REVOLUTIONIZING UTILITY METER READING IN DEVELOPING ECONOMIES: A COMPUTER VISION POWERED SOLUTION - A CASE STUDY OF PAKISTAN

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ABSTRACT

This research paper explores the modernization of meter reading processes in third-world countries, with a specific focus on Pakistan. Traditional manual meter reading practices in these regions are labour-intensive, error-prone, and time-consuming, leading to suboptimal utility management and financial losses. To address these challenges, our study introduces a digitalized meter reading system enhanced by computer vision and machine learning technologies. This system automates data collection, enables real-time monitoring, and employs data analytics to enhance accuracy and efficiency. By reducing human error and ensuring timely data transmission, this digitized assistant empowers utility providers to make informed decisions and optimize resource allocation. Using Pakistan as a case study, we evaluate the impact of the digitized meter reading assistant on operational efficiency, cost-effectiveness, and overall utility management. Through key performance indicators and case studies, we demonstrate how computer vision and machine learning can enhance service delivery, reduce financial losses, and promote sustainability in third-world economies. This research contributes to the discourse on technological interventions in developing countries by highlighting the potential of digitizing essential services like meter reading. The findings offer valuable insights for policymakers, utility providers, and researchers seeking innovative solutions to address operational challenges in similar socio-economic contexts.

KEYWORDS

OCR, Low-cost, Edge Deployment, Angle invariant, Light invariant

1. INTRODUCTION

The Smart Grid, a key focus of global research and discussion, represents the evolution of the electrical supply industry towards a system enabling bidirectional flows of information and power. It integrates Information Technology with the Electrical Grid. A critical component, the Advanced Metering Infrastructure (AMI), allows for communication between consumer smart meters and the smart grid [1].

In a rapidly evolving technological landscape, the integration of innovative solutions is imperative, especially in regions facing socio-economic challenges. This paper explores utility management in third-world countries, specifically focusing on meter reading as a crucial aspect

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of efficient resource allocation. Furthermore, it addresses the prevalent issues associated with manual meter reading in resource-constrained environments.

Manual meters', as shown in Figure 1, reading is a significant challenge in developing nations, characterized by labour-intensive processes, susceptibility to errors, and time-consuming procedures. These errors contribute to suboptimal utility management, resulting in financial losses and hindrances to sustainable development. We examine Pakistan as a case study to illustrate these challenges and emphasize the need for transformative interventions.

Figure 1. K-Electric electricity meters.

In response to these challenges, our research proposes an innovative solution: a meter reading app powered by computer vision and machine learning technologies. This digital assistant aims to revolutionize traditional meter reading practices, offering a streamlined and error-resistant alternative tailored to the unique challenges faced by third-world economies. Through a comprehensive case study in Pakistan, we explore the potential impact of this technological intervention on operational efficiency, cost-effectiveness, and overall utility management.

By highlighting the transformative potential of digitizing essential services in developing countries, our study aims to provide valuable insights for policymakers, utility providers, and researchers grappling with operational challenges in similar socio-economic contexts.

In summary, this research aims to bridge the technological gap in utility management, offering a tailored solution to the challenges faced by third-world countries. By harnessing computer vision and machine learning, our digitized meter reading assistant strives to catalyze positive change, facilitate informed decision-making, reduce financial losses, and contribute to the sustainable development of underserved regions.

2. PREVIOUS WORK

The integration of digital technologies into utility management, particularly in meter reading, represents a significant advancement in addressing the inefficiencies of traditional methods [2]. This section reviews pertinent literature covering digital meter reading systems, the application of computer vision in utility management, and the context of developing countries, with a focus on Pakistan.

[3] provides a comprehensive analysis of smart meter data analytics, emphasizing its pivotal role in optimizing power grid operations and promoting sustainable energy practices. It categorizes analytics into three phases: descriptive, predictive, and prescriptive, highlighting their significance in tasks such as load pattern analysis and forecasting. The study also delves into contemporary research developments, including big data challenges, innovative machine learning

methods, evolving business frameworks, energy system transformations, and the critical importance of data privacy and security in smart metering systems.

Maria Spichkova and Johan Van Zyl [4] conduct an extensive analysis of integrating computer vision technologies in utility meter reading. They perform a comparative study between TensorFlow Object Detection, an open-source framework, and Anyline, a commercial solution, evaluating their accuracy and processing speed. The study demonstrates TensorFlow's superiority in automated utility meter reading, offering a more accurate and reliable solution compared to Anyline. This research aims to identify the most efficient method for automating meter reading, addressing current challenges, and providing insights for future advancements.

The authors in [5] present a sophisticated approach to automatic reading of residential meters using a modified Faster R-CNN deep learning algorithm. They developed a solution that is both accessible and cost-effective, leveraging smartphones and neural networks to eliminate the need for additional hardware. The method involves a detailed process of object detection for meter counters and serial numbers, followed by Optical Character Recognition (OCR) for digit reading. The paper outlines the creation of a manually annotated database for training, the implementation of image augmentation techniques to expand the dataset, and a modification of Faster R-CNN to accurately represent and detect the regions of interest with minimal noise. This approach demonstrated robustness across various types of meters and achieved high accuracy in detecting relevant meter regions, showcasing the potential for integration with existing or new consumption tracking systems.

In [6] study, they introduce a system designed to identify and decipher numbers on various utility meters in natural environments, utilizing deep neural networks for both detection and recognition. The detection phase uses a Convolutional Neural Network for accurate pixel-level classification, while the recognition phase employs another deep neural network to determine the length and each digit of the meter number. They demonstrated the system's resilience to extreme perspective distortions, various lighting conditions, and blurry images, as well as its ability to detect small-scale digits. This method is advantageous for billing companies seeking to enhance efficiency and reduce the time spent on manual verifications during the billing process.

In the realm of Automatic Meter Reading (AMR) within unconstrained settings, the research [7] delineates a pioneering end-to-end methodology that synergizes the prowess of advanced Convolutional Neural Networks (CNNs) with an optimized variant of YOLOv4, termed Fast-YOLOv4-SmallObj, to ensure high accuracy and efficiency. This study introduces an innovative phase within the AMR pipeline, emphasizing corner detection and counter classification. This phase is instrumental in rectifying the counter region and excluding illegible or faulty meters prior to recognition, thereby enhancing the system's efficacy. Central to their approach is the utilization of Fast-YOLOv4-SmallObj for the meticulous detection of counters. This adaptation specifically augments the model's proficiency in identifying small objects across a multitude of conditions, making it a critical component in the initial stages of the AMR process. By modifying YOLOv4 to facilitate bounding box predictions at three distinct scales, the authors significantly bolster the model's ability to accurately discern small objects within complex backgrounds. Furthermore, the provision of the Copel-AMR dataset, a publicly available collection of meter images captured under real-life conditions—including those deemed faulty or illegible—marks a substantial contribution to the domain. The cascaded operation involving three networks, with the specialized Fast-YOLOv4-SmallObj playing a pivotal role, culminates in a system that not only surpasses existing methodologies in recognition rate and efficiency but also sets a new benchmark in the field of AMR. This integration of advanced detection and classification techniques presents a significant stride forward, offering insights and methodologies that could potentially reshape the landscape of automatic utility meter reading.

Pakistan's power sector faces critical challenges, including electricity theft, transmission losses, and circular debt, resulting in a rapid increase in electricity prices. Recommendations include policy reforms, tariff adjustments, investment in renewable energy, infrastructure modernization, and consumer education to create a sustainable and efficient power sector in Pakistan [8].

Current systems primarily comprise electronic energy meters that measure consumption in kilowatt-hours (kWh). Meter readers manually record these kWh readings monthly, a process managed by meter reading companies. For billing, these companies must correlate each user's electricity consumption data to determine the amount due based on the electricity usage [9].

In summary, existing literature forms the basis for implementing a digitalized meter reading system in Pakistan. The convergence of digital meter reading systems, computer vision, and machine learning technologies, aligned with the socio-economic context of developing countries, particularly Pakistan, informs our research. Building on these insights, our study aims to contribute significantly to the discourse on technological interventions in utility management within third-world economies.

3. METHODOLOGY

Our process workflow is structured to ensure maximum accuracy and efficiency, beginning with the capture of meter images. Following image capture, each image undergoes a series of pre processing steps to enhance quality and facilitate accurate digit detection. The processed images are then fed into our CNN models for digit detection and recognition. Each step in the workflow is monitored for quality control, with feedback loops in place to continuously improve model performance.

3.1. Data Preparation and Preprocessing

This section outlines the comprehensive process employed to prepare and preprocess the dataset for efficient meter reading using an AI-powered solution. The goal was to address the inefficiencies of manual meter reading by employing advanced techniques for digit detection and recognition. The entire dataset underwent meticulous cleaning and annotation using the LabelImg tool [10], followed by a multifaceted approach to enhance model performance.

3.2. Dataset Combination

The dataset, comprising images from both KE (K-Electric) and the Street View House Numbers (SVHN) dataset [11], underwent digit detection and recognition using Yolov3 [12] and a custom CNN [13] model. To diversify the dataset, we incorporated images from both datasets and applied histogram equalization [14]. Two variants of the dataset were created, one with histogram equalization and one without, to facilitate subsequent training of the digit recognizer.

3.3. Recognizer Data Preprocessing

To optimize the recognizer's performance, the single-digit KE dataset underwent augmentation through a multi-step process:

- Integration of additional SVHN data (1.2 GB) without further augmentation, leading to a substantial increase in the dataset size from 22,000 to 800,000 images.
- Random rotation with a maximum rotation angle of 7 degrees using Augmentor.
- Histogram equalization.

Prior to training, class imbalance in the dataset was addressed through under-sampling, ensuring a balanced representation of digit classes.

3.4. Methodological Enhancements for Automated Meter Reading

To bolster the effectiveness and reliability of our automated meter reading system, significant enhancements have been made in the areas of data collection and image pre processing. These improvements are aimed at addressing the challenges posed by diverse environmental conditions and the inherent variability in utility meter presentations.

3.4.1. Advanced Data Collection Techniques

Recognizing the critical importance of a robust training dataset, we have expanded our data collection protocols to include a wider array of environmental conditions, camera angles, and resolution settings. This approach ensures comprehensive coverage of real-world scenarios, significantly improving the system's adaptability and performance. By systematically capturing images of utility meters under varied lighting conditions and from different perspectives, our model is better equipped to achieve reliable digit recognition across a spectrum of challenging conditions.

3.4.2. Pre Processing Enhancements

Concurrently, we have refined our image preprocessing methodology to address common issues that affect image quality, such as low visibility and lack of focus. Through the application of dynamic range adjustments, we enhance the visibility of meter digits in poorly lit conditions, ensuring that the details necessary for accurate recognition are preserved. Additionally, the implementation of sharpening filters rectifies slight focus issues, clarifying digit edges and enhancing their recognizability. These preprocessing techniques are integral to maintaining the high accuracy of digit recognition, ensuring that subsequent stages of detection and classification are based on the best possible image quality.

Together, these methodological enhancements fortify the foundation of our automated meter reading system. By improving the diversity and quality of our dataset and refining the initial stages of image processing, we lay the groundwork for more accurate and reliable digit detection and recognition, paving the way for further advancements in utility management automation.

3.5. Digit Detection Using Yolov3

For the detection of meter LCDs and numerical digits, an end-to-end pipeline was designed, integrating two yolov3 models with distinct training strategies. The first yolov3 model was trained on the original KE images, while the second yolov3 model was specifically trained on *horizontally flipped* images. This deliberate use of data augmentation aimed to introduce variability to the training set, enhancing the model's adaptability to diverse orientations and real-world scenarios.

Upon receiving an input image, it underwent *decoding* from base64, representation. Subsequently, a duplicate of the original image was generated. This duplicated image, now horizontally flipped, was fed into the yolov3 model trained on flipped images. The model was configured with default *Non-Maximal Suppression* (NMS) [15] parameters, including a *threshold* of 0.45 and a *detection threshold* of 0.4. Concurrently, the original image was processed by the

yolov3 model trained on regular images, utilizing default NMS settings (0.45) and a detection threshold of 0.4.

The bounding boxes generated by both models were combined and subjected to a *custom* NMS operation with a threshold set at 0.5. This operation yielded the final set of bounding boxes which were then sorted based on the x_{min} value to ensure a sequential reading order. These bounding boxes were adjusted to the resized image dimensions of *416 x 416* hence they were scaled to accurately represent digit regions relative to the original image size, predominantly *250 x 500* (height x width). This scaling operation was seamlessly integrated into the inference pipeline.

Lastly, the pipeline involved utilizing the final set of bounding boxes to precisely crop the corresponding digits from the original image. This end-to-end pipeline, enriched using horizontally flipped images for training, not only served as a robust strategy for data augmentation [16] but also contributed significantly to the model's versatility and accuracy in recognizing meter displays and numerical digits across various real-world scenarios. The dual-model approach, combined with data preprocessing, formed the foundation of an adaptable system for accurate digit detection in diverse contexts.

3.6. Digit Recognition Using Custom CNN

To achieve accurate digit recognition, we trained a separate CNN on cropped digit images, enabling the model to identify each digit individually. For optimal results, a pipeline of data augmentation techniques was employed as explained in Section 3.3. The proposed model architecture is shown in Table 1.

In the conclusive configuration of our research pipeline, hyperparameter values were carefully selected to optimize the performance of the yolov3 object detection model. Specifically, confidence thresholds of 0.3 were applied to filter the detection results, ensuring a balance between sensitivity and precision. The non-maximum suppression (NMS) step, a crucial element in eliminating redundant detections, utilized a default threshold of 0.45 for the yolov3 NMS and 0.5 for a custom NMS tailored to our digit recognizing task. The recognized digits were then arranged in order based on their respective bounding boxes, yielding the final meter reading.
It is noteworthy that, despite considerations for enhancing feature visibility and contrast, histogram equalization was excluded from the final pipeline's inference stage. The decision to omit histogram equalization was made to maintain a streamlined and efficient processing workflow, as it was determined that the model achieved satisfactory results without the additional complexity introduced by this image enhancement technique.

Table 1. Model Architecture.

Layer (type)	Output Shape	Param #	Connected to
image (InputLayer)	(None, 200, 50, 1)	0	image[0][0]
Conv1 (Conv2D)	(None, 200, 50, 32)	320	image[0][0]
pool1 (MaxPooling2D)	(None, 100, 25, 32)	0	Conv1[0][0]
Conv2 (Cov2D)	(None, 100, 25, 64)	18946	pool1[0][0]
pool2 (MaxPooling2D)	(None, 50, 12, 64)	0	Conv2[0][0]
reshape (Reshape)	(None, 50, 768)	0	pool2[0][0]
dense1 (Desnse)	(None, 50, 64)	49216	reshape[0][0]
dropout_1 (Dropout)	(None, 50, 64)	0	dense1[0][0]
bidirectional_2 (Bidirectional)	(None, 50, 256)	197632	dropouy_1[0][0]
bidirectional_3 (Bidirectional)	(None, 50, 128)	164352	bidirectional_2[0][0]
label (InputLayer)	(None, None)	0	label[0][0]
dense2 (Desnse)	(None, 50, 11)	1419	bidirectional_3[0][0]
ctc_loss (CTCLayer	(None, 50, 11)	0	dense2[0][0]

4. RESULTS

Table 2 outlines the parameters utilized for evaluating the efficacy of the proposed pipeline. Insights drawn from these parameters are comprehensively presented in Table 3, and also displayed in Figure 2. Additionally, the outcomes derived from the testing phase are systematically compiled in Table 4, providing a thorough understanding of the pipeline's performance.

Table 2. Pipeline Parameters.

Parameter	Value
Yolo threshold	0.2
Yolo flip threshold	(0.2
Yolo IOU threshold	0.5
Yolo flip IOU threshold	0.8
NMS	0.3

Table 3. Baseline Results.

Accuracy	Coverage	Avg.	Min	Max	Std. dev	Count of identified
54.61%	99.54%	3.20E+11	0	4.11E+13	1.15E+13	1286

Table 4. Test Results.

Accuracy	Residual				Count of identified	Coverage	Precision
	Min	Max	Avg.	Std. dev			
95.12%	0	8E+6	33900.55	4.8E+5	943	100%	95.1%

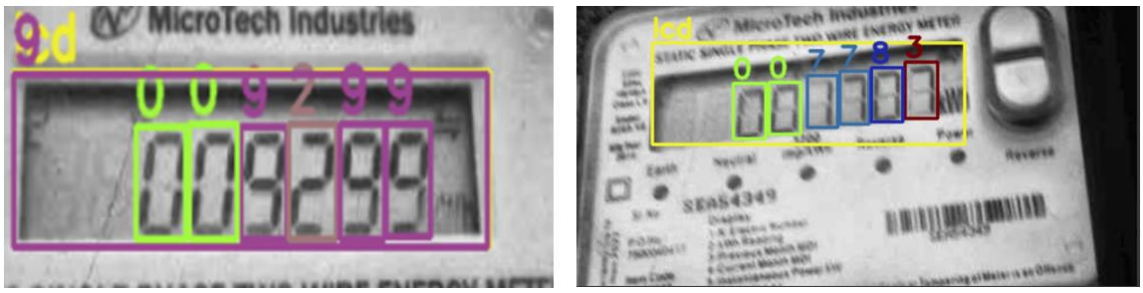

Figure 2. Results of our pipeline.

While our system demonstrates promising accuracy in automated meter reading, we acknowledge the challenge of differentiating closely resembling digits and dealing with varying image qualities. We are actively exploring advanced machine learning techniques and deep learning architectures to overcome these limitations. Furthermore, continuous data collection and model retraining strategies are being implemented to adapt to new challenges as they arise.

5. CONCLUSIONS AND FUTURE WORK

In conclusion, this research marks a significant stride towards automating meter reading in Pakistan using Convolutional Neural Networks (CNNs). Despite the promising outcomes, a critical issue was identified: the CNN's inability to accurately differentiate between the digits 0 and 1. This limitation is a primary contributor to incorrect digit recognition, posing a challenge for accurate utility management. Addressing this issue is pivotal for the future work in this field.
To further enhance the system's robustness and accuracy, especially under conditions that challenge image quality such as wide angles, low visibility, and unfocused captures, we propose the following strategies:

- **Advanced Preprocessing Techniques:** Implementing sophisticated image preprocessing techniques to improve visibility and sharpness, making it easier for the CNN to recognize digits under varied conditions.
- **Angle Correction and Image Stabilization:** Employing algorithms to correct perspectives and stabilize images, ensuring that digits are accurately captured even when the camera angle is not ideal.
- **Deep Learning Enhancements:** Enriching the training dataset with a wider array of image conditions and exploring advanced neural network architectures designed to handle distortions and quality issues more effectively.
- **Feedback Loop for Continuous Improvement:** Establishing a system where problematic images are manually reviewed, allowing for continuous model training and refinement based on real-world challenges.

Techniques such as dynamic range adjustment can be employed to enhance the visibility of digits in images captured under poor lighting conditions. Similarly, sharpening filters are applied to images that are slightly out of focus, ensuring that the digit edges are more defined and thus more recognizable by our system. These preprocessing steps are crucial for maintaining high accuracy in digit recognition.

Future research should focus on enhancing the CNN architecture or training methodologies to improve digit discrimination, and exploring alternative machine learning models or hybrid systems might offer more robust solutions. Integrating the aforementioned strategies will address

both the specific issue of digit differentiation and the broader challenges related to image quality, promising more efficient, cost-effective, and accurate meter reading processes. This would not only benefit operational efficiency in Pakistan but also set a precedent for other developing economies facing similar challenges. The long-term goal is to fully realize the potential of AI in utility management, bridging the technological gap and fostering sustainable development in these regions.

6. DATA PROTECTION AND MEASURES

To safeguard the privacy and security of the data collected by our system, we employ robust data protection measures. These include end-to-end encryption of data transmission, stringent access controls, and comprehensive data anonymization techniques. Our commitment to data protection is paramount, ensuring that all data is handled in compliance with relevant privacy laws and regulations.

6.1. Potential Risks and Mitigations

We recognize the potential security and privacy risks associated with the collection and processing of utility meter data. To mitigate these risks, we have implemented a multi-layered security strategy, including regular security audits, penetration testing, and the adoption of best practices in cybersecurity. Additionally, we continuously monitor for emerging threats and vulnerabilities, ensuring that our system remains secure against potential attacks.

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