TECHNICAL SCIENCES

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OBJECT-ORIENTED INTELLIGENT SYSTEM FOR NEURAL NETWORK DETECTION OF SUGAR CRYSTALLIZATION ZONES

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Introductions. Taking into account the constant increase in requirements for product quality and the need to optimize production processes, accurate and fast detection of crystallization zones becomes a critically important task for manufacturers of sugar products. Crystallization zones in the process of sugar production are a key stage that allows you to effectively separate sugar from other components. The industrial process of crystallization requires several stages due to the difficulty of separating crystals from the intercrystalline solution with a high content of crystals in the syrup [1]. For further extraction of sugar, special processes are used, for example, replacing alkaline ions with magnesium ions in the syrup outflow.

Optimizing the efficiency of crystallization departments includes setting high requirements for syrup quality, clarification procedures and outflows. Analysis of the reasons for the formation of crystal conglomerates during the boiling of syrups helps to improve the process. In addition, recommendations for improving the granulometric parameters of granulated sugar contribute to the optimal operation of departments [2].

One of the key advantages of using neural network methods is their ability to adapt to a variety of production conditions and variables. This is especially important in the food industry, where production conditions can change from one process to another, and external factors such as air humidity, temperature, and others can also affect [3].

Additionally, neural network models can learn on the fly, adapt to new conditions, and optimize their performance over time [4, 5]. This provides continuous improvement in the efficiency of the crystallization zone detection process and allows manufacturers to ensure consistent quality of their products.

In addition, automated methods based on neural networks can significantly reduce the time required to identify crystallization zones, which in turn increases the overall efficiency of production and allows manufacturers to react more promptly to any inconsistencies in the production process [6].

Aim. The aim of the work is to increase the efficiency of sugar production due to the automated detection of sugar crystallization zones in the production process. For this purpose, a method of image detection of sugar crystallization zones in the production process and a corresponding object-oriented intelligent system have been developed.

Materials and methods. The method of detecting sugar crystallization zones in the production process is intended for the optimization of sugar production processes and the automated detection of potential problems in the sugar production process. The scheme and steps of the method are shown in Figure 1.

The input data of the method for detecting sugar crystallization zones in the production process are a trained neural network model and an image for detecting crystallization zones.

The first step is to load the trained model, which is the input data, and prepare it to run. The next step is image preprocessing, which includes scaling and converting to a byte array. The third step is to submit the image to a neural network model for classification, which makes predictions about whether the image sample belongs to one of the four zones of sugar crystallization. The last step is the formation of a conclusion regarding the image belonging to the crystallization zones.

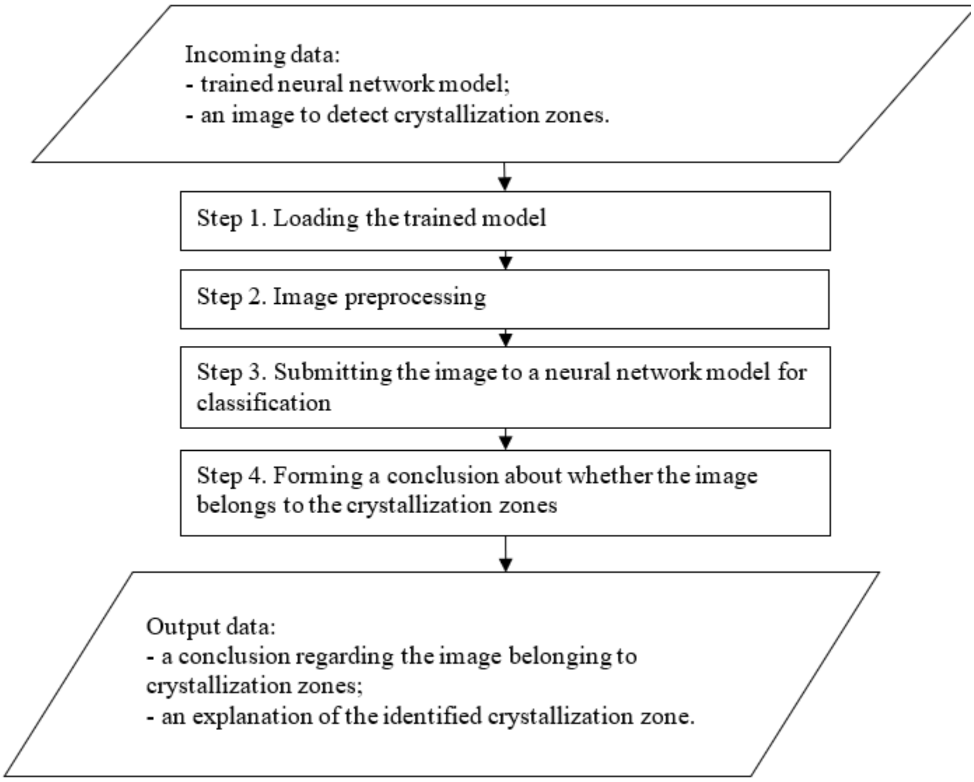

Fig. 1. Scheme and steps of the method of detecting sugar crystallization zones in the production process

The method returns output data in the format of a conclusion regarding the image belonging to crystallization zones and an explanation of the detected crystallization zone.

The intelligent object-oriented system, which uses the developed method to detect sugar crystallization zones on images, consists of 4 subsystems, namely: «Sugar crystallization zone detection subsystem», «Sugar crystallization zone image database subsystem», «Sugar crystallization zone image database subsystem» study of the effectiveness of detecting sugar crystallization zones», and «Neural network learning subsystem».

The neural network learning subsystem is designed to train a neural network classifier that will be able to perform the task of multiclassification, and as a result, perform the preservation of the trained neural network model. Also, this subsystem performs such functions as the selection of a data set for training, the formation of a pipeline, the training of a neural network model, the evaluation of performance according to the metric of macro-accuracy, and the preservation of the trained neural network model. This subsystem does not provide a graphical user interface.

The subsystem for working with the database of images of sugar crystallization zones is designed to interact with the data set, and provides the following basic functions: selection of the crystallization zone for working with the image database, displaying the names of images belonging to the selected crystallization zone, detailing information about the selected image sample, deleting the selected image sample, adding a new sample to the selected image category, making changes to the information about the selected sample in the image database.

The sugar crystallization zone detection subsystem is designed for neural network detection of sugar crystallization zones by image, and performs the following main functions: uploading an image to detect crystallization zones, detecting sugar crystallization zones by image, percentage assessment of belonging to sugar crystallization zone classes, outputting a description for the specified zone crystallization.

The sugar crystallization zone detection performance subsystem is designed to evaluate the effectiveness of the neural network classifier by metrics, and can also perform the following functions: selection of data sets for performance studies from existing ones, selection of data sets for performance studies from the hard disk, output of results of performance studies by metrics, output results of efficiency research in the form of incorrectly identified samples.

Results and discussion. The software structure of the object-oriented intelligent system for detecting sugar crystallization zones in the production process is shown in Figure 2.

The «Sugar_model» class is intended for training a neural network to detect sugar crystallization zones in the production process.

The BuildPipeline() method is used to build the pipeline as well as to process the data and train the model. It defines the sequence of operations that are applied to the data before training the model.

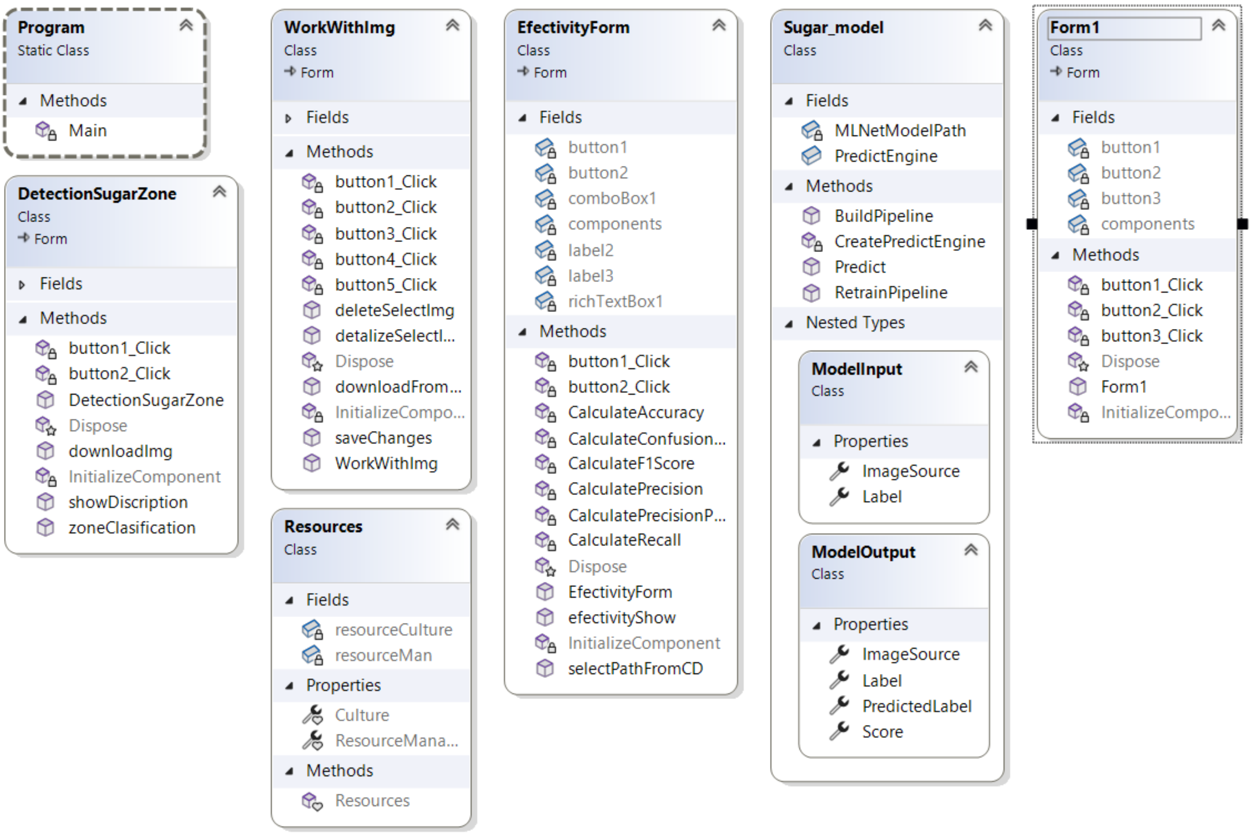

Fig. 2. Class diagram of the object-oriented intelligent system for detecting sugar crystallization zones on the image

The RetrainPipeline() method, in turn, uses this constructed pipeline to train the model on new data.

The «Form1» class is designed to implement the main menu, and performs an auxiliary role.

The purpose of the «WorkWithImg» class is to work with images. The button2_Click() method accepts the text selected by the user in the drop-down list of classes and outputs a list of images corresponding to it.

The detalizeSelectImg() method is responsible for detailing the selected image from the list. A graphic image is displayed in pictureBox1, and data about it is displayed in text fields.

The deleteSelectImg() method is designed to remove the selected image from the list, and the downloadFromLocalDisk() method is designed to add an image from the local disk to the image database for the selected category. The saveChanges() method is designed to save changes when editing image information.

The «DetectionSugarZone» class is intended directly for the detection of sugar crystallization zones on the image. It uses a pre-trained neural network model from the «Sugar_model» class. The downloadImg() method is designed to download an image file for classification from local disk. The zoneClassification() method is designed to identify the crystallization zone.

The purpose of the showDiscription() method is to display the results and description of the identified crystallization zone.

The «EffectivenessForm» class is designed to investigate the effectiveness of trained neural network models. It contains a set of methods for calculating metrics, as well as for displaying the results on the screen.

The CalculateAccuracy() method is designed to calculate the overall classification accuracy based on the actual labels and predicted labels.

The CalculatePrecisionPerClass() method is designed to calculate the classification precision per class based on the actual labels and predicted labels.

The CalculatePrecision() method is designed to calculate the average accuracy (precision) of the classification based on the actual and predicted class labels. Takes as input two lists of strings: actualLabels, which contains the actual class labels, and predictedLabels , which contains the model's predicted class labels for the same data.

The CalculateRecall() method is designed to calculate the average completeness (recall) of classification based on actual and predicted class labels.

The method first identifies the unique classes occurring in the actual and predicted labels and creates a dictionary to store the number of correct predictions for each class. The number of correct predictions for each class is then calculated by comparing the actual and predicted labels. Completeness is then calculated for each class, defined as the ratio of the number of correct predictions for that class to the total number of data belonging to that class. Finally, the average value of completeness for all classes is calculated. This allows us to evaluate the model's performance in terms of how well it did at recognizing each particular class relative to all classes.

The CalculateF1Score() method is designed to calculate the value of the

F_1-score, which is a harmonic mean between precision and recall of the classification. The value of the F_1-score takes into account both accuracy and completeness, which allows you to balance these two indicators in one number.

The CalculateConfusionMatrix() method is designed to calculate the confusion matrix based on the actual and predicted class labels.

Based on the given structure of the information system, a software application was developed that uses a neural network for multi-classification of sugar crystallization zones based on the image.

Among the critically important components is the implementation of learning the neural network model of the «Sugar_model» class. The BuildPipeline() method performs such steps as converting the value of labels to numeric indices (MapValueToKey). This is necessary in order to be able to use these values in the model. The step of training a model for image classification (ImageClassification). The multiclass classification algorithm (MulticlassClassification) is used, which is designed to work with many categories. The next step is to convert the predicted numeric indices back to the corresponding labels (MapKeyToValue).

The RetrainPipeline() method uses the constructed pipeline from the BuildPipeline() method to train the model on new data. It takes as input an MLContext object that represents the machine learning environment and an IDataView trainData that contains the data to train the model. By calling the fit(trainData) method on the constructed pipeline, the method trains the model and returns the already trained model (ITransformer) which is used to make predictions on the new data.

The zoneClassification() method of the «DetectionSugarZone» class, which is designed to identify the crystallization zone, performs such steps as reading the image from a file in the form of a byte array using the File.ReadAllBytes(@filePath) method, preparing data for prediction by creating a Sugar_model object. A ModelInput that contains the data for prediction. In this case, the object contains an image represented as a byte array in the ImageSource property. The next step is to execute the forecast. The Sugar_model.Predict(sampleData) method uses a pre-trained model to make a prediction on the input sampleData and then processes the prediction results. The prediction result is contained in the predictionResult variable. The index with the highest probability of the class is found using the Array.IndexOf(predictionResult.Score, predictionResult.Score.Max()) method. After that, the maxLabelInfo line is formed, which contains information about the class with the highest probability, as well as the probability itself. An example of this method is shown in Figure 3.

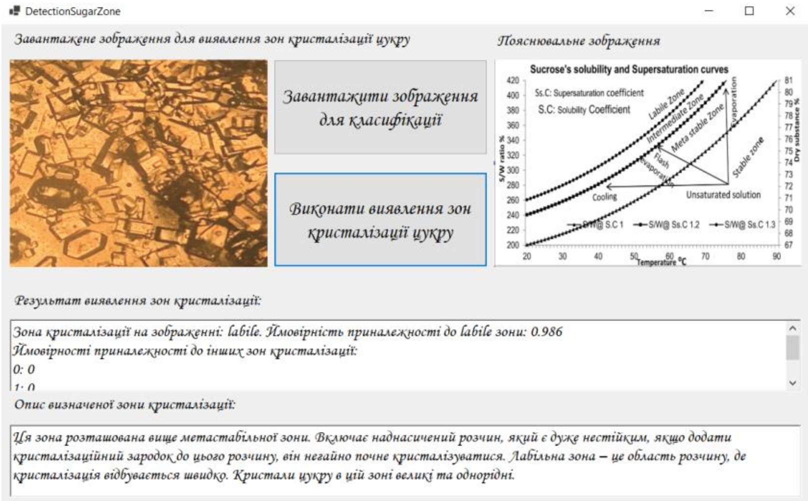

Fig. 3. Example of detection of sugar crystallization zones

As part of the implementation of the «Sugar Crystallization Zone Effectiveness Research Subsystem» processing of classification results for a test set of images using the constructed model was implemented.

The subsystem is implemented in the «EffectivenessForm» class. First, we get the path to the folder with the test images and create lists to store the real and predicted classes. Initializes two lists that will be used to store the actual and predicted class labels for each image.

Next, the list of classes in the test set is obtained and the images are processed. For each class, all images in the test set are processed. The foreach loop loops through each folder (class) in the test suite, and then through each image in each folder. An image is read into a byte array, an instance of the ModelInput class is instantiated with that image, and model prediction is applied to obtain the predicted class label.

In the step of storing the predicted and actual class labels for each image, the predicted class label is added to the list of predicted labels and the actual class label is added to the list of real labels. If the predicted label does not match the actual one, an incorrect prediction message is displayed.

After all images are processed, performance metrics are calculated: accuracy, hit, completeness, F1-score, and confusion matrix.

The resulting values of the performance metrics are displayed, and the confusion matrix and accuracy for each class are also displayed. An example of the functionality of the described class is shown in Figure 4.

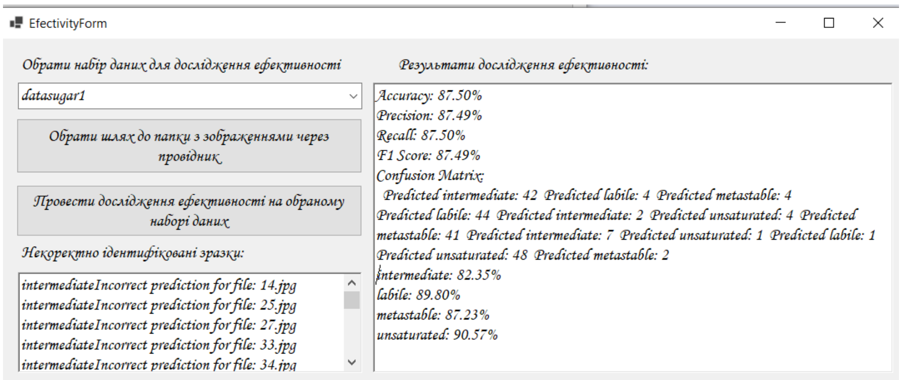

Fig. 4. An example of performing an efficiency study using an object-oriented intelligent system

Conclusions. Therefore, a method was created for the detection of sugar crystallization zones in the production process, designed for the optimization of sugar production processes and the automated detection of potential problems in the production process, which works by transforming input data in the form of a trained neural network model and images to detect crystallization zones into output data in the format of the conclusion regarding the belonging of the image to the crystallization zones and the explanation regarding the identified crystallization zone. The design architecture of the object-oriented intelligent system for detecting sugar crystallization zones on the image is presented, consisting of four subsystems and a database, and their main purpose and functions are described. The structure of an object-oriented intelligent system consisting of nine classes is designed and the functional purpose of the software components of the object-oriented intelligent system for detecting sugar crystallization zones from an image based on neural network multiclassification is described. Features of the implementation of the software components of the object-oriented intelligent system for the detection of sugar crystallization zones, which uses a neural network for multi-classification by image, have been determined.

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