Diagnostics and assessment of imprint quality using pattern recognition methods and digital photography for image processing

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Abstract
Using the latest technologies in printing and decorating printing and packaging products requires manufacturers to find new and improve existing methods of assessing the quality of printed images. A methodology is proposed for evaluating the reproduction quality of graphic and tonal images on imprints created by offset, flexographic, thermal transfer, and digital printing methods on paper, film, and fabric substrates. The assessment methodology is based on the application of modern laser technologies, optical methods of data selection and their mathematical and statistical processing. The methodology combines the study of the surface structure of the printing substrate and qualitative indicators of imprint quality. The algorithmic structural adaptive classifier of the imprint diagnosis process and determination of the integral quality indicator of the printed image are described.

Keywords
diagnostics, quality, imprints, pattern recognition, optical methods, digital registration and image processing

1. Introduction

The modern printing industry uses various technologies for printing and finishing products using a wide range of image carriers - paper, cardboard, microcorrugated cardboard, synthetic films, fabrics, etc. Printing enterprises that operate effectively on world markets rely on fast and reliable technological equipment that ensures the production of high-quality products. Therefore, an urgent task is to improve the existing and create new diagnostic methods for assessing the quality of printing and packaging products. The existing modern methods for evaluating the quality of reproduction of images on various surfaces during the printing process

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are based on densitometric, colourimetric measurements, and the use of test scales to control the reproduction of graphic and tonal images by the requirements of international ISO standards [1]. However, the diverse structure of substrates for reproduction of printed images by modern printing methods requires in-depth research into the mechanism of fixing printing inks, varnishes, etc. on their surface. This encourages product manufacturers to search for and create new means of measurement and control, which are based on modern laser technologies, optical methods of data selection and their mathematical and statistical processing [2-13].

2. Related Works

The method for determining the comprehensive quality indicator of flexographic and offset imprints is proposed in work [14] according to the generalized criterion for optimizing single indicators based on Harrington's desirability function. It was established that the unit values of the desirability function of the optical density of the halftone background and the uniformity of printing on coated corrugated cardboard liners are in the range from 0.95 to 0.99; and the grey balance indicators regardless of the area of imprint filling (75%, 50%, 25%), sliding, contrast and raster dot squeezing approach 1. On imprints without coating, these indicators are much lower and vary in the range from 0.04 to 0.55. The effect of the structure of the printed substrate and its physical and mechanical properties on the quality of imprints was studied in the paper [15].

Studies given in works [16] showed that the topographical structure of the printed substrate, in particular its morphology, and the presence of valleys and protrusions on the surface, affects the quality of imprints and the adhesion of adhesives to the surface of substrates in the offset printing method. Electron microscopic studies conducted in [17] showed that the quality of the reproduced image depends to a large extent on the texture of the material, the composition and thickness of the ink layer and the interaction of the ink with the printed substrate. The study of the quality of imprints on film materials using optimization models is given in [18]. As is known, the final result of the printing process is obtaining a uniform image with specified spectral characteristics (colour, intensity), which should be stable under operating conditions [19,20].

3. Proposed methodology

The object of the study was imprints of offset, flexographic, thermal transfer and digital printing.

The methodology for assessing the quality of printed images on various surfaces provided for the use of a diagnostic device model, the principle of which is based on modern laser technology of digital photography and pattern recognition and optical methods of data selection, the scheme of which is shown in Figure 1.

In imprint diagnostics, when turning on the PS power supply unit, laser 1 and light source 3 are turned on (Figure 1). The beam of the laser ILB with the help of system 2 is directed to the area of the image VS of the imprint, which is placed on the table. At the same time, optical illumination IOR is directed to the same area by the optical system 4. After hitting the surface area VS, the reflected optical rays ROR are registered by digital camera 5, and the reflected laser beam RLB – by camera 6. The registered images are submitted for analysis to a PC, where spectrodensitometric indicators of the image are calculated according to a mathematical model, taking into account the texture of the printed substrate [21].

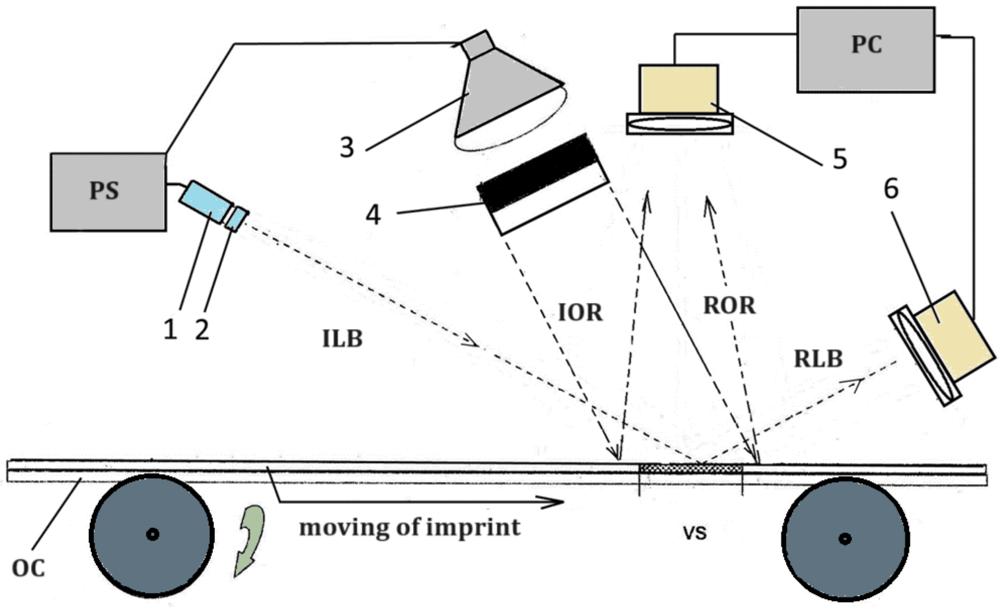

Figure 1: Scheme of the device for diagnosing printed images with angular optical and laser illumination: PS – power supply unit of the optical system; 1 – laser; 2 – an optical system of laser beam formation; 3 – light source; 4 – an optical system of forming an incident light beam; 5, 6 – digital camera Arca – Swiss Inc. (1512×1162 pixels); PC - personal computer; ILB – incident laser beam; RLB – reflected laser beam; VS – sounding area; IOR – incident optical rays; ROR – reflected optical rays; OC - output conveyor.

4. Analysis of methods for diagnosing the quality of printed images

High and reliable quality of imprints in all printing methods is provided by properly prepared original, high-quality printing plates, materials, and planned and organized production process in the presence of control and measurement systems that effectively control the printing process in dynamic mode and in real-time. To detect the heterogeneity of the structure of the printed material, the following can be applied: the theory of raster structures, stochastic spatial geometry, the theory of pattern recognition, and digital photography for image processing. The use of these methods, which have proven themselves well in providing constructive diagnostics and are known in theoretical and practical mathematics, as well as the use of computer programs for processing digital images, makes it possible to control and identify defective signs that caused a lack of products on various image carriers [22-24].

To assess the structural and dynamic distortions of imprints, an urgent task is to adapt the methods of digital registration and image processing to identify the characteristic features that provoked the lack of products on film, fabric and paper materials. These methods, respectively, make it possible to detect:

- structural defects of materials before the start of printing (spatial heterogeneity, stains, stretching and deformations);
- structural changes of the material during the printing process (paper, fabric, film, ribbon) and the behaviour of the system «ink-substrate material»;
- differentiate hardware failures from technological ones.
- Accordingly, the following tools can be used to detect the spatial structure of low-quality areas in the places of printed images in the diagnostic mode:
- computational geometry, stochastic spatial geometry;
- pattern recognition theory and fuzzy classification;
- methods of digital graphics and photography for processing lack areas of images.

So, the methods of modern digital photography and laser technologies make it possible to build diagnostic systems for printed products made by any printing method. The use of methods of computer graphics and digital processing and recognition of electronic images provide a constructive diagnosis and are the basis for the selection and classification of factors of influence of hardware, software representation of images, and parameters of input materials on the quality of products.

The process of diagnosing the quality of imprints based on image distortion during printing can reveal features that are informative for decision-making when evaluating imprint quality.

Let's highlight the main features of distortions:

- S1 – poor-quality spatial structure and its defects;
- S2, S6 – heterogeneity of the colour gamut of the ink composition, etc.;
- S3, S5 – deformations of the printing substrate due to a violation of the paper-conducting and output system of the printing equipment, lack of colour matching during multi-colour printing, etc.;
- S7 – contamination of printing, ink rollers and printing base;
- S8 – violation of image integrity, and the presence of printing defects on imprints.

Algorithms for the diagnostics of the printing system can be represented accordingly based on the test structure in the form of a quality algorithm. Based on the adaptive classifier of imprint quality, decisions are made regarding optimizing the printing process. The algorithmic structural scheme of the adaptive classifier of the diagnostic process includes the following units:

1. Database of test images.
2. Generator of image cycles.
3. Structural electronic image.
4. Program for managing the printing process.
5. Executive mechanisms (thermal transfer head and ribbon feed system).

6,7. Material and energy resources.

8,9. A digital system for highlighting text or illustration defects on the image from block 8 – finished products.

10. Formation of distortion features.
11. Representation model of the functionality of imprint quality.

12. Adaptive classifier of imprint quality with printing mode optimizer.

The first position of the adaptive quality classifier is the test database, which contains a set of standard samples of printed images. In the second position (generator of electronic image cycles), test images are formed based on a digital image. According to positions 1, and 2 (base of test images and generator of image cycles), an electronic test image is formed, which is transferred to block 4 (program for controlling the printing process) for evaluation of the electronic image of the imprint. At the 6th and 7th levels, according to executive mechanism 5, an electronic sample of the image agreed with the customer is formed, the quality of which to a certain extent depends on the quality of the original, the quality of consumables, their physical and mechanical properties, as well as the stability of energy processes. On the 9th level, based on the knowledge base of stochastic geometry, in the test element selection block, image processing is carried out to select technological features, based on which the quality function is formed (10 unit). According to the quality function (unit 11), which meets the customer's requirements, the specified parameters are compared with the original. If the conditions are not fulfilled in unit 12, the printing modes are adapted according to the original order.

Technical diagnostics uses methods and means of detecting defects of research objects, forecasting the state at a certain moment, and detecting discrepancies between the standard and the imprint.

The main tasks of diagnostics of the printing process are:

- checking the serviceability and readiness for operation of the printing press according to the program (algorithm);
- search for the causes of a defect that violates printing modes and includes the following components: software, algorithmic, technological;
- search for defects in input materials for printing and construction of models of dynamic structural changes, their properties during the printing process (deformations, displacement, heterogeneity, change in physical and chemical properties of materials), and quality control of the printed image.

Technological diagnostics of prints is based on the detection of failure elements, which use physico-chemical, thermodynamic, deformation and other phenomena in the printing process, models of printing processes.

The methods of applying diagnostics are based on:

- models and algorithms of element-by-element checks of technological operations;
- methods of analyzing failure symptoms based on the values of the features, using methods of printed image recognition and analysis of diagnostic indicators;
- automatic control models of the functioning of controllers, processors, and systems, which are characterized by methods of detecting defects and errors caused by hardware failure, operator errors, virus attacks and other influencing factors.

The block diagram of imprint quality diagnostics has a hierarchical structure and includes the following levels:

1. The knowledge base of printing technologies, which includes technology models, tests, reference standards, description of functionality and quality criteria.
2. Block of software testing and control of hardware (algorithms and programs, graphs and plans of technological modes).
3. Block of software testing and hardware control of printing devices (control of executive mechanisms, permissible standards and limit modes of printing speed).
4. Block of diagnostics of input materials for technological properties using the effects of information-energy interaction (optical, physicochemical).
5. Printing process control system.
6. Classifier of the quality of text, colour, graphic and tonal elements, based on the procedures for recognizing and classifying dynamic images and checking a set of features per reference imprints:

$$\forall_i \in T_{ö} \left(\left\{H_{1i}: I_T^{i>} < I_{lT}\right\} \wedge \left\{H_{2j}: I_g^{i>} < I_{lg}\right\} \wedge \left\{H_{3k}^{i}: I_M^{i>} < I_{Ml}\right\}\right) \rightarrow \tag{1}$$

$$\longrightarrow \left(KL_n \begin{matrix} \rightarrow f \rightarrow \begin{pmatrix} Procedure\ for\ correction\ and\ adaptation \\ of\ the\ printing\ control\ mode \end{pmatrix}; \\ \rightarrow t \rightarrow (The\ quality\ corresponds\ to\ the\ norm) \end{matrix} \right)$$

7. Block of integral product quality assessment.
8. Block for recognition of dynamic distortions and defects using a set of reference samples of imprints.
9. Block of formation of control, adaptation (in the case when the complex functionality of quality does not meet the standard) (Figure 2).

The structure of the block diagram of the formation of imprint quality components depends on the main technological factors of the printing process, for example, Ut, Ukr – correct adjustment of the printing system; Ikm – diagnostics of the operation of the ink, conveying and output system, software, hardware and control support of the printing press; Ikd – quality and conformity of materials used for printing products. If the main parameters of the test images (H1i, H2j, H3k) meet the specified quality standard, it is possible to start printing.

Based on the selection of diagnostic criteria that take into account the peculiarities of the printing process, we build an integral quality criterion:

$$I_{\text{Int}} \equiv \langle I_{kpt}, I_{kta}, I_{kam}, I_u, I_p | I_{Icon} \rangle; \tag{2}$$

where we have the corresponding typesetting components:

I_{pt} – process hardware quality;

I_{kta} – software and hardware quality

$$I_{kta} = \sum I_{kpi} \cup \sum I_{kta}; \tag{3}$$

I_{kam} – the quality of input materials included in the technological process

$$I_{kam} = onpt \left[\bigotimes_i I_{kami} \right]; \tag{4}$$

I_u – the quality of the printing management system

$$I_u = \langle I_t, I_g, I_k \rangle; \tag{5}$$

with an assessment of colour reproduction and graphics of the thermal transfer image;

I_{Icon} – criterion of image distortions when choosing a printing method based on machine and human (visual) control.

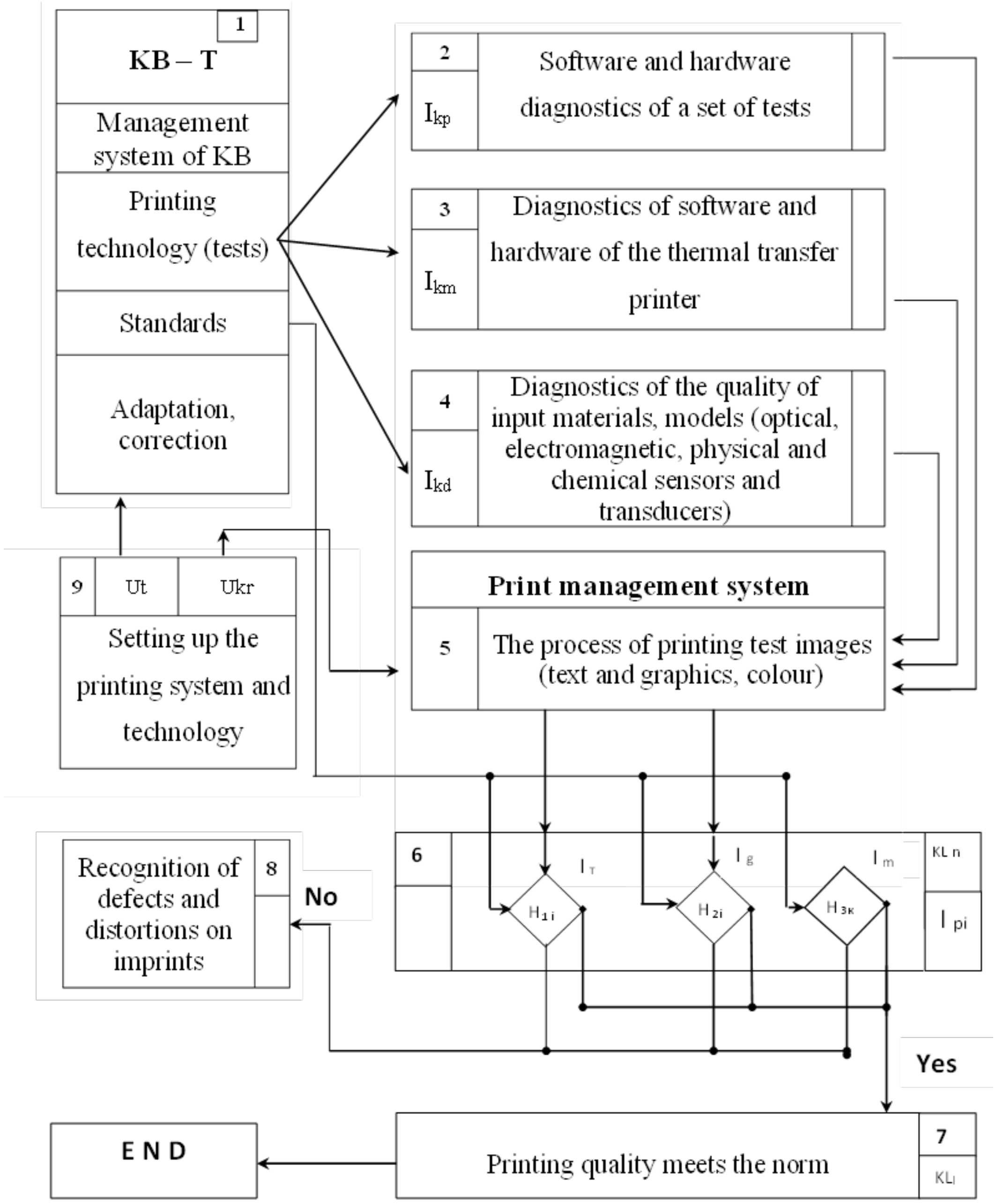

Figure 2: Block diagram of information diagnostics of imprint quality.

At the same time, the optimization procedural conditions must be fulfilled:

$$\lim_{P \to P_{max}} (I_{int}|T_m) \to \max_{T_m} I_D(P_{max}); \quad (6)$$

$$I_{con}(TD_i) \triangleq Str(T_i|Nej); \quad (7)$$

and with the additive structure of the criteria

$$\lim_{P \to P_{max}} [I_{icon}(T_m|p(t;\tau)] \to \min_{P_{max}} [1 - I_{int}(T_m)]; \quad (8)$$

it is necessary to minimize the number of defects with maximum printing productivity.

The diagnostic procedure based on the selected quality criteria should include a classifier of printing distortions and combine it with a method of image perception of printing distortions by a person and a machine recognition system, which performs the functions of an intelligent classifier of the image (current and reference) of the printed element.

The conceptual model of quality control includes the following approaches and methods:

- laser control of the structure and properties of the material;
- laser illumination for assessing distortions of micro elements of printed texts and graphics;
- digital photography for evaluating the microstructure of fabric materials and samples with laser illumination, fluorescent light, and white (matte) light;
- microscopy of samples (fine structure);
- digital image processing and scaling and defect detection technologies;
- analysis of the dynamics of transitions in digital automata under conditions of disturbances (synchronization and power failures);
- analysis of the impact on the quality of information and energy sustainability of the automated technological process management system;
- analysis of the influence of the vagueness of management and testing strategies of the hardware and software complex on the quality of imprints;
- analysis of the nature of distortions of printed elements by methods of stochastic geometry and methods of image recognizing of elements on imprints (Figure 3).

The synthesis of the intelligent classifier system can be carried out for the following modes of product control:

- continuous control and detection of defective prints based on the concept and methods of pattern recognition and decision-making theory;
- selective control by the methods of digital photography and its combination with the operator's visual assessment;
- complex recognition and diagnosis of defects by combined methods based on printing test images of elements. This approach provides the most effective way of diagnosing and classifying imprint defects.

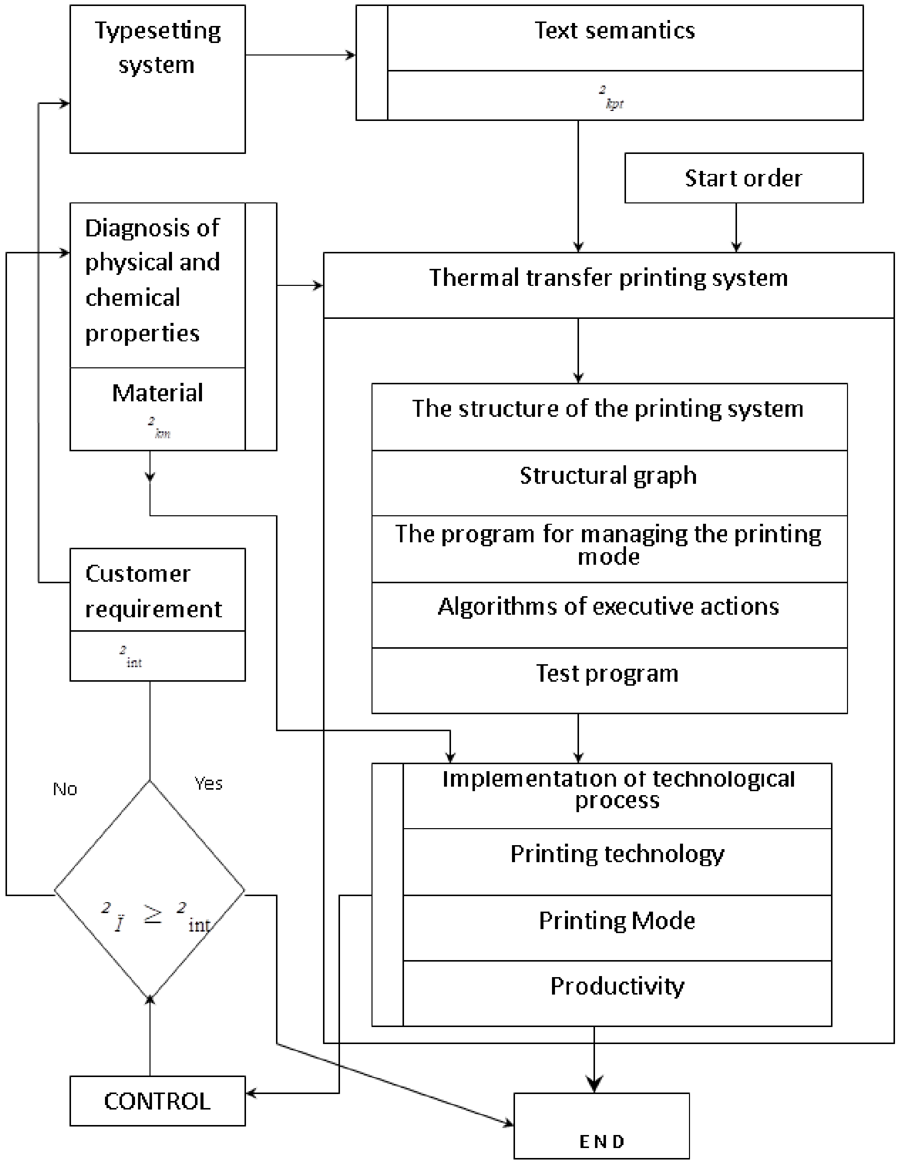

Figure 3. Scheme of information components of imprint quality diagnostics

5. Results

According to the diagnostic scheme, groups and classes of factors influencing the process and printing quality can be distinguished:

- instability of the mains voltage, which affects all elements of the printing process control system;
- change of printing modes, which leads to changes in printing parameters;
- software failures (informational and technological defects);
- failures in the control system of the synchronization process and the printed substrate supply drive; ink (varnish) etc;

- defects in the structure and physical and mechanical properties of materials;
- shortcomings of technology and wear and tear of the mechanisms of the printing press during operation.

6. Conclusions

The problem of diagnosis is complex and systemic and requires modern research methods based on laser and digital technologies and appropriate mathematical support and software for material selection and recognition of defects in printed images on imprints for its solution. Approbation of the proposed method for evaluating the quality of images confirmed the influence of the structure of the printed substrate on the value of optical densities, contrast, print stability, and colour characteristics, which contributed to the reduction of the number of defects when printing products.

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