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A new method proposal to enhance foreground images against noisy backgrounds: Haytham Thresholding

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Abstract

Since only pixel intensities are taken into account in the binarization of gray images during the thresholding stage, it brings with it a significant problem. Because, since the relationship between pixels in the image is neglected, it is seen that noises are sometimes defined as an object, sometimes plays a role in changing the detected object, especially in noisy images where illumination is not uniform. In this study, a locally adaptive thresholding algorithm called Haytham Thresholding is proposed in order to eliminate these limitations of global thresholding algorithms and to eliminate noise caused by lighting during the binarization of the image. Especially in the literature, it is seen that noise is high in methods performed by taking the standard deviation into account when the image has a gradient feature. To prevent this, pixel values were normalized by taking into account the weights of the pixels in the window region instead of their standard deviation. These normalized values were added to the matrix values obtained by the average filter and then subtracted from the original image matrix. In the experiments, the proposed method was compared with Otsu and three different local thresholding algorithms by using four different image types also used in the literature. The comparison of the methods was made both visually and with image quality metrics such as PSNR and SSIM. As a result, it has been observed that the proposed method produces successful results compared to both global thresholding and local thresholding algorithms frequently used in the literature.

Keywords: Binarization, Image Segmentation, Image Enhancement, Image Processing, Local Tresholding

1. Introduction

The scientific world has spent the last half century in the fields of artificial intelligence, computer vision and image processing [1]. Especially with Industry 4.0 and digitalization, these areas continue to increase their popularity with the spread of self-learning devices and systems [2]. Although these expressions seem to be intertwined, according to the generally accepted opinion, image processing is among the sub-branches of computer vision and computer vision is among the sub-branches of artificial intelligence [3].

While image processing is used to prepare the resulting images for processing such as noise removal and image transformation, computer vision is used to produce meaningful data from images such as object recognition, feature extraction and classification [4]. In other words, while image processing is used for operations with images as inputs and outputs in the literature, operations whose input is image, but output is meaningful data are considered as computer vision [5].

Figure 1 shows the flowchart mostly used in the field of computer vision. Pre-processing in this diagram and Binarization, which is the subject of this study, are the stages used in image processing. As can be seen from this figure, Binarization is the last step in image processing [6] and in a sense, it is extremely important for the segmentation and following other operations to be performed correctly [7]. Because if an object on the

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image cannot be detected correctly, neither the classification of this object nor its features can be extracted in the next stages. This shows that both preprocessing and binarization stages are very important [8]. Binarization is the process of distinguishing whether pixels belong to the background or foreground object according to a certain threshold value from the two-dimensional gray image [9]. Considering the importance of the subject, it is seen that the studies focus on obtaining the threshold value used to determine whether the pixel belongs to the background or the object. For this purpose, many algorithms and techniques, which are grouped as local, global and adaptive, have been proposed in the literature [10].

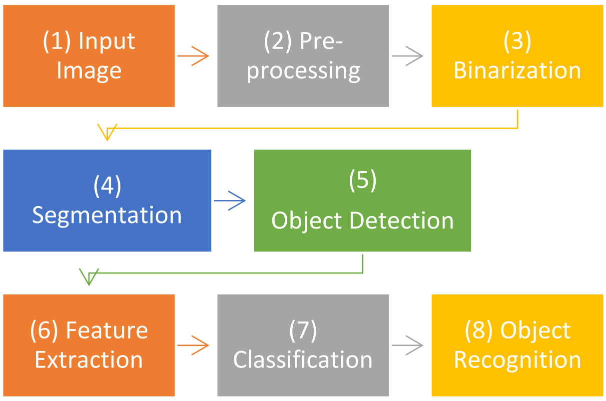

Figure 1. Flow diagram of computer vision

The techniques used and suggested in the literature for binarization consisting of 0 and 1 values are known as thresholding. As seen in Figure-2, thresholding is also one of the simplest image segmentation techniques known, which is the separation of each object in that image [11]. Yanowitz and Bruckstein proposed a segmentation technique based on adaptive thresholding for situations where it is difficult to separate the object from the background in images where the illumination is not uniform [12]. They used double thresholding method to perform segmentation of white blood cell from acute lymphoblastic leukemia images. They applied the thresholding method to the gray format of the image and the HSV format separately and continued the flow by obtaining a binary image from the intersection of both outputs [13]. They proposed a dynamic thresholding algorithm for the segmentation and classification of colored skin images. They drew attention to two important problems in studies that normally use fixed thresholding values: First, there are pixels that are classified as skin even though there is no skin. The other is with pixels that are treated as background even though they are skin [14]. First, they identified the most important weakness of the Otsu global thresholding algorithm as follows: If the difference between the background and foreground in the image does not change significantly, that is, if there is no contrast between these two situations, then Otsu cannot provide accurate thresholding. In order to avoid this negative situation, they proposed the gray stretching method, which reveals the wavelet transform-based class variance change [15]. They proposed a new local thresholding algorithm to solve the time-consuming problems of traditional local thresholding algorithms. For this purpose, instead of the standard deviation used in traditional methods, they used an integral image to obtain the mean process at the local level in a shorter time [16]. They identified a shortcoming in the study of Otsu, the most well-known global thresholding algorithm, and made a new proposal to improve it. They argued that Otsu thresholding algorithm produces the threshold value closer to the class with high variance value if the difference in variance within the class is high in the image, and they presented a proposal that adjusts the threshold value to adjust for this deficiency [17]. They proposed an algorithm that works adaptively in the local structure to determine the threshold value in gradient images where the illumination is variable. Because they claimed that global thresholding algorithms are insufficient to process such images correctly, instead local algorithms produce more appropriate threshold values [18]. Similarly, they proposed a new method based on average filters and gradients to determine the correct threshold value for images with variable illumination and contrast. The averaging filter is used to normalize the noisy background [19]. Inspired by nature, they proposed a much more interesting neutrosophic-based thresholding algorithm. Because the neutrosophic has a natural ability to obtain uncertain data. With the Neutrosophic technique, the values of the noise-based uncertain pixels in the image can be obtained [20].

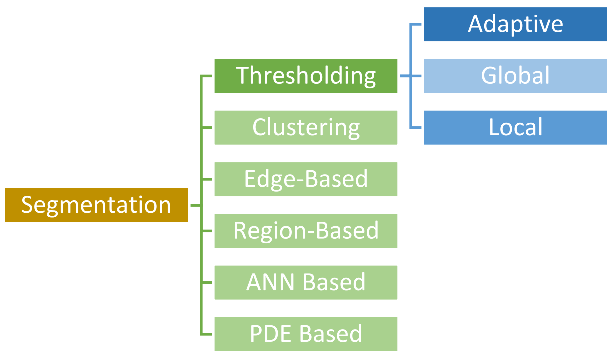

Figure 2. Methods of image segmentation

As a result, the following conclusions can be drawn from the literature review:

- If the image does not have a lighting problem and the background has a uniform distribution, then global thresholding algorithms produce effective results.
- If the color contrast between the background and foreground of the image is high, then global thresholding techniques will give successful results.

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- Adaptive local thresholding algorithms give better results in images with lighting problems and close contrast between background and foreground objects.
- Thresholding algorithms are still widely used in image segmentation.

In the method emphasized in this study, a new matrix is created using the pixel weights of local regions. This matrix, which normalizes pixel values according to neighboring pixel values, is used in the final stage to reveal the background in the image. Thus, each pixel plays a role in separating the ground in its own region from the foreground.

The following sections of the study are organized as follows: First, the method proposed in the study is explained comprehensively with examples at the algorithmic level. Then, experiments are performed and analyzes are made on test images frequently used in these areas in the literature. In the last stage, the findings are expressed as a result.

2. Materials and Methods

Binarization is known as taking the values of 1 and 0 according to a certain threshold value so that the pixels on the image can be processed more easily [21]. In fact, the main purpose of the process is to divide the image into two separate parts, the background and the foreground [22]. Thresholding techniques, which are one of the most important subjects of image processing and generally divided into two as local and global in the literature, are used for this process [23]. However, in this study, the adaptive method, which is one of the popular thresholding techniques of recent times, was preferred. Because mostly the images obtained are exposed to different noises, especially regionally, it becomes difficult to detect the objects in these images. Adaptive methods improve binary conversion by using different thresholding values in different regions on the same image [24].

In this study, a binarization method is proposed to accurately convert images with non-uniform illumination into binary images. The basic idea behind the proposed method is to create a second copy of the original image, which is weaker in terms of pixels, and to subtract this copy image from the original image. Thus, in the final image, the background pixels are represented with a truly zero value, while the foreground pixels are represented with higher pixel values. Therefore, the minimum contrast value required to separate the background from the foreground can be reduced to only 1 pixel. In fact, in Figure 3, this situation is expressed as the separation of pixels with a value of zero as background in the binarization stage.

The step-by-step process flow chart of the proposed method is shown in Figure 3. In addition, since the proposed method performs local thresholding, it was applied by scanning the original image with a window of a certain size, as in the literature. As seen in the figure, the process starts by taking a new frame from the image. Average filter, normalization, subtraction, binarization and morphological decompression operations are applied sequentially to each frame. The stage that distinguishes the study from the literature is the normalization stage, in which the coefficient to be used in the extraction stage is obtained. Because the aim at this stage is to strengthen the background region of the image or the pixel values close to the background region and mark them as the background region in the difference process. This situation is clearly seen in the 5th image in the images given in Figure 7, where the difference process is performed, and the pixels are brought very close to the background region. Therefore, in the last stage, the pixel values that do not have a zero value (or have a value >=1) are marked as part of the foreground.

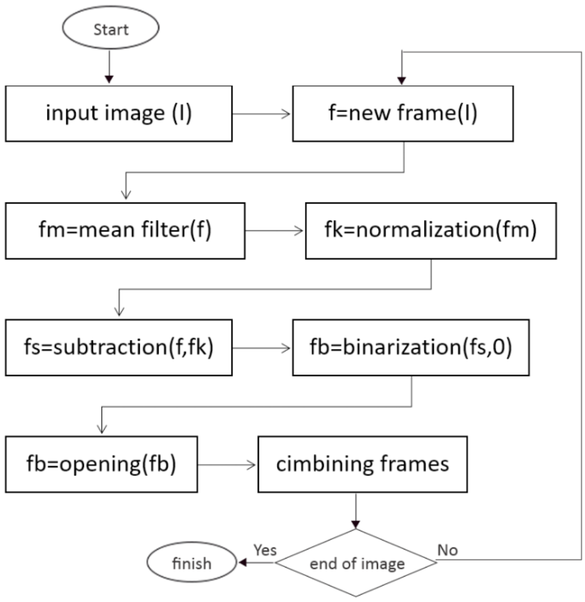

Figure 3. The flow chart of the proposed method

According to Figure 4, in the next step, high value pixels are reduced by applying the Mean filter to the image converted to gray. As it is known, this filter changes the value of the pixel according to the average of the pixels in the determined group [25]. After applying the mean filter, a formula is proposed in this study to make the background and foreground distinction clear, and this stage is named Normalization in Figure 3.

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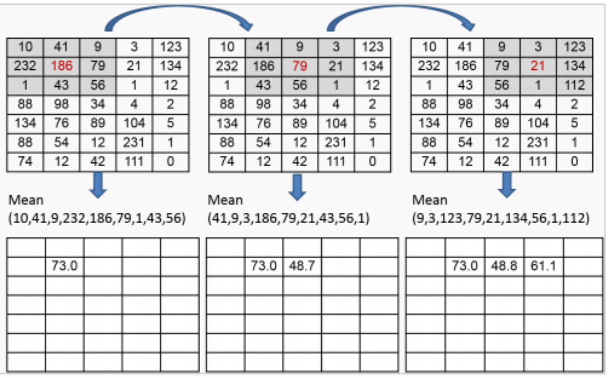

Figure 4. Step-by-step mean filter representation

The calculation used in the local thresholding algorithm proposed in this study is performed by taking the difference of the input image matrix from the normalization matrix, as given in Equation-3.1. In this equation, f refers to the next frame matrix obtained from the input image and fk refers to the normalization matrix. The step of obtaining the normalization matrix in this equation is given in Equation-3.2. In this equation, the image softened by the average filter is expanded by adding it with the k coefficient expressed in Equation-3.3. This value, which is unique to this study and produced dynamically with this equation in each image frame, is actually included in the process as a constant value in the traditional local thresholding algorithm. The aim here is to minimize the noise that is likely to remain in the image. n is the digital conversion resolution value of the processed image. Since 8-bit images were used in this study, the calculation was made as n = 8. Each equation is repeated for the pixel values of all frames obtained from the input image.

$$fs(x,y) = f(x,y) - fk(x,y) \quad (3.1)$$

$$fk(x,y) = fm(x,y) + k \quad (3.2)$$

$$k = \frac{2^n}{mean(f)} \quad (3.3)$$

In the subtraction step, the normalized matrix value is subtracted from the frame matrix, which is converted to gray. In fact, with this subtraction, the image background is set to zero, which is the lowest pixel value. The changes in the pixel values in the image matrix from the beginning to the end of the proposed method in the study are illustrated in Figure 5. In this figure, the “a” matrix part belongs to the original gray image, the “b” matrix part belongs to the normalization process, and the “c” matrix part belongs to the difference matrix. In this process, zero values seen in the "c" matrix are determined as background, while other values are interpreted as belonging to the foreground object.

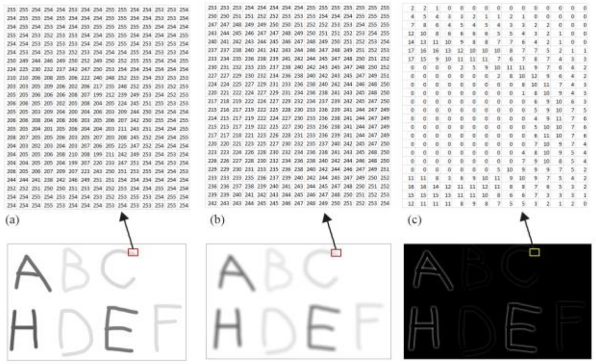

Figure 5. Image pixel values resulting from different algorithm steps (a: input matrix; b: normalization matrix; c: subtraction matrix)

The effect of the normalization process proposed in this study on the output image and its contribution to the study are depicted in Figure-5. If thresholding had been done without normalization, the output image shown as (a) in Figure 6, which was quite noisy, would have been obtained. However, as a result of the normalization process, these noises were eliminated and the image (b) in Figure 6 was obtained.

Figure 6. Difference of mean filter and normalization stages in the output matrix (a: mean filter matrix; b: normalization matrix)

During the binarization phase, the "c" matrix seen in Figure 5 is converted to binary format by taking the zero value as a reference. Therefore, pixels with a value of "0" are decomposed as background, and pixels with a value greater than "0" are decomposed as foreground.

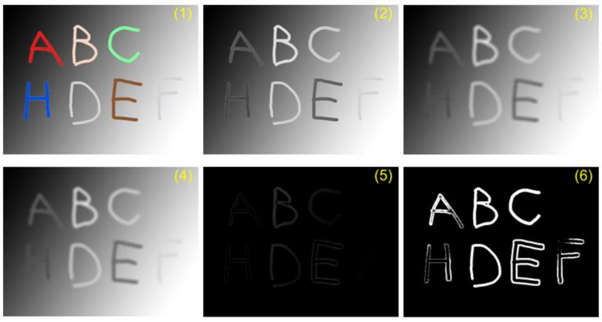

Figure 7. Illustrated explanation of the stages of the proposed method

Figure 7 shows the effects of all the steps performed in the proposed method on the images separately. These images show the following operations in order:
(1): Input image
(2): Gray conversion of input image
(3): Image with mean filter
(4): Normalized image with Equation 3.2 and 3.3
(5): Arithmetic subtraction of Image-4 from Image-2 using Equation 3.1
(6): Binary image obtained from image 5 with 0 value pixels as background and other pixels as foreground

3. Findings and Discussion

This study presents a proposal to optimally obtain the threshold value of images with gradient colour distribution, where global thresholding algorithms are quite unsuccessful. For this, the mean filtered image was subjected to normalization with the process seen in Equation-1, and thus the background values of the image were brought very close to the 0 value. In order to demonstrate the success of the proposed method, some images used in the literature have also been tested in this method.

Figure 8 shows the test images used in this study. When selecting test images, the fact that they were used in the literature was the reason for preference. In addition, for the success of the proposed method, it was preferred that both the background and foreground have a gradient image feature.

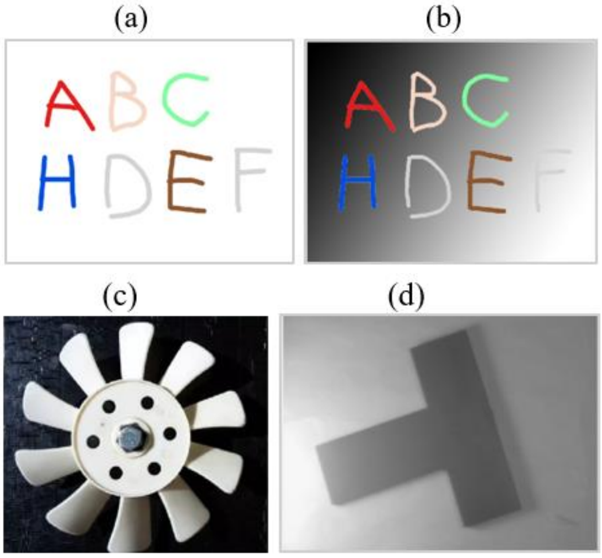

Figure 8. Test images used in the study

In Figure 9, the threshold value obtained by the Otsu Algorithm is used for binary image conversion. These results show that the success of global thresholding algorithms is very poor in cases where the color distributions in the image are opposite. Because, as it is known, global thresholding algorithms use the same threshold value in the entire image. Therefore, when the color intensity of the background changes or the color intensity of the objects qualified as foreground differs, the result is quite unsuccessful. Figure 10 illustrates examples of thresholding operations performed with the method proposed in this study. When the samples are examined in detail, it is seen that the method is very successful especially in images with gradient colour density.

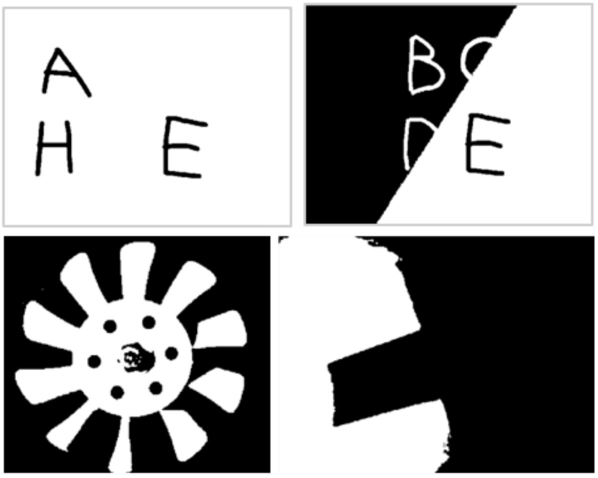

Figure 9. Test results with global thresholding algorithm (Otsu)

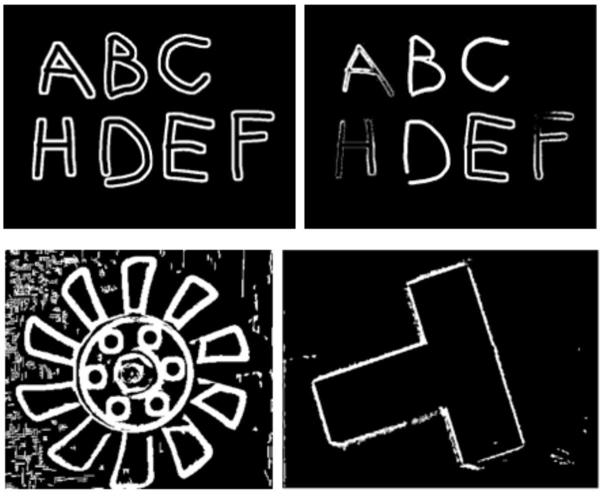

Figure 10. The results obtained with the local adaptive thresholding method proposed in this study

In many projects based on image processing or computer vision, maximum system success can be achieved by creating special areas at the point of getting the most ideal image. However, nowadays, since such projects are spread over the general and open area, it can be checked whether the image is obtained in the most ideal way after the image is taken. In this case, the field of machine learning comes into play, as whether

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the images obtained are unavoidably appropriate or not depends on the learning of the system. Here, the method proposed in this study will be an indispensable part of such a system. Because the images are directly proportional to the light intensity and in many cases it becomes difficult for the light to affect each part of the image at the same rate. Therefore, sometimes the resulting image may have a gradient colour feature. The detection of objects in such an image will be possible with the methods proposed in this study.

Finally, the contribution of the normalization stage to the output image, which makes this study stand out in the literature, is clearly seen in Figure-11. In this figure, (a) and (d) show the input test image, (b) and (e) show the binary image formed with the average filter, and (c) and (f) show the binary image formed with the normalization process. It has produced very successful results, especially in converting images with gradient background illumination into binary images (see e and f). If the images are to be interpreted, it appears that the normalization stage has eliminated any possible noise in the image.

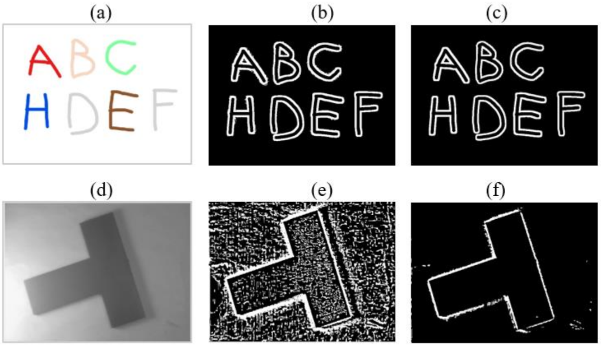

Figure 11. Contribution of the normalization stage to the quality of the output image

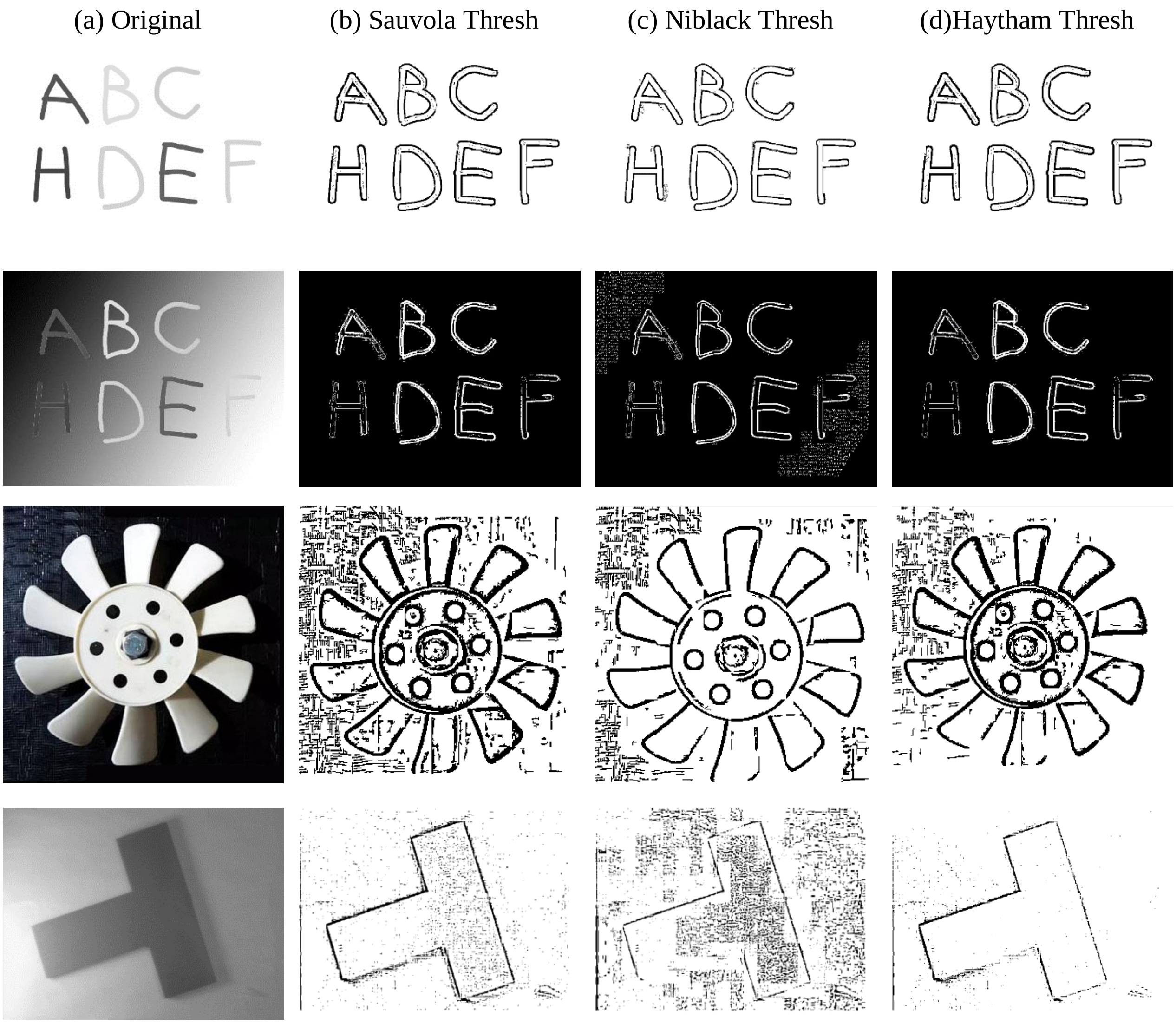

Figure 12. Comparison with some local thresholding methods in the literature

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Figure 12 contains a visual comparison of three local thresholding techniques frequently used in the literature and the technique proposed in this study. In the experiments, images with only a gradient background were not preferred. It was also preferred in images where the contrast between the foreground and background was low. It is seen that the proposed technique has a clear advantage over other methods in both high contrast and gradient background samples.

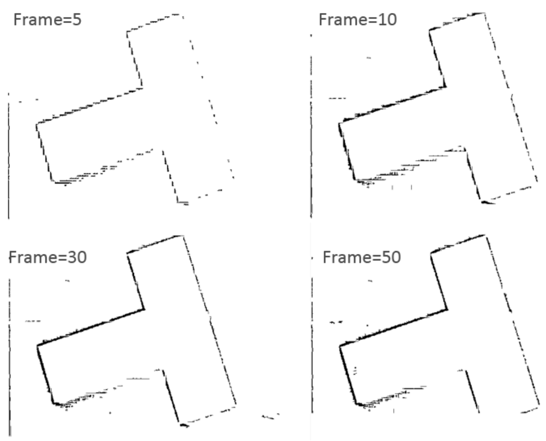

Figure 13. Effects of frame size on the success of the method in local scanning

Figure 13 illustrates the effects of the frame sizes used by the proposed method during image scanning on the success of the method. It is observed that as the frame gets smaller, the number of lost pixels increases, while as the frame gets larger, the number of false pixels thought to belong to the object increases.

Table 1 gives a quantitative comparison of the proposed method with important local thresholding techniques frequently used in the literature, in terms of measurement with image quality metrics. As can be seen from this table, the proposed method could not achieve the best result only in test image number 3. The reason for this is that the contrast between the background and foreground in the test image is high and it can be easily segmented with the global thresholding method. However, it is clearly seen that the proposed method has better image quality metrics than the other two methods. Other than that, in all test images, the methods in the literature fell behind the proposed method.

Table 1. Measuring test results with image quality metrics

Image	**Sauvola**		**Niblack**		**Bernsen**		**Haytham**	
	PSNR	**SSIM**	**PSNR**	**SSIM**	**PSNR**	**SSIM**	**PSNR**	**SSIM**
Test image 1 (Fig 10.a)	36.61	0.795	37.45	0.804	33.78	0.749	38.05	0.815
Test image 2 (Fig 10.b)	34.36	0.698	31.38	0.556	29.65	0.488	36.25	0.758
Test image 3 (Fig 10.c)	27.36	0.336	29.43	0.441	30.74	0.535	29.74	0.491
Test image 4 (Fig 10.d)	37.41	0.4994	31.44	0.347	31.47	0.323	40.54	0.665

Table 2 shows the calculation times used by the method used in the literature and proposed in this study during the binarization process of the test images. As can be clearly seen from this table, the method proposed in this study performs similar results to other methods in terms of running time. Therefore, this technique can be easily used instead of other techniques in the detection and segmentation stages of images.

Table 2. Measuring test results in terms of computation time

Image	**Computation Time**			
	Sauvola	**Niblack**	**Bernsen**	**Haytham**
Test image 1 (Fig 10.a)	0.414	0.371	0.793	0.401
Test image 2 (Fig 10.b)	0.373	0.384	0.812	0.379
Test image 3 (Fig 10.c)	0.174	0.182	0.511	0.175
Test image 4 (Fig 10.d)	0.294	0.316	0.565	0.305

4. Conclusion

In this study, the problem of obtaining threshold values of images with gradient colour density in thresholding, which is one of the most critical stages of image processing, has been solved. For this purpose, a new normalization matrix was created using the weights of the relevant pixel region and the output image was created with this matrix. To demonstrate the success of the proposed method, it was compared with both global and local thresholding algorithms frequently used in the literature. In the comparison, images with gradient background and gradient foreground features were preferred, along with images in which the contrast between the background and foreground was minimal. The success of the proposed method is clearly evident in the visual outputs and is also demonstrated qualitatively by PSNR and SSIM image quality metrics. Therefore, the method proposed in this study can be easily used both in cases where general thresholding is required and in situations where illumination is problematic. When evaluated in terms of future projection of the study, the expectations are as follows: Since the success of the proposed method is directly related to the normalization matrix created, the success of the method can be further increased by developing this matrix with different techniques in the literature or by combining it with other local thresholding techniques.

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Author's Contributions

Esin Mutlu: Performing experiments, comparisons with scientific metrics and helped in manuscript preparation.

Serkan Dereli: Created the algorithm, coded it in Matlab and result interpretation.

Ethics
There are no ethical issues after the publication of this manuscript.

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