

Application of Matlab for automatic reading of analogue measuring instruments

Abstract. The paper presents the methodology of using the Matlab environment to develop the algorithm for automatic reading of an analogue measuring instrument. It can be applied to measurements conducted with the use of linear scales, where the deflection of the pointer is proportional to the magnitude of the measured physical quantity. The proposed algorithm is based on the Hough transform, which allows detecting the pointer in the image of the instrument dial.

Streszczenie. W niniejszym artykule została przedstawiona metodyka wykorzystania środowiska Matlab do opracowania algorytmu automatycznego odczytu wskazania miernika analogowego. Jego zastosowanie jest możliwe w przypadku wykorzystywania liniowych podziałek, dla których wychylenie wskazówki miernika jest proporcjonalne do wartości wielkości mierzonej. Opracowany algorytm oparty jest na transformacji Hougha, która umożliwia wykrycie wskazówki na obrazie tarczy miernika. (Zastosowanie Matlaba do automatycznego odczytu wskazania mierników analogowych).

Keywords: analogue measuring instruments, automatic reading, Hough transform.

Słowa kluczowe: analogowe przyrządy pomiarowe, automatyczny odczyt, transformacja Hougha.

Introduction

Nowadays, analogue measuring instruments are substituted with digital ones because of their obvious advantages. However, there are cases when dealing with analogue meters is inevitable and there is a great need to send their readings to the computer for further processing. There are many older measuring systems with such meters and they should be remotely and digitally controlled to prevent the objects they monitor from possible damage. Many calibration laboratories offer services including calibration of analogue instruments and the procedures for doing so are based on manual writing of the indications despite the equipment used to adjust an instrument accuracy is usually digitally controlled. Advanced techniques of digital image processing seem to be the proper approach enabling automation of the analogue meter readings using an image of its display, which has already been discussed and described in [1, 2, 3].

Reading the value indicated by an analogue measuring instrument involves determining the deflection angle of a pointer from its zero value position. Thus, to automate the described process, it is necessary to detect the pointer in an acquired image of the analogue instrument display. This task can be performed comprehensively using the widely known Matlab programming environment with its possibility to acquire digital images and to detect straight lines in them with the use of the algorithm called the Hough transform. The paper presents the methodology for doing so, including description and usage of the Matlab functions required for the necessary pre-processing.

Basics of the Hough transform

The Hough transform is a method of detecting regular shapes in digital images. Its origin version enables locating only straight lines. Then it was developed and generalized to identify the position of shapes which can be described analytically, for examples circles, and finally any arbitrary shapes [4, 5, 6]. An important advantage of the Hough transform is the possibility of detecting straight lines or other shapes which are not perfect, for example their continuity is disturbed because of noise or partial covering [7].

In the Cartesian coordinate system (x, y) the straight line k is described by the following well-known equation:

$$(1) \quad y = a \cdot x + b$$

where: a – the tangent of the angle between the straight line k and the x -axis, which is called the slope or gradient of the line, b – the y coordinate of the point where the line k intercepts with the y -axis. In the slope-intercept form of the straight line described by the equation (1), the parameters a and b take the infinitive values for vertical lines. Such a problem does not occur while using the normal form of the straight line equation:

$$(2) \quad \rho = x \cdot \cos \theta + y \cdot \sin \theta$$

where: ρ – the distance between the line k and the origin of the coordinate system, θ – the angle between the x -axis and the line connecting the origin of the coordinate system with the closest point of the straight line k . The values of the ρ parameter are positive for lines intercepting with the x -axis in points greater than 0 and negative when straight lines intercept with the x -axis in points less than 0. If a line passes through the point $(0, 0)$, the parameter ρ takes value 0. The parameter θ can take values from the interval $[0^\circ, 180^\circ)$. θ is equal to 0° for vertical lines and 90° for horizontal ones.

Considering parameters ρ and θ as variables and variables x and y as parameters, the equation (2) describes the relation between the curve in the (ρ, θ) plane and the point in the original (x, y) plane. A straight line in the coordinate system (x, y) corresponds to a point in the (ρ, θ) plane and a point in the original plane corresponds to a sinusoidal curve in the (ρ, θ) plane [7].

The Hough transform involves determining curves in the (ρ, θ) plane that correspond to all characteristic pixels of an processed image according to the formula (2) and finding the point (ρ_i, θ_i) where the largest number of the obtained curves intercepts. The point (ρ_i, θ_i) corresponds to the straight line in the (x, y) plane that passes through the largest number of the characteristic points in the image [7].

Discussion of the processing

In compliance with the main scope of the paper, the calculation procedure of the proposed algorithm for automatic reading of an analogue measuring instrument was created using Matlab. It is a computing and programming environment which includes many useful functions, which enable both acquiring and processing images. Moreover, the procedure performing detection of straight lines in images is also available as the function

though, computing the Standard Hough Transform (STH). The input argument of this procedure must be a binary image but widely used cameras acquire colourful or grayscale images. Therefore, it is necessary to carry out the initial step of image processing before performing the Hough transform. Assuming that the original image is colour, in the first step of the procedure the image has to be transformed to the grayscale one. It can be achieved using the Matlab function `rgb2gray` [8, 9]. Figure 1 presents the grayscale equivalent of the original colour image of a dial of an analogue measuring instrument, which was obtained with the use of the mentioned Matlab function.

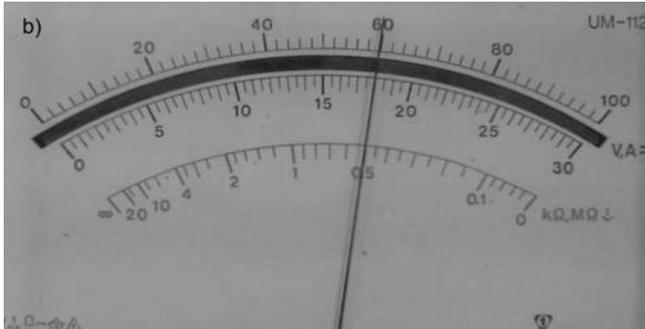


Fig. 1. The grayscale equivalent of the original colour image of an analogue display

Image enhancement is the next stage of image pre-processing. The aim of this procedure is to increase the contrast of an image. Pixels of an 8-bit grayscale image can take integer values from 0 to 255. But hardly ever is the whole possible range of pixel intensities used in an acquired image. Broadening the range of used pixel values to the whole available one, it is possible to obtain an increase in image contrast. Such a procedure is usually called image normalization or histogram stretching. In the Matlab environment the function `imadjust` is available, which performs the described operation of image enhancement [7, 8]. Figure 2 shows the output image of the function `imadjust` applied to the image presented in figure 1. It can be noticed that contrast of the output image is significantly higher than the contrast of the input one.

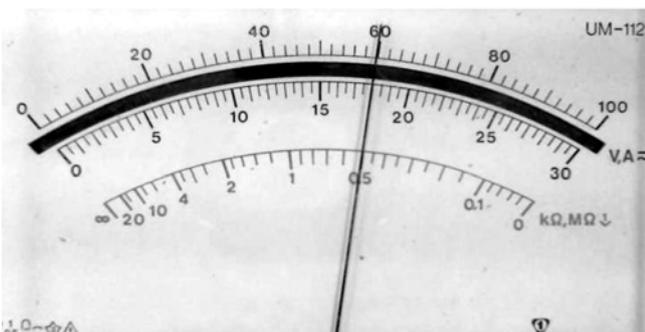


Fig. 2. The result of the normalization of the grayscale image showed in figure 1

It has been already mentioned that the calculation procedure of the Hough transform requires a binary image as an input argument. Therefore, it is necessary to convert a grayscale image to a binary one. Such a conversion can be carried out with the use of the thresholding technique. There are various thresholding methods. The simplest ones used just one upper or lower threshold, more advanced methods used two or more thresholds. Moreover, threshold values can be equal for a whole image (global thresholding)

or differ for various parts of an image (local thresholding). The choice of the thresholding method depends on the content of a processed image and properties of its relevant elements [7].

In the presented issue the pointer is the most important element in an image. A pointer of an analogue measuring instrument is usually black, so that it will be visible and easily noticeable on a white background of a meter scale. In this case, it seems to be enough to apply a global method of thresholding with one upper threshold. Such an operation is described as follows:

$$(3) \quad I_w(x, y) = \begin{cases} 1, & I(x, y) < t \\ 0, & I(x, y) \geq t \end{cases}$$

where: $I(x, y)$, $I_w(x, y)$ – intensity of a pixel with coordinates x and y in the input and output image of the procedure respectively, t – the threshold value. To obtain a satisfactory result of thresholding, it is crucial to determine an accurate threshold value. In the proposed algorithm, a threshold value is calculated taking into account the maximum of an input image histogram, which occurs for pixel intensities representing a background of an instrument scale.

Figure 3 presents the binary image obtained by applying the described method of thresholding to the grayscale image showed in figure 2. Undoubtedly, it would be a better result if there was only a pointer in the output image. Unfortunately, there are other elements in the input image in similar shades of grey as a pointer, such as scale marks and descriptions or a mirror which helps users to eliminate the parallax error. Therefore, it is not possible to obtain exclusively the pointer in the output image of the used method of thresholding. It can be supposed that even more sophisticated methods of thresholding would not yield better results due to the presence of other elements in grey shades of a pointer on the analogue display.

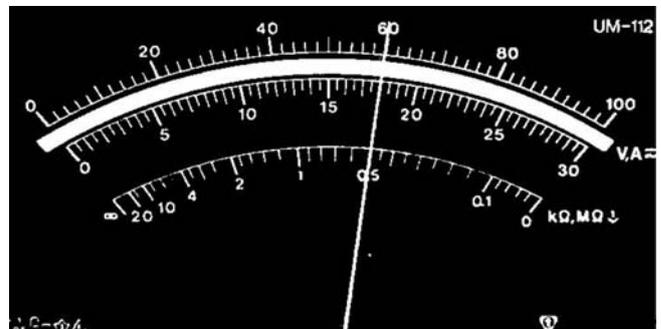


Fig. 3. The binary image obtained as the result of the thresholding applied to the image presented in figure 2

The detection of a pointer in the output image of the thresholding procedure can encounter some problems. It may happen that straight lines will be found in the area representing a mirror surface. A changing width of a line corresponding to the pointer can be another problem, which was mentioned in [2]. In order to eliminate such troubles, the skeletonization procedure can be applied to the binary image. Skeletonization is one of morphological operations which transforms a binary images into a set of thin lines and curves [7]. In the Matlab computing environment the procedure of skeletonization is performed by the function `bwmorph` with the appropriate string value of the argument defining the type of the morphological operation. The full version of the applied function is as follows:

```
out_im = bwmorph(in_im, 'skel', Inf)
```

and its result is illustrated in figure 4.

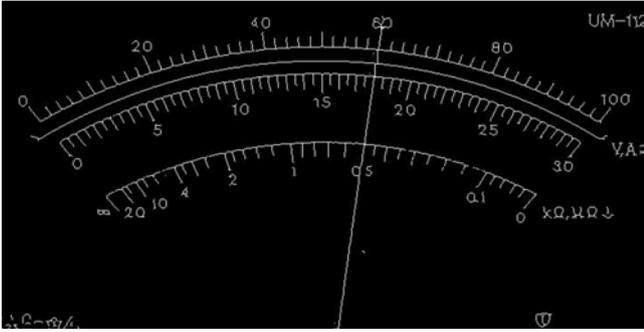


Fig. 4. The image obtained as a result of skeletonization procedure applied to the image showed in figure 3

Skeletonization is the last stage of image pre-processing applied in the proposed algorithm. In the next step, the detection of an instrument pointer is performed using the Hough transform. The calculation procedure of the transform is implemented in the Matlab environment and involves invoking the function `hough`. The output argument of the function is a transformation matrix of the Hough transform, which is the representation of a binary input image in the Hough space (the parameter plane (ρ, θ)). Each element of the transformation matrix corresponds to a point in the Hough space and it is described by a pair of values (ρ_i, θ_i) . The value of a given element represents the number of sinusoidal curves passing through the point (ρ_i, θ_i) . In the next step of the proposed procedure the transformation matrix is searched for its maximum value. Finally, it is necessary to determine the values of ρ and θ corresponding to the maximum value, which describe a straight line in the original plane passing through the large number of characteristic points (white pixels) of an input image. As a result of performing the presented procedure, the parameters ρ and θ of the longest, but not necessarily continuous, straight line are determined.

It can be noticed that the presented method of detecting the pointer performs properly if and only if the longest line in a processed image corresponds to the pointer. Looking at the input image of the calculation procedure of the Hough transform, presented in figure 4, it can be noticed that the longest line corresponds to the pointer of the analogue measuring instrument.

In the Matlab environment the parameter θ takes values from the interval $[-90^\circ, 90^\circ]$. θ is equal -90° for horizontal lines. Other negative values of θ describe lines with negative values of the gradient, positive – lines with positive values of the gradient. θ is equal to 0 for vertical lines. After determining the value of θ for the actual and extreme positions of the pointer it is possible to calculate the magnitude of the measured physical quantity indicated by the analogue measuring instrument. The result of the measurement can be calculated as follows:

$$(4) \quad X_m = \frac{\alpha}{\alpha_{max}} \cdot X_N$$

where: α – an angle of the pointer deflection from the zero scale value position, α_{max} – the maximum angle of the scale, X_N – a chosen subrange of the measuring instrument. Values of α and α_{max} can be determined using the following relations:

$$(5) \quad \alpha = |\theta - \theta_0|$$

$$(6) \quad \alpha_{max} = |\theta_{max} - \theta_0|$$

where: θ – an angle corresponding to the position of the pointer during the measurement, θ_0, θ_{max} – angles

corresponding to the positions of the pointer indicating the beginning and the end of the scale. Inserting (5) and (6) into (4), we obtain the final relation (absolute values can be neglected):

$$(7) \quad X_m = \frac{\theta - \theta_0}{\theta_{max} - \theta_0} \cdot X_N$$

Values of X_N, θ_0 and θ_{max} have to be defined before the analysis. During the measurement process only the value of θ corresponding to the actual deflection of the pointer is determined. After setting the proper values of θ_0 and θ_{max} , θ can takes values from θ_0 to θ_{max} . Therefore, while computing the transformation matrix of the Hough transform, the limited interval of θ values is taken into consideration. That enables performing the computation faster and decreasing the probability of obtaining the wrong result.

The results

The correct detection of a pointer in the image is dependent on the chosen region of interest. As it was mentioned before, the proposed algorithm detects only the longest line in the image. Therefore, the algorithm can work properly if the analysed image presents only the instrument dial with the pointer being the longest straight line (fig. 5a). When there are spare elements in the image, such as instrument housing and neighbourhood, it is quite sure that the obtained result will be wrong (fig. 5b). Figure 6 presents images which are the results of the skeletonization procedure of the images showed in figure 5. It can be easily noticed that the longest line in the first image (fig. 6a) corresponds to the pointer. However, in the second image (fig. 6b) there are many other lines, which are longer than the one which represents the pointer.

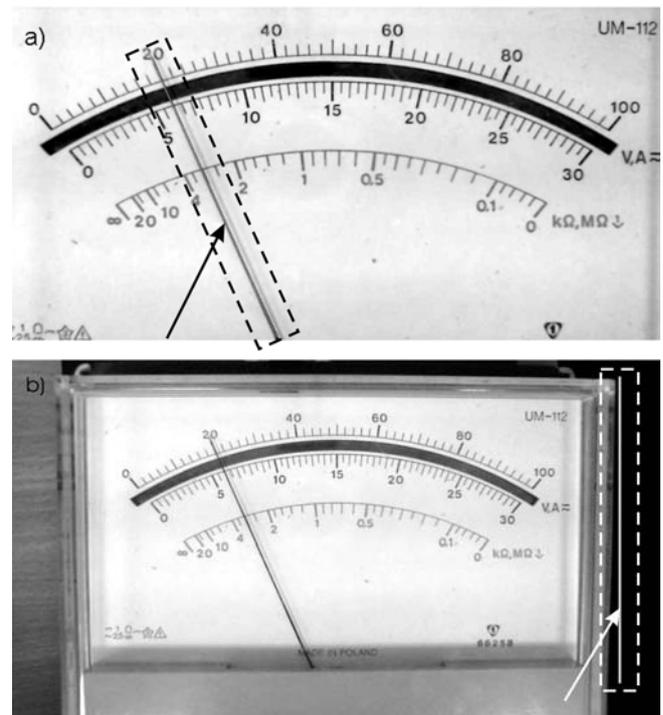


Fig. 5. The results of correct (a) and incorrect (b) detection of the pointer

The correct detection of the pointer and the determination of the proper positions of the pointer for the zero and full scale values enable obtaining the correct value indicated by the analogue measuring instrument. Table 1

summarizes the absolute errors introduced by the system corresponding to the user's readings of the multimeter indications for several image resolutions.

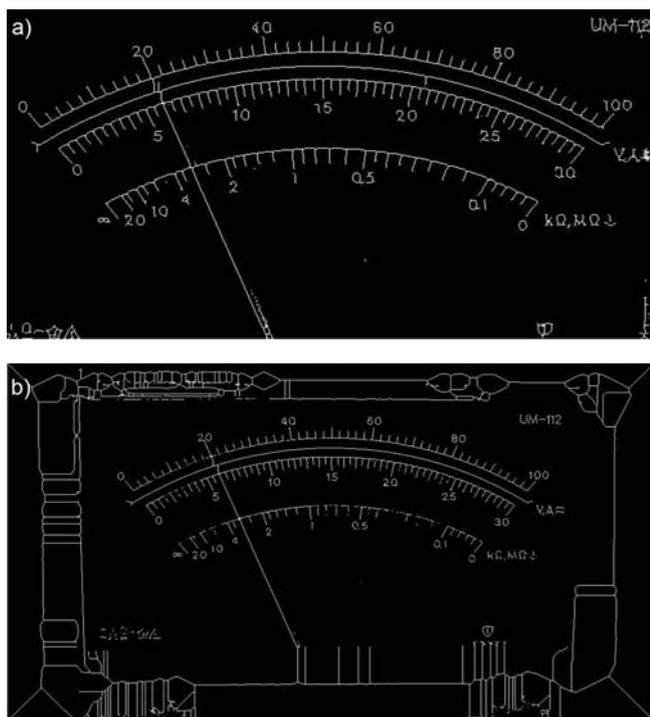


Fig. 6. The output images of the skeletonization procedure applied to the images presented in figure 5

Table 1. The specification of measurement errors (provided in scale divisions as absolute values) obtained by the proposed algorithm

No.	Image resolution							
	1341x673		726x376		584x307		303x165	
	User's reading	Absolute error	User's reading	Absolute error	User's reading	Absolute error	User's reading	Absolute error
1.	20,0	0	80,0	0,5	80,0	0,5	80,0	0,5
2.	40,5	0	60,0	0	59,5	0,5	60,0	0,5
3.	60,0	0,5	39,5	0,5	40,0	0	40,0	0,5
4.	80,0	0,5	20,0	0	20,0	0	20,0	0,5
5.	100,0	0	0,0	0,0	0,0	0,5	10,0	0,5
6.	90,0	0,5	10,0	0	10,0	0	30,0	0
7.	70,0	0,5	30,0	0	30,0	0	50,0	0
8.	50,0	0,5	50,0	0	50,0	0,5	70,0	0,5
9.	30,0	0	70,0	0,5	70,0	0,5	90,0	0,5
10.	10,0	0	90,0	0	90,0	0	100,0	0,5
11.	0,5	0,5	100,0	0,5	100,0	0,5	94,0	0
12.	3,0	0	96,0	0,5	96,0	0	83,0	0,5
13.	14,5	0	91,5	0,5	87,5	0	77,0	0,5
14.	23,5	0,5	82,0	0,5	81,0	0	68,0	1,0
15.	35,0	0	76,0	0,5	72,0	0,5	64,0	0
16.	46,0	0,5	69,0	0,5	65,0	0,5	56,0	0
17.	54,0	0,5	62,0	0,5	56,0	0	53,0	0,5
18.	68,0	0,5	56,0	0,5	45,0	0,5	45,0	0,5
19.	77,0	0,5	47,0	0	34,5	0,5	36,5	0
20.	86,0	0,5	33,0	0	23,0	0	28,5	0

The weak influence of resolution on the accuracy is an important observation as it gives the possibility to develop an embedded system for the digitization with reasonable requirements. The measurements were conducted using the linear scale consisting of 100 divisions with the reading accuracy of 0,5 division. It can be noticed, that in most cases the difference between the automatic and user's

readings is less than the reading accuracy. A bigger difference was obtained only in one case for images with the lowest resolution.

Conclusion

In the paper, the methodology of using Matlab for automatic reading of an analogue measuring instrument is presented. It can be applied to measurements conducted with the use of linear scales, where the deflection of the pointer is proportional to the magnitude of the measured physical quantity. The proposed algorithm is based on the Hough transform, which allows successful detection of the pointer in the image of the instrument dial, even with the use of relatively low resolution images. Moreover, the proposed method of image pre-processing makes the process of the pointer detection independent from the width of the pointer. However, to obtain the correct result of the proposed algorithm performance, it is necessary to indicate the appropriate region of interest for being processed. The analysed image should contain the instrument dial and as long as possible part of the pointer. Simultaneously, it should lack any spare elements such as the instrument housing. The successful detection of the pointer enables obtaining the correct value indicated by the analogue measuring instrument under the condition that the zero and full scale values have been properly determined.

As a result of the presented work, the software was developed which enables the application of the proposed algorithm in measuring practice. The performance of the algorithm was tested using the multimeter UM-112 and satisfactory results were obtained. It can be supposed that the proposed algorithm would yield similar results while using other analogue measuring instruments under the condition that the described requirements concerning the region of interest are satisfied.

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REFERENCES

- [1] Sablating R., Kropatsch W. G., Automatic reading of analog display instruments, *Proceedings of the 12th International Conference on Pattern Recognition*, 1994
- [2] Szlachta A., Sidor K., Stanowisko do automatycznego odczytu wartości mierzonej miernikiem analogowym, *Pomiary, Automatyka, Kontrola*, vol. 60 (2014), nr 8, 548-551
- [3] Lima D., Pereira G., Vasconcelos F., A computer vision system to read meter displays, *16th IMEKO TC4 Symposium, Exploring new frontiers of Instrumentation and Methods for Electrical and Electronic Measurements* (2008)
- [4] Duda R.O., Hart P.E., Use of the Hough Transformation to Detect Lines and Curves in Pictures, *Communication of the ACM*, Volume 15 (1972), Issue 1, 11-15
- [5] Yuen H.K., Princen J., Illingworth J., Kittler J., Comparative study of Hough Transform methods for circle finding, *Image and Vision Computing*, Volume 8 (1990), Issue 1, 71-77
- [6] Ballard D.H., Generalizing the Hough transform to detect arbitrary shapes, *Pattern Recognition*, Vol. 13 (1981), Issue 2, 714-725
- [7] Malina W., Smiatacz M., *Cyfrowe przetwarzanie obrazów, EXIT Publishing, Warsaw 2008*
- [8] Wróbel Z., Koprowski R., *Praktyka przetwarzania obrazów z zadaniami w programie Matlab, EXIT Publishing, Warsaw 2008*
- [9] Gonzalez R., et. al., *Digital Image Processing Using Matlab, Gatesmark Publishing, USA 2009*