International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 7 Issue 2, February - 2023, Pages: 1-9

Binarization Methods in Multimedia Systems when Recognizing License Plates of Cars

Amer Tahseen Abu-Jassar[1], Svitlana Sotnik[2], Tetiana Sinelnikova[3], Vyacheslav Lyashenko[4]

[1]Faculty of Computer Science and Information Technology, Ajloun National University, Jordan

[2]Department of Computer-Integrated Technologies, Automation and Mechatronics, Kharkiv National University of Radio Electronics, Ukraine

[3]Department of Informatics, Kharkiv National University of Radio Electronics, Ukraine

[4]Department of Media Systems and Technology, Kharkiv National University of Radio Electronics, Ukraine
e-mail: lyashenko.vyacheslav@gmail.com

Abstract: *This work is aimed at analyzing methods of binarization in multimedia systems when recognizing license plates of cars. In order to carry out binarization license plates, features of existing (LPC) were first analyzed. A review of most well-known classification of binarization methods was carried out, and on basis of analysis, classification was proposed, which will be divided into four general classes, which distinguishes our classification from known ones. A fallback class has also been added. As result, pros and cons of all binarization methods have been determined.*

Keywords—recognition; images; symbols; license plate of cars; binarization methods

1. INTRODUCTION

Today, multimedia systems (MS) are in great demand in various fields, ranging from healthcare to transport, logistics and navigation [1], [2]. Multimedia systems open up wide opportunities for various areas, starting with opportunities for obtaining new knowledge, ending with application in business, which ensures its development and finding non-standard approaches to solving problems. This allows us to talk about the possibility of using classical approaches [3]- [7], and non-standard methods, which are used to solve problems in various fields [8]-[16].

Such wide application of multimedia systems is explained by number of pros:

- simplicity and convenience of multimedia systems interfaces;

- ability to store large amount of various information on one medium;

- ability to compare images and process them by variety of programs, etc.

In this paper, just describe possibilities of solving problems of cars license plates recognizing in MS.

Automatic recognition of car license plates is quite urgent and practically important problem, which is caused by:

- with help of license plate recognition systems (LPRS), it is possible to organize safety at pedestrian crossings and various checkpoints;

- management of traffic flows with help of LPRS, for example, at some urban infrastructure facilities, since there is need for passage of authorized vehicles to specific/secret territory;

- car registration;

- control over time spent by vehicles on territory, etc.

A license plate is basic concept for identifying various cars.

Generally, license plate recognition (LPR) system takes image or video stream as input to system and, if given frame contains auto it outputs content of license plate, usually as text [17].

In LPR systems, many different methods of detecting and recognizing objects are used at moment, which will be discussed in this work.

2. RELATED WORK

Since proposed work involves classification of various methods of binarization of license plates images, we will briefly consider works of other authors of this subject area.

Binarization can be used as first step in most text image analysis applications [18], [19].

The main purpose of text images binarization is to segment document into separate components. Recently, methods based on segmentation are quite popular in detecting text of scene, as results of segmentation can more accurately describe text of various forms scene [20], [21].

There are various methods of binarization: widespread use of morphological filtering in binary image processing – image processing method based on set theory, lattice theory, topology and random function [22], [23]; histogram of structuring elements [24], [25].

The threshold value is simplest approach to binarization. Binary image processing, classified on basis of threshold value

using Otsu algorithm [26]; Niblack and Sauvola techniques [27]; Burnsen [28].

Binarization of digital documents is task of classifying each pixel in document image [29].

3. Features of Car License Plates

The license plate (LP) is mandatory element of any car, and in each region LP has its own characteristics, for example, size of plate (Table 1), color (Fig. 1), font, presentation standards that must be taken into account when creating LPRS [30].

Table 1: Examples of LP UK standard size options

View	Size
AB02 ABC	464 mm x 105 mm
BI23 ABC	432 mm x 105 mm
A23 ABC	404 mm x 105 mm
BI2 ABC	369 mm x 105 mm
A2 ABC	344 mm x 105 mm
BI ABC	309 mm x 105 mm
2 ABC	288 mm x 105 mm
I ABC	249 mm x 105 mm
2 AB	224 mm x 105 mm
I BC	189 mm x 105 mm

LP with height of 105 mm have been considered, but according to standard, for example, great Britain, there are also LP with height: 90 mm, 167 mm, 203 mm.

This variety is caused by fact that on some cars license plate of standard size will not work, and it is better reduced in size so that it is placed in recess of car, which can be in front or behind car.

The color of font on LP depends on car type, so

- white and black – private vehicles have license plates with white background and black inscriptions (fig. 1, a, b) [31];

- yellow and black – commercial vehicles have license plates with yellow background (Fig. 1, c) and black letters;

- green: electric vehicles receive green license plates (Fig. 1, d).

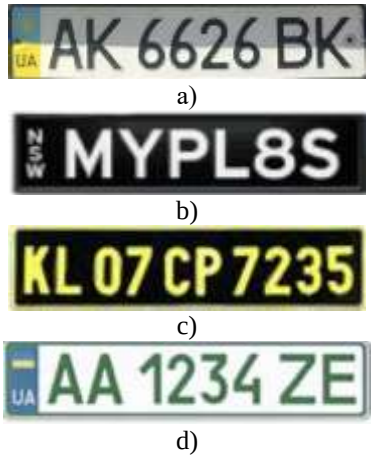


Figure 1: Font colors

Transit license plates now have only red background and black symbols.

All license plates must comply with following font rules:

- symbols must be 79 mm high;

- symbols (other than number 1 or letter I) must be 50 mm wide;

- stroke of symbols (black print thickness) shall be 14 mm;

- distance between symbols shall be 11 mm;

- space between groups of characters must be 33 mm;

- vertical space between groups must be 19 mm;

- top, bottom and side margins must be at least 11 mm.

It occurs that region (for example, United States) determines its own font size.

The type of font also in each region can be different, for example, auto Germany (FE-Schrift; Eurostile, as well as it can be simply selected (e.g. Wepfont, Dave Hansen, Times New Roman, Heaven Castro), etc.

As for standards, there is euro standard; there are room standards, for example, in UK and Ukraine, etc.

The review of features of car license plates is necessary to take this into account in LPRS.

4. Basic Binarization Methods

Input images in LPRS can describe both moving and stationary objects.

The degree of detail of recognition stages is described by each author in different ways, and we will summarize, and let LPRS include three main stages: preprocessing, segmentation and recognition process itself.

Preprocessing involves binarizing input image to reduce amount of information and then analyze it.

Image binarization makes it easier to separate characters for later recognition, as foreground (symbol) and background pixels receive opposite "colors" in binarization.

Binarization is classic task of processing text images [32].

The process of binarization consists in converting color image or image in grayscale to two-tone, for example, black and white.

The general concept of binarization is to divide original array of multicolored pixels into two sets: set of pixels belonging to objects or significant pixels, and set of pixels related to background – background pixels [33], [34].

There are various methods of binarization, but in general they all belong to two groups:

- global (threshold);

- local (adaptive).

In global methods, key parameter is threshold. In course of binarization, there is binarization threshold of 1, by which division into black and white occurs, and value of threshold 1 remains unchanged throughout binarization process.

Global methods are classified [35]-[37]:

- bottom-threshold binarization

- binaryization with an upper threshold;

- binaryization with double restriction;

- incomplete threshold processing;

- multi-level threshold transformation.

In local (adaptive) methods, key parameter is also threshold. During binarization, image is divided into several areas, for each of which it is necessary to calculate threshold based on information about intensity of pixels.

For example, if we consider binarization in OpenCV, thresholds are [37], [38]:

- binary threshold – value exceeding threshold is maximum value, remaining values are 0;

- antibinar threshold – threshold value is 0, remaining values are maximum;

- truncation threshold – value that exceeds threshold is threshold, and other values remain unchanged;

- threshold value is 0 – threshold value has not changed, and rest are set to 0;

- threshold is reduced to 0 – threshold value is 0, rest remain unchanged.

So, there are ways to choose threshold of image binarization, which provides significant variability in solving practical problems.

There is also classification of binarization methods into three classes [39]-[41]:

- Global method – first, background of image is evaluated, and then normalized image is generated using help information. After that, method of global binarization is used.

- Patch-based method – binarization patch by patch. At each site, binarization is evaluated using global binarization method. After that, some post-processing is performed to make sure that binarization threshold in neighboring patches has smooth transition.

- Moving-window method – binarization is performed pixel by pixel. To calculate pixel statistics, moving window is configured inside window, and based on statistics, threshold for central pixel inside window is calculated.

5. Classification of Binarization Methods

License plates on car are artificial objects that take certain shapes and always contain external contour and internal shape, which is directly displayed in images that will be subject to binarization and recognition.

We consider such classification of binarization methods, which will be divided into four general classes (Table 2):

- BO – binarization with areas that contain significant pixels grouped into areas in image;

- BC – binarization with contours on which boundaries of objects are highlighted;

- BS – after binarization, "skeletons" of objects remain;

- RM – reserve methods.

BO methods consist of:

- methods of threshold filtration (MTF);

- methods based on work with histograms (MH);

- methods based on working with contour filters (MCF).

MPF – threshold filtration methods. The result of filtering is to obtain from original image of same size to which certain rules were applied.

The essence of threshold filtering is division of image by means of given binarization threshold into pixels: set of significant and background pixels are produced.

Table 2: Classification of binarization methods

<table>
<tr><td colspan="6">Binarization</td></tr>
<tr><td colspan="6">BO</td></tr>
<tr><td>MTF</td><td colspan="3">MH</td><td colspan="2">MCF</td></tr>
<tr><td>A 1.1</td><td colspan="3">A 2.1</td><td colspan="2" rowspan="3">A 3.1</td></tr>
<tr><td>A 1.2</td><td colspan="3">A 2.2</td></tr>
<tr><td>A 1.3</td><td colspan="3">A 2.3</td></tr>
<tr><td>A 1.4</td><td colspan="3">A 2.4</td><td colspan="2" rowspan="3">A 3.2</td></tr>
<tr><td>A 1.5</td><td colspan="3" rowspan="2">A 2.5</td></tr>
<tr><td>A 1.6</td></tr>
<tr><td colspan="6">BC</td></tr>
<tr><td rowspan="2">B 1.1</td><td rowspan="2">B 2.1</td><td rowspan="2">B 2.1.1</td><td colspan="3">2.1.1.1</td></tr>
<tr><td colspan="3">2.1.1.2</td></tr>
<tr><td rowspan="5">B 1.2</td><td rowspan="5">B 2.2</td><td colspan="4">B 2.2.1</td></tr>
<tr><td colspan="4">B 2.2.2</td></tr>
<tr><td colspan="4">B 2.2.3</td></tr>
<tr><td colspan="4">B 2.2.4</td></tr>
<tr><td colspan="4">B 2.2.5</td></tr>
<tr><td colspan="6">BS</td></tr>
<tr><td>C 1.1</td><td colspan="2">C 1.2</td><td colspan="2">C 1.3</td><td>C 1.4</td></tr>
<tr><td colspan="6">RM</td></tr>
<tr><td colspan="3">D 1.1</td><td colspan="3">D 1.2 и т.д.</td></tr>
</table>

A 1.1 – methods with areas that have clear boundaries.

A 1.2 – methods with areas that have fuzzy boundaries (complex: use of threshold filtration, morphological operations "erosion" or "dilatation").

Erosion or narrowing is used when it is necessary to clarify contours of black objects. It also eliminates light noise pixels on black background, some of which may be noise of CCD matrix (charge-coupled device), some of which may be noise of analog-to-digital converter, etc. [42], [43].

Dilation, that is, expansion, allows you to refine contours of light objects, as well as remove isolated black pixels on light background [44].

A 1.1 – methods with areas that have clear boundaries:

A 1.1.1 is mod method in which it is assumed that image contains known number of uniform brightness classes points. Boundary areas between closed areas occupy relatively small area of image. Therefore, on histogram, they must correspond to intermode depressions, within which segmentation thresholds are set.

The mod method uses histogram of pixels brightness in image. The mod method can be used for images with well-distinguishable object and background. As result of binarization, matrix of pixels with values of 0 and 1 is obtained.

The main pros of mod method is simplicity when working with images that have well-distinguishable object and background.

The main cons of mod method is that real images do not satisfy hypotheses put forward in this method, so, for example, image has very low brightness, then significant errors arise during operation of algorithm.

And 1.1.2 – methods for improving histogram, which include:

A 1.1.2.1 – based on local properties of image using gradient information.

A 1.1.2.2 based on second-order statistics;

A 1.1.2.3 – based on analysis of integral distribution function curvature.

A 1.1.3 – methods for approximating histogram with mixture of normal distributions and applying statistical methods for optimal separation of this mixture.

The main pros of histogram approximation method is that it is possible to conduct studies of various characteristics of objects (qualitative and numerical).

The image histogram allows you to estimate number and variety of image shades, as well as overall brightness level of image.

The main cons of this method is high computational complexity, in addition, Gaussoids often do not adequately approximate real modes.

A 1.1.4 – methods with empirical measure of segmented image quality and maximization of corresponding criterion function:

A 1.1.4.1 – discriminant approach;

The main pros of discriminant method is strong smoothing effect in relation to indentation of brightness original histogram.

The main cons of discriminant method is that if areas of object and background differ sharply from each other, histogram of criterion function can be multimodal, which means that it is necessary to determine all local peaks, which seriously reduces competitiveness of method.

A 1.1.4.2 – entropy approach (Tsallis entropy; Kapur's entropy; minimal cross entropy; fuzzy entropy; Schreiber's entropy, etc.);

The main pros of methods with entropic approach is preliminary cutting off of unnecessary fragments of image that do not contain useful information, which is important task.

The cons of methods with entropy approach include:

- criterion function may have several maxima close in value;

- it can be distinguished that with increase in threshold number, entropy increases proportionally, which greatly reduces quality of image.

A 1.1.4.3 – moment approach is based on comparison of initial moments of segmented and original images.

The main pros of moment approach method is to provide highest quality segmentation of complex images.

The main cons of moment approach method is complexity of calculations when using high-order moments.

A 1.1.5 – method of selecting threshold directly by local characteristics.

The main pros of threshold choosing method by local characteristics:

- allows you to segment complex real images more qualitatively;

- choice of threshold when highlighting small objects seems promising.

The main cons of choosing threshold method by local signs is more complex process and takes more time.

A 1.1.6 – method of maximum average contrast (heuristic determination of optimal threshold: threshold that highlights more high-contrast and fewer low-contrast brightness differences than any other threshold is considered optimal for image segmentation).

The main pros of maximum average contrast method is simplicity of implementation.

The main cons of method – large required amount of additional memory.

MH – methods based on working with histograms. A histogram is graph of tones in image distribution. Methods based on working with histograms:

A 2.1 – Bernsen's method (pros – high-quality separation of background from objects in uniform / uneven lighting; objects with large surface are correctly marked. Cons – after processing monotonous areas of brightness, strong parasitic interference is formed, in some cases leads to appearance of false black spots).

A 2.2 – Niblack's method (pros – well recognizes objects that do not have large surface; is used in practice for quick filtering of sufficiently contrasting images on which there are no strongly noisy areas with smooth brightness transitions; has high stability of work in wide dynamic brightness range. Cons – internal areas of objects of interest with large surface area are marked as ackground, which can lead to erroneous classification of objects of interest and to incorrect definition of their geometric characteristics; in places of smooth transition of brightness, method gives false objects with little noise).

A 2.3 – Otsu method (pros – good adaptation to various kinds of images, choosing most optimal threshold and speed; ease of implementation. Cons – sensitivity to uneven brightness of image; loss of small details and "sticking" of nearby symbols is possible).

A 2.4 – Janowitz and Huntington method (pros – effective for processing scanned paper images; effective when working with images that have luminance zonal unevenness, while same image objects in different parts have significant differences in brightness. Cons – attribute extremely slow speed of work) [45].

A 2.5 – Ekvall's method (pros – high-performance method; often used to process clear and contrast images, although it processes images with uneven lighting and noise noise well; it processes objects with large surface area well. Cons – strongly pronounced shadows are marked as objects, which can lead to decrease in accuracy of determining geometric characteristics in future; when processing thin intersecting lines, tears may occur, so method is good for thick lines and large objects).

MCF – methods based on working with contour filters:

A 3.1 – method based on Prewitt operator (pros – good performance in detecting vertical and horizontal edges);

An effective operator to determine orientation of image. Cons – diagonal direction points are not always preserved; sensitivity to noise in image; less accurate than Sobel operator).

A 3.2 – method based on Sobel operator (pros – ease of implementation; ease of searching for smooth edges; smoothes out parasitic effects in image. Cons – high sensitivity to noise; not very accurate detection of edges; detection with thick and rough edges does not give proper results; lack of rotational symmetry in matrices to calculate values of approximate derivatives in vertical and horizontal directions, which leads to "loss" of some contours).

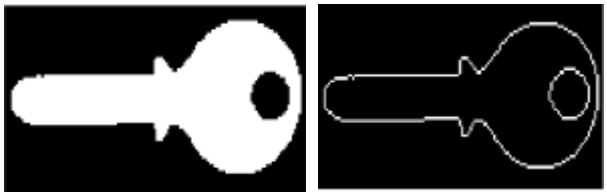
Binarization methods with paths on which boundaries of objects are highlighted can be attributed to two groups: methods with "delineation"; linear and nonlinear filtration;

B 1.1 – MTF + "internal contouring". Such complex method is implemented by alternately applying erosion and subtracting transformed image from original (Fig. 2, a).

B 1.2 – MTF + "external contouring". Such complex method is implemented by alternately applying dilatation and subtracting original image from converted one (Fig. 2, b).

The result of delineation methods are single-pixel contours of all objects in image. Area delineation is used to highlight

objects with specified properties in images. The result of delineation is binary or hierarchical (multiphase) image, where each level of image corresponds to certain class of selected objects.



a) b)

Figure 2: "Contouring" method

The pros of delineation methods include:

- information ability of contour images is very high;

- greatly facilitates work of decoders.

To cons of "contouring" methods:

- contour may have significant thickness, therefore, it is practically unsuitable for scanning due to excess of points included in it and has coordinates of points, both corresponding to object and background ("external contouring"); - perhaps an increased thickness of contour in areas having inclination of about +-45 degrees ("external contouring");

- sometimes large memory capacity is required to store circuit, then scanning procedure will be longer in time.

- B 2.1 – linear filtration methods.

To summarize, pros of linear filtering methods are simplicity of implementation and interpretation; lead to smoothing of sharp changes in brightness of images that have been processed.

If we generalize, cons of methods include:

- use of linear filtering methods does not allow to obtain acceptable solution in number of practically important applications;

- along with reduction of noise, simultaneously there is blurring of image contours;

- for contrast images, it is inefficient, as it leads to blurring of contrasting images details contours.

Linear filtration methods:

- B 2.1.1 – optimal filtering method (implemented when signal and additive interference are independent and have normal distribution).

Linear and median filters do not take into account changes in statistical characteristics in image itself. Therefore, in classification we will take into account only 2.1.1.

Algorithms that allow you to take into account such changes are called adaptive.

B 2.1.1 includes:

- B 2.1.1.1 – method based on Wiener filter (pros – noise removal with moderate complexity; can often be calculated in real time; minimize average error of estimate squared. Cons – relatively slow implementation, since it works in frequency domain; difficulty in estimating power spectra; cannot be implemented with perfect accuracy).

- B 2.1.1.2 – method based on Kalman filter (pros – ease of implementation; ability to "build" image with ultra-high resolution. Cons – when setting inaccurate initial parameters, filter does not even go to approximate error estimate; excessively large size of matrices that need to be processed when obtaining high-resolution images).

- B 2.2 – nonlinear filtering methods. It is realized by approximation to differential operators by forming differences of neighboring elements of digital image [46].

To summarize, pros of nonlinear filtering methods include fact that when filtering real contrasting noisy images, filter allows you to save sharp border without blurring it; are actively used to improve clarity of image; effective when working with pulsed noise.

The cons of each nonlinear filtering method are different, they are given below.

Methods of nonlinear filtering:

- B 2.2.1 – method based on Roberts operator (implementation using 2 x 2 view window moving through image) (pros – ease of implementation; speed of calculations. Cons – there is no clearly defined central element, which significantly affects result of filtering; significant sensitivity to noise).

- B 2.2.2 – method based on homomorphic filters (implemented where output signal is formed as product of two different signals) (pros – makes it possible to normalize brightness of image and increase its contrast; at same time, you can increase contrast and compress dynamic range. Cons – not particularly effective when working with problem of extreme lighting).

- B 2.2.3 – filter-based methods based on ordinal statistics are called spatial filters (implemented by pre-ranking input values, and then selecting value that is at certain position of ordered sequence) (pros – to remove impulse noise; occupy average value in terms of speed / quality ratio; are quite effective for noise with significant dispersion; effective when only additive component of noise is present. Cons – require preliminary ranking; removal of pulse noise entails change in brightness values of almost all pixels of image, which often significantly affects result of images study).

- B 2.2.3.1 median filter;

- B 2.2.3.2 filter based on calculation of maximum and minimum;

- B 2.2.3.3 midpoint filter;

- B 2.2.3.4 average average filter.

- B 2.2.4 – method based on neural networks (implemented using interconnection of nonlinear elements, that is, artificial neurons) (pros – ability to simulate most of nonlinear systems. Cons – general convergence of training algorithms, such as reverse propagation algorithm, is not guaranteed).

- B 2.2.5 – method based on polynomial filters (with finite number of coefficients is capable of approximating large class of nonlinear systems with soft nonlinearity) (pros – ability to approximate large class of nonlinear systems with soft nonlinearity; cons – complexity of implementation due to fact that amount of memory and, accordingly, number of model coefficients increase; large number of coefficients are needed for adequate implementation).

BS methods (after binarization, "skeletons" of objects remain) include:

- C 1.1 – morphological analysis methods of "skeletons". Example of such methods is implemented by selecting possible solutions for individual parts of problem (morphological features that characterize device) and subsequent systematic obtaining of their combinations (combination) [47], [48];

- C 1.2 – methods based on modifications of erosion algorithm;

- C 1.3 – methods based on various types of vectorization;

- C 1.4 – methods based on deformable models.

Comparison of undeformed images and images obtained by skeletonization in Fig. 3 [49].

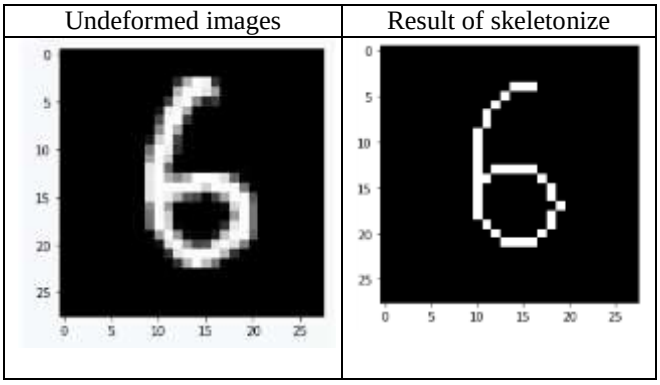


Figure 3: Comparison of undeformed and skeletonized images

To pros of "skeletonization" methods – effective for retrieving objects and / or representing their topology; Reduce blobs to 1-pixel-wide view.

Each method of "skeletonization" has its drawbacks and such cons include: blurring diagonal lines with thickness of 2 pixels; skeletonization of objects only in two-dimensional space and is not applicable for processing multidimensional data, with number of measurements greater than two. When working with "three-dimensional skeletons" – there may be violation of connectivity in skeleton; loss of branching points; violation of midline centrality in object; increasing thickness of line in skeleton.

RM methods – fallback methods (methods that are not included in above classes):

- D 1.1 – Bradley method (pros – ease of implementation and high speed of implementation; effective when working with heterogeneous background; resistant to noise. Cons – poor sensitivity to low-contrast image details; errors occur when processing shadows);

- D 1.2 – Gonzalez and Woods method (in this class, since it includes 2 categories of algorithms: 1) algorithms based on finding boundaries – registration of objects contours using discontinuity property; 2) algorithms based on finding areas – localization of objects in accordance with properties of similarity), etc. Pros – effective if all objects of working scene are evenly lit.

Cons – sensitivity to lighting; ineffectiveness in presence of light spots in image; not effective when objects have large shadows. The results largely coincide with results of Otsu method.

The above classification does not pretend to be complete, but demonstrates in detail diversity of main types of image processing, namely binarization and segmentation. Each of these four classes has its pros and cons.

6. Conclusion

This work is aimed at analyzing methods of binarization and segmentation in multimedia systems when recognizing license plates of cars.

In order to carry out binarization of license plates, features of existing LP were first analyzed:

size of plate, color and font, presentation standards that need to be taken into account when creating LPRS.

A review of most well-known classification of binarization methods was carried out, and on basis of analysis, classification was proposed, which will be divided into four general classes, which distinguishes our classification from known ones. A fallback class has also been added. As result, pros and cons of all these methods have been identified.

When choosing method for binarizing digital images, eliminating noise, obtaining contours of LP, after which process of directly recognizing patterns will go on, most suitable methods are those that demonstrated high quality of image processing of working scene with uneven lighting, dividing image into background and objects of interest,

weeding out shadows from objects of interest, for example, Ekvall and Bernsen. Also, choice of method depends on LPRS development environment.

7. REFERENCES

[1] Dougherty, E. R. (2020). Digital image processing methods. CRC Press.

[2] Garg, N., & Garg, N. (2013). Binarization techniques used for grey scale images. International Journal of Computer Applications, 71(1), 8-11.

[3] Lyashenko, V., & et al.. (2021). Wavelet ideology as a universal tool for data processing and analysis: some application examples. International Journal of Academic Information Systems Research (IJAISR), 5(9), 25-30.

[4] Deineko, Zh., & et al.. (2021). Color space image as a factor in the choice of its processing technology. Abstracts of I International scientific-practical conference «Problems of modern science and practice» (September 21-24, 2021). Boston, USA, pp. 389-394.

[5] Lyashenko, V., Kobylin, O., & Ahmad, M. A. (2014). General Methodology for Implementation of Image Normalization Procedure Using its Wavelet Transform. International Journal of Science and Research (IJSR), 3(11), 2870-2877.

[6] Lyashenko, V. V., Babker, A. M. A. A., & Kobylin, O. A. (2016). The methodology of wavelet analysis as a tool for cytology preparations image processing. Cukurova Medical Journal, 41(3), 453-463.

[7] Kobylin, O., & Lyashenko, V. (2014). Comparison of standard image edge detection techniques and of method based on wavelet transform. International Journal, 2(8), 572-580.

[8] Jassar, A. A. (2018). An analysis of QoS in SDN-based network by queuing model. Telecommunications and Radio Engineering, 77(4).

[9] Deineko, Zh., Kraievska, N., & Lyashenko, V. (2022). QR Code as an Element of Educational Activity. International Journal of Academic Information Systems Research (IJAISR), 6(4), 26-31.

[10] Lyashenko, V., Deineko, Z., & Ahmad, A. (2015). Properties of Wavelet Coefficients of Self-Similar Time Series. International Journal of Scientific and Engineering Research, 6, 1492-1499.

[11] Kuzemin, O., & Lyashenko, V. Microsituation Concept in GMES Decision Support Systems/A. Kuzemin, V. Lyashenko. Intelligent Data Processing in Global Monitoring for Environment and Security (pp. 217–238).–2011.–P, 217-238.

[12] Maksymova, S., & et al.. (2017). Voice Control for an Industrial Robot as a Combination of Various Robotic Assembly Process Models. Journal of Computer and Communications, 5, 1-15.

[13] Lyashenko, V., & et al.. (2021). Recognition of Voice Commands Based on Neural Network. TEM Journal: Technology, Education, Management, Informatics, 10(2), 583-591.

[14] Lyashenko, V., & et al.. (2021). Semantic Model Workspace Industrial Robot. International Journal of Academic Engineering Research, 5(9), 40-48.

[15] Al-Sherrawi, M. H., & et al.. (2018). Corrosion of metal construction structures. International Journal of Civil Engineering and Technology, 9(6), 437-446.

[16] Lyashenko, V. V., & et al.. (2017). Methodology of Wavelets in Relativistic Heavy Ion Collisions in One Dimensional Phase Space. Journal of High Energy Physics, 3, 254-266.

[17] Shashirangana, J., & et al.. (2020). Automated license plate recognition: a survey on methods and techniques. IEEE Access, 9, 11203-11225.

[18] Hrytsyk, V., & Petryk, M. (2017). Image segmentation in computer vision diagnostic systems. Системні технології, (6), 92-101.

[19] Zhou, W., Ma, X., & Zhang, Y. (2020, August). Research on image preprocessing algorithm and deep learning of iris recognition. In Journal of Physics: Conference Series (Vol. 1621, No. 1, p. 012008). IOP Publishing.

[20] Chauhan, S., Sharma, E., & Doegar, A. (2016, September). Binarization techniques for degraded document images—A review. In 2016 5th international conference on reliability, infocom technologies and optimization (Trends and Future Directions)(ICRITO) (pp. 163-166). IEEE.

[21] Liao, M., & et al.. (2020, April). Real-time scene text detection with differentiable binarization. In Proceedings of the AAAI conference on artificial intelligence (Vol. 34, No. 07, pp. 11474-11481).

[22] De Natale, F. G., & Boato, G. (2017). Detecting morphological filtering of binary images. IEEE Transactions on Information Forensics and Security, 12(5), 1207-1217.

[23] Hu, L., & et al.. (2018). An improved heuristic optimization algorithm for feature learning based on morphological filtering and its application. IEEE Access, 6, 22754-22763.

[24] Lu, W., & et al.. (2019). Binary image steganalysis based on histogram of structuring elements. IEEE Transactions on Circuits and Systems for Video Technology, 30(9), 3081-3094.

[25] Ismail, W., & et al.. (2020, October). An adaptive image processing model of plant disease diagnosis and quantification based on color and texture histogram. In 2020 2nd International Conference on Computer and Information Sciences (ICCIS) (pp. 1-6). IEEE.

[26] Lee, S., & et al.. (2022). Thermographic inspection of CLP defects on the subsurface based on binary image.

International Journal of Precision Engineering and Manufacturing, 23(3), 269-279.

[27] Saddami, K., & et al.. (2018, September). A new adaptive thresholding technique for binarizing ancient document. In 2018 Indonesian Association for Pattern Recognition International Conference (INAPR) (pp. 57-61). IEEE.

[28] Khairnar, S., Thepade, S. D., & Gite, S. (2021). Effect of image binarization thresholds on breast cancer identification in mammography images using OTSU, Niblack, Burnsen, Thepade's SBTC. Intelligent Systems with Applications, 10, 200046.

[29] Ayyalasomayajula, K. R., Malmberg, F., & Brun, A. (2019). PDNet: Semantic segmentation integrated with a primal-dual network for document binarization. Pattern Recognition Letters, 121, 52-60.

[30] Jain, V., & et al.. (2016, December). Deep automatic license plate recognition system. In Proceedings of the Tenth Indian Conference on Computer Vision, Graphics and Image Processing (pp. 1-8).

[31] Shivakumara, P., & et al.. (2018). CNN-RNN based method for license plate recognition. CAAI Transactions on Intelligence Technology, 3(3), 169-175.

[32] Paul, N., & Tunga, H. (2016, July). Improved Method for Document Image Binarization. In National Conference on Recent Innovations in Computer Science & Communication Engineering.

[33] Sheikh Abdullah, S. N. H., & et al.. (2021). Novel adaptive binarization method for degraded document images. Computers, Materials & Continua, 67(3), 3815-3832.

[34] Rani, U., Kaur, A., & Josan, G. (2019). A new binarization method for degraded document images. International Journal of Information Technology, 1-19.

[35] Eyupoglu, C. (2017). Implementation of Bernsen's locally adaptive binarization method for gray scale images. The Online Journal of Science and Technology, 7(2), 68-72.

[36] Khakimov E. (2021). Image binarization methods. Online: Linkedin.com.

[37] Brenner, R., Priyadarshi, J., & Itti, L. (2016). Perfect accuracy with human-in-the-loop object detection. In Computer Vision–ECCV 2016 Workshops: Amsterdam, The Netherlands, October 8-10 and 15-16, 2016, Proceedings, Part II 14 (pp. 360-374). Springer International Publishing.

[38] Hou, Y., Wang, G., & Cui, Z. (2016, November). The Rice Impurity Vision Inspection Method based OpenCV. In 6th International Conference on Information Engineering for Mechanics and Materials (pp. 553-558). Atlantis Press.

[39] Xu, L., & et al.. (2015). Oil spill candidate detection from SAR imagery using a thresholding-guided stochastic fully-connected conditional random field model. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops (pp. 79-86).

[40] Chen, G., & Krzyzak, A. (2022). Feature Extraction for Patch Matching in Patch-Based Denoising Methods. Image Analysis & Stereology, 41(3), 217-227.

[41] Haritha, C., Ganesan, M., & Sumesh, E. P. (2016, March). A survey on modern trends in ECG noise removal techniques. In 2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT) (pp. 1-7). IEEE.

[42] Saito, S., & et al.. (2021). Image processing method for automatic measurement of number of DNA breaks. Journal of Advanced Simulation in Science and Engineering, 8(2), 173-193.

[43] El-Messiry, H. (2017). Robust segmentation of deform objects using morphological scale space. Technology, 8(4), 138-145.

[44] Pastore, J., & et al.. (2016, April). New windows based color morphological operators for biomedical image processing. In Journal of Physics: Conference Series (Vol. 705, No. 1, p. 012023). IOP Publishing.

[45] Oliveira, H. C., & et al.. (2018). Failure detection in row crops from UAV images using morphological operators. IEEE Geoscience and Remote Sensing Letters, 15(7), 991-995.

[46] Khrustalev P. E. (2011). Algorithm of Automatic Calculation of Threshold of Binarization of Multispectral Images. DSPA : Questions of application of digital treatment of signals, 1(4), 208-212.

[47] Astola, J., & Kuosmanen, P. (2020). Fundamentals of nonlinear digital filtering. CRC press.

[48] Silva, A. C. M., Hirata, N. S., & Jiang, X. (2020, September). Skeletal similarity based structural performance evaluation for document binarization. In 2020 17th International Conference on Frontiers in Handwriting Recognition (ICFHR) (pp. 37-42). IEEE.

[49] Shevlyakov, A. N., & Lobanov, V. P. (2022, March). Recognition of the MNIST-dataset with skeletonized images. In Journal of Physics: Conference Series (Vol. 2182, No. 1, p. 012032). IOP Publishing.