The car paintwork defects contactless control system mathematical model

Anton Kozlov, *Ludmila* Ugarova*, *Vadim* Gulyaev, and *Nikolay* Loginov

Togliatti State University, Belarusian Street, 14, Togliatti City, Samara Region, 445020, Russian Federation

Abstract. The research is aimed at solving the problem of automating the search for visual defects in the car body paintwork. A digital image was used to search for paintwork defects. It is proposed to use a system based on a personal computer and an opto-digital module to obtain it. The image recognition process automation is achieved by applying various algorithms that ensure the corresponding subsystems operation. The image processing process involves the procedures for its evaluation and quality improvement production, as well as the objects recognition and the characteristics determination in the image. Carrying out these procedures requires the development of appropriate algorithms. The evaluating and improving the quality algorithm main function input image in relation to the problem being solved is to find possible paintwork defects in the image and bring the image quality to acceptable for further processing in case of defects.

1 Introduction

The modern car paint coatings are not only its exterior design element, but also a body parts protective coating. From the consumer view, the car paintwork, first of all, must meet aesthetic requirements, which implies the visible defects absence. From the car manufacturer's view, the paintwork protective functions are also important, the performance of which is also influenced by the defects various kinds presence [1].

The detecting paintwork defects automated systems have been actively developed recently. This direction is quite promising, but difficult to implement, as it requires the special technical means and specialized software development, which makes these systems expensive. In this regard, the car paintwork visual defects search automating is a promising scientific and technical task.

The current level of paint coating technology development allows for the appearance of various defects at various application stages. The possible defects types are regulated by the relevant standard [2]. Defects in the paintwork have a different origin nature and can appear at painting technological process various stages, as well as during the bodies transportation and during the assembling the car technological process. Currently, visual, instrumental and optical control methods are used to control paintwork defects [3].

* Corresponding author: L.Ugarova@tltsu.ru

2 Materials and methods

After analyzing the data obtained on possible paintwork defects, we come to the following conclusions: the designed system should not have a mechanical, chemical or other effect on the paintwork, leading to its damage. The system must detect the presence of defects on the surface in automatic mode. The system should be able to determine the defects geometric characteristics with a defect minimum size to be determined from 0.1 mm, regardless of the control direction. In order to ensure the preliminary identification of the defects ' causes, it is also necessary to provide for the possibility of their classification. The above can be done using a contactless control system based on digital image processing. The key issue in this control method implementation is the input image quality. In order to provide the image quality control necessary for the process, various algorithms are used to improve it. The analyzed input images feature is a pronounced texture presence on them, which must be preserved for further analysis, while improving the image quality itself. The essence of the technique consists in sequentially moving a certain closed area that calculates the output image values throughout the image, which is demonstrated graphically in Figure 1.

The general appearance of this processing kind is described by the expression:

$$g(n_1, n_2) = G[\{f(n_1 - m_1, n_2 - m_2)\}, (n_1, n_2) \in D] \tag{1}$$

Where $g(n_1, n_2)$, $f(n_1, n_2)$ – are two–dimensional sequences of the input and output images samples, respectively; G – is the transformation operator; D – is finite samples set given relative to the origin and determining the processing window shape and size.

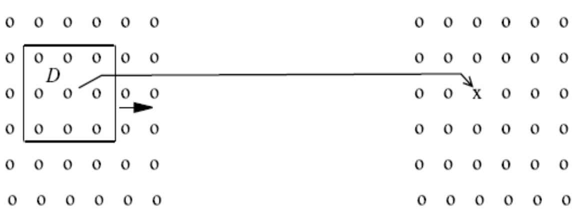

Fig. 1. Graphical representation of the "sliding window" method.

In this case, the conversion is most effective using a system based on a finite impulse response (conversion by a FIR filter). In order to determine the filter output signal value in the window, it is necessary to make the input signal with the filter pulse characteristic a digital convolution, that is, the input samples summation.

This approach involves a large calculations amount, since it is necessary to calculate all non-zero samples of the impulse response. From a practical view, this means that calculations can be carried out only for a short impulse response, that is, the windows should have insignificant dimensions. Based on the features of the problem being solved, the applied window size should be large, which will lead to a significant increase in calculations. The solution to this problem is possible in several ways. The first is the fast convolution algorithms use. This approach is the easiest to implement, but according to the data, in many cases it leads only to a slight reduction in calculations, which is not acceptable in this case. The second way is to use a parallel recursive implementation [4]. These algorithms are more complex to implement, but they can dramatically increase the calculations efficiency. The use of such algorithms makes it possible to obtain images histograms, calculate the average brightness, image dispersion, filter and perform other image transformations [5]. The recursive processing method is implemented by using the current counts and the previous step counts for calculations at the current step.

The filters with infinite impulse response use, that is, linear recursive filtering, have a significant drawback, which is poor stability. The stability problem solution in this case is made by using finite pulse filters [6].

There are quite a lot of options for implementing this approach. One of the simplest versions of the filter with a coordinate-separable impulse response proved to be the most effective.

This filter is a one-dimensional recursive FIR filter processing, that is, recursive image processing columns separately and row-by-row processing of the obtained column processing results. In this case, the calculations required number does not depend on the size of non-zero samples and will be determined only from recursions. In this case, the calculations required number is determined by the window D size. In practice, when using this method, a rectangular window is used, since it is not possible to filter for an arbitrary area.

The using recursive polynomial bases effectiveness evaluating allows us to conclude that a filter based on an even polynomial basis shows the best characteristics, since it has the largest Mahalanobis distance. The automatic processing algorithms effectiveness depends primarily on their ability to adapt to changing conditions, that is, on the ability to adapt to the processed data properties. Image filtering is performed in the following sequence. First, the processing algorithm class is determined. Next, the structural, statistical and other image characteristics are determined, that is, its analysis is performed. Then, according to these parameters, the algorithm parameters that filter the image are determined.

In the practical implementation of the approach described above, the processing algorithms class should be described in advance. If it is necessary to get a specific result, then the optimization problem should be solved for a objects certain class. At the same time, it should be taken into account that the obtaining process this optimal value will not be optimal, since it will not correspond to the algorithm described earlier.

Image processing and analysis tasks are solved most effectively by selecting and heuristically synthesizing a processing procedures variety. This is explained by the fact that various mathematical models are used to form optical signals, and the solved problems are poorly formalized. Also, certain difficulties are caused by processing quality criteria selection.

This approach has a number of significant drawbacks, which are associated with a processing algorithm variety aimed at solving a specific narrowly focused task. Consequently, these algorithms have low efficiency and are not able to provide the required processing quality in all cases. In order to eliminate these shortcomings, it is necessary to complicate the design of systems and software.

3 Results

The above disadvantages elimination is possible by applying a fundamentally different approach, which consists in making a decision based on a precedent with a previously unknown conversion mechanism, that is, the system is given the necessary processing result in advance. As a result, the system itself synthesizes the algorithm for constructing the decisive rule. Image processing in this case will be the given result definition in the data obtained from the input image.

Let's consider this approach in more detail. We have an input image F for which it is necessary to obtain a transformation G, which should be as close as possible to the ideal image reference transformation to the required output G_0, which any complexity and formalizability level can be.

Matched pairs (F, G_0) are used as a training sample. This will create a classifier that will use the input image F to determine the feature vector that the output image G should correspond to. Based on the difference between G and G_0, that is, the image quality assessment, the classifier features and the type set can be changed [7].

Schematically, the classifier training according to the procedure described above is shown in Figure 2. It is important to note that the classifier configured in this way only works with the same class images.

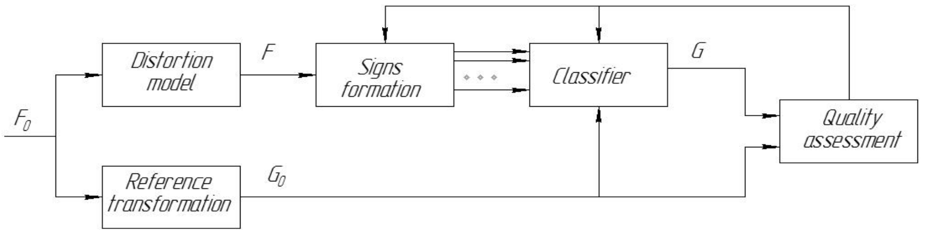

Fig. 2. The classifier training procedure scheme.

Figure 3 schematically shows the processing process for this classifier.

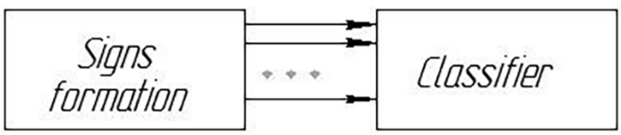

Fig. 3. Image processing scheme using a classifier.

The restored and the reference image comparison is a difficult task, the most rational solution of which is based on conducting a preliminary binarization procedure.

The input image consists of sections with certain homogeneous characteristics. In this case, the image can be represented as a small number one of the types disjoint areas. During analysis such an image, its map is determined, that is, the area type and its geometric characteristics. The obtaining process this map is called segmentation. In the dividing plots into two type's case, such segmentation is called binarization, which is the segmentation simplest type.

The binarization process is based on the features set definition by which different sites types can be distinguished. Average brightness, dispersion variance, and correlation properties are usually used as features. The most common areas differ in average brightness. If it is the same, the dispersion variance is analyzed. Correlation properties represent the change of smooth slow brightness dispersions significantly faster. When analyzing real images, there are cases when it is necessary to use characteristics set described above to separate the sections.

The automating the process of image binarization key issue is the processing threshold determination. Various methods are used to solve it, the most effective of which is the original image analysis by its histogram [8].

This method is based on the analysis of a histogram, which has the form w(x), 0≤x≤255, where 0 is black, 255 is white. In the histogram, each class has a distribution with one maximum, and the number of boundary points is relatively small. Based on these considerations, each class is defined by separate modes, the troughs of the histogram are the points of the boundary regions, that is, in fact, they are segmentation thresholds. Figure 4 shows an illustration of these arguments in relation to binarization.

This method is based on the histogram analysis, which has the form $w(x)$, $0 \leq x \leq 255$, where 0 is black, 255 is white. In the histogram, each class has a distribution with one maximum, and the boundary point's number is relatively small. Based on these considerations, each class is defined by separate modes, the histogram troughs are the boundary regions points, and that is, in fact, they are segmentation thresholds. Figure 4 shows an illustration of these arguments in relation to binarization.

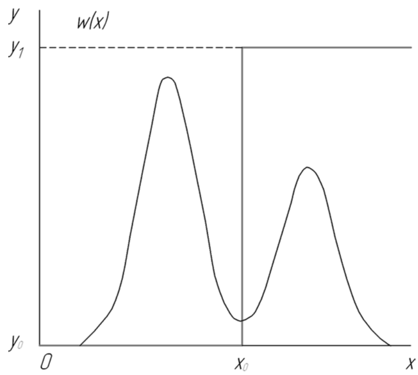

Fig. 4. Image binarization threshold.

Let us illustrate the automatic binarization algorithm operation described above using the example of the "cracking" defect shown in Figure 5. The processing result is shown in Figure 6.

Fig. 5. The original image of the "cracking" defect.

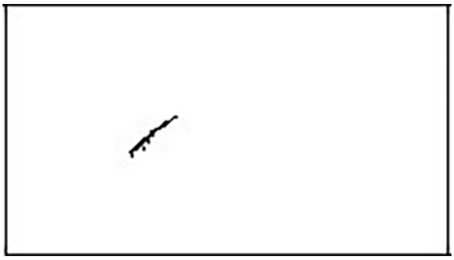

Fig. 6. Results of automatic binarization of the "cracking" defect.

The histogram of the original image is shown in Figure 7. The determining results the discriminant function $n(x_0^*)$ from this histogram are shown in Figure 8.

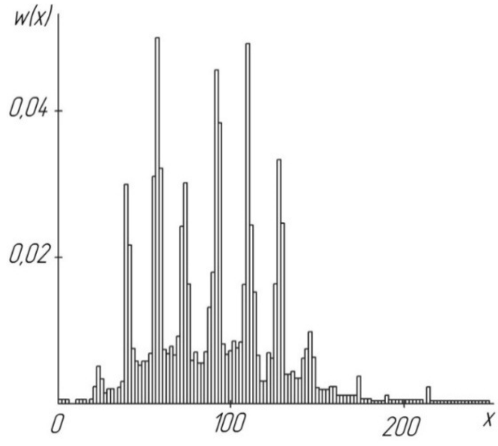

Fig. 7. Image histogram.

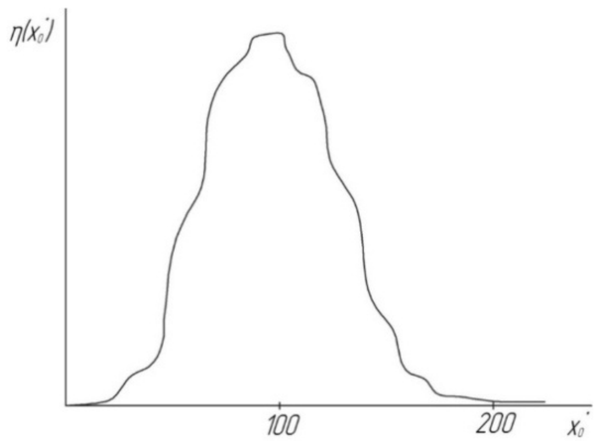

Fig. 8. Discriminant function.

After analyzing the data in Figures 7 and 8, we come to the following conclusions. The histogram of the original image has many differences, which makes it impossible to separate classes, since there is no single minimum. Determining the threshold by the discriminant function is much simpler, since its graph is unimodal, that is, it has a pronounced single extremum. In this example, this threshold will be $x_0 = 100$. The input images automatic binarization proposed method has shown good results in solving the problem.

Further image analysis is based on comparison with the reference image based on texture analysis. This analysis allows you to determine, save the image textural characteristics and compare them with the reference image features. At the same time, this analysis can be performed not only for the entire image as a whole, but also for its individual parts.

In some cases, when analyzing an image, measurements are required, that is, to obtain such parameters that will somehow characterize it as a whole or it part. Such tasks most often include determining an image the statistical characteristics, detecting objects on it, determining their coordinates, and evaluating their geometric parameters.

In the paintwork defects case, the most important is the evaluating geometric characteristics task, such as the defect size, its area and location.

The following algorithm is used for this [9]. In the binary image case, the main background will be white, and the defects display will be black. Thus, the background value is zero, and the defect value is one.

Let's consider the algorithm operation using the determining the object area example. The desired area each sample is given as the unit area square shown in Figure 9, and the entire defect can be determined using the four-connectivity criterion.

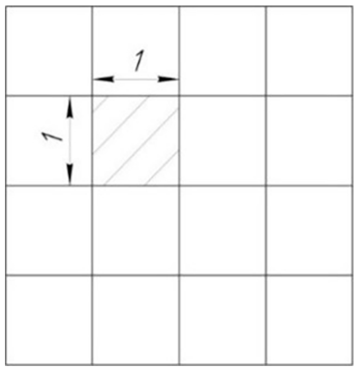

Fig. 9. The unit area square.

The sample matrix is processed as a line-by-line scan, that is, from top to bottom and from left to right. First, consider the processing procedure for a non-boundary reference $f(n_1, n_2)$. If the count $f(n_1, n_2) = 0$, that is, belongs to the background, then the next step is performed. If the count $f(n_1, n_2) = 1$, that is, it is not a background, then it is necessary to analyze it and refer it to the image object.

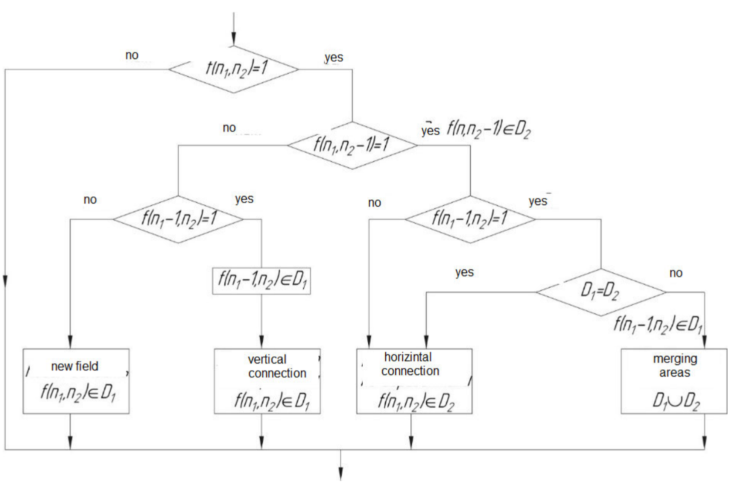

Fig. 10. Determining geometric characteristics algorithm.

This procedure involves considering neighboring counts $f(n_1 - 1, n_2)$ and 0 $f(n_1, n_2 - 1)$. If the condition $(n_1 - 1, n_2) = f(n_1, n_2 - 1) = 0$ is met, the estimated count will be the beginning of a new area, that is, it is a new object and the corresponding values are entered in the table of the areas characteristics. When the condition $f(n_1 - 1, n_2) = 0$ and $f(n_1, n_2 - 1) = 1$ is met, the estimated sample is included in the reference area $(f(n_1, n_2 - 1))$, and its area increases by one unit. Similarly, when the condition $f(n_1 - 1, n_2) = 1$ and $f(n_1, n_2 - 1) = 0$ is met, the current count is included in the area

$(f(n_1 - 1, n_2))$ and the corresponding area calculations are performed. If the condition $f(n_1 - 1, n_2) = f(n_1, n_2 - 1) = 1$ is met, it is necessary to analyze the data areas of the samples. If neighboring counts belong to the same area, then the current count is also attached to it. If neighboring counts belong to different regions, then the current counts, as well as the regions themselves, are combined into one, and their area is recalculated [7].

Figure 10 shows the determining geometric objects algorithm in the image.

Figure 11 shows a fragment with a dimension of 5 × 5 and an object on it, the area of which needs to be determined. Figure 12 shows the algorithm marking up areas.

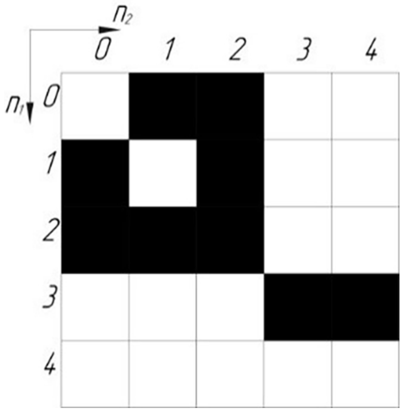

Fig. 11. Image fragment.

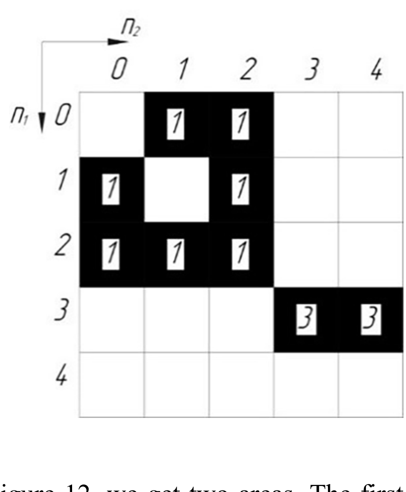

Fig. 12. Marking up areas.

In accordance with Figure 12, we get two areas. The first square area is 7 counts, the second square area is 2 counts. The other object characteristics in the image are determined using similar algorithms. To do this, a rule is used to calculate the combined area characteristics by the combined areas characteristics, which are described by the following expression:

$$F(D_1 \cup D_2) = \Phi[F(D_1), F(D_2)] \ (D_1 \cap D_2 = \emptyset - don't\ intersect) \qquad (2)$$

$F(D)$ is a characteristic defined by the set D [3].

The characteristics satisfying this restriction have the following form. For additive characteristics:

$$F(D) = \sum_{(n_1,n_2)\in D}\big(\Phi(n_1, n_2)\big) \qquad (3)$$

$\Phi(n_1, n_2)$ – is an arbitrary function of the coordinates n_1, n_2 [3].

Figure 13 shows an example of a figure for which it is necessary to determine its geometric characteristics.

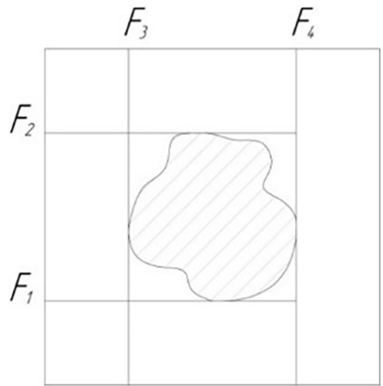

Fig. 13. The area edges in the image coordinates.

This figure area is determined by:

$$F(D) = \sum_{(n_1,n_2)\in D} 1. \tag{4}$$

The function $\Phi(n_1, n_2) \equiv 1$ in this case is an additive characteristic.

The image edge coordinates vertically and horizontally are determined by the expressions:

$$F_1(D) = \max_{(n_1,n_2)\in D} \{n_1\} \tag{5}$$

$$F_2(D) = \min_{(n_1,n_2)\in D} \{n_1\} \tag{6}$$

$$F_3(D) = \max_{(n_1,n_2)\in D} \{n_2\} \tag{7}$$

$$F_4(D) = \min_{(n_1,n_2)\in D} \{n_2\} \tag{8}$$

Functions $\Psi(n_1, n_2) = n_1$ и $\Psi(n_1, n_2) = n_2$, in this case are extreme characteristics.

Based on these characteristics, the center of the object area and its overall dimensions can be determined.

4 Conclusion

Thus, the given technique gives adequate results in the case of solving the problems under consideration to determine the paint coating geometric characteristics. The result is a mathematical image processing device that will automate the process of searching for paintwork defects. This problem solution was achieved through the input image quality preliminary improvement use based on the training procedure by the classifier using sliding window processing. An algorithm for automatic image binarization based on threshold processing is also proposed. It is proposed to evaluate the image using image texture analysis algorithms by comparing it with a reference, which allows you to accurately determine the defect in the input image presence. In addition, to evaluate the image, it is proposed to use algorithms for determining the paintwork detected defects geometric characteristics.

References

1. A. Kozlov, *Improving the quality of car body clearance control by automating the process* (Togliatti, 2005)

2. OST RF 9.072–2017. A unified system of protection against corrosion and aging. Paint and varnish coatings. Terms and definitions
3. V. Gulyaev, A. Kozlov, N. Loginov, AIP Conf. Proc. **2650** 020002 (2022). https://doi.org/10.1063/5.0106415
4. V. Surin, Autometry **54**, 2 (2008)
5. V. Surin, Bulletin of SUSU. Series: Mathematics. Mechanics. Physics **13(1)**, 14-21 (2021)
6. M. Kharinov, Bulletin of BGU Mathematics, computer science **9** (2021)
7. I. Gruzman, *Digital image processing in information systems* (Novosibirsk, EDP NSTU, 2022)
8. A. Pylkin, *Methods and algorithms of image segmentation* (Moscow, EDP Hotline-Telecom Publishing House, 2010)
9. K. Joe, O. Gerget, Automation and Modeling in Design and Management of 2020 **2** 11-16 (2020)