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MIGUEL RODRIGUEZ

GEOVANNI BERDUGO

DALADIER JABBA

MARIA CALLE

MIGUEL JIMENO

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HD_MR: a new algorithm for number recognition in electrical meters

Miguel RODRÍGUEZ^{1,*}, Giovanni BERDUGO², Daladier JABBA¹,
Maria CALLE², Miguel JIMENO¹

¹Department of System Engineering, Engineering Division, Universidad del Norte, Barranquilla, Colombia

²Department of Electrical and Electronics Engineering, Engineering Division, Universidad del Norte,
Barranquilla, Colombia

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Abstract: Utility companies in developing countries employ analog electrical meters to determine consumption and bill their customers accordingly. Obtaining an accurate reading is an expensive and time-consuming process. High consumption levels of water, energy, or gas are fined by the government; thus, it is necessary to develop tools that allow users to be informed about their consumption in real time. This paper proposes a new number recognition algorithm named the Hausdorff distance for meter reading (HD_MR). Experiments prove that HD_MR can achieve a 99.9% recognition rate, even when recognized numbers are under rotation. The maximum recognition time is 31 ms; hence, the proposed method proves to be effective and capable in real time for the task proposed.

Key words: Image recognition, Hausdorff distance, template matching, electrical meter

1. Introduction

Responsible use of resources such as water, electricity, and natural gas has been enforced in the last few years. One of the measures adopted by the Colombian government includes fining customers with high consumption levels. Usage information is necessary for customers to regulate their own behavior and to create saving policies. The customer can read the meter installed by the utility company to be informed about service utilization. The problem with this method lies in the location of such meters, usually in places with difficult access. The problem of accessibility can be solved by installing a camera in front of the meter. Finally, obtaining information from the usage values becomes an optical character recognition (OCR) problem.

The task of recognizing characters in digital images has been addressed in several applications. The Hausdorff distance (HD) with template matching methods has been used in OCR and image recognition [1–4]. The car license plate recognition system described in [5] uses HD to compare the extracted characters from license plates to a set of templates obtained from images of characters. The recognition rate accomplished in this work was 93.76% for English characters. The authors of [6] developed a modification to the HD calculation to match words written in Bulgarian on scanned textbook pages using different distance metrics. The experiences mentioned above motivated the construction of an algorithm based on the HD to approach the meter reading recognition problem.

HD takes 2 binary images and computes how similar they are. The work in [7,8] defined HD as a metric and states its advantages in the pattern recognition process as the speed of computation, natural allowance, and small image perturbation. HD is formally expressed as follows [8].

*Correspondence: erodriguez@uninorte.edu.co

Given 2 finite point sets,

$$\begin{aligned} A &= \{a_1, \dots, a_p\}(\text{template}), \\ B &= \{b_1, \dots, b_q\}(\text{target}), \end{aligned} \quad (1)$$

the HD calculation is defined as:

$$H(A, B) = \text{MAX}(h(A, B), h(B, A)), \quad (2)$$

where

$$h(A, B) = \text{MAX}_{a \in A} \text{MIN}_{b \in B} \|a - b\|. \quad (3)$$

Here, h is known as the directed distance and $\|\dots\|$ is a distance function for measuring the distance between 2 points (a and b).

The authors of [9] stated that HD is likely to be affected by noise or outlier points in the set corresponding to the extracted image. To avoid this problem, several modifications to the HD calculation have been proposed.

Partial HD [8] consists of modifying the directed distance calculation. The K th distance is selected from the ordered sequence of the minimum distances from the elements of A to the elements of B . Censored HD [10] is based on the concept of partial HD. The directed distance remains selecting the K th element of an ordered sequence. In this case, the ordered list contains the Q th distance of the elements from set A to set B , instead of the minimum distances. Modified HD (MHD), presented in [11], does not select an individual element of the sequence. Instead, MHD uses an average of the minimum distances from the elements of set A to the elements of set B . MHD increases with the object mismatch and it is accurate in the presence of outliers.

The M-Hausdorff distance (M-HD) proposed in [12] modifies the directed distance based on M-estimation. The authors included a cost function used to eliminate outliers based on a threshold value. The directed distance is an average of the cost function evaluated for each minimum distance from the elements of set A to the elements of set B . The study in [12] also proposed LTS-Hausdorff distance (LTS-HD); the method approaches the calculation of directed distances based on the least trimmed square. This variation requires an h parameter between 0 and 1, an H parameter defined as $h * N_a$, and the ordered sequence of the minimum distances from every point of set A to set B . The directed distance is calculated by averaging the first H elements of the ordered sequence. Spatially weighted HD and adaptive weighted HD [9,13] give more importance to certain regions of the images. These methods penalize the least important regions in the calculation of the directed distance. The first method penalizes predefined areas of the image, while the second method finds them dynamically.

The HD for meter reading (HD_MR) algorithm proposed in this work is based on HD calculations and takes advantage of storing previous readings to approach the meter reading problem. When a reading is correctly recognized, each digit on the reading is accepted and stored as the last correct reading. When the HD algorithm cannot recognize a number, it uses the last stored digit.

The reading of meters brings an issue not common in regular character recognition. While numbers and letters in regular applications stand still, the numbers in the meter are rotating. The study in [14,15] employed an artificial neural network (NN) of 3 layers implemented in a digital signal processor in order to obtain energy usage in kWh. The study reported recognition rates above 95% for complete numbers and recognition times of less than 9 s. The same work obtained 60% recognition rates for half numbers; hence, the system has difficulties handling this scenario.

The authors in [16] proposed extracting eigenvectors of segmented digits and the application of a best-match algorithm to read electrical meters. The study in [17] presented a method for number classification using

the k-nearest neighbor algorithm. Other research involving feature extractions to approach meter reading recognition can be found in [18,19]. The main contribution of this work lies in the capabilities of recognizing numbers even with digit rotation.

There are other methods used for number recognition, such as NNs, which could be applied to recognize rotating digits. However, this research uses template matching-based algorithms for the following reasons: NN algorithms require a rigorous training process and introducing rotating numbers increases the amount of training images required. Finally, users of the electrical meter reading algorithm are electrical service users, who are more likely familiar with template image capturing than artificial NN training, as a calibration process.

The paper is organized as follows: Section 2 presents the new HD_MR algorithm, including preprocessing, location, segmentation, and binarization. Section 3 describes the experimental design. Section 4 presents the HD_MR results, comparing them with other methods. Section 5 concludes the paper.

2. The HD_MR algorithm

Recognizing numbers in digital images requires several subprocesses, as shown in Figure 1. The proposed recognition algorithm relies on prior processes to obtain suitable binary images of the individual digits. Through this document, a meter reading includes all 5 digits.



Figure 1. Different stages of the recognition system.

2.1. Image capture

Obtaining appropriate images for the recognition algorithm to work correctly is an essential part of the system. There are 2 particular conditions required: the first condition includes the camera position, distance, and angle from the lens to the object. The distance from the floor to the base of the camera is set to 29 cm, the distance from the floor to the base of the electrical meter is set to 22 cm, and, finally, the distance from camera lens to the meter is set to 5.5 cm. Figure 2 shows the distance conditions. These conditions are required because there are no preprocessing procedures and no algorithm for angle correction.

The second important condition is lighting, since meters have a protecting glass that produces undesirable reflections.

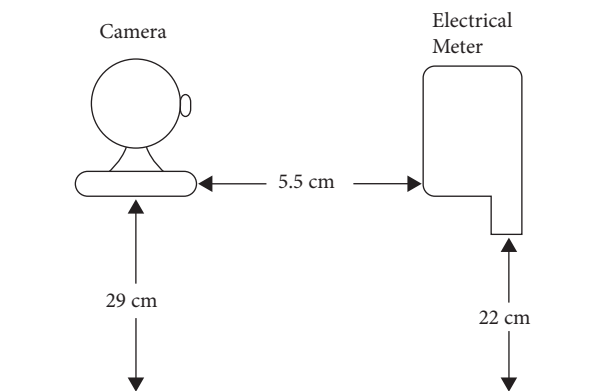


Figure 2. Distance conditions and image capturing.

2.2. Preprocessing

Preprocessing consists of locating the numbers in the image (image location), separating the numbers individually (segmentation), and representing the image with 2 levels, black and white. The preprocessing in this paper is based on the hue, saturation, and value (HSV) color model. HSV has been used to locate car license plates [20]. The method is advantageous in meter reading because of the combination of colors. The meter studied has a red digit surrounded by a red square in the rightmost position. Step 1 consists of classifying pixels in the image as red pixels and nonred pixels. It is possible to obtain a horizontal frequency histogram to determine the vertical bounds of the reading. Step 2 computes a vertical frequency histogram in the area found in step 1. The histogram is analyzed to find gaps between the numbers. After the analysis is completed, the procedure obtains a set of segmented numbers.

Finally, the segmented numbers are binarized using the HSV color model to classify them as white and nonwhite pixels.

2.3. Number recognition

After obtaining a segmented image in binary form, the recognition process begins. The following subsection explains HD_MR in detail.

2.3.1. HD for meter reading

The procedure must start with a reading of the complete numbers (digits that are not rotating). The requirement is based on the necessity of storing a reading history that autoevaluates the following recognitions. The proposed method uses regular HD to recognize complete numbers and store the result of the recognition. The following steps of the procedure are applied to each digit from right to left, until a complete reading is recognized.

Step 1: The step recognizes if a single fragmented frame represents a complete number or parts of 2 numbers when they are rotating. For this purpose we define 2 portions of the frame, the upper part and the lower part. The upper part represents the percentage of the frame with the number that will be replaced after rotation. The lower part represents the percentage of the frame with the number that will replace the prior number in the reading. This kind of discrimination is possible because of the blank space area between the numbers in rotation. Figure 3 shows the different stages of a rotating number.



Figure 3. Rotation stages.

Step 2: The procedure defines a threshold for a rotating number to be designated as ‘complete’. For this application, the threshold is set to 85% of the lower part. In other words, the system will only attempt to recognize a number when it has reached 85% visibility by the camera. This measure increases the HD recognition rate for individual numbers.

Step 3: Recognition is not attempted on partial numbers with a visibility under the established threshold. The reading for this specific position is kept identical to the one previously stored. Hence, this position is not considered to have changed its value yet. By applying this strategy, the recognition time is reduced because the system only attempts to recognize an image when it surpasses the threshold.

Step 4: When all of the frames corresponding to a reading are recognized, the previous recognition value is used to evaluate the correctness of the actual reading. The actual reading must be greater than or at least equal to the last one stored. If this is not the case, the reading is set to the one previously stored.

Step 5: The actual reading is stored as the previous recognition; the system waits until a new image is ready to be recognized and it starts again with step 1.

Figure 4 presents a flowchart of the recognition algorithm. It will give a complete idea of the structure of the proposed algorithm.

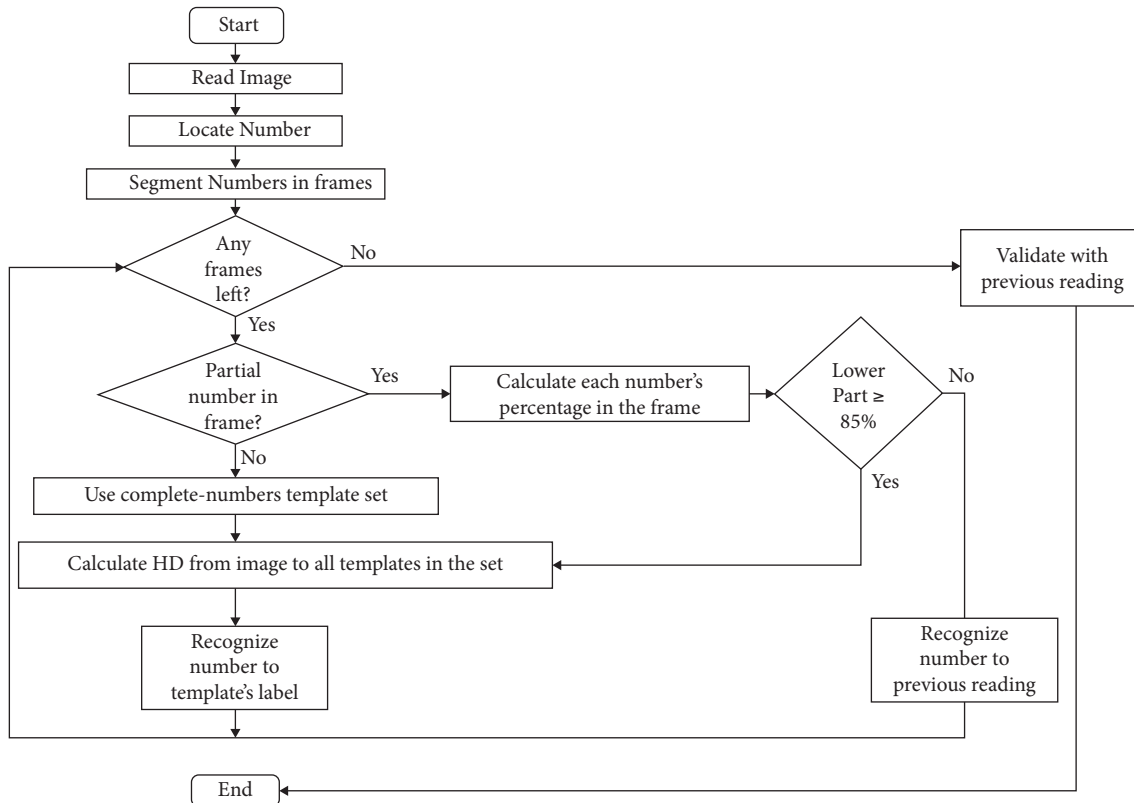


Figure 4. Flowchart of the proposed algorithm.

2.4. Different meters

The HD_MR method described in the previous section is designed with a meter model donated by an electricity company. However, the algorithm can be easily adapted for any meter by making a few changes: using an appropriate template set for the new meter and making sure to recognize the color surrounding the last digit in the reading. When the color is transformed into its HSV color model, it can be used to locate the reading in the meter; hence, the reading mechanism remains the same.

3. Experimental design

All of the experiments were executed on a MacBook Pro laptop with a 2.4-GHz Intel®Core™2 Duo processor, 4-GB DDR3 RAM, 250-GB SATA hard drive, and Mac OS X 10.6 operating system. The images were extracted from a Schlumberger IEC521 electrical meter. A FOSCAM FI8918W IP wireless camera was used to collect

the pictures for the experiments. The Java programming language was used to implement each algorithm, from number location to recognition.

Two metrics were used to evaluate the results of the proposed algorithm. The first metric is the recognition rate of a meter reading. A correct reading is defined as the correct recognition of each of the 5 digits shown in the meter. The second metric proposed is the maximum amount of time needed to complete a meter reading, either right or wrong.

3.1. The offline scenario

Two groups, consisting of 150 and 600 images with partial and complete numbers, were randomly selected to evaluate some critical points of recognizing the readings.

1. The first part of the test was built up to recognize the right-most moving number from 0 to 9 and returning to 0. The scenario considers the case where this rotation moves the 2 closest left neighbors to the last digit. Figure 5 represents the last 3 rotating numbers. The correct reading for this scenario is 12,399.
2. The second part of the test consisted of rotating the right-most digit of the reading completely. When the digit returns to 0, it moves its 3 closest neighbors. This scenario is represented in Figure 6. The correct reading is 12,999.
3. Finally, the last test turns the last digit until it reaches 0 and rotates every digit of the reading to its next number. The correct reading for Figure 7 corresponds to 19,999.

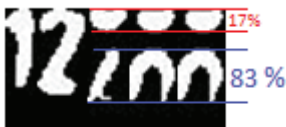


Figure 5. Rotating numbers, the last 3 numbers.



Figure 6. Rotating numbers, the last 4 numbers.

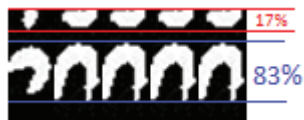


Figure 7. Rotating numbers, all of the digits move.

3.2. The online scenario

To test the HD_MR algorithm online, the camera was placed in front of the meter for 3.23 h consecutively. Our algorithm processed a total of 11,653 images corresponding to 1 snapshot per second. The FTP client embedded in the camera was used to store the snapshots of the meter. Our program accessed the FTP server and recognized the readings one by one.

The scenario was implemented in a laboratory to regulate the lighting conditions, location, and accessibility of the meter. The metering device was connected to an electrical source and different resistances in order to make the digits rotate. A wireless router was used to communicate to the FTP server and the camera.

Representative images of each number were chosen from a database of segmented numbers previously captured and processed; we call this set of images the set of templates. The set of templates used in this scenario was the same one used in the HD comparison and is illustrated in Figure 8.

Finally, this scenario will demonstrate that the HD_MR algorithm is capable of real-time number recognition.



Figure 8. Set of templates.

3.3. HD_MR comparisons

Since the literature presents some methods applied to rotating numbers with low recognition rates, incompatible scenarios, and experimental designs, for example [14,15], where a NN is tested on a digital signal processor with wireless communication via a ZigBee module, we decided to compare HD_MR to different variations of HD. Nevertheless, their results are included to provide a discussion on both online and offline scenarios.

A block of images measuring 19×45 pixels was used to compare the proposed algorithm to 3 different HD variations. The particular variations were regular HD [8], MHD [11], and LTS-HD [12]. Such comparisons show the potential of MR_HD reading digits under rotation compared to regular HD methods.

The proposed method was also compared to the approach developed in [14] because their work mentioned preliminary results on rotating numbers. The 3-layer NN described in their work was implemented on our experimental setup using the back-propagation algorithm and the results are compared to HD_MR in terms of the correct readings as described before.

4. Results

4.1. Offline results

This study analyzes the performance of HD algorithms (including the proposed HD, HD_MR) for the 2 experiments mentioned in Section 3.1: the first with 150 test images and the other with 600. The data set of meter images used in offline tests includes complete and partial numbers (simulating the rotation of one digit).

Table 1 summarizes results for the test with 150 images. Note that regular HD methods offer low recognition rate levels (less than 24.7%); the reason for this behavior is that the algorithms work with images containing complete numbers, but not with partial number images. However, the HD_MR algorithm exhibits the highest recognition rate, which indicates that this new method offers better performance for the same scenario.

Table 1. Summary results for the test with 150 images.

Algorithm	Maximum time (ms)	Images	Successful readings	Recognition rate	90% confidence interval	
					Lower	Upper
HD	36	150	37	24.70%	18.88%	30.46%
MHD	36	150	37	24.70%	18.88%	30.46%
LTS-HD	41	150	13	8.70%	4.89%	12.45%
Proposed HD_MR	31	150	150	100%	100%	100%

The same experiment is repeated with 600 images, the results are listed in Table 2. As it is expected, the recognition rate for regular HD methods presents a decreasing trend, because more partial number images are added to the data set in comparison with the first test (150 images).

Table 2. Results for the test with 600 images.

Algorithm	Maximum time (ms)	Images	Successful readings	Recognition rate	90% confidence interval	
					Lower	Upper
HD	35	600	89	14.80%	12.43%	17.19%
MHD	37	600	85	14.10%	11.80%	16.48%
LTS-HD	42	600	31	5.20%	3.67%	6.64%
Proposed HD_MR	30	600	600	100%	100%	100%

The maximum processing time is an important metric because it presents the worst-case scenario in real-time applications. In both tests (150 and 600 images), the HD_MR algorithm offers the lowest values, 31 and 30 ms, respectively, proving to be effective and capable in real time for the task. Table 3 shows the results obtained by the authors of [16], where we can appreciate that our method outperforms the recognition rate of their approach. However, the method in [16] does not mention tests regarding rotating numbers.

Table 3. Eigenvector-based method recognition rates [16].

Algorithm	Images	Successful readings	Recognition rate
Eigenvectors	200	195	97.5%

4.2. Online results

Because regular HD algorithms have not been tested in real-time applications, only results for the new HD_MR method are listed on Table 4. When comparing the offline and online results, the recognition rate decreased from 100% to 99.9%. Table 5 shows the results obtained by replicating the NN approach proposed by the authors of [14], comparable with our online results.

Table 4. Results for the online test.

Algorithm	Maximum time (ms)	Images	Successful readings	Recognition rate	90% confidence interval	
					Lower	Upper
Proposed HD_MR	31	11,653	11,643	99.9%	99.87%	99.96%

Table 5. NN-based recognition rates.

Algorithm	Images	Successful readings	Recognition rate
NN [14]	500	475	95%

The online tests were developed during the daytime, where dark lighting conditions would make the online scenario as similar as possible to the laboratory conditions. However, light is one of the reasons the online scenario failed to recognize all of the readings from the electrical meter. The main reason is the high level

of light that reflects on the meter's numbers. The reflection causes missegmentation and misinterpretations by the color model, creating reading errors. Figure 9 illustrates some elements affected by the lighting conditions.



Figure 9. Errors after preprocessing on number 0.

Another source of error identified in our model is the poor image capture capabilities of the device used to monitor the meter. If the image resolution increases, the chances of misreading due to lighting conditions may decrease because the HSV color model will not misinterpret colors.

The results shown in this section demonstrate the online capabilities of the HD_MR algorithm and the reasons why the algorithm fails to recognize some readings. Finally, we consider that more efforts should be directed towards managing dark light conditions, as well as better ways to treat low-resolution images in VGA format.

5. Conclusions

The task of recognizing patterns in digital images is not straightforward, even though it has been researched for a long time. Different methods have been proposed to approach the problem depending on the target pattern to be recognized. In the case of number recognition, HD-based methods have been used successfully in a wide variety of scenarios. On the other hand, the recognition of rotating numbers still represents a challenge. Our proposed HD_MR method is an approach to the number-in-motion recognition problem. Given the results of a 99.9% recognition rate and 31 ms maximum recognition time, the method is reliable and suitable for real-time applications.

The HD_MR method was developed to be used by utility company customers rather than the company itself. A proposed future work includes real-life environment test scenarios that require an adjustment of the location, segmentation, and binarization processes. Additional future work should study different methods for suppressing the need for a previous reading.

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