

Efficient Way of Reading Rotary Dial Utility Meter Using Image Processing

Moussa Souaré, Dr. Frank Merat, and Dr. Christos Papachristou
Electrical/Computer Engineering, Case Western Reserve University, Cleveland, Ohio 44106

Abstract—Reading a rotary dial utility meter can be difficult and, more importantly, inaccurate. This paper has developed a computationally efficient method to read a rotary dial utility meter via image processing. The method has been developed as an algorithm with the ultimate goal of implementing the system with a microprocessor and inexpensive camera. The algorithm registers successive dial images, subtracts them to detect dial movement, and uses pattern recognition to locate each dial. The movement of each dial is then used to calculate utility consumption. Sample meter images were obtained by scanning an actual rotary meter. The algorithm's image resolution requirements were determined. The algorithm was simulated in Matlab and timing analysis performed to determine where the algorithm may be improved. The algorithm was successfully run with sample meter images with the algorithm correctly determining the indicated consumption.

Keywords—Rotary dial utility meter, image resolution, image processing.

I. INTRODUCTION AND BACKGROUND

Exhibiting a simple architecture, rotary dial meters are widely used by utility companies for various purposes such as monitoring and evaluating energy, gas and water consumption. However, their structural simplicity does not prevent reading difficulties. To read a rotary dial meter with precision is not as simple as it seems. This is mainly due to human factors such as the human visual localization of the dial and manual data recording leading subsequently to inaccurate billings. For many applications such as energy auditing it is highly desirable to have an automatic, accurate way to read rotary dial meters and provide the usage in an electronic form.

This paper presents a new approach to mitigate issues related to rotary dial meter reading. Based upon image processing this new approach uses successive images of the rotary dial to effectively localize the dial positions subtract two images from different times, and calculate the angles the dials have moved. The dial movement thus obtained can be used to calculate the energy or utility consumption.

Prior work on meter automatic reading is described in [1] where a digital display electricity utility meter was read using computer vision techniques. An image as shown in Fig.1 was captured by a camera and was transmitted to a computer. An

algorithm was then used to perform image segmentation, boundary extraction, pattern matching, and neural network techniques for automatic digital number reading as illustrated in Fig.2.



Fig. 1. Partial display of the kilowatt-hour meter (Courtesy of [1])



Fig. 2. Display of the digital watt-hour meter and its segmentation result (Courtesy of [1])

This algorithm is accurate and can be used to monitor energy usage. However, a typical US meter uses rotary dials. A different algorithm is then required to monitor utility meters in the US.

II. METER RECOGNITION PROCESS

While a commercial non-invasive meter reading system is envisioned using an inexpensive digital camera, the images for this paper were obtained using a high-resolution scanner which allowed the effects of image resolution to be evaluated. A rotating dial meter face was placed on the scanner and manually rotated to represent varying utility consumption as shown in Fig.3.



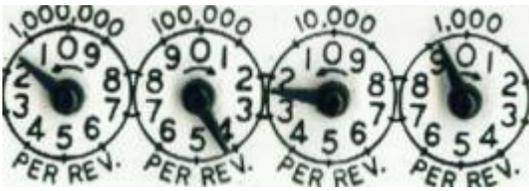


Fig. 3. Rotary dial meter at two different times

The resulting images were then processed by the algorithm described in this paper to calculate utility usage. Meter recognition is defined by the position of the dials and dial indicators as illustrated in Fig. 4.

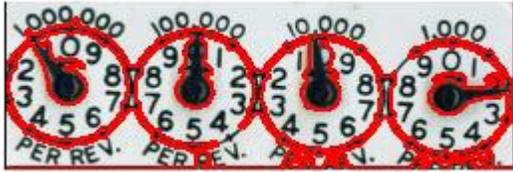


Fig. 4. Display of dials recognition on the meter

To reduce required processing time, the images were cropped to include only the meter dials and resized to the lowest necessary resolution (see Fig.5). It is important to mention that resolution affects the overall algorithm [2], processing time, and accuracy as explained further.

III. IMAGE PROCESSING TECHNIQUES

Since the 1920s, image processing techniques have been used in many engineering and science applications [3]. Companies such as Mathworks have developed software such as the Matlab Image Processing Toolbox with many commonly used functions. Since the goal of this paper is to develop an algorithm for a microprocessor based meter reader, Matlab will be used as a prototyping language for the algorithm while focusing on the image processing functions which are appropriate for microprocessor implementation.

A. Cropping and Resizing

After scanning the image of the meter, the Region Of Interest (ROI) was required to effectively distinguish the dials. To do this, the image was cropped to a specified spatial coordinate of a rectangle. A rectangle was chosen as it displays the dials and the dials indicators and it is a simple function to execute. Subsequent to cropping, the image was then resized as appropriate. The image was resized to a typical resolution of 95 x 269 pixels. This resolution was the lowest resolution at which the algorithm worked accurately.

Fig. 5 is the image of the meter image after being resized to a resolution of 95 x 269 pixels. The dials are still clearly readable at this resolution.

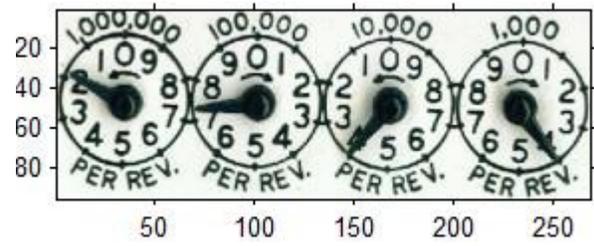


Fig. 5. Resized picture of the meter

B. Filtering

The Laplacian edge operator was used to extract the edges from the image of Fig. 5. The edges of the dial indicators are of particular interest.

1) *Laplacian*: For any given image represented by $f(x, y)$, the Laplacian is defined [3] by the following equation; where x and y are the pixel coordinates of the image.

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \quad (1)$$

The dials were extracted from the image by applying to the image the discrete form of (1) as defined in (2).

$$\nabla^2 f = [f(x + 1, y) + f(x - 1, y) + f(x, y + 1) + f(x, y - 1)] \quad (2)$$

The application of the Laplacian filter to a rotary dial meter image is shown in Fig. 6.

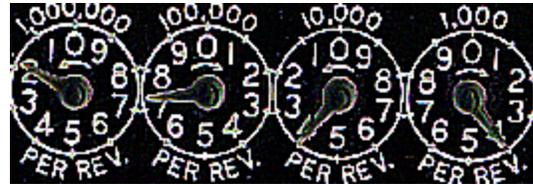


Fig. 6. Image of the meter subsequent to Laplacian filtering

It is clearly seen that the Laplacian filtering has extracted and highlighted the four dials of the rotary dial meter. The importance of displaying only the dials will be discussed in later sections.

C. Registration

Utility usage will be calculated by image subtraction as described in later sections. To accurately subtract images, it is necessary that they are precisely registered. Since the camera is not rigidly anchored to the meter, all images are registered [4]. The base image, also known as the reference image, is the reference to which all other input images are compared. In other words, all input images are aligned with the base image. To do so, a spatial transformation is applied to each input image to ensure the mapping of locations in each image to the reference image. Registration can be done by a number of

methods such as image correlation, where images pixels are directly correlated to each other [5]; the Fast Fourier Transform (FFT) that utilizes frequency domain of the image representation function [6]; and using specific features of the image like corners [7] to register the images.

For flexibility and computational efficiency, this paper used the affine transformation for registration. In the affine transformation, lines remain straight and parallel lines remain parallel, while rectangles are transformed to parallelograms. An affine transformation maps a pair of image coordinates (x_1, y_1) to another pair of image coordinates (x_2, y_2) by the following equations:

$$x_2 = x_1 + 2 * y_1, \quad (3)$$

$$y_2 = y_1 \quad (4)$$

In this paper the input and base points were entered and were chosen to be the centers and arbitrary points on the circles that constitute the meter dials. These coordinates were manually entered although this process could be automated in the future.

The difference between these registered pictures is shown in Fig. 7, which better display the angles formed by the indicators.

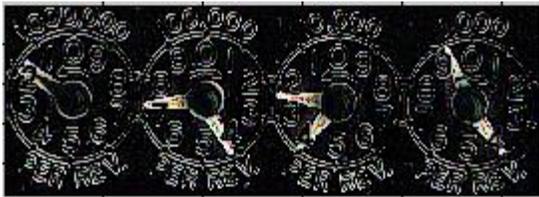


Fig. 7. Formation of angles by registered pictures

D. Images subtraction

The rotation (motion) of the dials is performed using motion segmentation. Image subtraction is a common method of motion segmentation; another is optical flow segmentation. In this paper, only image subtraction will be used as it is computationally simple and fast. Optical flow segmentation is computationally more intensive. Since only the dials change position over time, image subtraction can be applied to establish the dial change that occurred. Mathematically, this can be represented by [8]:

$$D(x, y) = im_2(x, y) - im_1(x, y) \quad (5)$$

where $im_2(x, y)$ and $im_1(x, y)$ are the input images and $D(x, y)$ is an output image.

Image subtraction as defined by (5) subtracts each element in array (im_1) from the corresponding element array (im_2) ; the output is the difference in the corresponding element as seen in Fig. 7. In general, this difference can be positive or negative. The absolute value of the difference is shown in Fig. 7.

Typically, image pixel values range between 0 and 255 (8-level gray) or 0 and 1 and negative differences cannot be displayed.

E. Binary conversion

The exterior boundaries of the meter dials are needed for usage calculations. The image is converted to a binary image which replaces all pixels in the input image with luminance greater than a given threshold with the value 1 (white) and replaces all other pixels with the value 0 (black) as shown in Fig. 8.

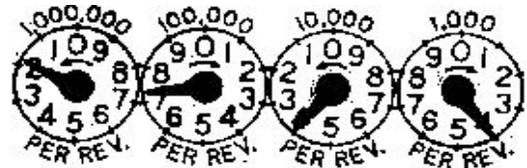


Fig. 8. Display of the binary image of the meter

F. Boundary plotting

As previously mentioned, the ROI is an important factor in minimizing the image processing needed to read the dials. As such, a more precise location of the dials is essential. To attain that objective, the exterior boundaries of the different dials as well as the boundaries of holes inside these dials are determined. Binary images are used because they are fast to execute and the image is basically binary with all nonzero pixels belonging to the dials and all zero pixels representing the background of the image.

To trace the exterior and the interior boundaries of the dials, an 8-connected neighborhood was used. Pixels are 8-connected if their edges or corners touch. This means that two adjoining pixels are part of the same object, regardless of whether they are connected along the horizontal, vertical, or diagonal direction as seen in Figure 9 below [9].

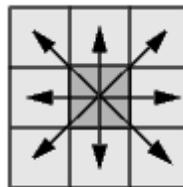


Fig. 9. An 8-connected neighborhood illustration (Courtesy of Mathworks)

The type of connectivity affects the number of objects in an image and the boundaries of those objects. For example, the results of many morphology operations differ depending upon the type of connectivity.

G. Erosion and Dilation

To isolate the dial indicators from the rest of the dial, erosion and dilation are used. They are fundamental image processing operations based upon image morphology and a

structuring element. Dilation will expand an image object whereas erosion will reduce (or erode) an image object. The erosion of the registered images $I(x, y)$ as shown in Fig. 7 by a disk D as the structuring element, is the set of all points p with D translated by p and contained in $I(x, y)$. Erosion can be defined by [10]:

$$I \ominus D = \{p \in \mathbf{R}^2 \mid D_p \subseteq I\} \quad (6)$$

Where p is the pixel element and D_p represents the translation of D by p .

In contrary, the dilation of $I(x, y)$ by D is the set of all displacements p , with the symmetric of D with respect to its origin and shifted by p , denoted by D' and $I(x, y)$ overlap by at least one pixel element.

$$I \oplus D = \{p \in \mathbf{R}^2 \mid D'_p \cap I \neq \emptyset\} \quad (7)$$

To apply these two processes the structuring element was chosen as a disk. Fig. 10 and 11 show the erosion and the dilation of fig. 7 respectively.

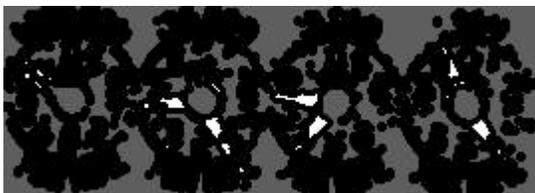


Fig. 10. Dials shown after erosion



Fig. 11. Dials shown after dilation

After dilation, the image in Fig. 11 clearly shows the dials indicators. For clarity, the dial indicators are shown in white in Fig. 12. The blue color indicates the centers of each dial.

H. Data collection

In order to evaluate the energy usage, the angles represented by the dial indicators must be calculated. The centroids of the dials indicated in red in Fig. 12, were automatically calculated using an algorithm written in Matlab.

TABLE I: ANGLE CALCULATION AND UTILITY CONSUMPTION OF THE FOUR DIALS

	Angle θ (rd)	Utility consumption (ft ³)
First Dial	0.21	334.10
Second Dial	1.89	300.69
Third Dial	1.01	16.07
Fourth Dial	2.89	4.60

Since only two centroids with one centroid on each indicator, along with the center of individual dial are needed for the angle calculation, one centroid is obtained per indicator. The algorithm in the centroids calculation is such that the centroids are obtained with the increment of two.

I. Angle and Utility consumption calculation

The angle formed by the dials as seen in Fig. 13 can be evaluated from the calculated centroids.

closing effect on dials



Fig. 12: Display of the centroids and the meter dials

The calculated angles are summarized in TABLE I above. The dial positions define an arc of a circle with the blue point indicating the center as seen in Fig. 12. The arclengths (when multiplied by the scale of each dial, e.g. 10000 per rev) will give the utility consumption. The total consumption is the sum of the individual dial consumptions. The utility consumption for this example is shown in TABLE I.

CONCLUSION

An algorithm to read a rotary dial utility meter is described in this paper. It is simple, so it is fast. The techniques described are commonly used in image processing. To reduce the execution time, the camera resolution could be lower. The algorithm was simulated in Matlab but could be implemented on a dedicated microprocessor as a future work.

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