Development of IoT-Enabled Smart Water Metering System

Saw Di Wen, Hazry Desa and Muhammad Azizi Azizan
Centre of Excellence for Unmanned Aerial Systems (COE-UAS), Universiti Malaysia Perlis, Block E, Pusat Perniagaan Pengkalan Jaya, Jalan Kangar – Alor Setar, 01000 Kangar, Perlis, Malaysia.

Abadal-Salam T. Hussain
Department of Medical Equipment Technology Engineering, College of Engineering Technology, Al-Kitab University, Kirkuk, Iraq.

Muhammad Hassan Tanveer
Department of Robotics and Mechatronics Engineering, Kennesaw State University, Marietta, GA, 30067, USA.

Rizwan Patan
Department of Software Engineering and Game Development, Kennesaw State University, Marietta, GA, 30067, USA.

Email: hazry@unimap.edu.my
www.unimap.edu.my

Abstract

This paper introduces a smart water meter that utilizes the capabilities of the Internet of Things (IoT) to automate the collection of meter readings. The primary goal of this project is to create an IoT-based device for reading water meters, while simultaneously developing a compatible mobile application. Instead of relying on manual meter reading, which requires human effort, this project proposes the use of an IoT-enabled water meter to collect the data automatically. The device employs a camera and Convolutional Neural Network (CNN) for image processing, making it easy to detect the meter reading accurately. The IoT system architecture involves the use of an ESP32 CAM for data collection, a laptop as a gateway, and the Message Queuing Telemetry Transport (MQTT) protocol for data transfer. The collected data is stored in Firebase's real-time database, and the mobile application is designed to monitor and analyze the data. A functional prototype of the device is constructed and tested in a housing area. The collected data is then monitored through the developed mobile application. Lastly, the data is analyzed to assess the suitability of the proposed method, and recommendations for future improvements are provided.

Keywords: IoT, Neural Network, Smart Water Management, Message Queuing system.

1. Introduction

Water consumption is currently in high demand and has been increasing due to population growth. Insufficient water management capacity, unstructured management, and the adverse effects of urbanization contribute to water shortages [1], [2], [3]. Particularly in residential areas, households consume a significant amount of water daily [4], [5]. This excessive consumption, exceeding the available water supply, raises concerns about future water shortages. Lack of public awareness, a significant percentage of non-revenue water, inefficient water demand management, and low water tariffs are generally recognized as the main causes of excessive water usage [6]. Excessive water consumption is also attributed to water losses. To address this issue, the water balance needs to be calculated, distinguishing between revenue water and non-revenue water. Unbilled permitted use and water losses are further categorized into apparent losses, which include customer meter errors and unauthorized use, and true losses, such as leaks in mains, service connections, and storage tanks [7].

Traditionally, water meters have been used for invoicing water consumption, and manual meter reading is the prevailing method. However, this approach requires a significant workforce and is prone to errors that can harm water companies. Moreover, manual meter reading often necessitates entering indoor premises, adding to the challenges faced by users and hindering daily operations [8]. Mechanical water meters, while reliable and affordable, do not allow for automatic or real-time monitoring of water usage. Consequently, water management companies have relied solely on them, despite the labor-intensive, time-consuming, and error-prone nature of the process [8]. The market is gradually shifting towards smart meter reading methods, which eliminate the need for manual reading. This transition began in industrialized Western countries, with the United States leading the adoption of smart meter reading technology in the 1980s [9].

The automated collection and analysis of meter data are facilitated by smart water metering (SWM) systems, which incorporate various technologies. Customers can access their water usage data through online platforms such as websites or mobile applications, allowing them to manage their daily water usage more efficiently. Smart metering improves operations by reducing costs associated with operation and maintenance, per capita usage, waste, and leaks. Key benefits include monitoring water flow, distribution, and consumption, improving access to clean and safe water, enabling frequent or real-time access to water consumption information and billing, reducing the need for manual meter reading, enhancing leak and fraud detection, and improving data collection accuracy [10].

2. Methodology

2.1. Hardware Requirement

The primary microcontroller employed in this project is the ESP32 Cam, which runs the main program. The program code is uploaded to the microcontroller using a programming software platform. Additionally, an SD card is utilized to expand the memory capacity, enabling the installation of the program, and recording of collected data. The camera module, a crucial component, is connected to the microcontroller and serves the purpose of monitoring the water meter by capturing images of the meter reading as shown in Fig. 1.

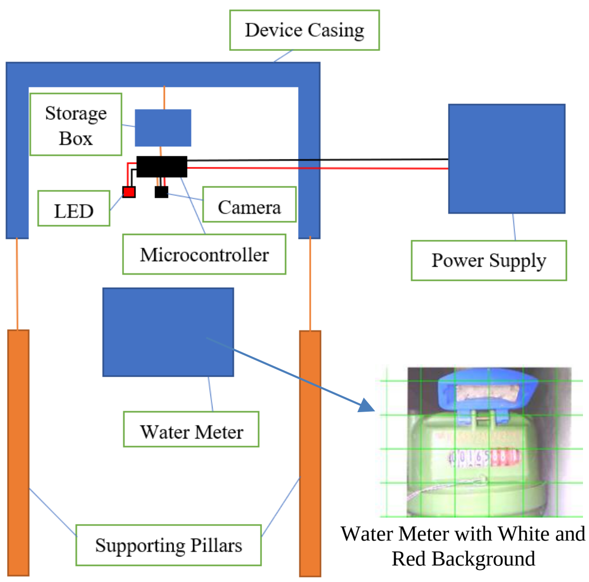


Fig. 1. The construction of a smart water meter featuring a display with white and red backgrounds.

2.2. Image Processing

The image processing algorithm used in this project has been modified from an open-source codebase originally created by Jomjol [11]. When an image is captured, it is sent to a web server for processing. On the server, the image alignment is adjusted to a specific orientation to facilitate smooth text recognition. Image segmentation can also be fine-tuned within a certain range to accurately detect numbers within the image. Additionally, artificial intelligence has been integrated into the image processing algorithm. By employing a Convolutional Neural Network (CNN) and training it with various types of water meter images, the accuracy of number recognition has significantly improved. The introduction of AI has enabled the microcontroller to perform data computation at the edge, rather than relying on cloud computing. This approach minimizes delays in obtaining data. Instead of waiting for data to be processed in the cloud, the microcontroller can analyze the information locally, resulting in real-time or near-real-time data processing.

2.3. Data Transfer

The image processing software developed by Jomjol utilizes MQTT to transfer data. The configuration for MQTT can be pre-set within the web server [11]. In this project, the microcontroller remains powered on for 24 hours, and data is collected at 30-minute intervals. To facilitate data transfer using the MQTT protocol, an MQTT broker must be installed on a device to host the server. In this case, the Aedes broker was chosen due to its easy installation process. Additionally, the Aedes broker is compatible with Node-Red, a programming tool used for sending data to Firebase. With some coding, the microcontroller can function as an MQTT publisher, responsible for publishing data on a specific topic. The Aedes broker then manages the published message and alerts subscribers who have subscribed to the same topic. In this scenario, the published message refers to the processed data, while the laptop acts as a subscriber, having Node-Red installed to receive the data. As a result, the microcontroller can establish communication with the laptop for data transfer. Leveraging the capabilities of Node-Red, the data can be further transmitted and stored in the real-time database of Firebase.

2.4. Cloud

For data transfer via MQTT, a connectivity platform is required, and in this case, a laptop is utilized as the gateway. The laptop acts as an intermediary, receiving data from the microcontroller and sending it to the cloud. Facilitating this communication is Node-Red, which has been installed on the laptop. All the data transmitted by the microcontroller is written into the Firebase real-time database. This includes the initial water meter reading as well as the most recent reading, along with timestamps indicating when the data was captured. The presence of data stored in the Firebase real-time database is considered a successful transfer of data from the microcontroller to the cloud at this stage. This mechanism aligns with the cloud and network aspects in the architecture of IoT.

2.5. Application

The final component of the IoT architecture involves application and data analysis. In terms of application, users can access the water meter data through a dedicated app from anywhere, as long as they are connected to a Wi-Fi network. Achieving this functionality involves synchronizing the database with the developed mobile application. Additionally, the app has the capability to generate a bill based on the collected data.

2.6. Flowchart

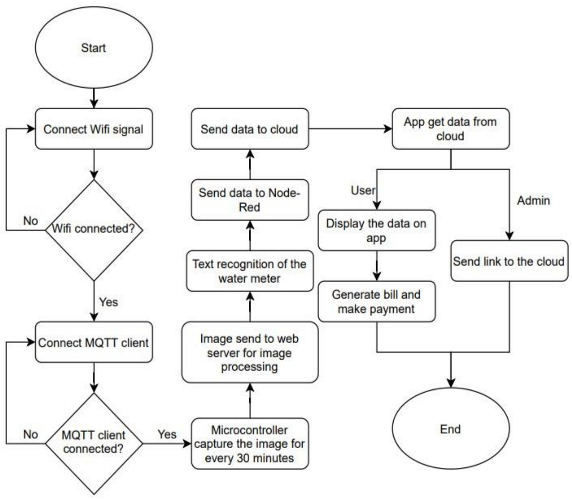


Fig. 2. Smart water meter system flowchart.

This paper proposes a method for obtaining water meter readings through a smart water meter system. To initiate the system, the microcontroller is powered on using a 5V DC power supply, enabling it to connect to a Wi-Fi network. Once a stable Wi-Fi connection is established, the program is designed to connect to the MQTT broker as a client. Once all connections are established, the microcontroller is ready to commence its operations.

The camera captures the first photo of the water meter immediately upon activation, with the triggering interval set to every 30 minutes. The captured image is then uploaded to a web server for further processing, aimed at extracting the data from the image. The text recognition process concludes by sending the detected value to the database via a tool called Node-Red.

The mobile application serves as a means for consumers to retrieve and monitor data from the cloud. It allows them to access the water meter readings and view them on their mobile devices. Additionally, administrators can utilize the app to monitor the readings and even send payment links to the cloud. Fig. 2 shows the flowcharts of the developed smart water meter system.

2.7. Circuit Connection

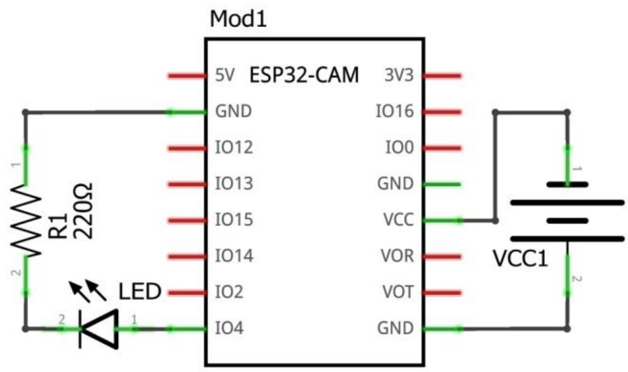


Fig. 3. Schematic diagram.

Fig. 3 illustrates the schematic diagram of the Smart Water Meter, showcasing the essential components of the electronic circuit setup for this project. The ESP32 Cam is a highly functional microcontroller board that integrates a powerful ESP32 chip, along with built-in Wi-Fi and Bluetooth capabilities. It serves as the primary component of the setup. Additionally, the hardware includes a camera module, enabling the device to stream video and capture high-resolution images. Furthermore, the microcontroller and an SD card are utilized to store the programmed code, offering versatile and expandable storage options. To enhance the lighting conditions for image capture, an additional LED is incorporated to illuminate the surroundings.

Regarding the power supply, this project utilizes a DC power source. To ensure compatibility with the hardware components, a 5V converter is employed. Acting as a crucial intermediary, the converter transforms the incoming AC power into a reliable 5V DC supply, which powers the main component of the project. This configuration guarantees a consistent and dependable power source, facilitating the smooth operation of the hardware and efficient execution of the programmed tasks.

3. Results and Discussions

3.1. Hardware Setup

A custom casing as shown in Fig. 4 has been designed specifically for the ESP32 Cam to serve as storage. This casing is positioned above the water meter and securely fixed in place using supporting pillars. This ensures that the captured images remain clear and avoid any blurring or distortion.

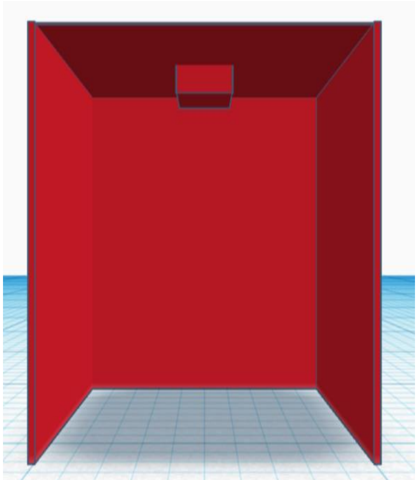


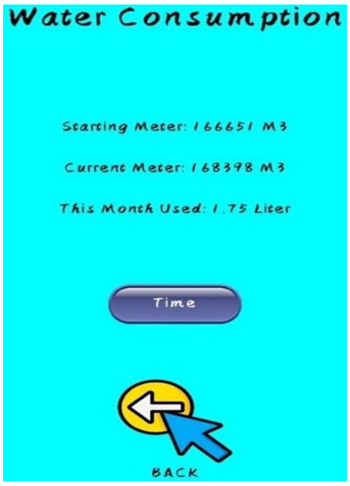
Fig. 4. Device casing - front view.

3.2. Mobile Application

A mobile application has been developed with various functionalities, including the ability to scan the Smart Water Meter to establish a connection with the app. It enables users to monitor their water consumption and generates bills based on their usage. The usage page provides insights into the user's water consumption, while the billing page generates the corresponding water bill. The app retrieves data directly from the connected smart water meter, ensuring accurate and up-to-date information.

With this mobile application, users can easily track their latest water usage and view the associated bill to understand the amount they need to pay. This functionality promotes increased awareness of current water consumption, leading to potential cost savings. By being more mindful of their water usage, users can effectively manage their consumption and make informed decisions to optimize their expenses. Fig. 5 illustrates the display of information in the developed app, specifically showcasing water usage details and the current usage bill. This information can be accessed within the app and has the capability to be printed for reference or documentation purposes.

(a)



(b)

Fig. 5. (a) Water usage page and (b) water bill page.

3.3. Data Analysis

Thorough analysis and discussion are conducted on the collected data, considering the output results. This data is obtained using the smart water meter device to retrieve the meter reading. All the collected data is extracted into an excel file to generate a graph for visualization as shown in Fig. 6. The blue line represents the value obtained after image processing, while the orange line represents the actual reading recorded from the captured image of the water meter.

Fig. 6 reveals the presence of spikes in the graph, indicating instances where the image processing detected false numbers from the water meter images. The primary cause of this issue is likely attributed to variations in the lighting conditions during image capture. The most common error occurs when detecting the last 3-digit number on the meter. Within the collected data, a cluster of errors is observed in the middle portion. This is attributed to a specific number repeatedly reading inaccurately, leading to the appearance of multiple spikes. However, as the dial turns to a different number, the errors diminish, resulting in fewer spikes toward the end of the data.

Another factor contributing to the occurrence of spikes is the presence of different background colors for the digits, specifically the red color shown in Fig. 1. The AI model used for the project was trained on images with a white background, which impacts the accuracy of the model and prevents it from reaching the desired level of performance.

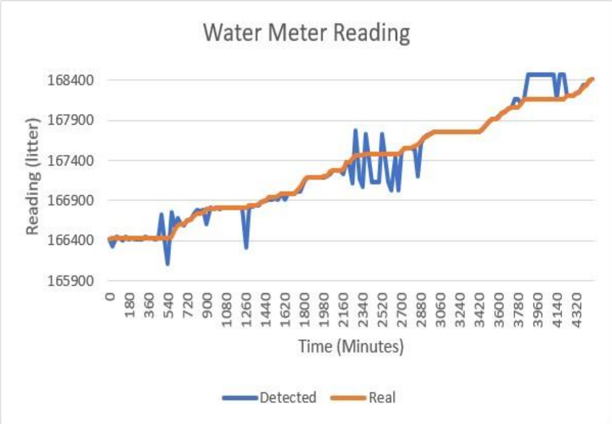


Fig. 6. Comparison of manual water meter actual reading between reading detected by the camera using image processing technique.

3.4. Data Accuracy

The spike in Fig. 6 may happen due to the different background color of the digits which is red color. The accuracy is only 3.33% for the device detecting all 8-digit numbers on the water meter. By reducing the last digit number with the red background, the accuracy has increased significantly to 53.33%. It is proved that the AI model can detect all the digits with white background as the accuracy for the first 5 digits is 100% accurate. The AI model is not trained with red background digit numbers, hence the accuracy for detecting the meter reading is not that high. Therefore, this explains the accuracy result in Fig. 7 that this AI model used has a low accuracy for detecting the meter digit number with red background.

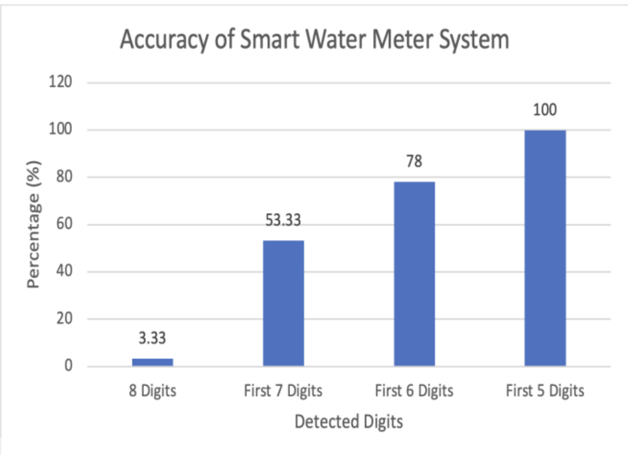


Fig. 7. White and red background effects on water scale meter accuracy.

4. Conclusion

Based on the aforementioned results, the system operates smoothly without encountering any critical errors, despite the detected data not being highly accurate. The accuracy of the data primarily depends on the AI model utilized for image processing. This discrepancy arises because the AI model was trained on a different type of water meter, distinct from the one employed in this project. Without proper training, the model's accuracy may be compromised. Nonetheless, the overall performance of the AI model is commendable, as it accurately identifies digits with a white background, exhibiting significantly higher accuracy than those with a red background. Thus, it can be concluded that a properly trained dataset greatly enhances accuracy. Utilizing the collected data enables us to ascertain the daily water usage for each household. By leveraging this data, predictions can be made to determine the water consumption in different areas, alerting the water supply company accordingly. This valuable information empowers the company to identify areas requiring additional water supply, ensuring residents do not face water shortages. Over time, as more data is gathered, the predictive capabilities of the system improve, resulting in more accurate forecasts. In summary, this IoT-based metering device resolves the issue of manpower required for water meter data collection while also offering long-term cost savings.

5. Future Recommendation

For the future implementation of this smart water meter system, there is a need to enhance the design of the device casing. The design should prioritize reliability and adhere to sound design principles. Additionally, the issue of sunlight penetration during the daytime must be addressed by reimagining the casing product. Furthermore, to address the common problem faced by all electronic devices, a comprehensive plan for sustainable energy usage in the power supply is necessary. Additionally, to improve the accuracy of the system, alternative algorithms can be explored and employed in conjunction with the AI model. Lastly, the mobile application can be enriched with additional features to enhance user experience. For example, incorporating a water leak detection feature would enable users to receive alerts regarding the condition of their pipes. Moreover, the billing system can be enhanced by expanding the range of payment methods, allowing for convenient online payments and improving user-friendliness.

Acknowledgment

This work was funded by the Universiti Malaysia Perlis (UniMAP) under the Commercialization Grant 9001-00748.

References

1. M. Nadason, Joint Press Release by FOMCA, WECAM, FAM: Celebrating World Water Day 2021 – Valuing Water, March, 2022.
2. H. Abdul Rahman, A Review on Water Issues in Malaysia, International Journal of Academic Research in Business and Social Sciences, Vol. 11(8), August, 2021, pp. 860-875.
3. S. Boatwright, S. Mounce, M. Romano and J. Boxall, Integrated Sensor Placement and Leak Localization Using Geospatial Genetic Algorithms, Journal of Water Resources Planning and Management, Vol. 149 (9), June, 2023.
4. L. Canale, T. Cholewa, G. Ficco, A. Suita-Olcha, D. Di Petra, P. Kolodziej and M. Dell'Isola, The Role of Individual Metering in Reducing Domestic Hot Water Consumption in Residential Buildings: A Long-Term Evaluation, Journal of Building engineering, Vol. 73, August, 2023.
5. M. Kavya, A. Mathew, P. R. Shekar and P. Sarwesh, Short Term Water Demand Forecast Modelling Using Artificial Intelligence for Smart Water Management, Sustainable Cities and Society, Vol. 95, August, 2023.
6. N.S. Muhammad, J. Abdullah, N. A. Rahman and N. A. Razali, Water Usage Behaviour: Case Study in a Southern State in Peninsular Malaysia, IOP Conference Series: Earth and Environmental Science, Vol. 646, 2021.
7. J. Cassidy, B. Barbosa, M. Damião, P. Ramalho, A. Ganhão, A. Santos and J. Feliciano, Taking Water Efficiency to the Next Level: Digital Tools to Reduce Non-Revenue Water, Journal of Hydroinformatics, Vol. 23(3), May, 2021, pp. 453-465.
8. J. Marais, R. Malekian, N. Ye and R. Wang, A Review of the Topologies Used in Smart Water Meter Networks: A Wireless Sensor Network Application, Journal of Sensors, Vol. 2016, October, 2016.
9. X. Cao, Design of Remote Water Meter Reading System Based on GPRS Technology, Journal of Physics: Conference Series, Vol. 1601, 2020.
10. T. Csaba, Challenges of Smart Water Metering, WM Systems LLC - Innovation in Smart IoT Systems, Mar. 11, 2021.
11. GitHub. Retrieved January 7, 2023, from https://github.com/jomjol/AI-on-the-edge-device

Authors Introduction

Mr. Saw Di Wen

He completed his bachelor's degree in Mechatronic Engineering from Universiti Malaysia Perlis and currently works as a Mechanical Design Engineer at Pentamaster Equipment Manufacturing Sdn Bhd in Penang, Malaysia.

Prof. Dr. Hazry Desa

He earned his Bachelor of Mechanical Engineering from Tokushima University, Japan, and proceeded to pursue his Ph.D. at the Artificial Life and Robotics Laboratory, Oita University, Japan, in 2003. Presently, he serves as the director at the Center of Excellence for Unmanned Aerial Systems (COE-UAS), Universiti Malaysia Perlis, Malaysia.

Dr. Muhammad Azizi Azizan

He received his PhD in Civil Engineering from the Universiti Malaysia Perlis. He is currently a senior lecturer in the same institution. He is head of Project Integration & Management (PIM) at Centre of Excellence for Unmanned Aerial System (COE-UAS), Universiti Malaysia Perlis.

Dr. Abadal-Salam T. Hussain

He is currently a Ph.D. faculty assistant professor and head of the department for Medical Instrumentation and Technique Engineering at Alkitab University. Previously, he was a staff member in the Faculty of Electrical Engineering Technology at Universiti Malaysia Perlis (UniMAP), Malaysia.

Dr. Muhammad Hassan Tanveer

He is an Assistant Professor of Robotics and Mechatronics Engineering at Kennesaw State University. Prior to that, he was a Post Doctoral Research Associate at Virginia Tech, USA where he was working on development of Bio-sonar sensor for UAVs navigations. He received his Ph.D. in Robotics and Autonomous Sytems with specilization in 'Collaboration of Heterogenous Team of Robots' from University of Genova, Italy, in 2019.

Dr. Rizwan Patan

He is currently working as a Assistant Professor in the Department of Software Engineering and Game Development at Kennesaw State University, Marietta, USA. He receives his Ph.D. in 2017 from the School of Computing Science and Engineering at the Vellore Institute of Technology.