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DEVELOPMENT AND ANALYSIS OF THE CAR REGISTRATION PLATE RECOGNITION SYSTEM

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Abstract

The main goal of this project is to create and test novel algorithms for detecting, segmenting, and classifying symbols in order to improve the performance of automatic recognition systems for automobile license plates based on neural networks under interference and distortion situations. The goal of this study is to look at the detection, segmentation, and classification techniques that are used to find objects in halftone and color photographs. The goal of the study is to increase the efficiency of video recording systems and vehicle traffic control by developing and modifying algorithms.

Introduction

The massive acceptance of information technologies in various aspects of human existence has characterized recent decades. We can solve the problem of improving traffic safety and the road situation by implementing and using intelligent transportation technologies. They usually consist of a collection of interconnected functional systems, such as systems for collecting data from traffic detectors and television cameras. The methodologies employed in their development may differ substantially because to the wide range of external situations in which these systems must operate. However, the majority of today's systems are made up of two basic components: picture collection and subsequent analysis, the latter of which is primarily controlled by the quality of the images collected. There are two basic ways to picture collection that may be recognized at this level in the development of car number recognition systems:

- the use of video capture devices for analog cameras directly in the computer. The disadvantage of such systems is the hardware limitation on the number of connected cameras and low frame resolution;
- the use of IP video cameras equipped with a CCD or CMOS sensor of photosensitive elements. A distinctive feature of this type of systems is the use of high-performance embedded components in them, such as microcontrollers and digital signal processors. In fact, each camera is a separate computer with an operating system installed and an application running for compressing, encoding and broadcasting a video stream.

At the first stage, the image obtained from the matrix is compressed using frame-by-frame (JPG) or streaming (H.264) encoding methods. The advantage of such a system is the high resolution of the video sequence.

There are a variety of external elements that alter the quality of a digital image, in addition to technological factors, such as the lighting of the surrounding scene, the movement of objects inside it, and etc. As a result, in order to achieve high accuracy in text character recognition on a car registration plate, algorithms must be developed that allow for the detection, segmentation, and recognition of text characters in the presence of noise, low image sharpness and contrast, erroneous white balance, and other interference in the field of digital image processing.

Nowadays, the building of video recording systems and automobile license plate identification systems has made great progress. However, owing to the usage of fixed parameters for the size and location of the item in the frame, there are unsolved issues in the transition to a higher resolution of the input video sequence. There is a class of jobs where simplicity of the license plate recognition system's operational circumstances becomes particularly critical, such as vehicle monitoring and control.

According to a review of recent scientific and technological literature, techniques based on are one of the most promising ways for recognizing text characters in digital pictures.
identification of key features or special points on the digital image;
calculating descriptors of areas of interest;
combined use of these two approaches.

The research for algorithms that perform without using a priori information about an object's features and allow finding the registration mark in the presence of interference on television pictures remains crucial for object identification jobs. As a result, at this point in science and technology development, developing and analyzing algorithms for recognizing, segmenting, and classifying symbols is a critical endeavor.

Methods

The general scheme of an automated system for recognizing text characters in a digital image.

Modern methods of digital image processing, computer vision, pattern recognition, mathematical analysis, probability theory and mathematical statistics were used to solve the tasks. For the practical implementation of algorithms, modern numerical methods, methods of programming in MatLab and methods of object-oriented programming in C++ were used.

The main design of an automated system for identifying text characters in a digital picture is presented in this paper. The following are the primary components of this system.

Image formation. The image received from the video camera is sent to the system input for further processing and analysis. This operation is of crucial importance, and the operability of the entire system as a whole depends on the hardware and software used at this stage.

License plate detection. It is used to detect objects of interest - numbered plates for the purpose of their subsequent analysis.

License plate segmentation. At this stage, the detected license plate is divided into separate characters by constructing dividing lines between them based on the least important pixels for the purpose of further character recognition.

Classification of text symbols. The symbols segmented at the previous stage are divided into 21 classes, copies of which are numbers and letters of the English alphabet, acceptable for use on state automobile registration plates in the Republic of Kazakhstan. In the future, it is also planned to classify foreign car license plates.

The systematization, analysis, and application of a number of well-known methods for identifying text symbols on digital pictures, including:
template comparison algorithms and window functions;
correlation algorithms;
algorithms based on morphological processing and projection calculation;
1algorithms based on the calculation of descriptors and subsequent classification of objects.

This research refers to the creation, modification, and analysis of algorithms for detecting, segmenting, and recognizing text characters on a digital picture in the presence of distortions and interference induced by practical needs for automatic license plate recognition systems.

A new algorithm based on the detection of point features in digital images

The search for point characteristics on a license plate on a digital picture is the first step in picking a license plate. Angles are one of these characteristics. A Harris angle detector is utilized to do this.

Start by looking at a digital grayscale images picture, which represents a two-dimensional intensity function (x,y). Write the weighted sum of squares of the differences between two adjacent image sections I(u,v) and I(u+x,v+y) as follows:

S(x,y) = $\sum_u \sum_v w(u,v)\ [I(u,v) - I(u+x,v+y)]^2$,

Where $w(u,v) = \frac{1}{2\pi\sigma^2} e^{\frac{u^2+v^2}{2\sigma^2}}$ - a two-dimensional Gaussian window function used to reduce the sensitivity of the algorithm to noise.

Within the local neighborhood of the pixel under study, the expression in square brackets can be approximated by the Taylor series:

$$I(u+x, v+y) \approx I(u,v) + \frac{\partial I}{\partial x}(u,v)x + \frac{\partial I}{\partial x}(u,v)y.$$

Substituting (2) into (1) and performing the approximation, we obtain in matrix form:

Where, $M(x,y) = \sum_u \sum_v w(u,v) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} = \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} -$ the Harris matrix.

The point feature of the image is characterized by a large change in the magnitude of S(x,y) in all directions. How large its value is at a given point can be judged based on the analysis of the eigenvalues of the Harris matrix. Denote them α and β, then the value of S(x,y) will be proportional to each of them. In this case, one of the following cases will be implemented:

α ≈ 0 и β ≈ 0 - no local point singularity;

α ≈ 0, β is a sufficiently large positive number - the presence of the border of the object;

α and β are large positive numbers - detection of a local point feature of the "corner" type.

As a result, determining the eigenvalues of the Harris matrix is required to detect point objects in the picture. Instead of directly finding the values α and β, a response function of the form: can be generated due to the high computing cost of their calculation.

$$R = (\alpha\beta) - k(\alpha+\beta)^2 = \det(M) - k\, trace^2(M).$$

The k parameter in the formula is determined via trial and error. The Harris corner map is a two-dimensional function of pixel coordinates that serves as a response function. R has a positive value in the angle region, a negative value in the edge area, and a tiny value in areas of uniform intensity. A map of the Harris corners for the test picture is shown in Fig. 1a. After that, it passes through a threshold processing (binarization) technique to separate the bright pixels that belong to the areas of interest from the dark pixels that relate to the background.

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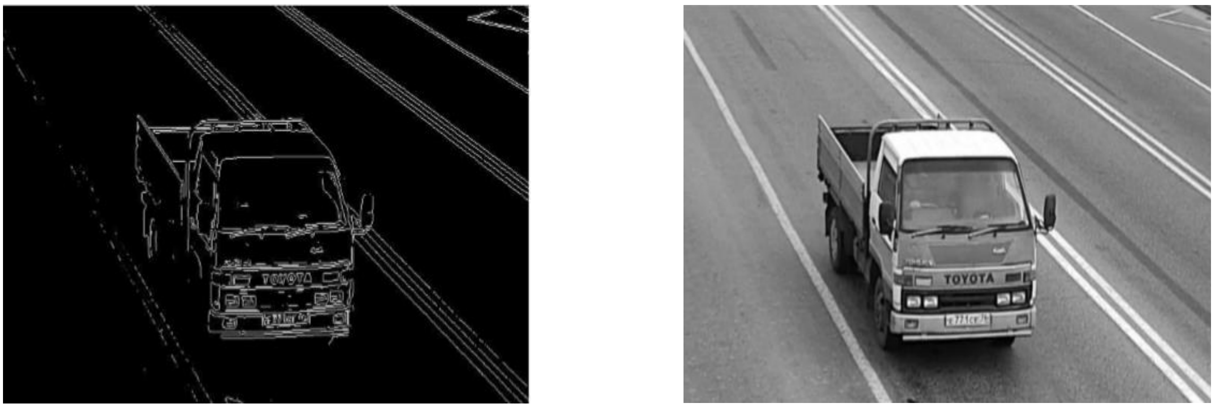

b)

Fig 1. License plate detection

a) a map of Harris corners; b) areas of interest in the original image

The allocation of an area of interest among a set of connected areas is carried out on the basis of HOG(Histogram of oriented gradients) descriptors, the calculation scheme of which is illustrated in Fig. 2. First, the intensity fadient of the image is calculated, then it is divided into cells. Next, the value of the modulus of the gradient vector at this point in the image is assigned a weighted voice, which is summed with the values of other vectors in this direction. At the next stage, the cells are combined into larger blocks, their normalization and the final feature vector is obtained, which fully describes each area of interest. To solve the binary problem of choosing among all the obtained areas of interest of the numbered plate, an anomaly detector was used.

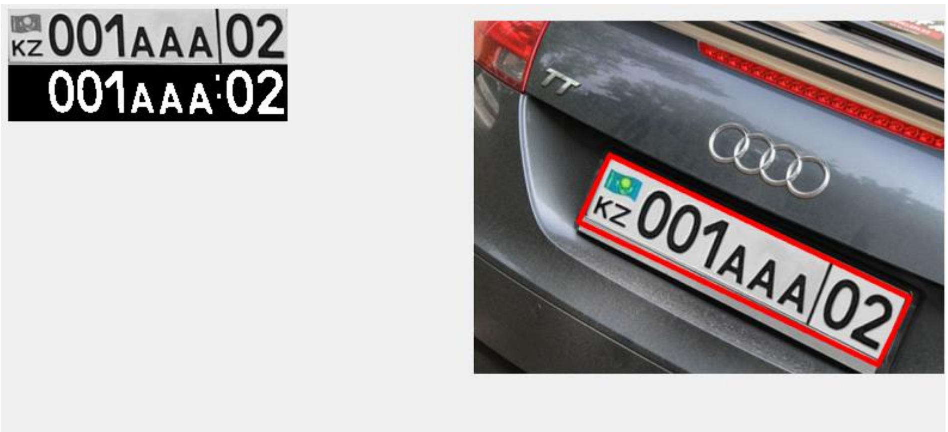

Fig. 2. Scheme of calculation of HOG descriptors

The analysis of the efficiency of the developed algorithm was carried out using the method of ROC (Receiver operating characteristic) curves. The dependence of the number plate detection accuracy on various parameters of the algorithm operation is investigated (Fig. 3 and Fig. 4).

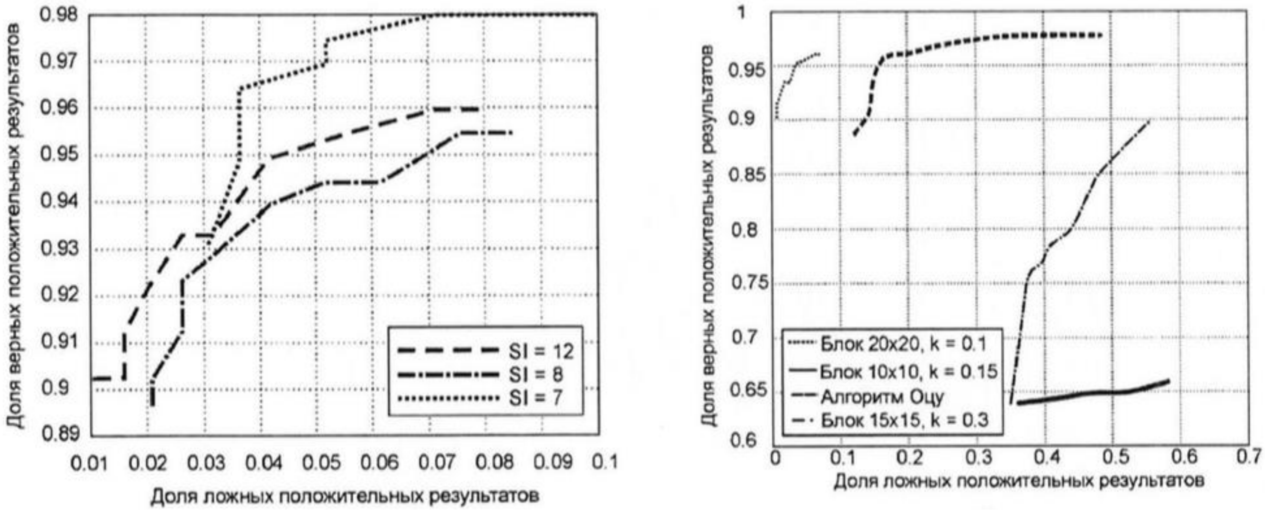

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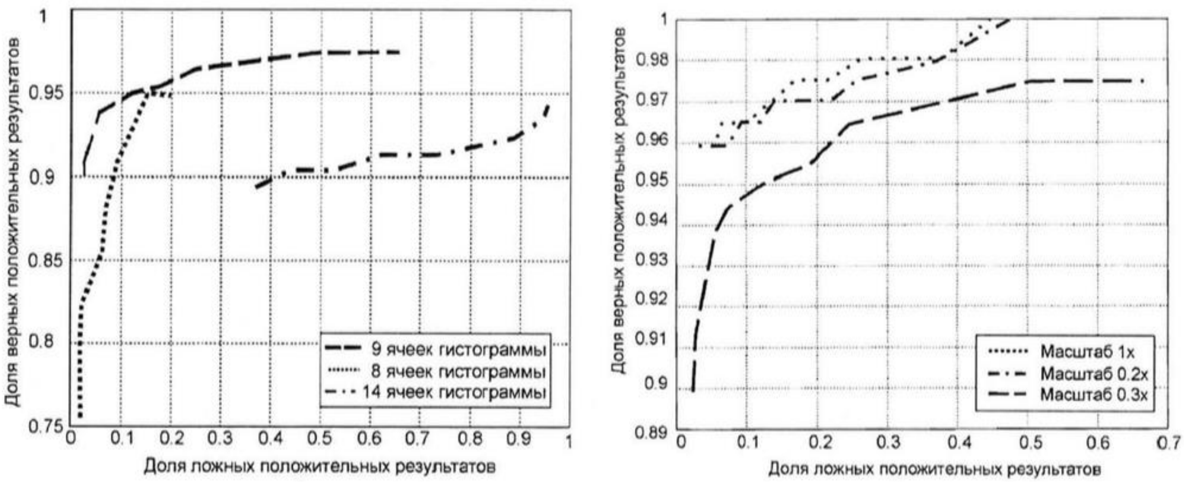
Fig 3. Dependence of the number plate detection accuracy on:

a) the size of the angle detector neighborhood; b) binarization parameters



b)

Fig. 4. The dependence of the accuracy of the number plate detection on:

a) the number of cells in the histogram of the LEO descriptor; b) the scale of the images when training the anomaly detector

It is important to obtain a precise estimate of the license plate's location in addition to the direct fact of detecting it. To do so, you must compare the automated algorithm's detection result with the reference markup (Fig. 5).

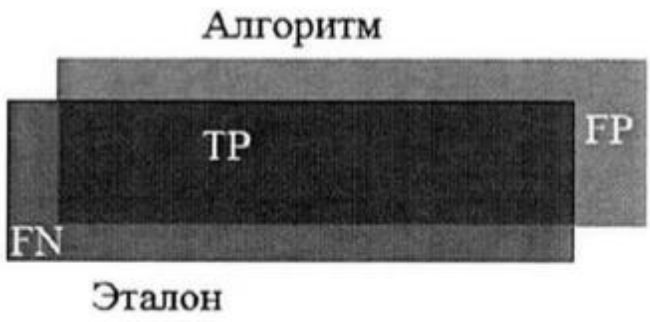
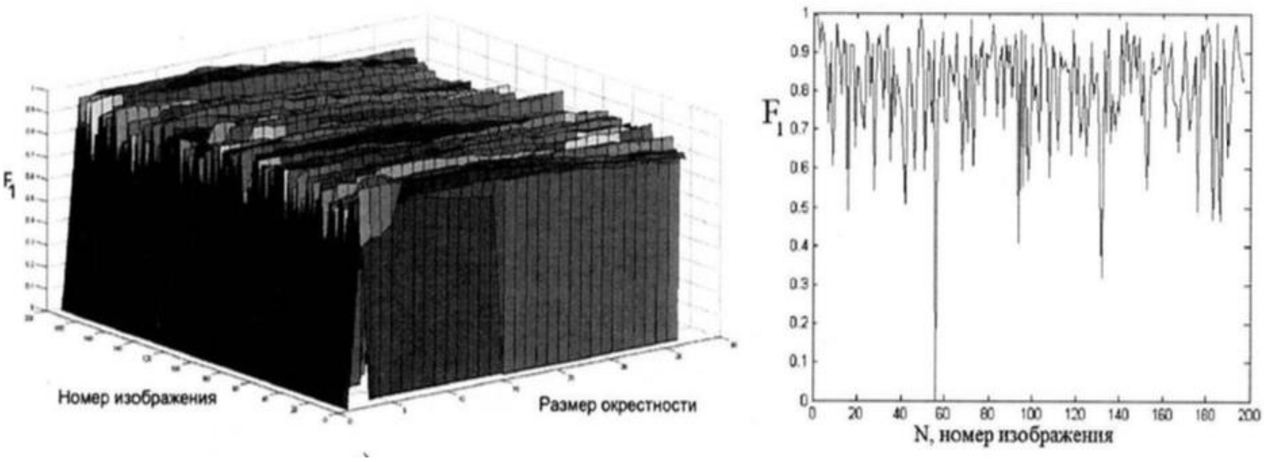


Fig. 5. Possible situations during detection

Thus, the accuracy of location determination will be as follows:

$$F_1 = \frac{2 * Precision \ * Recall}{Precision + Recall} = \frac{2 \ * TP}{2 \ * TP + FP + FN}$$

Figure 6a shows an example of the values of the F_1 function with one parameter of the algorithm under study and the others fixed.



b)

Fig. 6. Dependence of the value of F_1 on:

a) the size of the neighborhood of the Harris angle detector; b) image numbers of the test base

Figure 6b illustrates the relationship between the accuracy of recognizing F_1 in photos from the test database and the values of the internal parameters discovered earlier.

Segmentation algorithm of the previously detected number plate with the selection of the best parameters of its operation

The information content of the studied frame is taken into consideration by the algorithm. The key phases of the symbol segmentation procedure for the observed license plate are depicted in Figure 7. (Figure 7a).

The notion of a "cost function" is presented to determine the informative relevance of a pixel. This method returns a conditional value that indicates the importance of a certain pixel in the current picture. The structure and outlines of objects will be the most important aspects in the image while calculating it. They are visible on the gradient image:

$$e(I) = a \times \left|\frac{\partial I}{\partial x}\right| + b + \left|\frac{\partial I}{\partial y}\right|$$

Fig 7b.

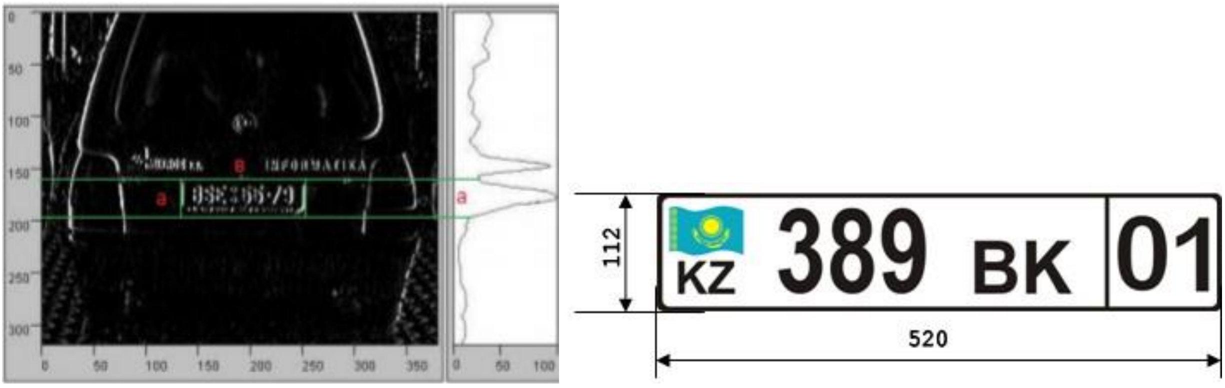


Fig. 7. Stages of the symbol segmentation algorithm:

a) the original image; b) gradient image; c) inheritance of pixel values;

d) a map of the cost of transitions; e) the energy accumulated in the last line;

f) formed lines of separation of characters

You must draw a dividing line between the characters based on the gradient picture. It is important to keep track of the state of pixel connection, which is used to divide pixels into segments. The picture is used to construct all passage pathways, which are 8-connected sets of pixels from top to bottom. The value of the least of its three predecessors, related pixels on the preceding line, is added to the current pixel value at each stage of the construction process (Fig.

7b). Obviously, the latter will include values that represent prior transitions (Fig. 7g). These aren't pixels anymore, but a cost function of probable transitions along the path S. (Fig. 7d).
Having a cost function $e(I)$, the cost of all such paths is calculated:

$$E(S) = E(I_s)\sum_{i=1}^{n} e(I(s_i))$$

The paths with the minimum cost are selected, which will be the dividing lines between the symbols:

$$s^* = min\,E(s) = min\sum_{i=1}^{n} e(I(s_i))$$

Such separation lines are shown in Fig. 7e. They are formed automatically and adaptively to the information content of the frame. Thus, the algorithm does not need a priori specification of the number format and is therefore more flexible.

When producing a gradient image, parameters a and b determine the optimal parameters of the algorithm, taking into consideration the fulfillment of the criterion of balance between sensitivity and specificity of the algorithm. The values of specificity and sensitivity are shown in Figure 8 as a function of the parameters *a* and *b*. These surfaces have common points that meet along specific curved generators, as can be observed. According to the criterion of sensitivity and specificity balancing, the produced intersection lines correspond to the optimal values of the algorithm parameters *a* and *b*.

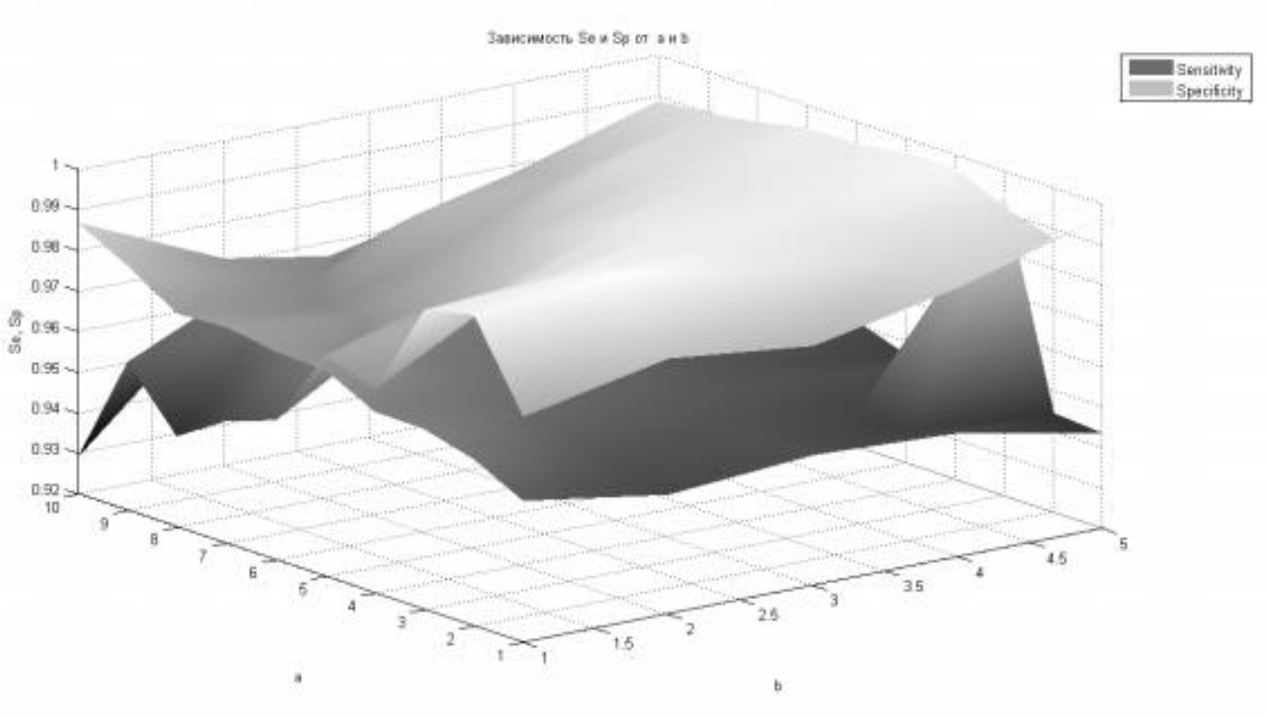


Fig. 8. Dependences of sensitivity and specificity on the parameters of the cost function

To correctly recognize a license plate, a simultaneous accurate classification of each symbol is required. Such an estimate for all images in the database has the following form:

$$S(a,b) = \sum_{j=1}^{N}\left(\prod_{i=1}^{k}\widetilde{P_{ij}}\right) = \sum_{j=1}^{N}\left(\prod_{i=1}^{k}(\alpha TP_{ij} + \beta FP_{ij} + \gamma FN_{ij})\right)$$

The resultant formula is an optimization objective function that describes the accuracy of the proper recognition of the whole license plate using the segmentation algorithm parameters. The maximum of this function will be reached at the point $[a_0, b_0] = argmax(S(a,b))$.

Thus, the values of the parameters of the cost function a and b are chosen based on the obtained dependencies, which are ideal in terms of accurate license plate recognition. At the same time, the most advantageous ratio between first and second-order mistakes has been accomplished, resulting in the most precise dividing line between neighboring symbols on the digital picture of the car's license plate.

Development and analysis of an algorithm for classifying text characters on a license plate

A limited Boltzmann machine is used to solve this problem. The probabilistic rule for triggering neurons of this network has the form:

$$p_i = P(\Delta E_i) = \frac{1}{1 + e^{-\frac{\Delta E_i}{T}}}$$

Where p_i - the probability of finding the i-th neuron in the active state; $P(x)$ - sigmoid function; $T -$ parameter similar to temperature; $E = -\frac{1}{2}\sum_{i \neq j}\sum w_{ij} y_i y_j + \sum_i T_i y_i$ - an energy function that analyzes the state of a neural network.

the input picture is permanently attached to the input blocks;

the hidden and output blocks' states are randomized, and the temperature gradually drops;

At a low value of the parameter T, the status of the network is monitored, and statistics on the states of the output blocks are gathered. A conclusion regarding the input image is reached based on these statistics.

A novel approach for training and functioning of a neural network is suggested to operate with correlated data. To make implementation easier, all networks have the same probability values for transitioning neurons to the next state and the same rules of temperature change. The relationship matrices of networks differ from one another. If an unknown picture (SD) is fed into the trained algorithm, the system must make the proper branching choice at each iteration based on the patterns detected in the training sample. Figure 9 depicts the topology of the classifier utilized in the created method.

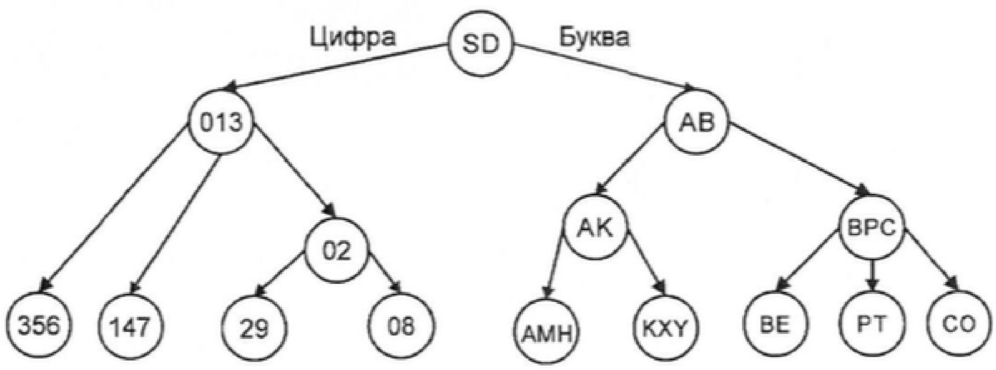


Fig. 9. Hierarchical tree structure of the classifier

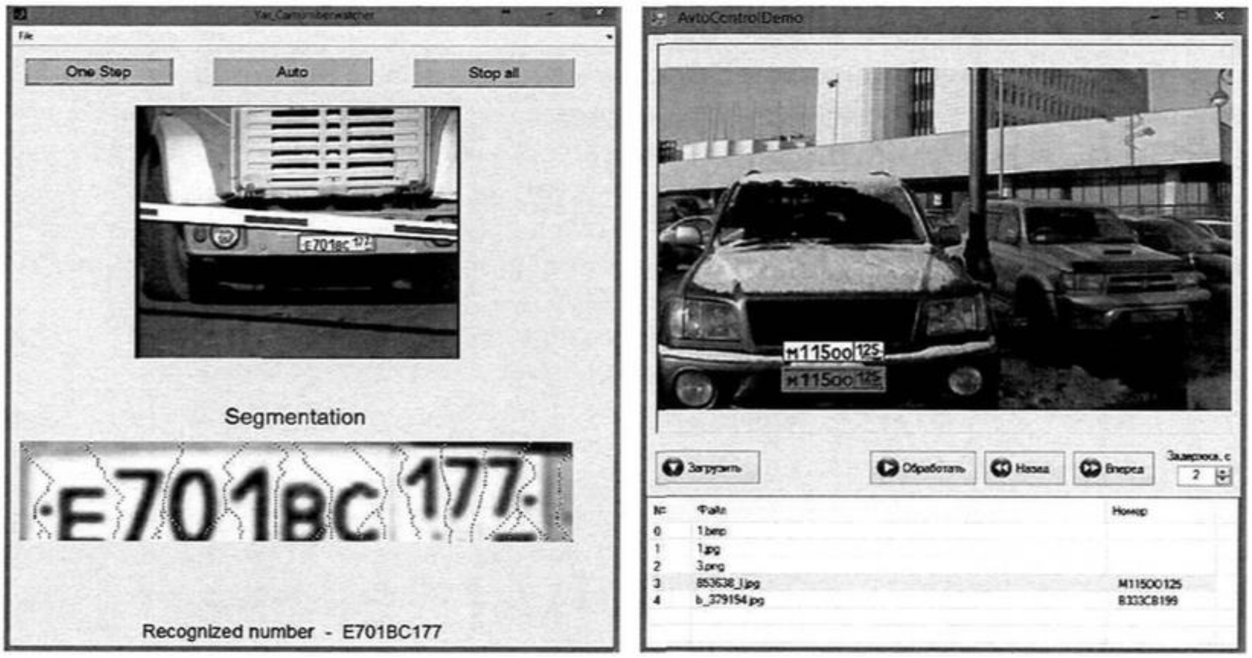
The suggested text symbol classification algorithm is compared to two other methods for handling this problem: the traditional template technique and a method based on logistic regression and principal component analysis (AGC). The first uses a simple neural network with a sigmoid function as an activation function and AGC to reduce the dimension of the vector of features coming into the neural network's input. The second uses a simple neural network with a sigmoid function as an activation function and AGC to reduce the dimension of the vector of features coming into the neural network's input. Table 1 shows the outcomes of the work of the character classification algorithms under consideration.

Algorithms	Level of recognition
Template method	83%
Logit model	92%
Restricted Boltzmann machine	96%

Table 1. The probability of recognition in the absence of noise in test images

In the absence of noise, it can be shown that all algorithms have a reasonably high degree of accurate recognition. The approach based on a constrained Boltzmann machine, on the other hand, has the best indication. It is employed as a text character classifier.

The implementation of the established algorithms for text character detection, segmentation, and classification within the framework of a single Yar Camumberwatcher software environment is also examined in this chapter. This software package is also compared to Avto-Control Demo, its commercial equivalent. Figure 10 depicts the user interfaces for these apps.



b)

Fig. 10. Examples of automatic license plate recognition programs: Yar_Camumberwatcher; b) Auto-Control Demo

An original library of test pictures including 100 photos of various resolutions was created to compare the results of the Yar Camumberwatcher methods with the Avto-Control Demo algorithms. Images must be no more than 720x576 pixels in size, with text characters limited to 14-27 pixels in height.

Table 2 shows a comparison of the results of recognizing car registration plates on a test database of photos.

Algorithms	Level of recognition
Avto-Control Demo	95%
Yar Camumberwatcher	90%

Table 2. Comparison of frame-by-frame car license plate recognition programs

The Auto-Control Demo system has a greater level of character recognition than the planned Yarumberwatcher software, according to the findings of the comparison. This benefit, however, is owing to embedded algorithms' usage of a substantial quantity of a priori knowledge. As a result, if the number format or size of the original image is modified, as well as if the image has distortions and interference, the recognition level of this application will be substantially lower. As a result, the Yar Camumberwatcher software is less affected by these shifts.

Results

Systematization, analysis and practical implementation of some well-known methods for solving problems of detection, segmentation and classification of text symbols on digital images in car registration number recognition systems has been carried out.

A multi-stage algorithm has been developed based on the detection of point features in digital images and allowing for the effective detection of vehicle registration numbers.

The suggested multi-stage method for recognizing automotive registration plates based on image point characteristics achieves a probability of proper detection of 97 percent, demonstrating its efficacy and competitiveness in comparison to similar recent techniques. The usage of a multi-stage data processing structure, on the other hand, increases the algorithm's computational complexity.

The main advantages of the proposed detection algorithm include the ability to process data in a more flexible manner thanks to a multi-stage scheme for identifying areas of interest, as well as independence from a priori knowledge of the license plate's properties such as size, aspect ratio, and so on.

A text character segmentation method has been created for digital photographs, which reads out the information content of the investigated frame.

Using the given algorithms for calculating the energy and cost functions, as well as the rules of passage for identifying the dividing lines between symbols, you may segment the license plate with a 97 percent chance of success.

The suggested segmentation algorithms' parameters have been tweaked based on visual and numerical character segmentation accuracy estimations.

The text symbol classification method for automobile registration plates has been enhanced, with a 96 percent right classification rate.

A commercial analogue is used to compare classification algorithms in the program to the job of identifying text characters on automobile registration plates. The created algorithms for recognizing, segmenting, and classifying automobile license plate symbols were implemented inside the framework of Yar Camumberwatcher, a single software environment for highway traffic monitoring. The suggested software package is compared to the Avto-Control Demo's commercial counterpart. The Yar Camumberwatcher software has been proven to be the most successful in a wide range of number kinds.

The suggested methods achieve remarkable efficiency in circumstances where it is feasible to qualitatively compute the energy and cost functions when processing the local region of a correctly identified license plate on a digital picture. The processing of highly textured photographs is an example.

Conclusion

The following new scientific results were obtained as part of the dissertation work. A combined algorithm for detecting the license plate of a car based on machine learning and the search for point features in digital images has been developed. An algorithm for segmentation of text characters based on the calculation of the best parameters of energy and cost functions has been developed. A modification of the classification algorithm has been developed for use in the task of recognizing the symbols of car registration plates.

Practical significance of the results obtained:

A combined algorithm for detecting objects in digital images has been proposed, which has shown its effectiveness in the presence of distortion and interference.

An original algorithm for segmentation of text characters contained in the detected license plate has been developed, which allows expanding the number of types of recognized numbers.

The possibilities of practical application of classification algorithms in the case of determining the textual information of car license plates have been expanded.

The main scientific provisions and results submitted for defense

A combined algorithm for detecting objects of a given shape based on machine learning and the search for point features in digital images.

The algorithm of segmentation of text characters based on the calculation of the parameters of energy and cost functions.

Modification of the classification algorithm of text symbols for use in the task of recognizing automobile registration plates.

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