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Digital Transmission of Conventional Water Meter using ESP32-CAM: A Review

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***Abstract*—This paper describes an innovative water metering system based on computer vision technology, which enables automated meter reading. The system relies on the ESP32-CAM module, which can take a high-resolution picture of a traditional analog water meter. The smart water meter takes a picture of a water meter. It uses computer vision algorithms to recognize the numeric digits on the meter dial, digitize the readings, and send the readings to users using a secure IoT (Internet of Things) platform for remote water consumption monitoring and management, thereby automating meter reading and eliminating labor costs and human error. The innovative water metering system was mounted in a tailored casing modeled and manufactured using Fusion 360, which protects the ESP32-CAM and electronic components from dust, water, and accidental impact in the field. Strong casing and mounting assist in making the device easy to install on different styles of water meters, improving the flexibility and functionality of the system. The potential uses of IoT connectivity not only allow access to data in real time but also foster new features such as automatic billing, notifications about water usage, and analytics, both for users and service providers. The focus of this project is to improve the efficiency and accuracy of water resource management and encourage positive consumption habits. By providing consistent and reliable data, the system supports data-driven decisions, as well as proactive maintenance, which is an interesting change for smart utilities.**

***Keywords*—component; formatting; style; styling; insert (key words)**

I. INTRODUCTION

Water meter reading is vital for efficient water management and billing. Traditional water meter reading involves a person reading the meter, which can often be inaccurate, manual, labor-intensive, or not efficient enough. With the availability of technology, automated advanced systems are being developed to overcome this issue. This project proposes an automated water meter reading using the ESP32 camera module and advanced image processing algorithms. The system uses a better-quality camera to capture high-quality images of the water meter, uploads them through Wi-Fi to the cloud, and processes the image to retrieve meter readings using Optical Character Recognition (OCR) through Google Vision and/or Tesseract. The system includes Twilio for consistent communications and data transfer and ultimately ensures consumer data is available in a timely manner for billing. This electronic capture of readings can provide improved accuracy and efficiency in the billing process, with endpoints to indicate where water was last billed and excellent enhancements on previous levels of consumption through consumption displays or easy access to billing history. The value of the project also provides tampering mechanisms or consumer irregularities while maintaining the billing system integrity to ensure consumers can trust it. The process of sending data from a traditional water meter using an ESP32-CAM involves taking advantage of the ESP32-CAM microcontroller's capability for wireless communication as well as image capture. Conventional water meters measure the flow of water that a residential or commercial entity consumes either through a mechanical dial (analog meter) or a digital signal (digital water meter). Using the ESP32-CAM with a water meter makes it possible to transmit the water meter reading for remote monitoring. Keeping track of water usage is part of the responsible management of resources in smart cities.

Traditional water meters consider the former manual verification and control an inefficient use of resources, as it can take much time. It is clumsy and results in costs associated with having to visit the meter manually, record the values, and submit the data to a computer. However, the ESP32-CAM can be used to automatically gain water meter readings remotely. The ESP32-CAM is an inexpensive all-in-one microcontroller that includes Wi-Fi, Bluetooth, and a camera model. Therefore, it is an excellent candidate for remote monitoring and Internet of Things (IoT) applications.

Water usage monitoring is an essential part of resource management in smart cities. Water is usually measured manually. This is tedious and inefficient. We can automate the process of monitoring water usage with an ESP32-CAM module, a low-cost microcontroller that offers Wi-Fi and Bluetooth native capabilities, and a camera module for remote monitoring and IoT applications.

Water metering forms the foundation of accountability in water usage, resource management, and billing. In its modern form, water meter reading is manual, time-consuming, and subject to human error. Manual reading of water meters can be removed with computer vision to automate the reading process and increase efficiency and accuracy. This is particularly beneficial in cases where meters are difficult to access or read (e.g., meters buried in a basement wall). These shortcomings, along with the pace at which the Internet of Things (IoT) and embedded systems are evolving, have led to the development of a concept to digitally read these traditional water meters as a cost-effective and non-invasive way of understanding water usage.

II. LITERATURE REVIEW

Standard mechanical water meters require a significant amount of manual labor, are subject to manual reading errors, and do not allow for real-time data. The consequence of this is that leak detection takes a considerable amount of time, leads to errors in billing, and generates poor resource use. With the worldwide concern over water availability increasing, we can no longer rely on traditional water meters as they exist today. The Internet of Things (IoT) provides an opportunity to upgrade the conventional water meter because IoT connects the physical world to the Internet, which allows for data collection, processing, and sharing in real-time (Mandal et al., 2025). The ESP32-Cam has emerged as an inexpensive, low-powered video and Wi-Fi product that makes it relatively simple to turn a conventional mechanical water meter into a smart digitalized one.

Rohini et al. present a simple and automated way of measuring electric energy utilization through the ESP32-CAM module with computer vision algorithms. It is based on taking pictures of analog energy meters, processing the image, segmenting the numbers, recognizing the number with appropriate character recognition, and then transmitting the data remotely. The authors believe the progression will limit human involvement, meaning fewer manual errors and more accurate data collection. The authors also consider measuring the performance of the method under various lighting conditions and angles and believe that the results were reasonably consistent with the system's ability to extract readings from the energy meters reliably. This paper suggests an engaging prospect for academic and commercial use of intelligent systems for energy management to develop systems with reliable, rapid, and efficient utility usage measurement with minimum error.

Krishnan et al. (2022) provide a comprehensive review of new water resource management, including Artificial Intelligence (AI) and Deep Learning (DL) technologies applied to the Internet of Things (IoT). The review covers topics including wastewater reuse and recycling, drinking water distribution, rainwater harvesting, and irrigation management. It shows how AI models, from machine learning algorithms to neural networks, can optimize water consumption, locate leaks, and monitor water flow and water quality levels. They emphasize the role of data, data-driven decision-making, and real-time monitoring and their role in meeting the challenge of water scarcity around the world - making these new methods an essential tool for sustainable water management.

Thai Vu Hien proposes an AI system on the ESP32-CAM platform for digital water meter reading using Optical Character Recognition (OCR). The research employs LoRa for data transmission, allowing for long-distance communication with minimal power requirements. The system provides an accuracy rate of 98.2%, indicating high reliability for digit recognition, and importantly, allows for application on low-power embedded devices. In contrast, the proposed design provides cost and ease of scalability, being low-cost and easily integrated into existing water meter infrastructures. This has exciting potential for innovative city proposals and industrial automation, which will provide better management of water resources.

Hudionetal. (2021) suggests a digital centralized water metering system through 433 MHz LoRa in response to the lack of accuracy and efficiency found in traditional analog water meters. The system is comprised of node devices with water flow sensors and Arduino microcontrollers that measure water usage and present the information to a concentrator, which sends it to the server through cellular space. Results show that transmission was conducted over a distance of up to 200 meters and reliably read a 97.31% accuracy rating, providing accurate data readings and measurements without requiring the existing analog meters to be replaced. This study also described the low energy consumption and cost-effective design of the system presented, which is suitable for smart city infrastructure and broader use with large-scale water distribution networks.

Van-Nam Pham and Ngoc-Khoat Nguyen provide an efficient, LoRa-based centralized digital water meter system that is considered appropriate for real-world implementation in Vietnam. The authors highlight the problems associated with traditional analog water meters, focusing on inaccuracy and inefficiency, and propose a solution of an electronic flow meter with LoRa wireless technology to transmit data to a middle receiver through a wired 3G/4G or Wi-Fi connection at a distance of up to 200 meters. The implementation of the new systems saved labor time, improved data accuracy, and provided real-time monitoring of water consumption. In addition, a management interface based online allowed water municipalities to manage customer water usage and track leaks and faulty meters. The authors noted the cost efficiencies created by imported systems and estimated that the production costs could decrease by 50% as it can be directly produced and procured in Vietnam. This is a scalable system for the performance of water resource management in residential or industrial water use and a promising utility to perform an important function.

Using LC sensors and Bluetooth Low Energy (BLE) connectivity interfaced with a mobile application for monitoring and token-based billing, Purboyo et al. present a prepaid water meter system. Manual water meter readings often produce inaccurate results that typify Indonesia's postpaid billing models. This research would benefit the user because they have a mobile application that allows for balance top-ups, to view the amount of remaining water credit, and to track past consumption. The authors stated that the LC sensor produced an error rate of only 1.33% and that BLE provides the user with uninterrupted data transfer onto their phone.

Palaniappan et al. (2015) provide a comprehensive study examining various Automated Meter Reading Systems (AMRS), highlighting the communication technologies included in their observation, including GSM, ZigBee, PLC, D-SCADA, and WiMAX. The study establishes the inefficiencies associated with human meter reading methods, such as human error, the nature of including labor, and slow billing time, and illustrates comparisons of the newer AMR technologies addressing cost, feasibility, reliability, and coverage. GSM-based systems were determined to be the most feasible and reliable with wide-ranging coverage and set-up cost, while PLC systems were more stable with communication range. The authors end their paper by emphasizing the potential of hybrid systems that integrate multiple technologies, creating a balance

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of cost-effective yet reliable latitude for scalability seen in large projects.

Mochammad Shaleh and colleagues detail a remote monitoring system for electricity meters based on the ESP32CAM microcontroller and Optical Character Recognition (OCR) analysis using MATLAB. The remote monitoring system takes periodic images of electricity meters and performs OCR analysis to extract readings, which are wirelessly transmitted. The design can be used for residential, commercial, or industrial electricity meters and provides real-time monitoring from a user-friendly interface. The study also illustrates the flexibility and cheapness of the remote monitoring system and promotes better energy management. They have additionally highlighted proactive maintenance through abnormality detection in electricity consumption, which allows for more sustainable electricity monitoring.

TABLE I. SUMMARY OF LITERATURE SURVEY

Reference Paper	Paper Authors	Technology Summary	Comparative Analysis	Trends/Gaps/Future Directions
[1]	L. T. Wallace	ESP32-CAM real-time usage monitoring	manual readings	Edge Computing for Real-Time Processing
[2]	Thái Vũ Hiền	LoRa technology for data transmission	long-range communication	Advanced Image Processing Techniques
[3]	M. Madhuri Latha, P. Sowmya, K. Aruna	Raspberry Pi technology is used	Deployment Complexity	data is transmitted to ThingSpeak, an IoT platform.
[4]	Mickeb	utilizes MQTT for data transmission	Power Consumption Low	Enhanced Data Security Measures
[5]	A. Majid, Jamaaluddin, A. Wiguna, H. Setiawan, A. Farihah	Automatic water flow sensor system	Managing water flow in real-time	Efficient Water Control
[6]	Ying Liu, Yan-bin Han, Yu-lin Zhang	Use of Digital Signal Processing (DSP) for character recognition	accurately recognizes meter characters	Advanced Image Processing Techniques
[7]	Miftahatur Rizqi Mifta	Using the NodeMCU ESP32	real-time monitoring and data visualization.	Deployment Complexity
[8]	Rifki Muhendra	Wireless Mesh Network System	low-power digital water meter reading system	Enhanced Data Security Measures
[9]	Baohua Sun, Michael Lin, Hao Sha, Lin Yang	Converts the traditional OCR task into an image captioning task,	Power Consumption Low	Energy-Efficient Communication
[10]	M.L., J.L.G., T.E., S.G., C.D., J.C.	ESP32 with Micro Python	Power Consumption Low	Advanced Image Processing Techniques
[11]	Jais Lia Gneskumar Kumaran;	Wireless communication	Focus on real-Time data handling	Energy-Efficient Communication

III. TECHNOLOGY USED

This system includes multiple technologies:

- IoT: The ESP32 chip itself is the embedded processor that does image capture, on-device processing, and communication; it is the "thing" of IoT.
- Arduino IDE is a great environment that is used extensively worldwide to write and upload code to microcontrollers like the ESP32. Using the IDE as a user-friendly environment to write code, the Arduino IDE implements C++ as a simplified framework that offers even more libraries. Many hobbyists and prototype users employ it as a simple way to develop quickly and build a utility for their projects.
- C/C++ is the programming language written for the firmware that runs on the ESP32-Cam.
- Cloud Application and Data Visualization: The incoming data is received and saved in a cloud database. This provider was chosen because it provides a cloud service with real-time data sync and built-for-scale options. Each time a new reading comes in, it updates the database; thus, you can check it immediately for your analysis and monitoring.
- Wi-Fi Libraries: Based on libraries that manage Wi-Fi connectivity, the device used to connect to Wi-Fi networks must deal with their network protocols.

IV. FUTURE SCOPE

The prospects of the Digital Transmission of Conventional Water Meters Using ESP32-Cam are bright, thanks to continued advancements in AI, connectivity, and power management. Future development would likely consider robust edge devices with more intelligence, where on-device AI models are able to self-calibrate and adapt to different types of meter records, as well as adverse environments (notably extreme glare condensation). Furthermore, the device's integration with Low-Power Wide-Area Network (LPWAN) integrated technologies will allow for deployment far beyond the reach of Wi-Fi hotspots. It would make the scope of the solution more suitable for a utility-scale in remote locations whilst improving battery life by an order of magnitude. The study would also explore advanced energy harvesting and other means of energy conversion, such as very high-efficiency solar panels, vibration energy harvesters, and flow harvesting technologies that are authorized to promote truly maintenance-free and long-term deployments.

Furthermore, the system would consider essential factors like predictive analytics for demand forecasting, the capability to measure historical consumption patterns to mitigate leaks proactively, and an advanced approach to managing data transmission with standards-based approaches to ease connectivity to broader innovative city frameworks. For instance, the protocol /format could be informed by solutions developed from other units and enhance how blockchain technologies come to ensure the integrity and security of data solutions. Interoperability should also build trust in the water consumption records that are formed.

[12]

V. CONCLUSION

This implementation of digital transmission of a conventional water meter with ESP32-Cam presents an exceptional and practical approach to modernizing water infrastructure cost-effectively and pragmatically. It deals effectively with issues associated with manual meter reading, including 1) real-time data collection, 2) increased precision, and 3) a more meaningful decrease in human errors. The ESP32-Cam with a built-in camera, Wi-Fi, on-device image processing, and embedded AI (optical character recognition or pointer detection) opens up the opportunity to automatically digitize conventional meters into smart-connected devices. While challenges such as the robustness of diverse environments and staying power for performance are noteworthy, continual innovation in edge connectivity and energy harvesting continue to demonstrate additional possibilities. In the end, given the opportunity to provide consumers and utility providers detailed insight into water consumption, this technology will have significant benefits in regards to managing water resources appropriately, allow for the early identification of leaks, and ultimately contribute to the onward global perspective of water sustainability.

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