ANNOTATION

of the doctoral dissertation for the degree of Doctor of Philosophy (PhD) in the educational program 8D06101 – "Information systems (by industry)"
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DEVELOPMENT OF MODELS AND ALGORITHMS FOR RECOGNITION OF SURFACE DEFECTS IN WELDED JOINTS

The relevance of research. The quality of welded joints must meet certain requirements, determining the serviceability of welded metal pipes. When manufacturing flexible corrugated stainless steel pipes on the production line, a mandatory stage is the visual inspection of the quality of welded joints, carried out by production personnel and allowing for the identification of surface defects arising from the welding. Human factor influences the result of visual inspection.

It is expedient to automate the process of visual inspection of the quality of welded joints in production to increase the reliability of its result and, consequently, to reduce production defects.

Modern technical means and technologies make it possible to automate visual inspection of the quality of welded joints through machine vision: acquiring, processing, and analyzing digital images.

The necessity of research is connected with the need to create methods, algorithms, and models for automatic detection and recognition in images of surface defects of welded joints made by tungsten inert gas welding (TIG). It is necessary to consider the rapidity of image processing, as it is required to analyze frames of video sequences received from a digital camera during welded pipe manufacturing.

The development of image processing and analysis systems requires the study of images and their features; analysis of the applicability of existing methods to solve the problem; development of new methods, algorithms, and models that take into account the specifics of the subject area; software implementation of the proposed algorithms; evaluation of the performance of the presented solutions.

Although research in the field of pattern recognition began in the '90s, many problems have not been fully solved, in addition, there are new production technologies and new products, and when recognizing its surface defects, it is necessary to consider their characteristic.

Scientists such as L. Shapiro, J. Stockman, R. Gonzalez, R. Woods, V.A. Soifer, D. Forsyth, J. Pons, B. Yane, E.R. Davis, R. Klette, M. Nixon, and others have contributed to the pattern recognition theory. The author highlights the research of A.A. Lukyanitsa and A.G. Shishkin in the digital video image processing field.

In Kazakhstan, research groups of institutes and universities are also engaged in solving various pattern recognition problems: Nazarbayev University, Institute of Information and Computational Technologies, al-Farabi Kazakh National University, Satbayev University, and others. Scientific papers of such

scientists as M.N. Kalimoldaev, E.N. Amirgaliev, B.S. Akhmetov, R.R. Musabaev, scientists of the Institute of Smart Systems and Artificial Intelligence of Nazarbayev University, and others have been published in foreign and Kazakhstan journals.

Authors of scientific papers related to recognizing defects in welded joints investigate defects arising from using different materials and metal welding techniques. Research is needed in the field under consideration when TIG welding is used. The research requires images and video sequences with normal welded joints and various defects occurring during metal welding. No comprehensive collection of datasets is available, so the acquisition of such images, and video sequences is required. In addition, some authors do not focus on solving the problem of defect detection but solve the problem of classification, that is, determining the type of defect in the images. Therefore, a solution is required to detect and recognize TIG welding defects on the surface of the pipe while it is moving on the production line. It is necessary to adapt existing and develop new methods and algorithms that will ensure rapid detection and recognition of defects in welded joints in the production process.

The research object is the automatic surface defects of welded joints of flexible stainless steel pipes recognition.

The research subject is methods, models, and algorithms of image processing and analysis that can be used for surface defects in welded joints detection and classification.

The research purpose is to develop methods, image processing algorithms, and building classification models that allow the defects in welded joints of flexible stainless steel pipes recognition.

The objectives of this research include:

− research of existing approaches, methods of detection, and recognition of defects in welded joints;

− development and software implementation of methods, algorithms of detection and localization of defects of welded joints on images for rapid inspection of metal welding quality in the manufacture of flexible stainless steel pipes;

− search and realization of a solution to the welding defect classification problem;

− experimental research, testing, and quality evaluation of the proposed algorithms and models.

Research methods. The methods of image processing, pattern recognition, and mathematical and statistical analysis were used for research. The algorithms were implemented based on visual and object-oriented programming technologies.

The research's scientific novelty is determined by the proposed set of methods, algorithms, and models for the surface defects of tungsten inert gas welding detection and recognition during the manufacture of flexible stainless steel pipes on the production line.

The main scientific provisions submitted for defense:

- method and algorithm for detecting surface defects of welded joints in images based on the homogeneity criterion;
- algorithm for automatic detection of surface defects in welded joints based on modeling and background subtraction;
- the model of defect classification in welded joints.

The practical significance lies in the possibility of using the proposed algorithm and models in automated visual inspection systems of the welded joints' quality in producing flexible corrugated stainless steel pipes.

Approbation of the research. Research results were discussed at the following conferences: VI Annual International Scientific and Practical Conference "Informatics and Applied Mathematics", Almaty, Kazakhstan, September 29 – October 02, 2021; Modern challenges of inverse problems. Novosibirsk, Russia, December 19-23, 2022; Computational and Information Technologies in Science, Engineering and Education (CITech-2023), Ust-Kamenogorsk, Kazakhstan, October 2-3, 2023.

Experimental researches were carried out in the production department on manufacturing flexible pipes from stainless steel of "Dobren Group" LLP, Ust-Kamenogorsk. There is a certificate.

The author's certificate No. 45182 dated April 26, 2024 "Program for recognition of surface defects of welded joints" was obtained for the developed program system.

Publications. 7 works are published on materials of the dissertation: 4 papers in scientific journals recommended by the Science and Higher Education Quality Assurance Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan; 2 publications in conference proceedings; 1 scientific paper in a journal included in the Scopus database (percentile 66).

The structure and scope of the dissertation. The dissertation consists of an introduction, three chapters, a conclusion, a list of used sources, and appendices. The total volume of the dissertation includes 109 pages.

The introduction substantiates the relevance of the dissertation, defines the object, subject, purpose, objectives, research methods, and scientific novelty, presents the scientific provisions put forward for defense, shows the practical significance of the work, and provides information on the approbation of the research and publications.

The first chapter describes the production process of stainless steel coiled pipes, emphasizing the visual inspection stage of welded joints. A functional model for the production and quality inspection of flexible corrugated stainless steel pipes is presented. A description of the main classes of TIG welding surface defects is given. A review of the main research directions for the automatic detection and classification of surface defects in welded joints has been conducted according to the typical information technology of image processing for pattern recognition. Methods for detection and classification that consider the specificity of defects occurring in TIG welding are highlighted based on the analysis performed.

The dissertation's second chapter presents algorithms for automatically detecting surface defects in welded joints developed based on reasonably selected methods. A description of the method and the derivation of a homogeneity criterion model for weld defect detection in an image based on the Ridge function and integral projections is presented. A solution algorithm is also proposed and described. Algorithms based on brightness histogram comparison, modeling, and background subtraction are considered in this work. Traditional machine learning methods are applied, which require the creation of a dataset consisting of a set of feature vectors to solve the problem of classifying defects in welded joints. The texture features that make up the dataset are described. The parameters of training algorithms for building classifiers are determined, and the quality of the obtained models is evaluated.

The third chapter describes the program system, and its structural diagram consisting of functional subsystems. The program system allows to detect and classify defects of welded joints on frames of video sequences and is developed based on algorithms and models proposed in the dissertation. Experimental results of the algorithms are presented, the steps of which are described in detail in the second chapter.

The conclusion of the dissertation shows the main results and concludes the dissertation research, thus confirming the scientific novelty and practical significance of the research.

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