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POLISH LICENCE PLATE NUMBERS RECOGNITION SYSTEM

Abstract. The article presents research carried out at OBRUM related to character recognition using an artificial neural network. The study concerned the recognition of Polish licence plate numbers of and was part of a project in the area of intelligent video analysis. The steps of licence number plate detection, segmentation, reconstruction and character recognition are discussed in detail. In conclusion, reference is made to the possibilities of using the research results in other applications.

Keywords: recognition of licence plate numbers, real-time systems, image processing, image analysis, artificial neural networks.

1. INTRODUCTION

The article presents research carried out on a system for recognising Polish licence plate numbers.

Studies of the literature on licence plate numbers recognition show that research is usually broken down into three major stages [1], [2], [3], [4]:

- licence plate detection;
- segmentation;
- character recognition.

However, the methodology adopted in this work included the following five stages:

- detection of potential licence plates;
- segmentation;
- reconstruction;
- recognition of characters and numbers in Polish licence plates;
- system adaptation;

in order to prepare more accurate data[1] for the artificial neural network, application of the rules of formulating Polish licence numbers to verify the reliability of the results, and to consider the possibility to adapt the developed solutions for application in other systems. Each of the stages named was broken down into subtasks which, for the sake of this paper, were called procedures.

[1]Here the term "more accurate data" means processing of the analysed areas of the image to approximate their features (colour, scale, rotation, sterility) to the template patterns of the licence plate characters used in the artificial neural network teaching process.

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System adaptation, that is the connection of the system with an external vehicle motion tracking system, has not been fully developed, and it therefore was presented here at the level of a concept. Vehicle monitoring system is beyond the scope of this work and, being a complex problem, it requires dealing with separately.

A requirement for this licence plate numbers recognition system was the ability to operate the system in real time, i.e. the system procedures had to be performed in a time no longer than 40 ms (image refresh rate 25 frames per second). This requirement proved to be fulfillable when the number of the analysed (potential) licence plates was limited[2] and when the resolution of the image analysed was not very high (explained further on in this paper).

The term system means a set of programming tools and a structured source code with files categorised into:

- arithmetic functions[3] (e.g. matrix multiplication, vector addition);
- geometric functions (e.g. a function that calculates the point of intersection of two segments);
- image processing and analysis functions (e.g. image normalisation, line fitting);
- test functions (e.g. comparison of text strings);
- constants (e.g. ratio of width to height of a standard single-line plate);
- artificial neural network for character recognition;
- main system procedures;
- object classes: TPlates (list of potential plates), TPlate (plate), TChar (character);
- TManager class for system management.

The test user interface, which facilitates system testing, selection of parameters and measurement of the time of execution of each system procedure, is shown in Figure 1.

[2]Architecture of the system has no limitations with regard to the number of analysed licence plates in a given image frame and enables identification of numbers of many vehicles. The number of potential plates can be limited by specifying minimum and maximum size of the plate to be analysed.

[3]Function in programming is defined as a unit of code that can be executed repeatedly from different program locations.

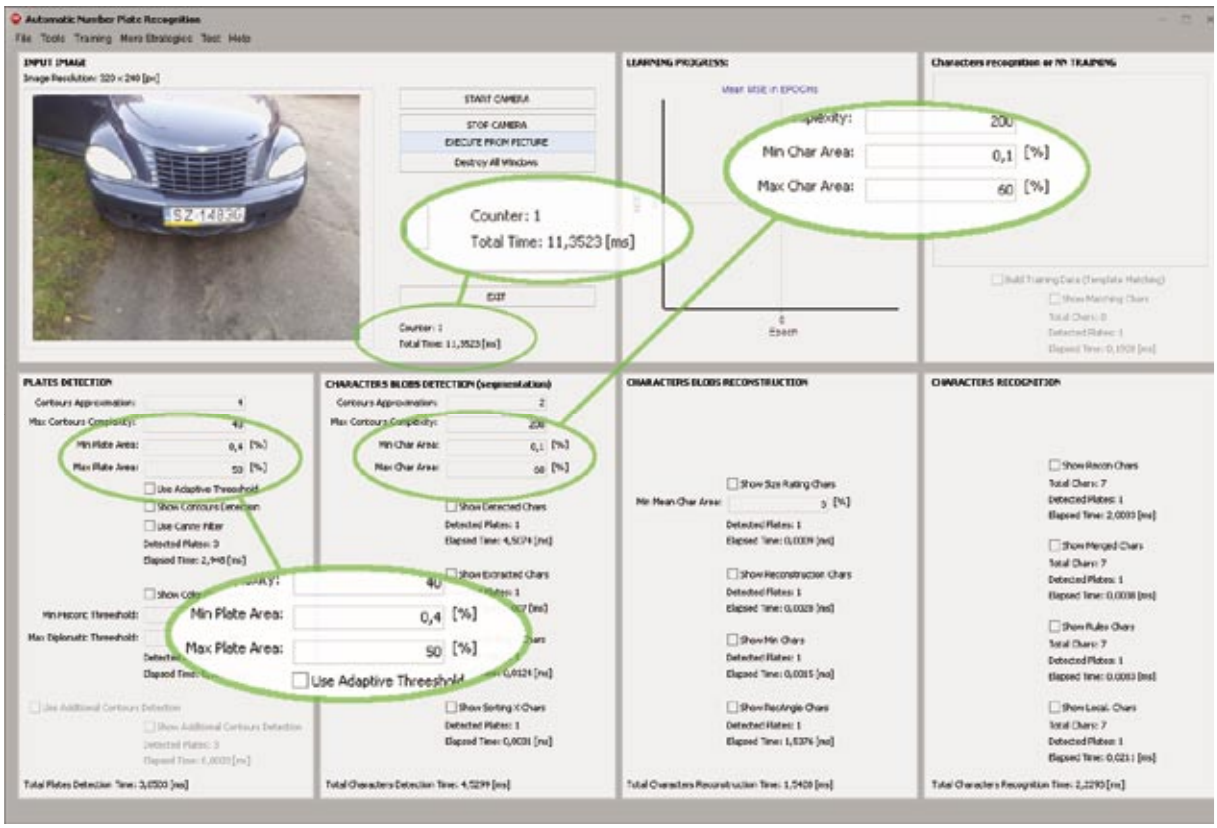


Fig. 1. User interface of the Polish licence plate numbers recognition system

The system was developed and tested on 100 images of varying characteristics[4] (graphic files) and on image from a webcam. Principal parameters of the test station: processor i7-3930K 3.2GHz, graphics card GeForce GTX 680. It is assumed that the reader is familiar with the basic terminology of image processing and analysis. The basics are described in literature, e.g. [6], [7].

2. STAGE 1. LICENCE PLATE DETECTION

Minimum height of characters in the licence number in the analysed image the system is able to handle (segmentation and reconstruction stages) and identify (character recognition stage) reaches 12 px. There is no need to analyse high-resolution (e.g. 1024x768 px or higher) image and unnecessarily slow down system operation. The selection of appropriate parameters depends mainly on the purpose of the system, the operating conditions and the position of the image recorder (camera) relative to the object, the vehicle of interest. The speed of the procedures (algorithms) in the first stage can be adjusted in several ways:

- limit the minimum and maximum area of a potential plate;
- determine the size of the image (lower resolutions, adjusted to operating conditions, are preferred);
- enable or disable additional detection[5].

[4]Characteristics varying in illumination conditions, image detail, distance between vehicle and camera, orientation of vehicles in relation to camera, types of licence plates. Test images also include examples from cameras with IR illuminators used at night.

[5]Additional licence plate detection techniques were introduced to promote system operation under unfavourable weather or at night, during which the image is less clear and may include many artifacts.

2.1. Procedure 1 - Primary detection of potential licence plates

The basic method of detecting potential license plates uses the technique of detecting contours and calculating image moments [5]. Visualisation of the contour detection technique in a binary image after normalisation histogram and thresholding (threshold 128) is shown in Figure 2. The threshold value is set by the user.

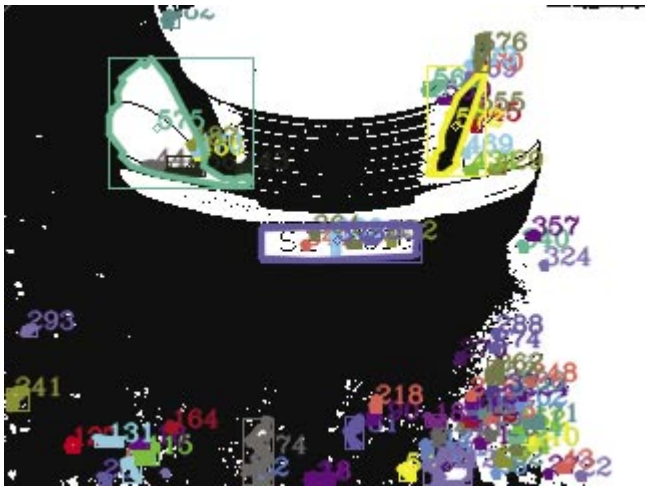


Fig. 2. Visualisation of the procedure of detection of potential licence plates

In the next step the rectangles circumscribed about the closed contours (Fig. 2) are evaluated for size and the rectangle height to width ratio is calculated. The algorithm pre-assigns the type of potential plate (single line, double line, motorcycle, moped) and rejects those that do not meet the size criterion (*Min Plate Area* and *Max Plate Area* parameters in Figure 1). The average execution time of the procedure for the image in Figure 2 (resolution 320x240 px) was 3 ms, and resulted in the acceptance of three potential plates (Fig. 3) and the collection of basic information describing the shape and position of the plates.

Fig. 3. Presentation of areas encompassing potential licence plates

2.2. Procedures 2 and 3 - Additional procedures of licence plates detection

The purpose of additional procedures of potential licence plates detection with the application of area isolation methods by adaptation thresholding (Bernsen method with Gaussian weights) and by drawing edges detected using the Canny algorithm [8], [9] (preceded by histogram equalisation) is to maintain high level of detectability of licence plates under adverse conditions (rain, snow, night, etc.). Both procedures are optional and make use of the same algorithms of contour detection and of geometric moment calculation in the next steps as Procedure 1, but they differ in preprocessing (Fig. 4). Differentiation of preprocessing enables detection of a higher number of potential licence plates under extreme operating conditions of the system. However, none of them proved to be versatile [6].

Inclusion of all additional detection methods may result in accepting of similar areas containing the same licence plate, which slows down the system (the total execution time of stage 1 may be up to 20 ms), but it increases the likelihood of correct identification of the licence number (the benefits of duplicates are discussed in more detail in step 4).

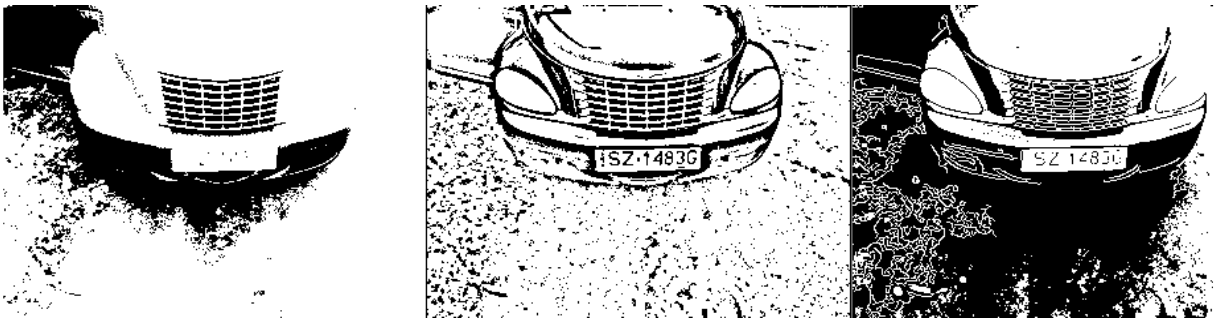


Fig. 4. Visualisation of preprocessing in Procedures 1, 2 and 3: thresholding at low threshold value, adaptation thresholding, standard thresholding with Canny edge detection

[6] None of the methods proved to be significantly more effective. The author is aware of the need to better investigate the methods of detecting licence plates in future research work and to automate the selection of methods (and their parameters) in future design work.

2.3. Procedure 4 - Colour analysis

The procedure consists in determining the average colour value of the potential licence plates (Fig. 5) and of the type of plate: standard plate, classic car plate (prevalent yellow), diplomatic plate (prevalent blue), temporary and temporary test plate (prevalent red).

Fig. 5. Visualisation of average colour value of potential licence plates

The main task of the procedure is to identify a diplomatic table and to inverse the value of its colours (standard font in Polish diplomatic licence plates is white, which is not tolerated at subsequent stages of analysis).

There are methods of more in-depth colour analysis [10], but such analysis proved to be unnecessary in the case of the tested images, and the rejection of potential licence plates only occurs with very low RGB values (selected experimentally on 100 test images). The execution time of the procedure is in the order of a fraction of a millisecond, and in the case of the analysed plates the average execution time was 0.1 ms.

3. STAGE 2 - CHARACTER SEGMENTATION

3.1. Procedure 5 - Character detection

In character detection use is made of the same contour detection methods as in Procedures 1, 2 and 3. However, the values of parameters are different: acceptance of higher contour complexity and lower value of contour approximation. The areas of potential plates, shown in Figure 3, are cut from the main image (shown in Figure 1) and appropriately scaled (optimisation and standardisation of the size of potential plates prior to launching the contour detection function). The next step is the evaluation of the size and proportions of characters.

The result of the procedure, and the indicated characters that have passed subsequent evaluation, are shown in Figure 6.

Procedure 5 is the longest of all procedures presented here, and it depends on the number of potential licence plates, which in turn depends on image complexity and on additional detection steps. In the case of the particular image, the Procedure 5 execution time was 5 ms.

Fig. 6. Illustrative visualisation of Procedure 5

3.2. Procedure 6 - Character extraction

Character extraction consists in creating a histogram of the distribution of character heights (characters circumscribed by rectangles, as shown in Fig. 6) and in retaining only the most numerous group in the given class of histogram [11]. The potential licence plates undergo evaluation of the number of accepted characters, after which, if some conditions are not satisfied (at least two characters in the most numerous class), these plates are rejected. Figure 7 shows potential licence plates that will be subjected to analysis during subsequent stages. In this particular case the algorithm retained one plate.

Fig. 7. Illustrative visualisation of potential licence plates that have passed evaluation in Procedure 7

The execution time of procedures, during which there is no image processing and analysis at pixel level, is very short. In this case it was 7 μs.

3.3. Procedure 7 - Vertical sorting

In order to discuss and display Procedure 7 in more detail, an image of higher complexity (Fig. 8) was taken. Additional detection of plates with the use of Canny algorithm (Procedure 3) was enabled for the evening scene.

Fig. 8. Test area of high complexity - sett paving and evening time

The purpose of Procedure 7 is to fit a maximum of two lines (one-line or two-line plate) to the characters so that inclination to the horizontal plane does not exceed 45 degrees, and the angle difference between the lines (if the algorithm allowed two lines) is not greater than 25 degrees. Using the information on the type of potential licence plate (Procedure 1), on the distance between the first and second lines (in two-line plate), basic methods of data analysis, and the fact that the characters that make up the licence number should be of similar height, it becomes possible to fit the line for a potential one-line plate (green) or a potential two-line plate (blue), as shown in Figure 9. If it is not possible to fit at least one line, the potential licence plate is rejected and is not taken into consideration in subsequernt procedures. Characters that are not intersected by lines (red characters in Fig. 9) are also rejected, and the corresponding plates are further processed in subsequent steps.

Fig. 9. Visualisation of Procedure 7

3.4. Procedure 8 - Horizontal sorting

Those characters that remain after eliminating characters that are not positioned on the lines that define rows of characters, are subjected to quantitative evaluation and distance evaluation. Plates that have no accepted characters are rejected, and the remaining characters

(marked green in Fig. 10) are sorted by their horizontal position (change in the sequence of characters in the list of characters in relation to position X) and analysed in the subsequent stage.

Fig. 10. Visualisation of Procedure 8 (rejection of three plates)

4. STAGE 3 - RECONSTRUCTION

4.1. Procedure 9 - Minimum character size

Procedure 9 is a less complex procedure of eliminating characters of very small area that are unfit for reconstruction (red characters in Figure 11). The system allows the user to enter a minimum character size, defined as the percentage of the area taken up by the character in relation to the total area of the potential licence plate (plate surface area). The default value of the parameter is 2%. Characters that do not meet the minimum size condition are rejected. Plates with no characters of appropriate minimum size are also rejected.

Fig. 11. Visualisation of Procedure 9 (rejection of five plates)

4.2. Procedure 10 - Character reconstruction

Reconstruction of characters is important when images are blurred and have a large number of artifacts. The test image (Fig. 12) was acquired in a night scenery and where part of the plate was obscured by a leaf.

Fig. 12. Test image with night scene and partly obscured licence plate

0The purpose of Procedure 10 is to find areas (potential characters) which have not been circumscribed with a contour (in procedure 5) or have been rejected in subsequent procedures of the segmentation stage. Figure 13 shows the areas that were evaluated and added by the current procedure (magenta). Definition of additional areas is not a major problem when information is provided on the average character size, position of characters and angle of inclination of the character lines (calculated in Procedure 7).

Fig. 13. Visualisation of Procedure 10

Analysis of two potential arrays with the same numbers (Fig. 13), resulting from additional pretreatment (Procedure 3), may seem redundant at this stage of the presentation of the system, but it is justified in stage 4.

4.3. Procedure 11 - Minimum number of characters

Procedure 11, like Procedure 9 (minimum character size), is a simple procedure that counts the number of characters after reconstruction, including one-line and two-line plates. Criteria on the minimum number of characters were established on the basis of the Notice of the Minister of Infrastructure and Construction of 2 June 2016 on the publication of the consolidated text of the Ordinance of the Minister of Infrastructure on registration and marking of vehicles [12]. Procedure 11 has not eliminated any of the potential licence plates shown in Figure 13.

4.4. Procedure 12 - Reconstruction of potential licence plates

The purpose of licence plate reconstruction is to prepare for the best possible character recognition (stage 4). Characters of potential one-line or two-line plates are cut out by contours

(calculated in Procedure 5) or reconstructed areas (estimated in Procedure 10), rotated by the angle of the lines defining the rows of characters (angle calculated in Procedure 7), scaled to the size of 24x32 pixels and segregated into one string (in two-line plates). The reconstructed licence plates are shown in Figure 14.

Fig. 14. Graphic representation of reconstructed licence plates

The set of operations in Procedure 12 removes the artifacts (Figs. 13 and 14) and approximates the shapes of characters to the letter and digit patterns of the Polish licence plates shown in Figure 15. The patterns were drawn up based on data provided in Notice [12]. Procedure execution time was 1.5 ms.

Fig. 15. Patterns of letters and digits of Polish licence plates (size 24x32 pixels)

5. STAGE 4 - RECOGNITION OF CHARACTERS AND NUMBERS IN POLISH LICENCE PLATES

5.1. Procedure 13 - Character recognition

There are many methods of character and text recognition in raster images [13], [14], [15]. This paper describes two methods in three variants, the detectability of which was tested on 250 test templates (Fig. 16):

1. Comparison of templates
   - recognizability: 87%
2. Artificial neural network with pattern training (Fig. 15)
   - recognizability: 79%
3. Artificial neural network with training on several tens of thousands of examples
   - recognizability: 95%

Fig. 16. 250 test templates

Character recognition was effected with the use of the neural network method [16] with the recognizability of 95%. The template comparison method is applied when the probability of correct character recognition obtained with the neural network method is low. The results of character analysis in Procedure 13 in potential licence plates shown in Figure 14 are presented in Table 1.

Table 1. Illustrative list of the results of character recognition procedure

	NEURAL NETWORK		COMPARISON OF TEMPLATES		
Plate	**Letter/Digit**	**Probability (%)**	**Letter/Digit**	**Probability (%)**	**Result**
1	S	99.98	-	-	S
	Z	96.70	-	-	Z
	1	100.00	-	-	1
	J	**37.38**	**4**	**5.50**	**?**
	3	**26.79**	**8**	**32.77**	**?**
	3	99.99	-	-	3
	G	99.98	-	-	G
2	S	99.98	-	-	S
	Z	97.01	-	-	Z
	1	100	-	-	1
	6	**43.87**	**4**	**5.58**	**?**
	3	**26.79**	**8**	**32.77**	**?**
	3	100.00	-	-	3
	G	99.98	-	-	G

The developed system for recognising numbers in licence plates is very restrictive in terms of certainty as to the individual characters, but it does not reject the collected results if some letters or digits in the character string in the plate are not accepted. It has been established experimentally that results of a certainty of less than 50% obtained by the artificial neural network will be verified using the method of template comparison (Fig. 17). If the letter or digit recognised by the two methods is identical and the sum of the probability values for both methods is higher than 50%, then the result is considered true. If the letters or digits are not identical, the result adopted is that obtained using the template comparison method, provided that the probability is higher than 90%. Table 1 shows that, despite the results obtained by the template comparison method being correct, the result was considered unreliable.

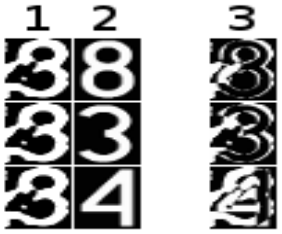


Fig. 17. Illustrative visualisation of the principle of the template comparison method (average grey channel width for the digit 8 is lowest in this case)

Average execution time of the procedure was 2 ms. The efficiency of the neural network of 95% was obtained after testing 30 strategies of creating example templates for network teaching (training)[7]. Principal parameters of the neural network used:

- method - error back propagation algorithm [17];
- activation function – sigmoid;
- network structure:

  - number of hidden layers: 2;
  - number of input neurons: 768;
  - number of neurons in first hidden layer: 164;
  - number of neurons in second hidden layer: 75;
  - number of output neurons: 35.

5.2. Procedure 14 - Combining the numbers

In the case of the example discussed, the results obtained in Procedure 13 are identical: *SZ1??3G* and *SZ1??3G,* and this (single) result is transmitted to the next procedure (Procedure 15).

[7]The developed system has tools that generate different template variants based on letter and digit patterns (templates with different rotation, scale, position, perspective, character thickness, and artifacts) that are used in neural network teaching. The system is able to automatically prepare the selected learning set, conduct a teaching process lasting a dozen or so minutes and test it out. There were plans to apply genetic algorithms [18] to improve the artificial neural network teaching process, but the time devoted to the project was too short.

For the purposes of properly explaining Procedure 14, let us assume that three results were obtained:

- SZ1??3G
- ?SZ148?G
- AA12345

The main purpose of the procedure is to segregate similar numbers by applying a measure of difference in strings (Damerau - Levenshtein distance[19]) and to combine the numbers into a single result, as shown in Table 2.

Table 2. Illustrative visualisation of the numbers combining algorithm

Plate	Plate number characters							
1	->	S	Z	1	?	?	3	G
2	?	S	Z	1	4	8	?	G
Result	?	S	Z	1	4	8	3	G

The results of the procedure for the example discussed are as follows:

- ?SZ1483G;
- AA12345.

5.3. Procedure 15 - Rules

The rules of composing Polish licence plate numbers specified in Notice[12] enable verification of the recognised number. If the number analysed does not match any of the rules (e.g. letter + letter + digit +digit + digit + digit + letter), it is not presented as the final result - the system provides an additional parameter called Proposal Number (Fig. 18).

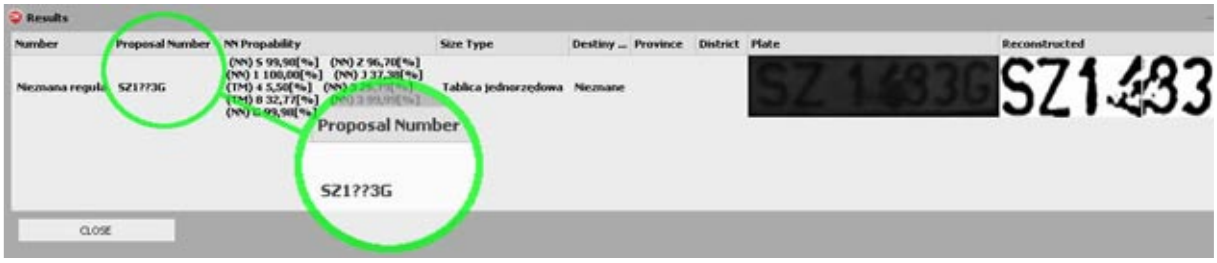


Fig. 18. Window of results of the Polish licence plate numbers recognition system when no matching rules were found

Numbers are analysed with the omission of '?' characters, and in the case of the example in Fig. 18, the number *SZ13G* (SZ1??3G) does not match any rule. This approach may, under extreme conditions, lead to misinterpretation of the licence number, but it is useful in cases of interpreting the European Union symbol and the letters "PL" on licence plates (*?SZ1483G*) as an additional character (Figure 13 presents a potential plate that could be interpreted in such a way).

The rules also allow to finally determine the type of licence plate:

- standard plate (one-letter discriminant);
- standard plate (two-letter discriminant);
- individual plate;
- classic car plate (one-letter discriminant);
- classic car plate (two-letter discriminant);
- temporary plate;
- temporary test plate;
- diplomatic plate.

5.4. Procedure 16 - Location and result collection

Fitting a number to a rule provides information on the province and district where the vehicle is registered (Fit. 19). Procedure 16 also enables interpretation of the number of special services, i.e. identifying the type of service and type of vehicle in case of a military licence plate.

Fig. 19. Window of results of the Polish licence plate numbers recognition system when the result is positive.

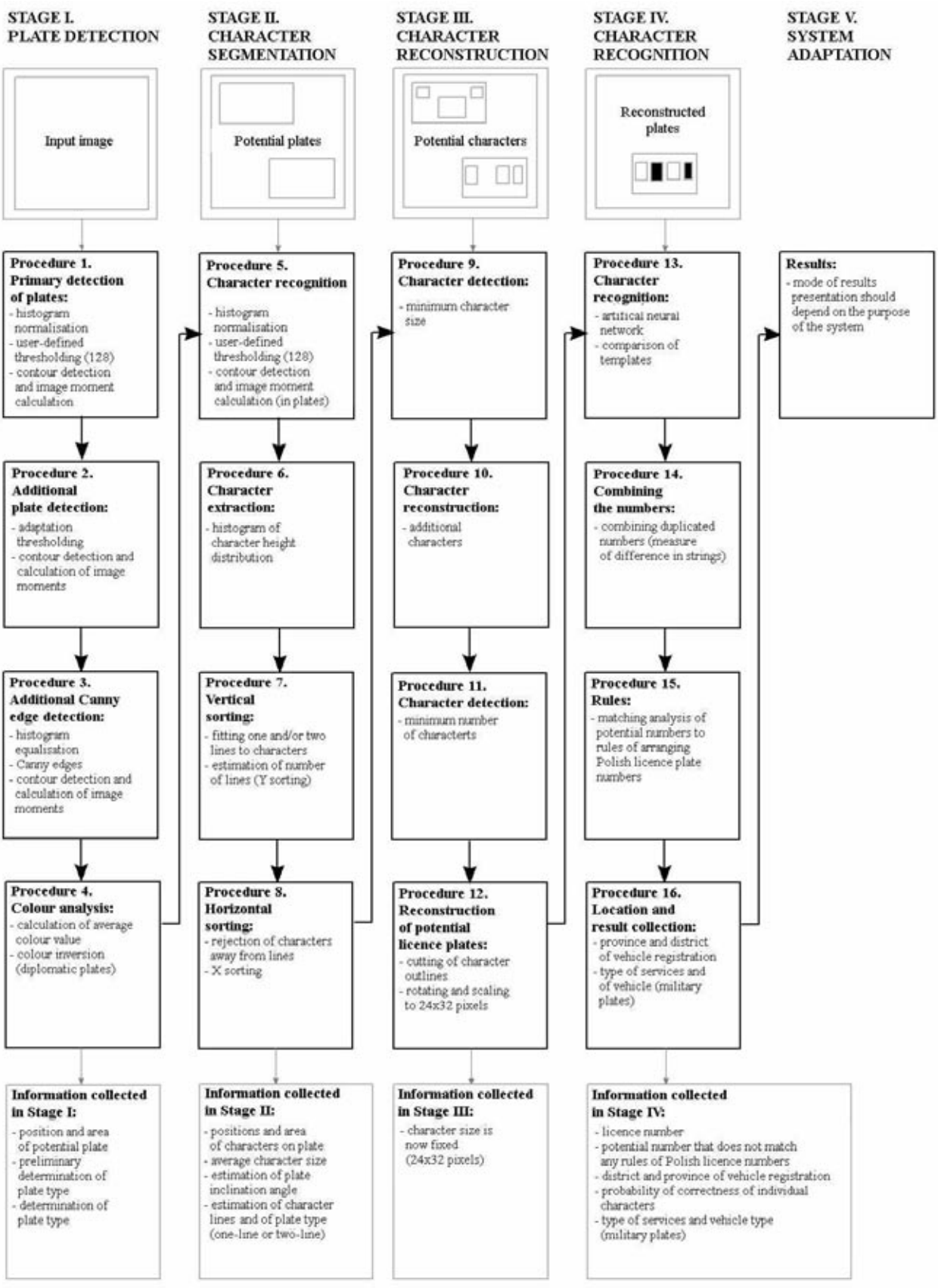
6. STAGE 5 - SYSTEM ADAPTATION

The result windows (Figs. 18 and 19) were designed for test purposes and for illustration in this paper - the results pertain to one image frame. The manner in which the results should be displayed and whether they should be displayed in each frame of the video depends on the operating conditions of the system, its purpose and its adaptation in the additional system.

The additional vehicle tracking (monitoring) system [20], [21] would enable collecting results from more tests (iterations) and obtain a more reliable result. Benefits of operating both systems would be mutual: on the one hand, the vehicle monitoring system could inform about the vehicle's location and limit the search area of potential licence plates; on the other hand, the number recognition system could guarantee correct identification of the tracked vehicle (in case of potential misrepresentation by the tracking system).

The system may be adapted to COM or DCOM technology [22]; data can be recorded directly in a database or transmitted using an Internet protocol.

7. ALGORITHM OF PROCEEDING



8. CONCLUSIONS

The Polish licence plate numbers recognition system presented in the paper is an efficient solution operating in real time. The average operation time of the system in the case of image in Fig. 3 was 12 ms and 21 ms with additional detection using the Canny algorithm. The system operation time (with additional detection) in the case of images in Figs. 8 and 12 was 62 ms and 35 ms, respectively.

The method (algorithm) taking the longest time to execute its instructions is the contour detection method. However, that method is fundamental in the developed system (licence plate detection, character detection, character cutting) and is difficult to replace. Further research on system development should focus on increasing the speed of that method.

There are many reports ([1], [2], [3], [4], [5], [10]) on methods of licence plate number recognition, most of which provide information on the reliability statistics of these methods. However, less is known about the samples being tested and evaluated. In order to select the most appropriate method, it would be advisable to carry out a study of all methods or to prepare a standard of samples that would help reliably evaluate a given method.

This article is a summary of research on the methods of recognising licence plate numbers and on the described system of recognising Polish license plate numbers.

Each of the procedures (steps) performed by the system developed was described in detail, bearing in mind that a separate paper could be devoted to every single procedure, for instance:

- development and establishment of the best method determining the identification of many potential licence plates (procedures 1, 2, 3);
- more in-depth colour analysis in procedure 4;
- development of a neural network learning process with the application of genetic algorithms;
- application of convolutional neural networks for licence plate detection;

enhancing the system functionality by providing additional procedures:

- assessment of vehicle position and orientation based on detected licence plate [23];
- recognition of licence plates of other European Union member countries (differences in licence number pattern).

Particular stress was laid on the important step of preparing data for analysis (the reconstruction stage), and on the benefits of using a vehicle tracking system in combination with the system developed.

The content of the article can be helpful in work on systems related to traffic monitoring, control and management, monitoring of car parks, petrol stations, electric cars charging stations and average speed measuring systems.

The experience gained from the implementation of the system described may help develop a system to streamline the operation of container terminals (container marking), inventory taking of fixed assets (inventory numbers), ID document readers, in the development of OCR technologies (full digitisation of documents) and many other.

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