Intelligent System for Determining the Presence of Falsification in Meat Products Based on Histological Methods

Alexander Bolshakov, Marina Nikitina, and Renata Kalimullina

Abstract An intelligent system is proposed to support decision-making to determine the presence of falsification in meat products based on histological studies. The tasks that must be solved for its development are formulated. The system architecture for the implementation of the formulated tasks is proposed. It includes, in particular, the expert subsystem and the decision support subsystem. Formalization of knowledge for making a decision about the presence of counterfeit is carried out on the basis of production rules. They are generated based on information contained in morphological tables. The development of a prototype ES is carried out in the programming language of artificial intelligence Prolog. The results of optimizing the approximation of a polychrome image of slices of meat products are described. A method for solving it based on a genetic algorithm is proposed. A program was developed in the C++ programming language, using which a complex of computational experiments was carried out to study the nature of the dependence of the convergence of the optimization process. Various parameters varied: the maximum number of iterations, the choice of the initial population. Further studies in this direction are related to the implementation of all the necessary image processing algorithms to automatically identify the required values of the characteristics of the image fragments for use in the cyber-physical system of automation of the process of identifying falsified meat products.

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1 Introduction

There is a direct link between nutritional quality and emerging diseases. Various diseases are initiated by the quality of nutrition. These include, but are not limited to, obesity, cardiovascular disease, diabetes mellitus, cancer, and others. This time dependence is evaluated as a geometric progression. Poultry and livestock products are carried out in accordance with technologies that use artificial metabolic disorders. As a result, an increase in live weight is observed. The value of these products is doubtful, and the breakdown of drugs significantly affects the safety and quality of the products [1–3].

Instead of meat, offal, such as head meat, internal organs, was usually added to meat products. Now, additives that are of plant origin with a carbohydrate and protein nature are mainly used [4, 5]. Existing technologies for the production of sausages and semi-finished products involve the differentiation of components of plant and animal origin, which have little in common with human needs, such as phosphates, carrageenas, confectionery proteins, and other substitutes or imitators of meat [6–8].

The unlimited authority for import substitution of goods provided by the state to domestic producers enables them to supply products with cheap, but not safe for human health substitutes, preservatives, and food additives to the agri-food market [9, 10].

The degree of deterioration in the quality of meat products due to freezing and further storage in this state depends on various aspects. These include conditions, as well as the duration of storage in a state of freezing, as well as the magnitude of biochemical changes that existed before freezing, as well as its speed. The duration of storage of frozen meat depends on the initial quality indicators of meat, type, and fatness of livestock and poultry, as well as storage technology, such as temperature, packing density, stack sizes, etc. [11, 12].

Determining the quality of meat products is very important. The degree of objectivity, as well as the efficiency of monitoring the characteristics of meat products significantly determines the quality of the products that are provided to the consumer. At the same time, the methods used to control the quality of meat as raw materials remain significantly time-consuming, focused on the use of expensive equipment [13–18].

The widespread distribution of counterfeit products in the consumer market is very negative. Relevant is the identification of actually used for the production of meat raw materials and meat products with the determination of the composition and the allocation of the corresponding components that are of animal and vegetable origin [19].

This identification is required to establish the true form, as well as the name of the product, its compliance with the regulatory documentation for the product, as well as labeling and invoices, etc. To identify the falsification of meat products, microstructural methods for identifying the composition of the product and raw materials are used, which were proposed by the laboratory of microstructural analysis of meat products of the All-Russian Research Institute of Meat Industry. The proposed methods are GOST R when conducting relevant studies [20].

An analysis of the proposed methods shows the presence and necessity of using electronic microscopes, as well as expert technologists for processing the obtained images of slices of meat and meat products during their implementation. The complexity of the procedure associated with image processing, identification of the type of counterfeit determines the relevance of the work aimed at their automation.

In this regard, the urgent task is to automate the process of identifying differentiated counterfeit products in raw meat and meat products. Currently, this process is carried out manually by technologists. Since this is a rather time-consuming task due to the large analytical work, it is advisable to reduce the role of the "human factor" in the process of analysis and decision-making on the presence of counterfeit meat products. To do this, it is necessary to automate the procedure in which the presence of falsification is determined by the input image of slices of meat products according to a number of its characteristics, such as shape, color, size. Further, based on the analysis of these characteristics, the decision support system forms a conclusion. As a similar system, it is proposed to use one of the varieties of intelligent systems—a hybrid expert system. Thus, the original task is divided into two: (1) obtaining and processing a color image of a slice of meat products; (2) the decision on the presence of counterfeit according to the results of processing the image of the slice.

The proposed system is advisable to use in the corresponding cyber-physical automated system for the identification of falsified meat products based on the principle of "digital double."

2 Description of the Process for Determining the Presence of Meat Falsification

The process of determining the presence of counterfeit meat products is regulated in the Federal laws of the Russian Federation, as well as the relevant State standards (GOSTs), for example. One of the most common methods is based on the so-called histological analysis [20]. Below is a diagram of the most popular histological method for determining the presence of falsification in meat products (see Fig. 1).

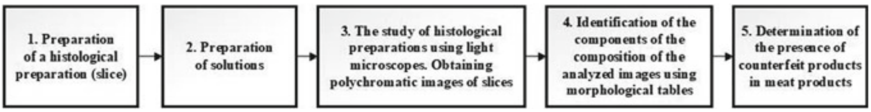


Fig. 1 Stages of the process of determining the presence of falsified meat in meat-based on histological analysis

Determination of the presence and type of counterfeit in meat products is carried out by technologists of sufficiently high qualification on the basis of the study of signs constructed as a result of the previous stages, which are of both quantitative and qualitative nature. Depending on the presence of these signs, their values, technologists determine the presence and type of falsified meat products.

Thus, the initial information for the construction and subsequent analysis of morphological tables are color images of slices of meat products, which are obtained in laboratories from electron microscopes. Therefore, the use of computer tools requires the application of appropriate methods and processing algorithms in the general case of color images.

3 Formulation of the Tasks

It is advisable to automate a rather laborious operation related to the identification and determination of the presence of counterfeit using morphological tables, which are given in the relevant GOSTs. In turn, automation is associated with the processing of images that are obtained by examining slices of meat products using electron microscopes. Thus, the functions of technologists in identification and decision-making must be transferred to the appropriate system to support decision-making on the presence and type of counterfeit meat.

Methods and algorithms have been developed that are used for segmentation and subsequent processing of selected fragments in the original images [21–27]. These include operations related to the selection of the boundaries of regions in the image under study and the determination of their structural characteristics. It should be noted that our analysis of morphological tables showed that in the general case, 8 colors are enough to describe the existing methods for identifying falsified by color. Therefore, it makes sense to optimize the original polychrome image. This will facilitate the procedure for identifying fragments in the studied image, as well as significantly reduce the amount of information for storing and transmitting data about the studied images of meat slices.

One of the conclusions of various existing scientific and practical studies is the recognition of the fact that the selection and development of a new method for solving problems related to digital image processing require quite a laborious testing on a test set of images in the studied subject area. This approach allows us to provide acceptable results based on the characteristics of the studied class of images.

In connection with the foregoing, we can formulate the purpose and objectives of the study. The goal is to increase the effectiveness of the process of determining the presence of counterfeit meat products based on the automation of image processing of sliced meat.

To achieve the goal it is necessary to solve the following tasks: (1) develop an image processing algorithm for automated detection of meat falsification; (2) develop a decision support system to determine if the meat is falsified.

4 Development of an Image Processing Algorithm for Automated Detection of Meat Falsification

4.1 Statement of the Task of Image Processing to Automate the Determination of Meat Falsification

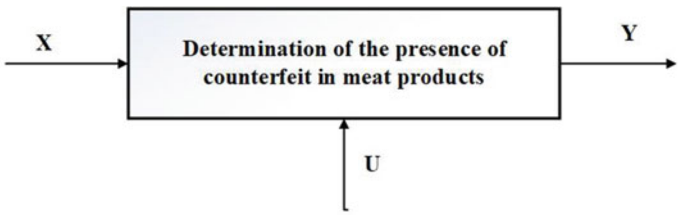
The process of determining the presence of meat falsification is presented in Fig. 1. The proposed automation concerns the last two stages of this process. We carry out a systematic analysis of the decision-making process that is performed at these stages. To do this, consider the circuit in Fig. 2.

The input variable **X**, representing the image in JPEG format contains information about the pixels, can be represented as a matrix of numbers. When translating, for example, from JPEG to RGB, each pixel is assigned 3 numbers from the range [0; 255].

The output variable **Y** represents the result of the procedure for identifying the presence of counterfeit on the basis of morphological tables containing a description of fragments of the image structure and their characteristics. The variable **Y** has a symbolic value that corresponds to the identification result, i.e. "Absence of counterfeit" or the name of the counterfeit.

The variable **U** includes the data necessary for the "adjustment" of the procedure for identifying falsified meat products related to image processing, segmentation, isolation and determination of structural elements, values of their characteristics, etc.

The process is as follows. The input is an image of a slice of meat **X**, which is then processed. Image processing **X**, in General, includes the following steps: preliminary processing of images of slices (noise removal, palette optimization, etc.); color segmentation based on minimizing the palette; approximation of the boundaries of the areas selected in the image; determining the size of areas; determination of



X - input variable, image of a slice of a sample of meat products in JPEG format;
Y is the output variable, the result of determining the presence and type of counterfeit, a character type from a given set;
U is a vector variable containing parameter values characterizing information about the type of meat products, types of falsifications, requirements for image processing and decision-making procedures.

Fig. 2 Determination of the presence of counterfeit in meat products the shape of particles; determination of the color of particles; identification of the presence of falsifications; conclusion of the results of determining the presence of falsified meat.

The consistent implementation of the above steps allows you to get an informed decision about the presence or absence of certain types of falsifications of meat products.

The next section proposes a generalized algorithm for processing images of slices of meat products, which can be implemented in the corresponding automated system.

4.2 Development of an Image Processing Algorithm to Automate the Detection of Meat Falsification

In accordance with the scheme in Fig. 2 in the previous subsection and the required stages of processing images of samples of meat products, the following algorithm for their implementation is proposed, which is presented in Fig. 3.

The functioning of the algorithm in accordance with the proposed block diagram in Fig. 3 is as follows.

Block "Cycle while" study of the samples is completed. A cycle is organized until the planned samples of meat products are examined.

Block "Image **X** input, procedure settings". A slice image of meat products in JPEG format is entered, as well as parameter values that are necessary for the appropriate adjustment of the image processing procedures, segmentation, etc.

Block "Pre-processing images of slices." The image is being converted from the JPEG format to the RGB format, which is more convenient for further digital processing. Then, the color palette of the polychrome image of the sample slice is minimized [26].

Block "Color segmentation based on minimizing the palette." Implements the coloring of the pixels of the source image in the colors of the optimized palette, based on the proximity condition of the source and selected from the optimized color palette.

Block "Approximation of the boundaries of the selected areas." The identification of lines and corresponding areas in the image of the slice of meat products using known algorithms and methods [21–23].

Block "Sizing of areas". Based on the results of the previous block, the corresponding sizes are calculated for the detected areas.

Block "Determining the shape of particles." Particles are detected in the image of the slice and their shape is determined using well-known algorithms and methods [24, 25].

Block "Particle color determination". For the particles detected and the shape of the particles identified by the results of the work, their color is determined.

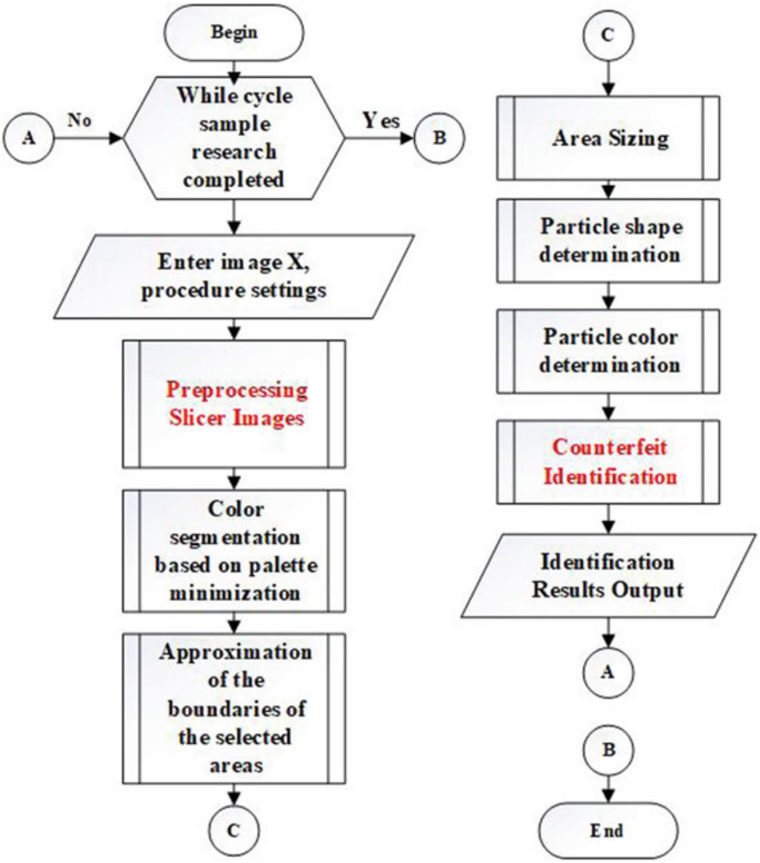


Fig. 3 Block diagram of the image processing algorithm for automating the detection of meat falsification

Block "Identification of the presence of falsifications." This block identifies the presence or absence of counterfeit meat products. In the first case, the type of falsification is also determined using morphological tables. The data are of a qualitative nature, which requires the use of appropriate methods, primarily intellectual. Intelligent methods allow formalizing high-quality information, which is necessary for implementation in automated control systems.

Block "Output identification results." The output obtained from the identification of the presence of falsified meat products is printed and/or screened, as well as in the database for storage and subsequent use.

5 Development of a Decision Support System for Determining the Presence of Meat Falsification

5.1 Statement of the Task of Developing a Decision Support System for Determining the Presence of Meat Falsification

The developed decision support system should have the necessary functions to automate the process of identifying counterfeit products in meat products.

These functions include the following: input of the necessary information (image slice samples in JPEG format, the values of the settings' characteristics of internal procedures); conclusion of identification results on the presence of counterfeit; image processing of slices to remove noise, optimize palettes, etc.; color segmentation based on the optimization of the color palette; approximation of the boundaries of the areas selected in the image; determining the size of areas; determination of the shape of particles; determination of the color of particles; identification of falsifications based on formalized knowledge.

Morphological tables contain a description of the signs of falsification and a description of their characteristics and values. In the general case, these characteristics are of a qualitative nature. Therefore, to formalize this information, it is advisable to use appropriate intellectual methods to formalize qualitative data and synthesize solutions based on them [26].

From the above list, it follows that the automation task is very complex, therefore, its solution should be divided into a number of stages. Of greatest interest to us are the tasks of preliminary processing of images of slices of samples of meat products, as well as the identification of the presence of falsifications based on formalized knowledge.

The solution to the first problem allows you to prepare information about the slice in the form that is most suitable for the remaining tasks, to ensure their successful implementation, because this eliminates noise, redundant information. The resulting image contains information about the most characteristic elements of the desired elements, areas associated with the possible presence of counterfeit. To determine a suitable truncated color palette, it is proposed to solve the corresponding optimization problem. Moreover, as a criterion for the solution, it is proposed to formulate a target function based on the degree of proximity of pixels in the RGB format.

The solution to the second problem is connected, as indicated above, with the formalization using the production rules of the information contained in the morphological tables described in the relevant regulatory documents. The decision-making procedure uses information about values that accept signs of fraud. With the proposed method, this information is introduced into the decision support system (DSS) by experts (technologists) based on the results of solving the first problem. It is also possible, if necessary when the original image is used. The decision result is displayed by the DSS for the user in an understandable form for him: the wording about the absence or presence of a certain falsification in the sample of meat products.

The above two problems are solved in this qualification work. The remaining tasks are the subject of further research. It should be noted that there is a fairly large arsenal of methods and algorithms for their solutions. A lot of resources are needed, first of all, temporary for comparative testing of existing approaches and identifying the most suitable. It also requires substantiating the feasibility of developing our methods and algorithms.

5.2 Building the Architecture of a Decision Support System for Determining the Presence of Meat Falsification

The proposed architecture of the decision support system for identifying the presence of falsification in samples of meat products (see Fig. 4) ensures the fulfillment of the functions that the DSS should fulfill. These functions are described above.

The proposed option includes a control module that controls the DSS subsystems, organizes interaction using the appropriate interface, communication with the administrator and authorized user. The system includes an information subsystem in the form of ES, as well as subsystems for PPR.

Here, ES is implied in the classical form and includes standard blocks: A knowledge base of production type; Inference mechanism; Working memory; Explanatory component.

The subsystem for supporting decision-making about the presence of falsification in samples of meat products for processing sliced images includes the following modules (subprograms): image processing of slices; color segmentation based on the optimization of the color palette; approximation of the boundaries of the areas selected in the image; determining the size of areas; determination of the shape of particles; particle color determination.

The functioning of the DSS is carried out, as indicated, under the control of the control module, which organizes the necessary interaction of the subsystems, information support, and two groups of users on the basis of the corresponding support. These include the administrator and operator (user, technologist, knowledge engineer).

The administrator manages the password system to differentiate access rights for different categories of users, enters, and corrects data in the database.

The user carries out the process of identifying the presence of counterfeit by inputting images in the iterative mode. In the process of this work, an appeal is made to the modules (subprograms) of the preliminary processing of the initial image of the slice, segmentation, etc.

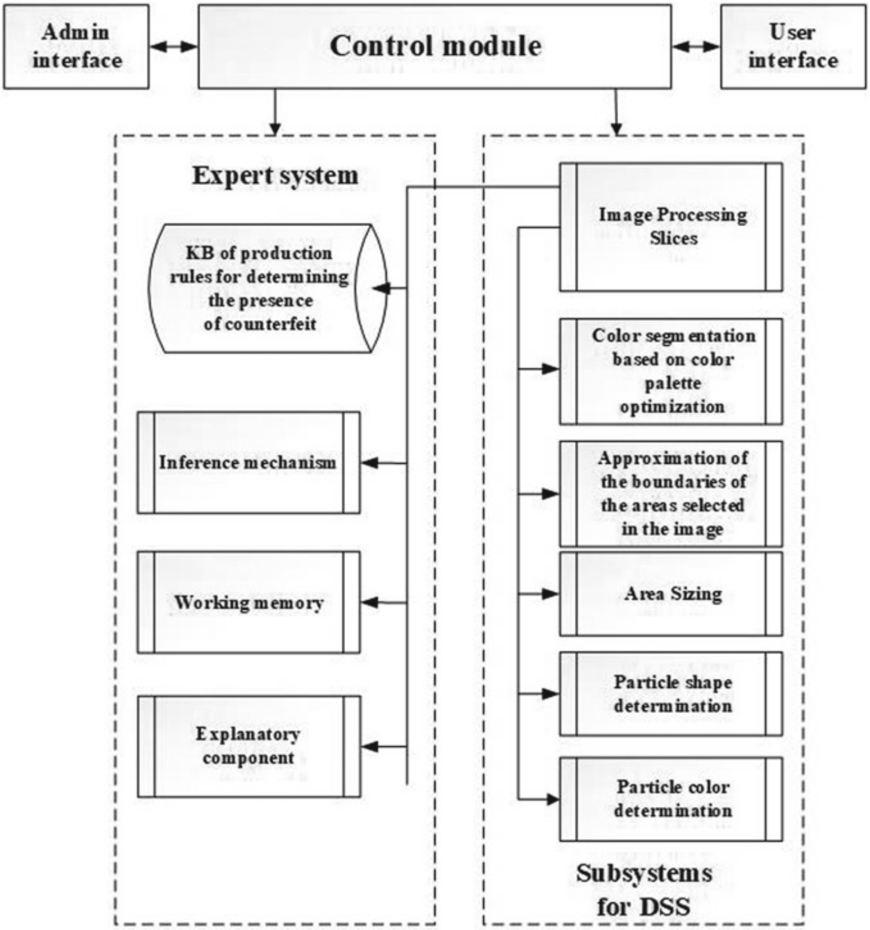


Fig. 4 The architecture of the decision support system for determining the presence of meat falsification

5.3 Development of a Prototype Expert System for Determining the Presence of Meat Falsification in Prolog

The methodology is proposed below and the results of developing a prototype expert system for DSS are described by the scheme shown in Fig. 4.

To develop a prototype, it is advisable to use the methodology of building expert systems [28–32]. According to this methodology, ES synthesis is carried out by the following steps.

1. Statement of the problem. The purpose of the construction of ES is to increase the effectiveness of determining the presence of falsification in samples of meat products.
2. Identification of the problem. This process is carried out by technologists (experts) based on a comparison of the data obtained after analysis of the samples prepared according to the instructive materials using electronic microscopes and morphological tables containing information on the correspondence of the revealed signs to the presence of certain falsifications. To reduce time as well as financial costs, it is proposed to develop an ES in which the knowledge presented in the relevant instructional materials, as well as, possibly, from expert technologists, is formalized.
3. Extraction of knowledge. As sources of knowledge, instructive documents, scientific publications [11–20], and experts were used. Systematization of this material made it possible to present information in the form of tables called morphological. The rows of these tables correspond to the characteristics, the content of which is established on the basis of visual analysis of images of slices of meat products prepared in special solutions, which are examined using electronic microscopes. Pillars—to certain types of counterfeit.
4. Conceptualization. At this stage, key concepts, relationships, and characteristics are identified that are necessary to describe the process of identifying the presence of a certain type of counterfeit. As such concepts, for example, are the identification features of plant components of protein nature: particle shape; particle size; the presence of fragments of the shell of soybean; tinctorial properties (with hematoxylin and eosin stain).

Depending on the detected values of the above characteristics, the following counterfeit variants are established: soy protein isolated; soybean concentrate; textured soy protein product.

Thus, information characterizes a limited set of attributes of a qualitative nature: the shape and size of particles, the presence of fragments, the coloring of particles and elements, etc. Given a given set of values for these characteristics, it is concluded that there is a certain counterfeit. If they are absent, a conclusion is drawn about the absence of counterfeit.

5. Formalization. In accordance with the above, we introduce the following values of the variables shown in Table 1.

The characteristics indicated in Table 1, corresponding to key concepts, can take on certain syntactic values, which are considered as constants. If the sign takes this value, then it is considered that the corresponding variable is equal to this value.

For example, according to Table 2, if it is revealed by the "Particle Shape" (A1) that it is observed that the shape is in the form of a rolled cord or bean, or rounded from a dark point in the center (C1), then A1 = C1 is considered.

Further, the assignment of the conditions for the identification of a certain counterfeit is carried out based on the rules of the form "IF…TO." In our case:

IF A1 = C1 and A2 = B1 and A3 = D1 and A4 = E1 THEN A5 = F1

Table 1 Description of key concepts

Key concept	Designation	Characteristic
Particle shape	A1	Introduces a user or slicer image processing system
Size	A2	Introduces a user or slicer image processing system
Tinctorial properties (when stained with Lugol's solution)	A3	Introduces a user or slicer image processing system
Tinctorial properties (when stained with hematoxylin and eosin)	A4	Introduces a user or slicer image processing system
Identification of the presence of counterfeit	A5	ES displayed

Table 2 Description of the values adopted by key concepts

A1	C1: {(a) folded harness (b) bean (c) rounded with a dark dot in the center}	C2: {Rounded particles combined into large aggregates}	C3: {Particles are heterogeneous and irregular in shape}	C4: {Particles are irregular, more uniform}	C5: {Separate plant cells or groups of cells. Each cell is surrounded by a clear, non-stained cellulose membrane}
…	…	…	…	…	…
A5	F1: {Starch}	F2: {Flour}	F3: {Carrageenan Semi-Purified}	F4: {Carrageenan Peeled}	F5: {Gums of guar, packaging and carob}

IF A1 = C2 and A2 = B2 and A3 = D1 and A4 = E1 THEN A5 = F2
IF A1 = C3 and A2 = B3 and A3 = D3 and A4 = E2 THEN A5 = F3
IF A1 = C4 and A2 = B3 and A3 = D2 and A4 = E2 THEN A5 = F4
IF A1 = C5 and A2 = B4 and A3 = D3 and A4 = E3 THEN A5 = F5

Thus, the information contained in the morphological table is presented in the form of production rules.

6. Execution. For a software implementation, the Prolog language of artificial intelligence was chosen, which allows the construction of production rules to be implemented and is widely used to create ES of relatively small sizes. Further studies on the development of the prototype and the creation of a full-fledged ES to determine the presence of counterfeit suggest formalization of knowledge of their various types according to the method described above. Further, tests involving experts are required.

6 Development of a Method for Optimizing the Approximation of a Polychrome Image

6.1 Statement of the Problem of Optimizing a Polychrome Image of a Slice of Meat Products

To make a decision about the presence of falsification in a meat product, it is necessary to identify the corresponding area in the image of the slice. To reduce the amount of memory occupied by the image and simplify its processing, it is advisable to reduce the number of colors in which this image is filled. Further, a set of such colors is called an image palette.

The image of the histological preparation arriving for processing has the JPEG format. The color model used is RGB. Thus, the color of each pixel of the image X_{ij} is determined by a tuple of integers $[R_{ij}, G_{ij}, B_{ij}]$ in the range [0…255], then these 3 numbers are called defining.

According to the National Standards for Determining the Presence of Fake, soy protein products and pea flour are stained with a solution of hematoxylin and eosin. Signs of falsification of meat products are: rounded pink particles; cylindrical or rounded particles in shades of red; red or purple bundles of fibers; unpainted particles.

Thus, to solve the recognition problem associated with determining the presence of a counterfeit, enough information about the presence in the image of fragments of several colors. Therefore, to reduce the amount of information when transmitting and storing images, it is necessary to determine the corresponding color palette, in which the number of colors is relatively small.

6.2 Formalization of the Task Statement

It is required to optimize the number of colors in a polychrome image to a given N, i.e. determine the value of the vector P_N, where N is the size of the palette. It is advisable to consider the following set of values of the N variable $C = \{2, 4, 8\}$ as possible values of the size of the palette, which is associated with the analysis of a priori information about the number of falsified flowers and, in fact, meat after appropriate processing of the slices with chemical reagents. Thus, based on the original polychrome image, it is required to obtain an optimized image that uses a given number of colors. In this case, all the colors of the original image are replaced with colors from the palette, based on the criterion of the proximity of the original and optimized images.

Input data: image of the histological preparation in the form of a matrix $X_{ij} = [R_{ij}, G_{ij}, B_{ij}]$, $i = 1,\ldots, W$, $j = 1,\ldots, H$, where W and H are the width and height of the image in pixels. We call such a matrix defining; many RGB color values that could potentially be present as fake; the number of colors N used in the resulting image; the maximum allowable time of the algorithm (number of iterations).

Output: vector P_N containing the resulting image palette.

The task is optimization, the essence of which is to build a palette that maximally approximates the original image. Determining the optimality of the palette, i.e. the degree of its approximation in accordance with the criterion for assessing the quality of the approximation, a description of the choice of which is given below.

6.3 Criteria for Assessing the Quality of Polychrome Image Approximation

The choice of a criterion for numerical quality assessment is very important since it is the main characteristic of evaluating the effectiveness of the algorithm. Since the selection of the resulting image, which should consist of a limited number of colors, i.e. 4 is a search and optimization task, then the criterion is necessary to determine the correct search direction and optimize the corresponding deviation according to the selected quality assessment criterion. The choice is limited to a modular criteria-based assessment.

Thus, to assess the quality, the operation of calculating the total (absolute) deviation modulus was used:

$$\Delta Q = \sum_{i=0}^{W} \sum_{j=0}^{H} \left| R_{ij}^{X} - R_{ij}^{P} \right| + \left| G_{ij}^{X} - G_{ij}^{P} \right| + \left| B_{ij}^{X} - B_{ij}^{P} \right|,$$

where R_{ij}^{X}, G_{ij}^{X}, B_{ij}^{X}—determining the pixel numbers of the original image, and R_{ij}^{P}, G_{ij}^{P}, B_{ij}^{P}—defining numbers of one of the values of the vector P.

The criterion contains the functions of taking the module; therefore, its differentiability in the Frechet sense cannot be guaranteed, as well as continuity. Therefore, it is not possible to use gradient extremum search methods. The use of exhaustive search methods and procedures for minimizing the zero level does not guarantee the optimal value, since the problem belongs to the number of *NP*-complete, i.e. with an exponentially increasing level of difficulty.

Therefore, it is advisable to use heuristic methods, which, in particular, include genetic algorithms.

In the next paragraph, based on an analytical review, a reasonable choice of simple genetic algorithms from among the considered methods is made.

6.4 The Choice of a Method for Solving the Problem of Minimizing the Polychrome Image Palette

The task of reducing the polychrome image palette is reduced in the previous subsection to the optimization one. As a criterion of optimization, a modular assessment is selected. The proposed objective function is not differentiable in the sense of Frechet; therefore, the use of gradient methods to solve the formulated search and optimization problem is impossible. In general, the finite set of solutions, that is, all possible combinations of 256 * 3 colors from the original palette, is too large to use the direct enumeration method. Therefore, this method of solution is very costly and does not guarantee the determination of the optimum. Therefore, to solve the proposed optimization problem, it is advisable to choose a heuristic algorithm.

A simple genetic algorithm was selected for the following reasons: (1) evolutionary programming does not use the recombination operator, which is required in the problem being solved; (2) swarm intelligence is mainly used in finding the optimal path, for calculating routes using graphs and for determining approximate solutions in the "traveling salesman problems"; (3) for the task of combinatorial type, the basic mechanisms of the genetic algorithm are sufficient, without additional information about the colony, as in swarm intelligence.

6.5 Construction of an Algorithm for Solving the Problem of Minimizing the Palette of a Polychrome Image of a Slice of Meat Products

The algorithm solves the optimization problem of search and allows you to form the optimal individual (palette).

An individual is the basic unit of the evolutionary process; in the context of this task, an individual is an image palette.

Each individual consists of two chromosomes. Moreover, the Alpha chromosome corresponds to the initial approximation of falsified colors specified by the user. Here, the Beta chromosome corresponds to the colors obtained during the algorithm without taking into account the initial approximation.

Each chromosome consists of genes that determine the genotype of an individual. A gene is a unit of hereditary information and an internal representation of an alternative solution. In the proposed algorithm, each gene contains a three-dimensional vector containing numbers in the range from 0 to 255, which corresponds to the color components in the RGB format.

The result of each iteration of the genetic algorithm is a population that is a collection of individuals.

The main stages of the method based on a genetic algorithm.

1. The formation of the initial population. The first stage of the algorithm is the formation of an initial population containing N_I individuals. To form the alpha chromosome, N_{alpha}, the color of the initial falsification approximation is randomly selected once, i.e. one of the colors that is specified by the user as the alleged color of falsification. For the formation of beta chromosomes, we can use two approaches. In the first case, N_{beta} randomly selects an element of the defining matrix, i.e. the color of the corresponding pixel, and its value is assigned to one of the genes of the beta chromosome. In the second case, a random color is selected for each beta chromosome gene.
2. Breeding. The idea of the genetic algorithm is to preserve the genotype of the best individuals in each of the newly formed generations and to transfer N_S of the most optimal individuals to the next generation at each iteration. To do this, it is proposed to introduce the following selection operator:

$$O_s(I) = \sum_{i=1}^{h}\sum_{j=1}^{w}\left(p_{i,j} - c\left(p_{i,j}\right)\right), \quad c\left(p_{i,j}\right) = \min\left(p_{i,j} - c_k\right),$$

where I is the individual, h is the height of the defining matrix, w is the width of the defining matrix, $p_{i,j}$ is the element of the defining matrix, $c(p_{i,j})$ is the color closest to $p_{i,j}$ from the palette, c_k—color of the palette.

Thus, the individual I_i is "more optimal" than the individual I_k if $O_s(I_i) < O_s(I_k)$.

The remaining space in the new generation equal to $N_I - N_S$ is filled with individuals obtained as a result of crossing and mutation.

3. Crossbreeding. The result of the operation of crossing two individuals $O_C(I_1, I_2)$ is their offspring containing the characteristics of both parents. The crossing process is as follows: at the first parent I_1 random sections of the alpha chromosome and beta chromosome are selected. This site passes into the descendant, and the remaining space is filled with the corresponding genes of the second parent I_2.
4. Mutation. For the convergence of the algorithm and the prevention of premature stabilization, it is very important that the diversity of individuals in each new generation is maintained. For this, it is proposed to introduce a mutation operator $O_M(I)$. This operator replaces the gene values in the alpha chromosome $N_{M_{alpha}}$ with others from the initial falsification approximation and in the $N_{M_{betta}}$ beta chromosome gene values with another randomly selected color.
5. Checking the stop condition. The condition for stopping the algorithm is to pass a given number of iterations $N_{i_{max}}$. The result of the algorithm is the most optimal individual obtained during all iterations of the algorithm.

6.6 Testing the Algorithm for Solving the Problem of Minimizing the Palette of a Polychrome Image of a Slice of Meat Products. Results Analysis

The program for minimizing the palette of a polychrome image of a slice of meat products is implemented in the C++ programming language. The program is generally intended to implement the procedure of minimizing the palette of a polychrome image specified in RGB format. The source data is presented in the form of a matrix of a given size with cells containing information about the image pixels. In this case, the color is represented using the RGB model. To assess the quality, a criterion is used based on the calculation of the total absolute module of deviations of the three-dimensional vector RGB of the original image from the approximating one. The program implements a genetic algorithm in which the genome is a pixel. The pixel is encoded in RGB format, i.e. is determined by three positive numbers in the range from 0 to 255. The result of the program is to determine the quantitative values of the approximating RGB palette that minimizes the initial polychrome image palette specified in the RGB format.

The proposed method for approximating a polychrome image of slices of meat products based on the use of a limited palette is reduced to solving the optimization problem. As shown above, the use of a genetic algorithm is most preferred. The advantage of GA is non-criticality to the properties of the objective function: continuity, differentiability, unimodality. In addition, it is relatively easy to take into account the constraints that form the region of feasible decision values. However, this requires studies related to the choice of the parameters of the GA, the study of the rate of convergence depending on the initial conditions and these parameters, as well as the presence of local extrema.

In connection with this, a technique is proposed that allows one to determine the most suitable values of the parameters of the proposed optimization method based on GA.

The initial information for the methodology contains test images with a given type of counterfeit and without its presence, a set of acceptable values of the algorithm parameters.

The output contains systematic data on the results of optimization according to the following criteria: values of the target (fitness) function, operating time (number of iterations).

It is proposed to vary the values of the following characteristics.

1. The variant of formation of the initial population:
   (a) Random selection of elements of the defining matrix
   (b) Random color generation
2. The number of selected individuals for selection:
   (a) $N_I \div 2$
   (b) $N_I \div 4$

Table 3 Optimization results for approximating a polychrome image based on GA

tmax	topt	penalty	iteration

3. The number of mutated genes $N_{M_{alpha}}$ и $N_{M_{beta}}$:
   (a) $N_{M_{alpha}} = N_{alpha} \div 2, \quad N_{M_{beta}} = N_{beta} \div 2$
   (b) $N_{M_{alpha}} = N_{alpha} \div 4, \quad N_{M_{beta}} = N_{beta} \div 4$
4. The number of iterations.
   (a) $N_{i_{max}} = 1000$
   (b) $N_{i_{max}} = 2000$
   (c) $N_{i_{max}} = 4000$

Thus, the technique represents an iterative procedure, each nested loop of which is represented by the steps described above.

The results are summarized in tables of the following form (see Table 3).

Here t_{max} is the specified maximum time to search for the optimal value; t_{opt}—time for which the optimal value is determined, sec.; *iteration*—the number of iterations that needed to be performed to find the optimal value for the formation of the best individual GA; *penalty*—a fitness function for assessing the quality of polychrome image approximation.

The proposed polychrome image approximation algorithm is aimed at reducing the color palette used. For computational experiments, the value of the size of the resulting image palette is further selected $C = 4$.

Moreover, the values of other parameters of the genetic algorithm are fixed and the following values are selected: the number of individuals in the population of 20; the number of selected individuals for selection $n_i = 2$; the number of mutated genes $N_{Mbeta} = 2$.

In the study of the genetic algorithm, the formation of the initial population changes, the following parameters vary:

1. Alpha chromosome used $N_{alpha} = 1$, those each individual has the color of one counterfeit, which could potentially be contained in a slice. The beta chromosome uses only elements of the defining matrix.
2. Only the beta chromosome is used, the gene values of which are initialized by the elements of the determining matrix.
3. Only the beta chromosome is used, the gene values of which are randomly selected.
4. Only the beta chromosome is used, the gene values of which are "central values" ($R = G = B = 128$).
5. Only the beta chromosome is used, the gene values of which are the extreme values of the three components of the RGB model, namely $R = G = B = 0$.
6. Only the beta chromosome is used, the gene values of which are the extreme values of the three components of the RGB model, namely $R = G = B = 255$.

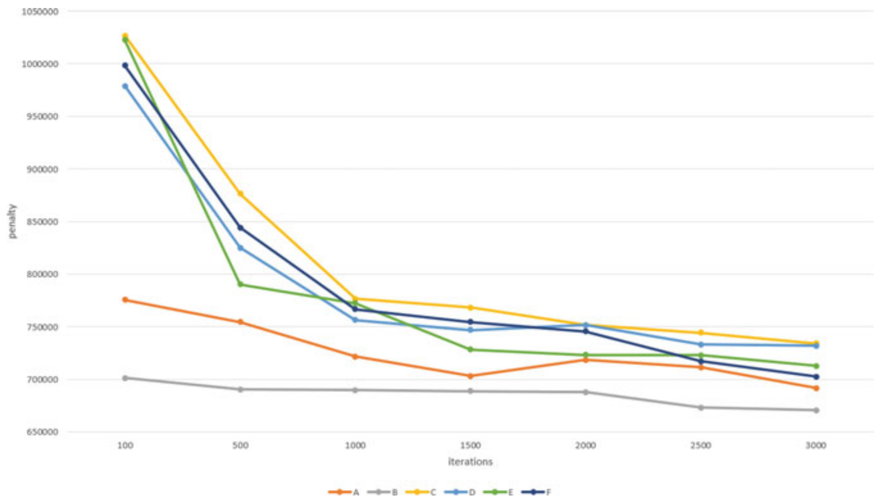


Fig. 5 Dependence of the value of the objective function on the number of iterations

For each formation of the initial population, a graph is constructed of the dependence of the objective function on the maximum allowable time of the algorithm (number of iterations). The graphs are presented in Fig. 5, 10 experiments were performed for each number of iterations, and the average value was calculated.

Based on the results obtained, the following conclusions can be drawn.

After the first thousand iterations, the convergence rate of the algorithm drops significantly, which makes further work of the algorithm impractical.

The best approximation was obtained by initializing the initial population with the colors present in the image (option *B*), however, the convergence rate is extremely low, which is explained by the small palette of the original image, i.e. the initial population always consists of a limited number of flowers. Because of the mutation, changes occur in the genes of an individual, however, the value of the objective function of a given individual is a priori greater than the initial ones, because the colors of the original palette are closer.

The best convergence rate is shown with a random selection of colors for the formation of the initial population (option *C*). However, this option shows the worst approximation, which seems logical enough.

With the above parameters, for each item in the list of initial population formation, the results of the algorithm for the number of iterations $N_i = 3000$ are visually demonstrated below (see Figs. 6 and 7).

Figure 7 shows the best result of the algorithm for other histological preparations.

Since the graph of the dependence of the objective function value on the number of iterations showed that when choosing the formation of the initial population of variant *B*, the *penalty* parameter is the smallest, this initialization is selected. Also, according to the results of the study, the number of iterations $N_i = 1000$ was selected.

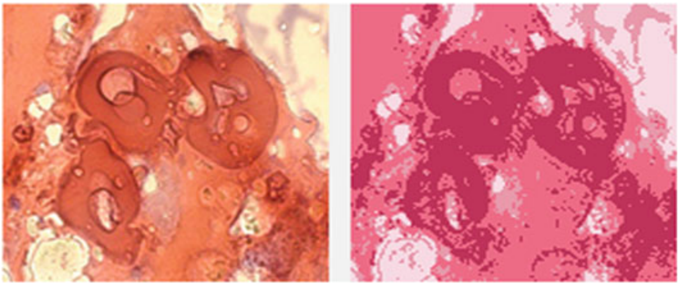


Fig. 6 Formation of the initial population option *C* (*penalty* = 732030)

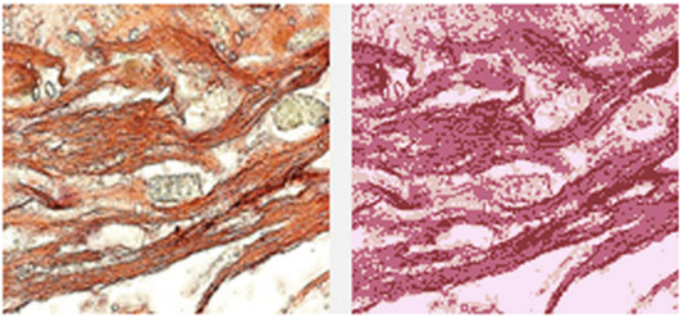


Fig. 7 Formation of the initial population option *F* (*penalty* = 830288)

7 Conclusions

A systematic analysis of the process of identifying the presence of counterfeit products in meat products was carried out, the last two stages that are expedient to automate to achieve this goal are highlighted. The purpose of the work was to increase the effectiveness of the process of determining the presence of meat falsification through automation. A generalized algorithm is developed for determining the presence of counterfeit based on the analysis of images of sections of product samples. The following tasks were selected: preliminary processing of images of slices of samples of meat products, as well as identification of the presence of falsifications based on formalized knowledge.

To automate the determination of counterfeit availability, a generalized algorithm and architecture of a decision support system are proposed, which includes two subsystems: expert and decision support. Formalization of knowledge for making a decision about the presence of counterfeit is carried out on the basis of production rules, which are generated on the basis of information contained in morphological tables. The development of a prototype ES is made in the programming language of artificial intelligence Prolog. To build an ES for identifying the presence of counterfeit, a technique is proposed based on the methodology for building expert systems.

The second solved problem is to optimize the approximation of a polychrome image. The analysis of the features of this problem is carried out, which made it possible to propose a method for solving it based on the genetic algorithm. A program was developed in the C++ programming language, using which a complex of computational experiments was carried out to study the nature of the dependence of the convergence of the optimization process. Different parameters and characteristics varied. Among them: the maximum number of iterations, the choice of the initial population, etc.

In the future, to determine the most significant parameters, it is advisable to develop an appropriate technique using the statistical hypothesis, methods of multidimensional processing of experimental data.

Further research in this direction is associated with the full implementation of all the necessary image processing algorithms for the automatic detection of the required values of the characteristics of fragments of images that are counterfeit. Another area of work is the formalization of knowledge in the corresponding knowledge base of the product type, which will allow the appropriate decision-making support system to be formed, as well as to explain the conclusions on the presence of detected falsifications based on the processing of images of sliced meat products. It is advisable to use the results obtained when constructing typical automated systems for identifying the presence of falsification in samples of meat products for use in promising cyber-physical systems in the studied subject area. In addition, it is recommended that algorithms and programs be used to study the tissues of living creatures and humans when conducting studies aimed at identifying abnormal phenomena.

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