MODEL OF A COMPUTER SUPPORT FOR THE DESIGN OF AOI SYSTEMS AIMED AT THE DETECTION OF SURFACE DEFECTS

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Summary

The article presents an original model supporting the design of AOI systems aimed at the detection of surface defects. The analysis of the state of the art shows that the problem of the design of automated systems employing noninvasive measurement methods, including AOI methods, dedicated to specialist tasks connected with surface quality control, is actually a prospective future research direction, as it is directly connected with the need to speed up and rationalise the design processes. The research problem presented in the article was defined through the determination of the scope of automated tasks aimed at the support of the design of AOI systems and methods for their execution. The research method consisted in the analysis of the available numerical methods and computer simulations enabling the selection of the solution facilitating the effectiveness of the decision-making process.

Keywords: expert system, automatic optical inspection, quality control, designing

MODEL KOMPUTEROWEGO WSPOMAGANIA PROJEKTOWANIA SYSTEMÓW AOI DETEKCJI WAD POWIERZCHNIOWYCH

Streszczenie

Artykuł przedstawia autorski model wspomagania projektowania systemów AOI przeznaczonych do detekcji wad powierzchniowych. Analiza stanu wiedzy wskazuje, że problematyka projektowania zautomatyzowanych systemów wykorzystujących nieinwazyjne metody pomiarowe, w tym metody AOI, dedykowanych do specjalizowanych zadań związanych z kontrolą jakości powierzchni jest perspektywicznym kierunkiem w rozwoju badań naukowych, co spowodowane jest koniecznością przyśpieszenia i jakościowego usprawnienia procesów projektowania. Problem badawczy podejmowany w artykule określony został poprzez ustalenie zakresu zautomatyzowanych działań, których celem jest wspomaganie prac projektowych nad systemami AOI oraz metod przeznaczonych do ich realizacji. Metoda badawcza polegała na przeprowadzeniu analizy dostępnych metod numerycznych, oraz symulacji komputerowych w celu wyłonienia rozwiązania, umożliwiającego skuteczne wspomaganie procesów decyzyjnych.

Słowa kluczowe: system ekspertowy, automatyczna optyczna inspekcja, kontrola jakości, projektowanie

1. INTRODUCTION

The automation of manufacturing processes [1] is a contemporary element of progress. The demand for such systems is constantly growing, which is mainly caused by the decrease in the costs of production and the concurrent increase in the quality of the manufactured goods. Another reason behind the growing interest in the topic of the automation of manufacturing processes is the technological progress connected with the growing complexity of final products and processes for their inspection and control. The organoleptic quality inspection has numerous disadvantages that stem from the limitations of the human senses and manual dexterity [2]. The repeatability also plays a crucial role here. Any human feels the effects of long work, which has a negative influence on the outcomes of the undertaken tasks. The automation of the production process ensures higher quality and greater repeatability, and therefore results in increased efficiency and effectiveness of a process. With reference to the technical equipment, the automation has an impact on the reliability and the availability of machines participating in the manufacturing processes. It also reduces the costs of servicing and maintenance.

The design of quality inspection systems is a complex issue [3]. The designers of such solutions have to have broad knowledge on mechanics, automation, electronics, information technologies, optics, etc. The design of an effective system that can be incorporated into a technological line requires a lot of experience and makes the entire process costly and time-consuming. What is required in the case of AOI systems [4] is the ability to solve interdisciplinary R&D tasks in the area of acquisition methods, digital image processing and

analysis, metrology, applied informatics, or knowledge and software engineering.

The analysis of the state-of-the-art suggests that the issue of the design of automated systems in which non-invasive measurement methods are used, including AOI methods, and which are dedicated for specialised tasks in the area of the inspection of quality of surfaces, constitutes a potential long-term research direction [5,6,7,8,9], which is particularly due to the following:

- The potentially vast possibilities for the design processes to be speeded up and their quality to be improved by means of the application of knowledge and competencies of the design teams, specialised databases and a holistic direction of the entire design process;
- The possibility for design works to be supported with the procedures for the selection of measurement methods determining the efficiency of the system, and the simulation of system operation for different application options, which enables the quick adjustment to the specific technical and functional requirements defined by the final user;
- The possibility to decide on the configuration of the system, particularly the multifunctional system that can be used in changeable manufacturing conditions, and select AOI methods that are most effective when it comes to the detection of surface defects and the image analysis.

The above listed reasons generate the necessity to develop the models and applications intended for the solution of such tasks. One of the ideas has the form of the developed original model aimed at supporting the design of the automatic quality inspection systems based on optical inspection and enabling the detection of surface defects.

2. MODEL FOR THE SUPPORT OF THE DESIGN OF AOI SYSTEMS

The proposed solution consists in the replacement of the classic and time-consuming design stage [10,11] composed of numerous analyses, the determination of optimisation criteria and the design and synthesizing of a model constituting the solution to the posed research questions, with an expert system linked to the knowledgebase (Fig. 1).

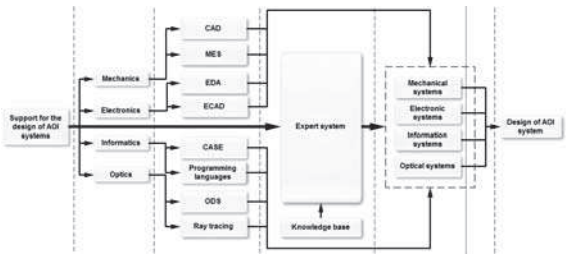

Figure 1. An expert system-based and knowledgebase-coupled model and a traditional model for the design of AOI systems for surface defect detection

The systemised knowledge of the experts [22] accumulated in the knowledgebase facilitates a more efficient creation of systems adjusted to new products or surface defects. The fact that some of the tasks previously executed personally by the designer are now performed by the IT expert system proposed in the model created, enables the costs of the design process to be cut, and the time needed for the development of a solution, satisfactory in terms of its design, reduced. IT models enabling parts of a classic design process to be replaced can differ. They can use simulation systems [13] and complex algorithms based on AI [14], including artificial neural networks, genetic algorithms, cellular automata, fuzzy logic, etc, which aim at the recreation of the phenomenon and the preservation of the real object with the use of numerical models.

In the proposed model, the classic design process was replaced with automatic inference with the configuration of the AOI system (hardware unit of the AOI system), and the structure of a detection algorithm (software unit of the AOI system) (Fig. 2).

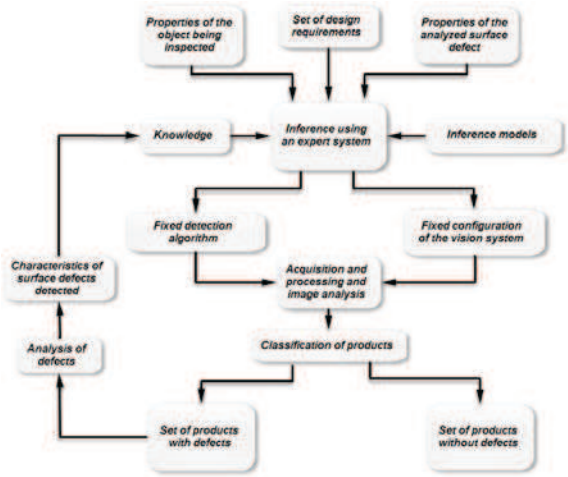

Figure 2. Functional model for the support of the design of AOI systems based on expert system-based inference

A characteristic feature of the developed expert model is, apart from the possibility of its adaptation to different types of surface defects and test objects, the feedback between the set of faulty products and the knowledgebase, which helps to supplement the existing knowledge on the types of surface defects, and therefore increases the effectiveness of the model. The structural model of the developed solution is presented in Fig. 3.

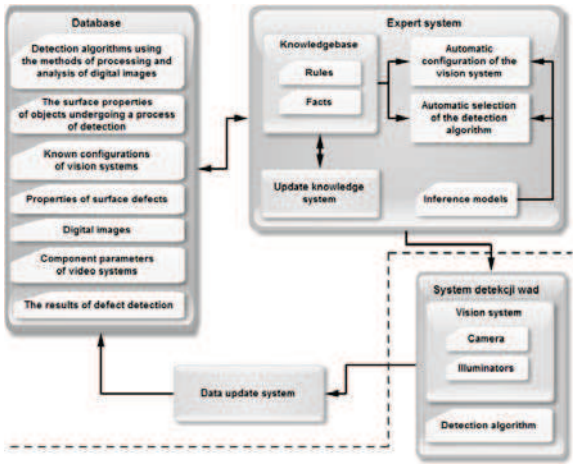

Figure 3. Structural model of the system for the support of the design of AOI systems intended for the detection of surface defects

The main element of the structural model is the expert system composed of two inference modules including the module of the automatic configuration of the vision system, and the automatic model for the selection of the detection algorithm. Other elements of the expert system are a knowledgebase built of facts and rules, a system of knowledge update, and inference models. The other two elements of the model include a database supplying the expert system, and a data update system. The model cooperates with the system for the detection of defects, whose such elements as the vision system or the detection algorithm are selected with the use of the expert system.

3. METHODOLOGY FOR THE CONFIGURATION OF VISION SYSTEM

The model of a vision system intended for the detection of surface defects in machine parts is composed of a camera with an optical system, whose role is to observe the surface of the inspected object onto which a beam of light is projected. The model of the vision system in three different configurations is presented in Fig. 4.

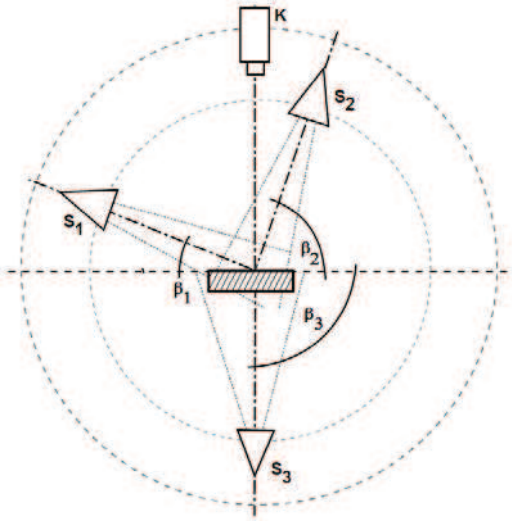

Figure 4. Model of the vision system intended for the detection of surface defects in three configurations of the light source S_1, S_2, S_3 , where K – camera with an optical system; $\beta_1, \beta_2, \beta_3$ - angles at which light is projected

The two essential configurations of the vision system consist in the adjustment of the angle at which light is projected onto the surface of the inspected object, and the adjustment of the light range in a way enabling the defect to stand out with reference to the remaining area of the surface of the object.

The configuration of the vision system is a multistage process that requires knowledge on numerous issues. The proposed methodology for the configuration of the vision system assumes the following stages: the determination of the lighting range, the setting of the angle at which the light is projected, the setting of camera parameters, the selection of the camera model, the determination of the values of the parameters of the lens, the selection of the lens model. The setting of the lighting range and the angle of light projection is executed with the use of fuzzy inference based on a Mamdani model. The determination of all the other output values is based on a classic two-valued logic in which a regression algorithm is used. In the process executed by the regression algorithm, individual hypotheses that are the goal of the inference, are either confirmed or abolished, based on the authenticity of the facts and rules. Such type of inference cannot be executed without thy hypothesis being determined and defined as goal driven. At each of the stages of the configuration of the vision system, the inference module is fed with knowledge necessary for the determination of the value of the required input parameters. In the case when the satisfactory configuration of the vision system that complies with all the design requirements cannot be set based on the knowledge accumulated in the knowledgebase, the combination of several configuration options into one functional structure is

allowed. In such case, the vision system can be composed of numerous illuminators or cameras. The defect detection process is then performed through the sequential analysis of images from individual configurations included in a complex structure of the vision system (Fig. 5).

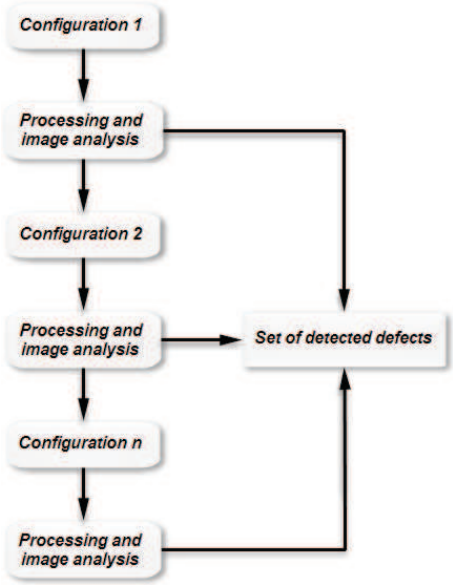

Figure 5. Defect detection process in a complex structure of the vision system

The next stage in the development of the AOI system consists in the determination of the structure of the detection algorithm intended for the processing and analysis of digital images.

4. METHODOLOGY FOR THE SELECTION OF THE STRUCTURE OF THE DETECTION ALGORITHM

Detection algorithms are built of numerous methods connected with image analysis and processing, therefore their selection has to be a complex process. The classification parameters in detection algorithms depend on the type of the inspected object and the types of defects that occur within the analysed surface. The main part of the algorithm is a set of methods for image processing and analysis (Fig. 6).

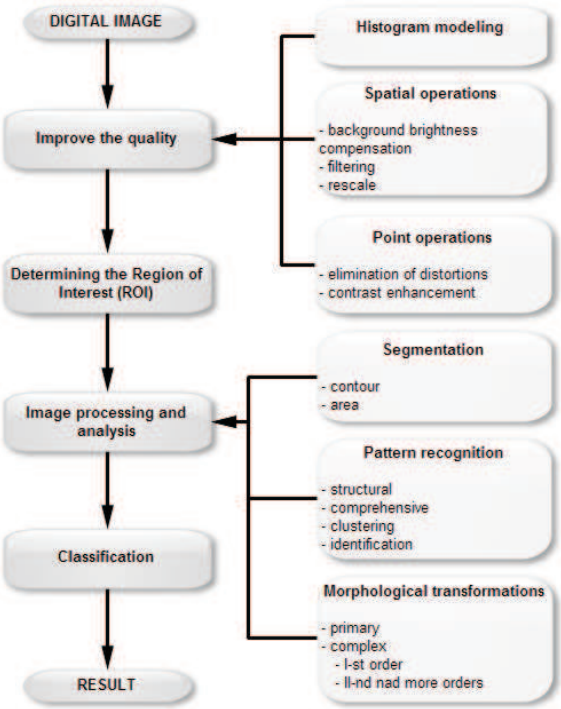

Figure 6. Structure of detection algorithms used in AOI systems for the detection of surface defects

The methods most commonly used in the structures of detection algorithms include the following: segmentation, morphological transformations, and image recognition. During the process of segmentation, the pixels are assigned to classes according to specific criteria such as location, or statistical distribution of brightness, or colour. Morphological methods enable the processing of the shapes of objects by image analysis using the so-called structurising elements [15], which are sections of the image with a highlighted focal point. Image recognition is an automatic identification of classes of objects and phenomena recorded in images [16]. The pattern recognition and pattern matching are related to image recognition. The inference concerning the structures of detection algorithms is performed based on the two-valued logic with the use of the progression model, where based on the facts and rules accumulated in the knowledgebase, new facts are generated up to the moment when a fact consistent with a proposed hypothesis, being an inference goal, can be found among the generated facts. A big advantage of such type of inference is the set of new facts, which can constitute valuable knowledge for the designers of detection algorithms. The methods included in the structure of detection algorithms are sequential, conditional or iterative, depending on the complexity of the defect detection problem. The developed methodology for the selection of the structure of the detection algorithm for use in the detection of surface defects involves the following stages: the determination of the area of image analysis, the verification of the need for the execution of the process for the improvement the

quality of images, the determination of the method for the improvement of image quality, the verification of the need for the image segmentation process, the determination of the method for image segmentation, and the determination of the image recognition method.

5. SUMMARY

The developed model for the support of the design of AOI systems significantly enhances the processes of vision system and detection algorithm creation, as it applies systematised knowledge and computing intelligence enabling the automatic inference. The adaptation of AOI systems to new types of products and surface defects occurring in technological lines is much easier, quicker and cheaper when the developed solution is applied. Through the application of the feedback loop between the set of faulty goods and the knowledgebase, a problem of information supply has been solved, which results in the increased effectiveness of the inference process. The formalisation of the structure of data representing selected thematic areas enables a quick exchange of information between the designers using the developed solution, whereas the separation of the expert knowledge from detection algorithms influences the reduction of numerical calculations. The opportunity to explore more efficient structures of detection algorithms for the analysis of digital images is an innovative approach that has not yet been taken into account in the literature. Knowledge presented in form of rules and facts has a lot of advantages, e.g. inference explanation facility. The mechanism of explanation presents how individual conclusions are drawn. Retrospective, hypothetical explanations and explanations against the facts are possible. The first enable the investigate the entire inference process from the stage of conclusion and comments to the rules, the second allows to check how the conclusion would change in the case when different values were assigned to the facts, whereas the third enable the explanation why it was impossible for a given conclusion to be drawn. The future extension and optimisation of the methodology is possible. It seems crucial to include the impact of external factors on the structure of the vision system. In such a case, the influence of the external factors could be included through the analysis of the probability of their occurrence with the use of Bayes networks or physical analysis employing numerous simulation methods based on the method of finite elements. Noteworthy are also data mining methods enabling the determination of associations (the creation of knowledge based on data) concerning the existing AOI systems, e.g. AIS, SETM, APriori, Elat, Levelwise, FreeSpan, etc. The methods of this kind are usually equipped with specific measures describing, inter alia, confidence, which would also constitute a crucial element supporting the designers of AOI systems.

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