circuit's components in order to determine whether the design would work. Each section's components were built and soldered on a Vero-board. The power supply unit was constructed initially, then the input unit, control unit, and finally the output unit. The power supply unit was tested, and the expected voltages of 5Vdc were met. Before going to the control unit, the input devices and power detection system were verified and confirmed to be operational. The input unit's output was connected to the microcontroller. The GSM module was then linked to the system, and SMS messages were delivered when the power detector detected a lack of power and when power was detected.

Packaging

The casing of the circuit was made by using plastic – glass, and the circuit was mounted inside the casing. The circuit was measured and the length and width portions of the PERPEX materials were cut out. The different parts of plastic were glued using a plastic gum as shown in figure 11.

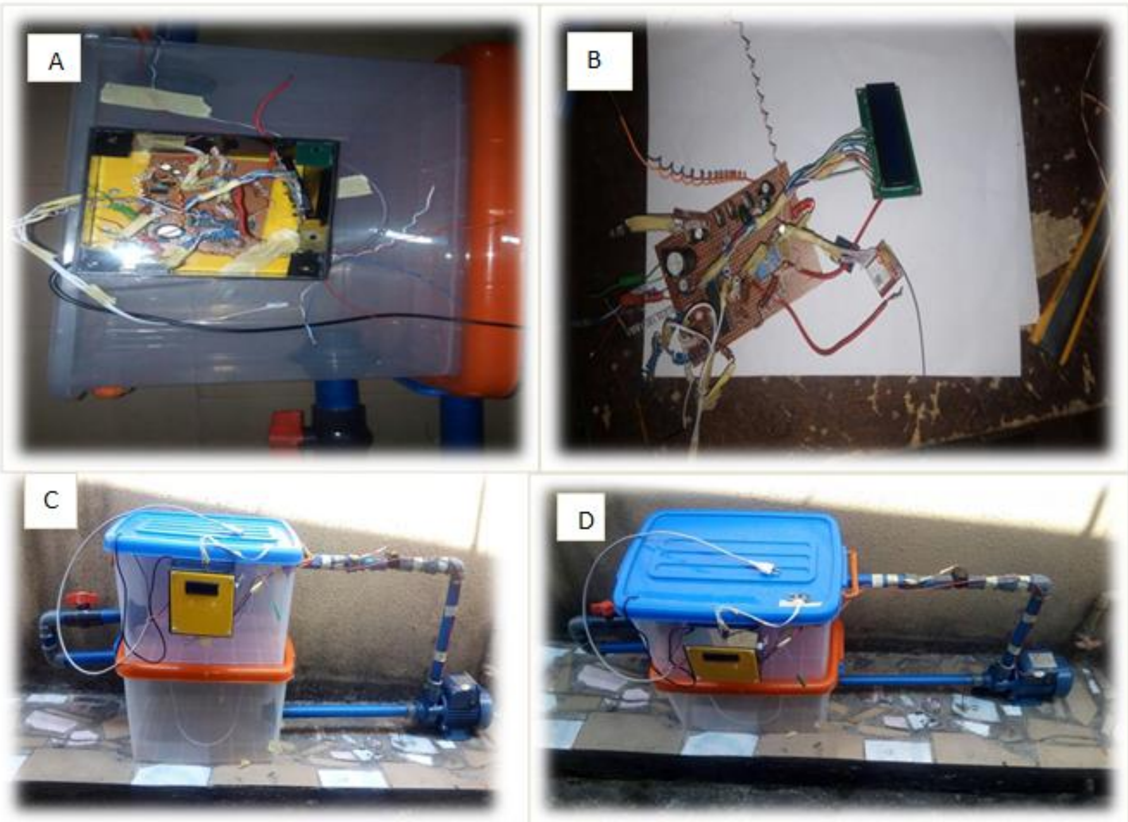

Figure 11: Microcontroller Circuit Connection (A) and Liquid Crystal Display Circuit Connection to Microcontroller (B). A bolt and nut were used to secure the transformer to the casing. The Vero-board is secured to the plastic shell using a bolt and nut. The system's tanks are made of two rubbers. Sensor and Microcontroller Mounting on the Tank (C), and Project Completion (D). After the packaging, the item was eventually tested and found to be functional

After the test revealed that the system is fully operational. The system could respond to its operation based on the following criteria: Electrical and electronic system that operates well. Furthermore, the microcontroller operates in accordance with the software design implementation program. It is worth noting how intriguing it is to witness a well-planned project succeed. This design will allow an oil industry operator to easily determine fluid parameters in order to keep the equipment in good operating order, lowering maintenance costs and optimizing the use of the equipment, i.e. pipelines.

CONCLUSION

The design and implementation of an industrial water tank level monitoring system and control was an exciting challenge to complete. The culmination of the entire effort was seeing that the hardware and software implementation worked as expected after multiple trial and error cycles. This project has provided us with a wealth of knowledge in the fields of communication and engineering. Communication theories learned during our undergraduate studies were implemented. This project will demonstrate how knowing the temperature, flow rate, and volume of liquid in a tank has enormous value in the oil and gas business.

REFERENCES

- Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A Survey. *Computer Network*, 54, 2787–2805.
- Akyildiz, I. F., Sun, Z., & Vuran, M. C. (2009). Signal propagation techniques for wireless underground communication networks. *Physical Communication*, 2, pp. 167–183.
- Akyildiz, I. F., & Stuntebeck, E. P. (2006). Wireless underground sensor networks: Research challenges. *Ad Hoc Networking*, 4, pp. 669–686.
- Ali, M. S., Metje, N., Chapman D. N., & Anthony C. J. (2014). Smart Pipes: Smart Wireless Sensor Networks Pipelines Detection in Water Pipelines. *Journal of Sensor and Actuator Networks*, 3, (pp. 64-78).
- Ahrary, A., Nassiraei, A., Kawamura, Y., Mikuriya Y., & Ishii K. (2007). Concept and Design of a fully autonomous sewer pipe inspection mobile robot "KANTARO". *The International Conference on Robotics and Applications (ICRA)*, IEEE. (pp. 136–143).
- Christin, D., Reinhardt, A., Mogre, P. S., & Steinmetz, R. (2009). Wireless Sensor Networks and the Internet of Things: Selected Challenges". *In Proceedings of the 8th GI/ITG KuVSFR.achgespräch Drahtlose Sensornetze, Hamburg, Germany*, (pp. 31–33).
- Giunta, G., Dionigi, F., Bernasconi, G., Del Giudice, S., & Rovetta, D. (2011a). Vibroacoustic Monitoring of Pigging Operations in Subsea Gas Transportation Pipelines, *ASNT Fall Conference, Palms Spring, USA.*
- Giunta G., Bernasconi G., & Del Giudice S. (2013). Vibroacoustic Monitoring of Gas-Filled Pipelines. *ASNT Fall Conference and quality testing show, Las Vegas, Nevada, USA.*
- Giudice, S., Rovetta, D., Schiavon, R., & Zanon, F. (2011b). Third Party Interference and Leak Detection on Buried Pipelines for Reliable Transportation of Fluids. *10th Offshore Mediterranean Conference, Ravenna, Italy*.
- Hieu, B., Choi, S., Kim, Y.U., Park, Y., & Jeong, T. (2011). Wireless transmission of acoustic emission signals for real-time monitoring of leakage in underground pipes. *KSCE J. Civil. Engineering*, 15, 805–812.
- Kingajay, M., & Jitson, T. (2008). Real-time laser monitoring based on pipe detective operation. *Proc World Acad Sci Eng Technol*, 44, 127–132.
- Kim, J. H. (2008). Design of a fully autonomous mobile pipeline exploration robot (FAMPER). Master's thesis. *Department of Computer Science, Louisiana State University*. (http://etd.lsu.edu/docs/available/etd-11112008-121037).
- Kim, J. H., Sharma, G., & Iyengar, S. S. (2010) FAMPER: A fully autonomous mobile robot for pipeline exploration.*The International Conference on Industrial Technology (ICIT)*. (IEEE), (pp. 517–523).
- Kim, J. H., Sharma, G., & Iyengar, S. S. (2010). Design concept and motion planning of a single-moduled autonomous pipeline exploration robot. *The 36th Annual Conference on Industrial Electronics Society (IECON)*, (IEEE), (pp. 1500–1505).
- Kwon, Y. S., Lim, H., Jung, E. J., & Yi, B. J. (2008). Design and motion planning of a two-moduled indoor pipeline inspection robot. *The International Conference on Robotics and Applications (ICRA)* (IEEE) (pp. 3998–4004).
- Khulief, Y. A., Khalifa, A., Ben Mansour, R., & Habib, M. A. (2012). Acoustic detection of leaks in water pipelines using measurements inside pipe. *J Pipeline Syst Eng Pract*, 3, 47–54.
- Liu, Z., & Kleiner, Y. (2012). State-of-the-art review of technologies for pipe structural health monitoring, *IEEE Sens J, 12*, 1987–1992.
- Li, H. N., Li, D. S., & Song, G. B. (2004). Recent applications of fiber optic sensors to health monitoring in civil engineering. *Eng Struct*, 26, 1647–1657.
- López-higuera, J. M., Cobo, L. R.., Incera, A. Q., & Cobo, A. (2011). Fiber optic sensors in structural health monitoring. *J Light Technol*, 29, 587–608.
- Mohamed, N., & Jawhar, I. (2008). A fault tolerant wired/wireless sensor network architecture for monitoring pipeline infrastructures. *The Second International Conference on Sensor Technologies and Applications (SENS*ORCOMM). (IEEE). (pp. 179–184)
- Myles, A. (2011). Permanent Leak Detection on Pipes using a Fibre Optic Based Continuous Sensor Technology. *In Proceedings of Pipelines Conference 2011: A Sound Conduit for Sharing Solutions, Seattle, WA, USA, 23–27*, 44–754.

- Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I. (2012). Internet of things: Vision, applications and research challenges. *Ad Hoc Netw*, 10, 1497–1516.
- Nakhkash, M. (2004). Water Leak Detection Using Ground Penetrating Radar. *In Proceedings of the 10th International Conference on Ground Penetrating Radar, Delft, The Netherlands, 21–24*, 525–528.
- Nikles, M. (2009). Long-distance fiber optic sensing solutions for pipeline leakage, intrusion and ground movement detection. *Proc. SPIE 2009, 7316*, 731602–731613.
- Okoli, A. I. C., & Orinya, S. (2013). Oil Vandalism and Nigeria's Security. *Global Journal of Human Social Science, Political Science, 13*(5), 67-75.
- Osunleke, A. S., Gablar, H. A., Inoue, A., Miyazaki, S., & Badmus, I. (2007). Mathematical Modelling Approach to pipeline leaks detection, location and control. *3rd International Workshop on Computational Intelligence and Applications IEEE SMC, Okayama University, Japan*, 1-3.
- Ravi, S., KarthikRaj, S., Sabareesan, S., & Kishore, R. (2016). Pipeline Monitoring Using Vibroacoustic Sensing. *International Research Journal of Engineering and Technology (IRJET), 3*(1), 1095-1099.
- Sinha, S. K., & Knight, M. A. (2004). Intelligent system for condition monitoring of underground pipelines. *Comput Civ Infrastruct Eng*, 19, 42–53.
- Tao, J., Peiwen, Q., & Zhengsu, T. (2004). Development of magnetic flux leakage pipe inspection robot using hall sensors. *The International Symposium on Micro-Nanomechatronics and Human Science (MHS).* (IEEE, 2004), (pp. 325–329).
- Walton, R., Sadeghioon, A.M., Metje, N., Chapman, D., & Ward, M. (2011). Smart Pipes: The Future for Proactive Asset Management."*In Proceedings of the International Conference on Pipelines and Trenchless Technology, Beijing, China, 26–29 October 2011*; (pp. 1512–1523).
- Yan, S. Z., & Chyan, L. S. (2010). Performance enhancement of BOTDR fiber optic sensor for oil and gas pipeline monitoring. *Opt Fiber Technol*, *16*, 100–109.
- Yu, X., Wu, P., Han, W., & Zhang, Z. (2012). Overview of wireless underground sensor networks for agriculture. *Af J Biotechnol*, *11*, 3942–3948.