Digital Transformation of Conventional Water Meter using ESP32-CAM

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ABSTRACT-

This project presents a cost-effective and efficient solution for automating the reading of conventional analog water meters by leveraging ESP32-CAM, a compact and affordable microcontroller with camera capabilities. Traditional analog water meters, while reliable and durable, require manual readings that are labor-intensive and prone to human error. To address these limitations, the proposed system uses image capture and Optical Character Recognition (OCR) techniques to digitally extract numerical readings from the meter. The extracted data is transmitted in real-time to an online server using the ESP32's built-in Wi-Fi, enabling remote monitoring. Additionally, a fallback mechanism is integrated using a microSD card module to store data offline in case of connectivity issues, ensuring data reliability. This solution minimizes human intervention, reduces errors, and enables efficient water usage monitoring, especially useful for smart city and utility applications.

Key Words: ESP32-CAM, Optical Character Recognition, IoT, Analog Water Meter, Image Processing, Remote Monitoring

1. INTRODUCTION

As urban populations grow and the demand for water increases, precise monitoring and conservation of water resources become increasingly important. Conventional analog water meters are widely used to measure the volume of water passing through pipelines, but they rely on manual readings, which are time-consuming, inconvenient, and prone to human error. To address these limitations, this project proposes a digital transformation of traditional water meters using the ESP32-CAM module.

Fig. 1 Analog Water Meter Reading

In the given image (Fig. 1), the analog meter display shows how manual readings can be misread, which this project aims to solve using OCR and automation.The readings are then transmitted via Wi-Fi to a cloud platform for storage and analysis. Additionally, a microSD card module ensures data is backed up locally in the event of connectivity issues. This approach ensures reliable, real-time monitoring of water consumption and supports the development of smart water management systems.

2. LITERATURE SURVEY

Multiple approaches have been proposed for automating meter reading systems, utilizing a combination of hardware and software techniques. Below are summaries of two relevant works considered in this project:

A. Automated Water Meter Reading through Image Recognition

This paper forms the foundation of our project. It presents a method to retrofit analog water meters using a Raspberry Pi, camera, and LED setup. It uses Optical Character Recognition (OCR) to extract numerical readings from captured images and uploads the data to the ThingSpeak IoT platform. The proposed system leverages Python-based image preprocessing, contour detection, and Tesseract OCR for digit recognition. The project emphasizes the advantages of cost-effective digitalization while addressing the limitations of manual reading, such as inaccuracy and time consumption.

B. Automatic Electricity Meter Reading Based on Image Processing

Although focused on electricity meters, this paper provides valuable insight into image processing workflows applicable to water meters. It proposes a smartphone-based solution that captures meter images, crops the numeric region, segments individual digits, and uses template matching for recognition. The system achieved a digit-level accuracy of 96.49% using a 32×32 template-based recognition model. Despite targeting digital meters, the robust segmentation and recognition strategy can be adapted for analog water meters as well, especially when combined with ESP32-CAM hardware.

3. PROPOSED SYSTEM

The proposed system aims to automate the process of reading conventional water meters using image recognition technology, implemented through a cost-effective and compact solution using the ESP32-CAM module. The system captures images of the water meter, processes them using a trained deep learning model, and displays the output through a web interface. The block diagram below (Fig. 2), illustrates the system components and data flow.

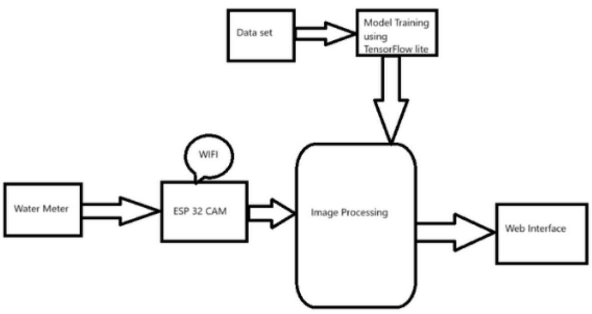

Fig. 2 Block diagram of Proposed System

A. ESP32- CAM

ESP32-CAM is the core hardware used in this system. It captures images of the water meter through its built-in camera module. The ESP32-CAM also has Wi-Fi capabilities, enabling it to send the captured images to a processing unit or server for further analysis. It is a cost-efficient, low-power microcontroller suitable for IoT and computer vision applications.

B. WATER METER

The analog water meter serves as the physical source of data. The ESP32-CAM is positioned to capture clear images of the digits displayed on the meter at regular intervals.

C. IMAGE PROCESSING

The captured images are sent via Wi-Fi for processing. This step involves applying Optical Character Recognition (OCR) to identify digits from the meter. A machine learning model, trained using TensorFlow Lite on a dataset of water meter images, is used for accurate digit detection. The trained model enhances reliability, especially in varied lighting and background conditions.

D. MODEL TRAINING

The image recognition model is developed using a dataset of water meter images and trained with TensorFlow Lite for deployment on resource-constrained devices. The training process involves preprocessing images, segmenting digits, and optimizing the model for efficient inference.

E. WEB INTERFACE

Recognized meter readings are displayed on a web interface for end-users. This interface provides real-time access to water consumption data, offering insights into usage trends and facilitating smart water management.

4. WORKFLOW

The project begins with setting up the ESP32-CAM module to capture high-quality images of a traditional water meter. These images are then preprocessed to enhance readability—steps include converting to grayscale, applying thresholding, and resizing them to match the input format required by the OCR model. A custom or pre-trained TensorFlow Lite model, specifically designed for digit recognition, is converted into .tflite format and deployed onto the ESP32-CAM using TensorFlow Lite for Microcontrollers. The image shown below (Fig. 3) outlines the basic workflow from image capture to processing.

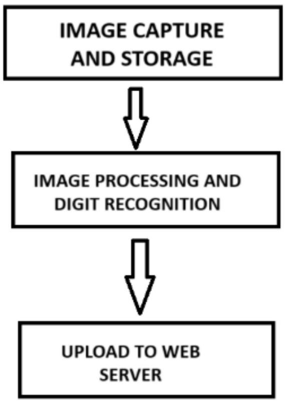

Fig 3. Basic Workflow

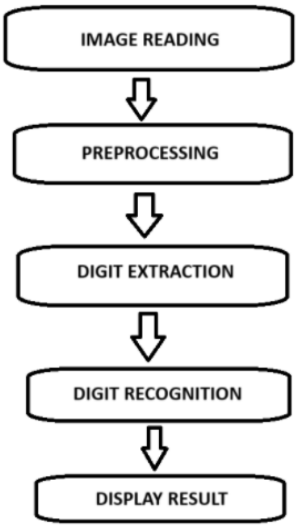

Fig. 4 Image Processing Workflow

In the above image (Fig. 4), the sequence of image processing steps—like grayscale conversion and thresholding—is shown in detail. Once the system captures and processes the image, it extracts the digits using the embedded model. The recognized water meter reading is then transmitted in real-time via an onboard web server hosted on the ESP32-CAM or through HTTP/MQTT protocols to a cloud server. A simple HTML and JavaScript-based web interface displays the current water usage data along with a timestamp, and optionally shows the meter image for verification. This allows users to remotely monitor water consumption conveniently.

To ensure reliability, the system is tested under different lighting and digit clarity conditions. The readings are compared with actual meter values to validate accuracy, and any performance issues are addressed by fine-tuning the preprocessing steps or improving the model. The project concludes with complete documentation, including system design, code, results, and a final presentation that showcases the process, challenges, and potential future improvements such as mobile app integration and support for other types of utility meters.

5. RESULTS

The digital water meter reading system was successfully implemented using the ESP32-CAM module. The system captures images of a conventional analog water meter and processes them to extract numerical readings using trained machine learning models. The image acquisition process is triggered at defined intervals, and each image serves as input to the digit detection module. As shown in the image (Fig. 5), the system setup with ESP32-CAM is compact and effective for field deployment.

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Fig. 5 ESP32-CAM Based Automated Water Meter System

The sample captured image (Fig. 6) shown above demonstrates how digits appear on the water meter. These images are transmitted via Wi-Fi to the processing unit, where image recognition techniques are applied. The captured frames, like the one shown below, serve as the input for the OCR model.

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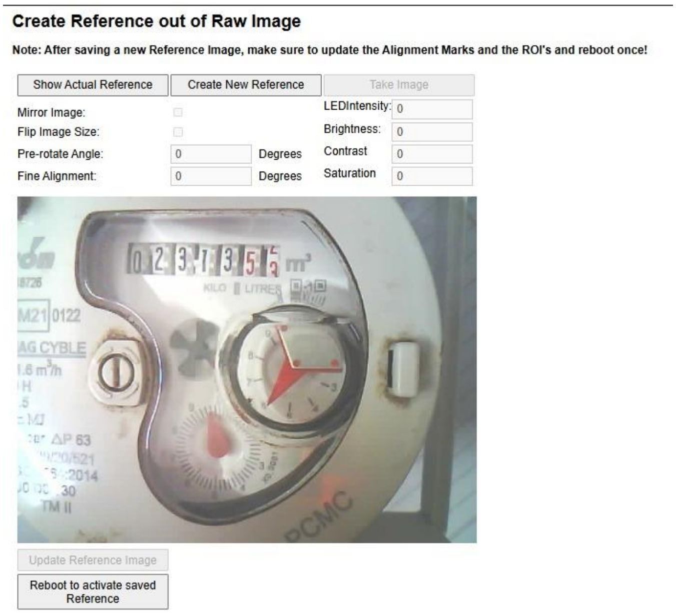

Fig. 6 Sample Captured Image from Water Meter

Captured images are saved locally or temporarily held in memory for processing. As seen in the given image (Fig. 7), the OCR system accurately extracts meter digits even under varying lighting conditions.

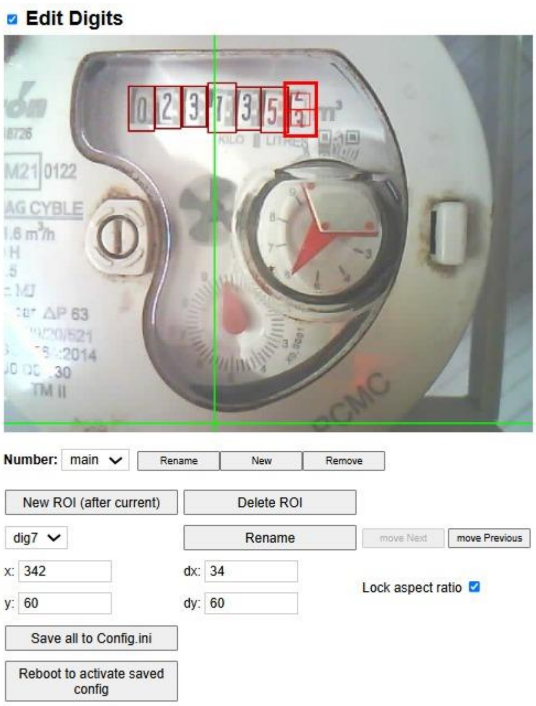

Fig. 7 Extracted Digits from Image

The extracted numerical readings are then displayed via a web interface. Users can view real-time readings and historical data. The interface also provides a simple dashboard for monitoring usage patterns over time.

Fig. 8 Web Interface Displaying Live Water Meter Readings

The system eliminates the need for manual readings and ensures that meter data is stored and organized in a way that allows users to monitor consumption trends. The web interface in the above image (Fig. 8) presents real-time readings with a user-friendly layout for remote monitoring.

6. CONCLUSIONS

This paper presents a compact, low-cost, and automated solution to replace manual water meter readings using the ESP32-CAM. It captures images of analog meters and applies OCR, powered by a TensorFlow Lite model, for accurate digit extraction in real-world conditions. The system uses built-in web Wi-Fi to transmit data to a interface and includes local storage for offline backup.
Overall, it improves efficiency, reduces errors, and enables smarter water management. The approach is scalable and can be extended to other utility meters like electricity or gas. Future enhancements may include mobile app integration, night vision, and solar-powered operation.

7. REFERENCES

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