Decision Support System for Color Control of Polymer Products Based on Fuzzy Models

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***Abstract*—The structure of the decision support system for controlling the color characteristics of polymer products based on fuzzy models is presented, the application of which will reduce the amount of scrap in production, reduce the size of production costs, as well as reduce the degree of environmental pollution. The observed system includes a module for evaluating color characteristics from fuzzy models, which makes the system hybrid, using both deterministic and fuzzy models in work, which allows you to more efficiently and qualitatively cope with the task of analyzing the color characteristics of polymer productions.**

Keywords—support for decision-making; polymers; polymer film; analysis; color characteristics; fuzzy models; quality trends; fuzzy logic; recycling; expert system; quality control

I. Introduction

The polymer industry is one of the most developed industries. More than 368 million tons of polymer products are produced in the world per year [1]. Together with the growth of production volumes, the volume of production waste is also growing. Thus, every day the task of processing secondary polymer materials becomes more and more urgent. Understanding of the importance and necessity of recycling materials has been achieved relatively recently, and the issue is now receiving a great deal of attention from industry, science and the public [2].

The main reasons why the direction of processing of recycled products is becoming more and more popular are the following prospects: reducing production costs, reducing environmental pollution both directly by production and final products, intensifying recycling and returning valuable raw materials to production [2, 3].

More and more companies and enterprises are resorting to the use of recyclables in production: in addition to pure material, recycled is also used. This situation creates a demand for new, more cost-effective and optimal solutions, both technical and software [2].

With the increase in the number of types of polymer materials returned to production, production volumes also grow, production is becoming increasingly typified - in various industries similar technological techniques and methods are used, corresponding equipment for carrying out technological processes [1, 3, 4].

The production of polymer products is a complicated and complex procedure that cannot be performed without specialized equipment and software that meets the requirements of time [6]. Modern productions of polymeric materials are characterized by a wide range of products, strict requirements to quality of semi-finished products, products, incompleteness of information on direct indicators of quality and their dependence on a set of process parameters, complexity of the proceeding physical processes, high cost of defects because of expensive, scarce raw materials, big power costs of production [8, 9, 10]. All this makes relevant the task of developing a decision support system for managing the color characteristics of polymer products based on fuzzy models, which would meet the requirements of time, provide users with all the necessary capabilities, and contribute to reducing the number of defective polymer products in production.

II. System location in big data analysis software package

The decision support system for color control of polymer products based on fuzzy models is one of the subsystems of a complex software package for big data mining and evaluation of key indicators of polymer film (SP) production efficiency [8, 9, 10], which in addition to it includes the following modules:

- calculation of extrudate quality indicators;
- estimation of the distribution of large production data;
- calculation of film thickness variability;
- estimation of the distribution of large production data;
- calculation of film shrinkage degree;
- prediction of film quality by adaptive boosting method;
- identification of emergency situations of their causes and formation of tips for elimination;
- estimation of extruder drive state based on spectral analysis of vibration signals;
- integration of large data of polymer films production and their import into the production parameter database;
- visualization of trends of control actions and output parameters of key stages;
- plotting a 3D graph of the dependence of thickness differences on control impacts;

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- output of film quality control tips;
- visualization of the film quality map for ordering;
- editing databases and knowledge base.

SP includes the following databases: film types, line equipment data, process regulations, controlled and calculated production parameters. As well as a library of coefficients of mathematical models, a knowledge base of emergency situations, their causes and recommendations for elimination.

Due to its flexibility and versatility, this SP is a good tool for solving both general production and more narrow tasks. Development belongs to the class of software packages used for big data analysis, quality monitoring and production process control [9].

As a rule, big data analysis systems have a significant drawback – it is likely that the program will receive an incorrect result when the input data is incomplete, which negatively affects the quality of the products. The SP being developed provides mechanisms to offset the negative impact of possible insufficiency of input data about the analyzed object. One such mechanism is the module for evaluation of color characteristics according to fuzzy models [11–14], whose work is based on analysis of not only quantitative, but also qualitative indicators.

III. Color Characteristics Evaluation Module Based on Fuzzy Models

In recent years, the technology for the production of colored polymers has developed greatly. The possibilities of measuring color have also significantly expanded. The use of computer calculations for fast and accurate reproduction of color has become a standard procedure [15], including the use of fuzzy logic methods [12–14].

The fuzzy model color evaluation module (CEM) works with input images of polymer materials in common graphics formats such as jpg and png. The functional structure of the module (Fig. 1) includes:

- Researcher interface – provides the user with the opportunity to load into the program the investigated image, choose the comparison method, as well as the value of the maximum deviation of the parameters of the studied sample from the reference indicators.
- Knowledge engineer interface – gives the user the same capabilities as the researcher interface, as well as the ability to view and edit the database of fuzzy product rules.
- Administrator interface – allows the user to edit the databases of materials and user accounts, and provides the ability to manage reports on the operation of the program.

After setting all the necessary parameters of CEM operation and loading the image of the tested sample, the module displays the work result, which includes: a reference sample image that allows the user to compare the reference and the analyzed sample loaded by the user with the localized areas on it with detected defects or deviations from regulatory indicators, trends that allow the user to compare the result with previous ones, as well as a message with control recommendations.

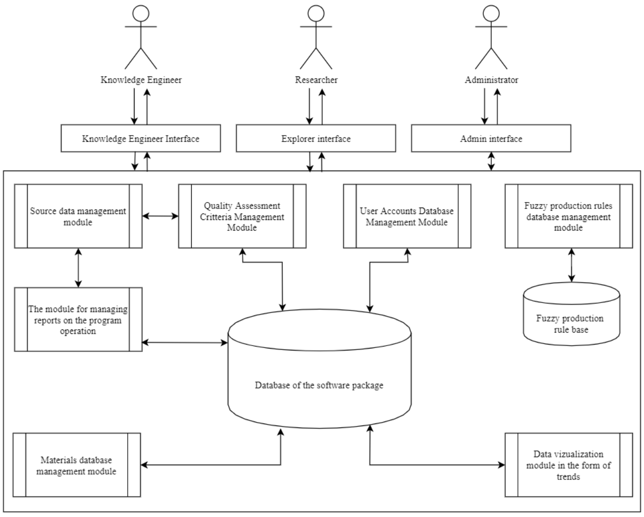

Fig. 1. Functional structure of the module for evaluation of color characteristics based on fuzzy models

CEM converts the RGB color space parameters into a CIELab color spatial model for color analysis of a user-loaded sample and for further comparison with a reference. In this module *L*, *a* and *b* – system coordinate symbols (L^* – lightness, and a^* and b^* – chromaticity coordinates). The direction of the red color is indicated by $+a$, green – by $-a$, yellow – by $+b$, blue by $-b$. L^* varies from 0 to 100, where 0 is dark black, 100 is bright white, and a^* and b^* – in the range from -128 to 127, at a^* and $b^* = 0$, they are considered to take true neutral gray values [15].

CIELab was developed in 1920 and is still relevant. Its difference from the RGB model is that it provides the ability to calculate a numerical measure ΔE, characterizing the Euclidean distance between two color coordinates, by which one can judge the degree of destruction of the material, by comparing the reference indicator set by the operator in accordance with the set technological tasks and the value obtained from the analysis [15].

CEM analyzes not the whole image entirely, breaks it into *n* equal squares, according to the established grid, and consistently analyzes them. Such approach allows distinguishing defects of various size, depending on the settings established by the user – than the size of cells of a grid is less, especially it is probable that the program will find even the most insignificant deviations [11–16]. This mechanism is one of many mechanisms of the developed system providing its flexibility. Thus the researcher, depending on the purposes and the applied production schedules, can adjust the program in a suitable way [11].

CEM is a hybrid system that combines both deterministic and fuzzy models to enable more comprehensive, comprehensive quality analysis. In this regard, the data obtained after the transformation of the color spatial model is transmitted to a fuzzy logic module, based on the calculation results of which the program concludes the state of the investigated material and reports this to the user.

The fuzzy logic module was developed based on the software package “Fuzzy Model Toolkit” [17], which is also the development of our scientific school. The work of the fuzzy logic module consists in the analysis of input variables obtained by comparing the characteristics of the reference sample and the image under investigation, as well as the base of fuzzy production rules, which can be called the core of the module, since it is based on expert knowledge and estimates in the field of polymer materials production.

Based on the operation of the fuzzy logic module, a message with control recommendations is generated. The result is then compared to the previous ones and quality trends are generated, and all this together with the image with localized defective areas is displayed to the user.

IV. Testing of the Color Characteristics Evaluation Module

To test the development, copies of reference and defective samples of polymer films provided by Klöckner Pentaplast Rus were used. Testing was successful; the program correctly recognized defects on samples with defects. The results of the program were in line with expectations.

V. Conclusion

The structure of a flexible customizable decision support system for controlling the color characteristics of polymer products based on fuzzy models was considered. This system is able to analyze the quality of polymer products even in conditions of drawback of input data on the object of study, which is achieved by using not only quantitative, but also qualitative parameters in the system – expert knowledge and assessments. The development will reduce the amount of defective products, increase production efficiency, and reduce the amount of production waste.

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