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(Review Article)

An IoT-based intelligent liquid metering and control system

Henry Ikemefuna Ugwu, Chinaza Nweze and ThankGod Izuchukwu Ozue *

Department of Electronic and Computer Engineering, Faculty of Engineering, University of Nigeria, 410001.

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Abstract

Metering is essential to utility service delivery, and this paper presents the detailed design, construction, and implementation of a smart liquid metering and control system. Most nondigital and digital liquid metering units require on-the-spot data logging, which is labour-intensive and easily interfered with. Automation and remote sensing were used to enhance core functionality, including data acquisition, flow control, and energy independence. The core of the system design is the ESP8266 module, which interfaces with the flow sensor to measure liquid volume and rate and also provides remote access. Flow control was implemented using a solenoid valve that acts as the final control element, regulating flow based on user-defined setpoints. The design featured a remote user interface for real-time data display and monitoring through the Blynk IoT platform. To enhance remote access, real-time data logging, and manual flow control from a portable device, a wireless communication module was also deployed. The system was implemented and tested, demonstrating metering accuracy, reliable automated control, and effective remote operation, thereby reducing human intervention and promoting efficient liquid resource management.

Keywords: Intelligent; Solenoid Valve; Android App; Liquid Monitoring; IoT

1. Introduction

The Earth consists of about 70% water, and as the most vital natural resource, it is essential for life, agriculture, and industry. Resource conservation is a critical foundation of a sustainable society, yet water waste remains an international issue, often exacerbated by a lack of public and administrative awareness [10]. To ensure that future generations are protected, water resources must be managed efficiently and sustainably. Metering is a vital measure for effective resource management. One major issue associated with it is the use of a single meter for an entire building, which generates a collective cost that is divided equally among households, leading to inaccurate user-based utilization charges.

Conventional metering relied on often-low-grade, single-function instruments with door-to-door data logging, which consumed significant manpower and resources. Rapid advances in electronics and information technology ended the era of manual meter reading, as electronic meters can report water information in a timely manner and sense the turnover state of the urban water distribution system [7]. Existing manual methods for liquid metering and control are prone to inaccuracies, are labor-intensive, and lack real-time monitoring capabilities. There is a need for an automated, accurate, and user-accessible system that can measure liquid flow, allow users to set desired quantities, automatically shut off the flow when the set volume is reached, and provide remote monitoring and control capabilities.

Various approaches have been explored in smart water metering research. One example is a self-powered smart water meter that uses a turbine generator for both flow sensing and power generation, but it faces challenges such as low-flow detection and high-flow saturation [6]. Another study employed cloud computing for remote meter reading and data analysis, thereby transforming a simple measurement unit into interactive network nodes [7]. And recent

* Corresponding author: ThankGod Izuchukwu Ozue

improvements have combined Narrowband IoT (NB-IoT) with image recognition, using a convolutional neural network to read displays [9]. While these systems offer advanced features, there remains a gap for a low-cost, user-friendly, and remotely controllable system based on widely accessible Wi-Fi and IoT platforms, which this project aims to fill [8, 10].

The Internet of Things (IoT) enables interconnected objects embedded with sensors and software to share information over the internet [10]. Smart water meters, leveraging IoT, electronic, and wireless transmission technologies, offer a solution by allowing individual consumption tracking. This research proposes a set of reasonable, low-cost, and easy-to-use smart water meter system solutions, enabling remote monitoring, data transmission, and intelligent control.

2. System methodology and design

In the system design, a microcontroller, sensors, and actuators were used to create an automated metering system. To measure the flow rate, the Hall Effect flow sensor outputs a pulse signal corresponding to the flow rate. This signal is sent to the microcontroller for processing. The information is then made accessible to the user remotely through Wi-Fi and the edge computation IoT platform, Blynk.

2.1. System Block Diagram

The system block diagram, shown in Fig. 1, comprises four main units, namely the sensing unit, processing unit, actuation unit, communication unit, and power unit. The unit houses the YF-S201 sensor, which provides a pulsed digital output where the frequency is proportional to the flow rate. This sensor operates on the principle of a turbine spinning as liquid passes through it. A magnet embedded in the rotor passes a Hall Effect sensor, which generates a digital pulse for each rotation. The frequency of these pulses is directly proportional to the flow rate, making it ideal for low-cost, simple microcontroller interfacing. The signal from the sensor is decoded by the central brain for processing sensor data, executing control logic, and managing Wi-Fi communication. A review of popular microcontrollers points to the ESP8266-based NodeMCU V3 as an excellent choice for IoT applications. The NodeMCU V3 is an open-source development board that centers around the ESP8266 Wi-Fi SoC. It integrates a USB-to-Serial converter (like the CH340G) and a voltage regulator onto a single board, eliminating the need for additional hardware for programming. Its key specifications include a 32-bit RISC CPU running at 80 MHz, 4 MB of flash memory, and integrated 802.11 b/g/n Wi-Fi. This "all-in-one" design makes it ideal for prototyping connected systems. Unlike its successor, the ESP32, the NodeMCU V3 does not include Bluetooth but offers a very low-cost solution for Wi-Fi connectivity. The actuation unit serves as an access control unit that regulates flow through the conduit according to the signal received from the processing unit. For this project, a Normally Closed (NC) 12V solenoid valve was chosen for its fast response time and simple on/off control. A microcontroller cannot drive this valve directly due to voltage and current mismatches, as well as the risk of inductive kickback. Therefore, a relay module is used as an intermediate switch. The relay uses a low-power signal from the microcontroller to energize an electromagnet, which physically closes a high-power circuit to control the solenoid valve, providing electrical isolation and protecting the control circuit. Energy sustainability is ensured by the power unit that comprises an energy storage module and a generating module.

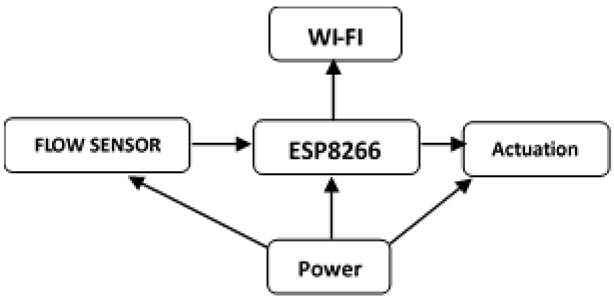

Figure 1 Block diagram of the system design

2.2. Circuit Diagram

A detailed circuit schematic, shown in Fig. 2, illustrates the interconnection of all components. The flow sensor connects to a GPIO pin on the NodeMCU. The relay module's signal pin is connected to another GPIO pin via a BC547 transistor driver circuit, which includes a 1kΩ base resistor and a flyback diode (1N4007) for protection. The solenoid valve is connected to the relay's common (COM) and normally open (NO) contacts. Power is supplied by a 12V solar panel and battery, regulated to 5V for the NodeMCU via a buck converter.

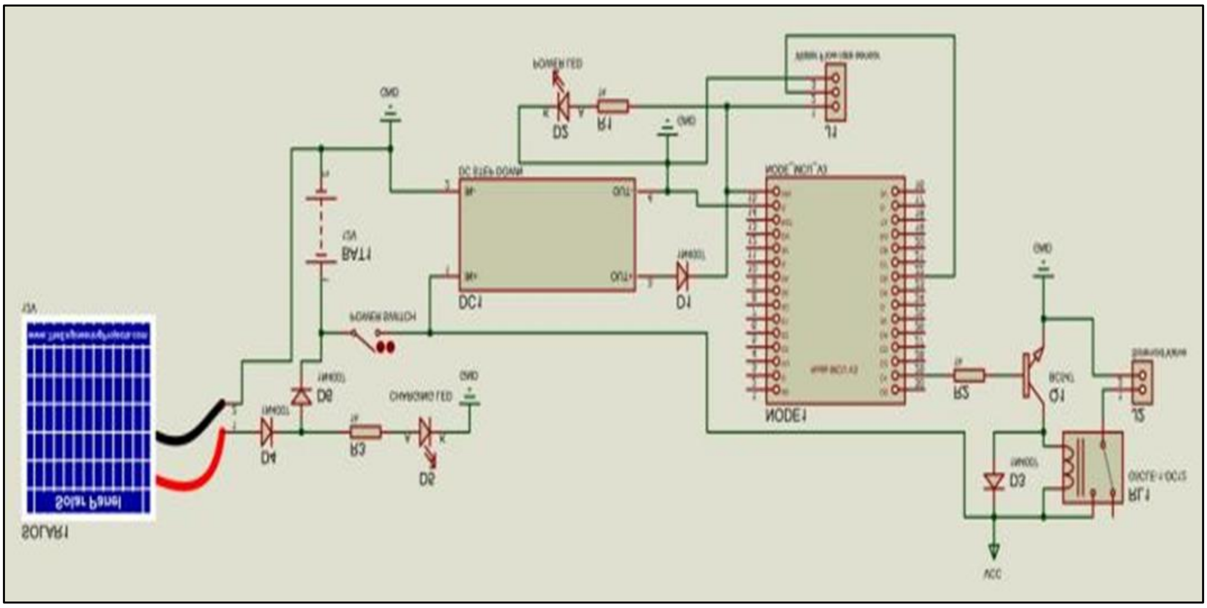

Figure 2 Circuit diagram of the system design

2.3. System Operation and Algorithm

The system algorithm, depicted in the flowchart in Fig. 3, operates as follows:

- Initialization: Serial communication, flow sensor interrupt, relay pin, and Wi-Fi (via WiFiManager) are initialized. The system connects to the Blynk cloud.
- Set Target Volume: The user inputs a desired volume via the Blynk app.
- Flow Monitoring: As liquid flows, the sensor sends pulses to the NodeMCU. An interrupt service routine (ISR) counts these pulses.
- Calculation: Every second, the main loop calculates the instantaneous flow rate and accumulates the total volume based on the pulse count and the sensor's K-factor.
- Display: Real-time data (flow rate, total volume) is sent to and displayed on the Blynk app interface.
- Control: The system continuously compares the total volume with the user-defined setpoint. When the total volume reaches or exceeds the setpoint, the NodeMCU de-energizes the relay, closing the solenoid valve and stopping the flow.
- Alert: The system updates the app interface, showing that the valve is closed and the target is reached.

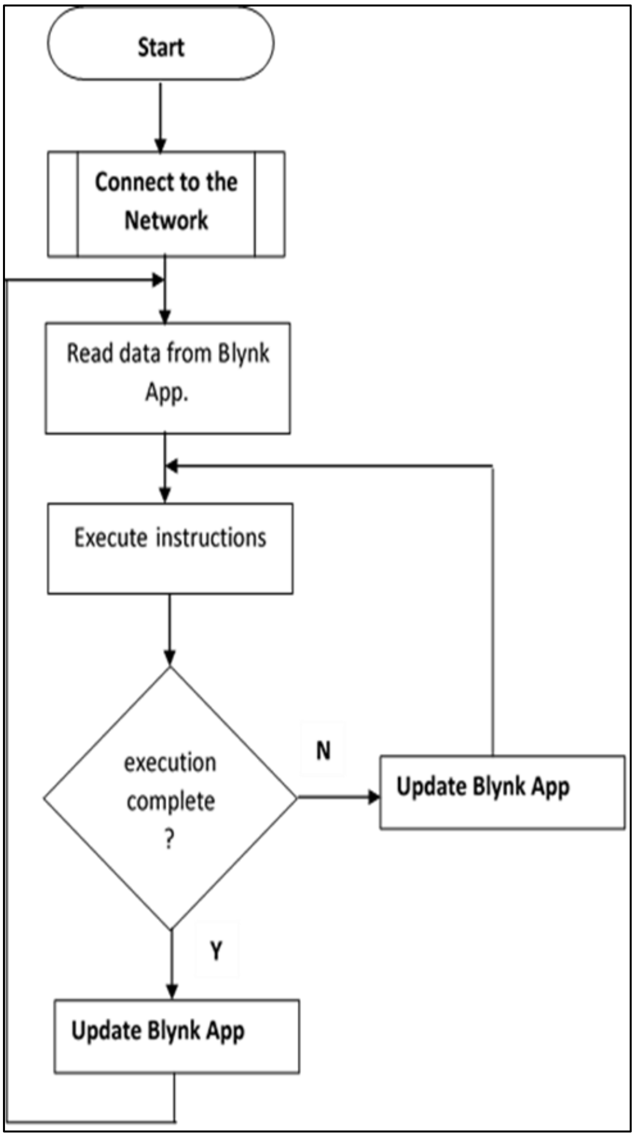

Figure 3 System operation flowchart diagram

3. Implementation, Testing, And Results

Following the circuit diagram, the hardware was assembled by soldering the NodeMCU, relay, and buck converter onto a perfboard, which was then enclosed in a waterproof project box with cable glands. The flow sensor and solenoid valve were installed in series on a test water line. The 12V battery and solar panel were connected to provide power, ensuring autonomous operation.

The firmware was successfully uploaded to the NodeMCU. The WiFiManager library allowed for easy configuration of Wi-Fi credentials. The device successfully connected to the Blynk cloud, and the virtual pins were synchronized with the smartphone dashboard, as shown in Fig. 4.

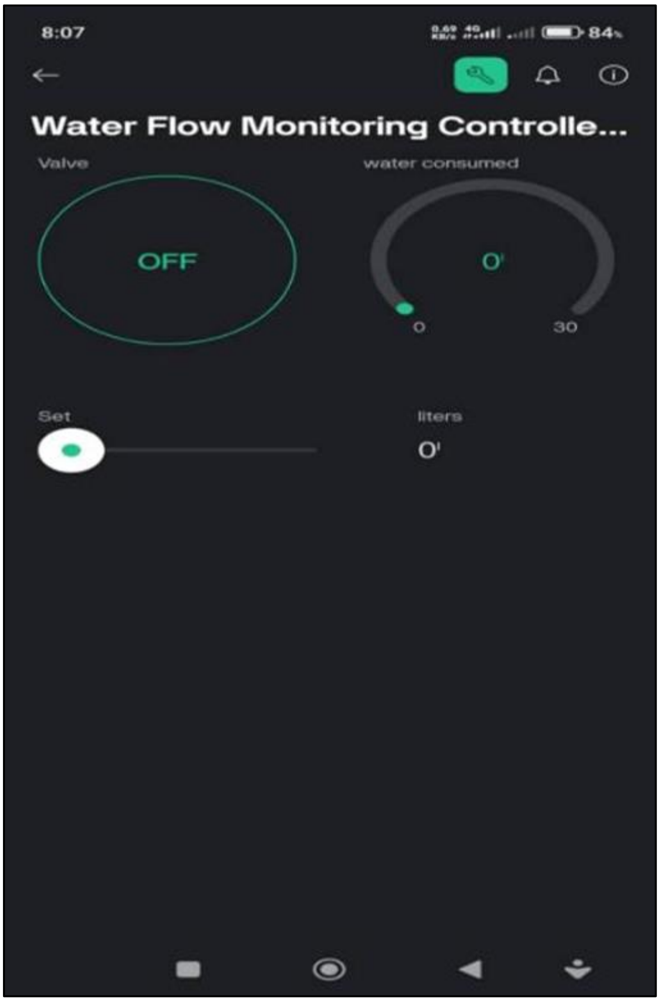

Figure 4 Software interface (Blynk App) for remote monitoring

3.1. System Testing and Calibration

The flow sensor was calibrated by allowing a well-known volume of water (10 litres) to flow through the system as the YF-S201 counts the pulses generated. Accordingly, the theoretical K-factor (450 pulses/litre) of the sensor was adjusted to 445 pulses/litre to match the actual measured volume, compensating for minor mechanical and installation-specific variations.

Functional Tests

- Accuracy: The volume measurement for the system was tested against a graduated cylinder for 1, 2, and 5 litres.
- Automatic Shut-off: the ability of the system to automatically close the valve upon achieving the desired volume was tested for 1L, 3L, and 5L.
- Remote Control: The manual open/close function and target volume setting were also tested through the Blynk app over a Wi-Fi connection.

The results of the accuracy tests regarding the volume measurement are presented in Table 1. This reveals that the system demonstrated a high degree of accuracy after calibration with an average error of less than 2% across the tested volumes. Furthermore, the automatic shut-off mechanism was reliable, closing the valve within 0.5 seconds of reaching the setpoint. The Blynk app was responsive for the remote-control function with minimal latency over a stable Wi-Fi connection.

The minimal deviations in measured volume could be attributed to water hammer effects, causing momentary inaccuracies in the sensor readings at the moment the valve closes. This could be improved on with software filtering or a gradual valve-closing mechanism. In general, the system successfully met all objectives, proving its capability for accurate and automated liquid management with a user-friendly remote interface.

Table 1 System accuracy test results

Test No.	Target Volume (L)	Measured Volume (L)	Actual Volume (L)	Error (%)
1	1.0	0.99	1.0	1.0
2	2.0	1.98	2.0	1.0
3	5.0	5.08	5.0	1.6

4. Conclusion

This work has successfully designed, implemented, and tested a functional prototype of a Smart Liquid Metering and Control System. The integration of a NodeMCU microcontroller, flow sensor, and actuating device to automate the process of measuring and dispensing a pre-defined volume of water was effectively done. The Wi-Fi connectivity and the Blynk IoT platform provided a modern, user-friendly interface for remote monitoring and control. This prototype demonstrates the practical application of an embedded system in automation. The system can be adapted for home automation, agriculture, and industrial processes. While the system enjoys several merits, there were a few limitations in that it was designed for low-pressure and non-corrosive liquids. It also relies heavily on Wi-Fi connectivity for remote access and does not include cellular backup. To enhance the system capabilities, future work could include implementing a cloud-based database, a leakage detection algorithm, and the incorporation of other sensor like pressure and water quality, for a more comprehensive liquid resource management.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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