Automated control of products by methods of short-wave electromagnetic radiation

M V Ovechkin
Federal State Budgetary Educational Institution of Higher Education «Orenburg State University, 13 st. Pobedy, Orenburg, 460018, Russia

E-mail: maxov-1@mail.ru

Abstract. The paper considers the problem of effective automation of non-destructive testing of welded joints. The boundaries of the study include short-wave methods of electromagnetic control of products on the example of radiography. The author describes the developed methodology for the automated control of products by the methods of short-wave electromagnetic radiation, which includes: automated control algorithms and software based on them; description of the generated sequence of automated control; software application practices, including end-to-end examples of automated control. An artificial neural network is used as a data processing method.

1. Introduction
Due to the increasing requirements for the quality and reliability of manufactured products, as well as the continuously increasing cost of products, physical methods of automated control of products that do not require the destruction of finished products or cutting samples are very important.

Automation of measurements and control is understood by the author as a set of methodological, software and technical means that ensure the process of control and measurement without the direct participation of a human.

It should be noted that the automation of control and measurement does not diminish the role of the controller, engineer or operator using the results of the control. On the contrary, it increases the productivity of their labor, requires them to have a higher level of knowledge not only of measuring and control tools, but also of the tasks that are solved when receiving and processing information, the ability to create an effective control program and give a professional interpretation of the measurement and control results.

Automated process control systems based on the control results of technical objects are currently quite common in various industries. In particular, they include non-destructive testing and diagnostics of parts and structures and optical inspection and diagnostics of welded joints. According to the research of the Russian scientist N.P. Aleshin, the leaders in efficiency (based on a point estimate) are the following methods: acoustic, optical, eddy current, and radiation. However, taking into account current data on cluster analysis [1] of equipment and the market for flaw detection services, we can conclude that electromagnetic methods of controlling critical products in production are the leaders [2].

In addition to electromagnetic and radiation methods, short-wave electromagnetic methods of control should also include (when using ultraviolet radiation) capillary methods, since these methods
of control have general directions both of the control mechanism itself and of the methods for analyzing its results. The main control approach in this case is the digital processing of the received images. At the same time, research and image processing, of course, are quite extensive and widespread. Among foreign authors, such works as: "Digital Image Processing" of Pratt W., "Digital Image Processing" of Woods R., Gonzalez R., "Handbook of pattern recognition and computer vision" of Chen C.H., "Digital image processing in MATLAB" of Gonzalez R., "Digital image processing and computer vision" of Shalkoff R.J. and others should be noted. At the same time, these studies and researches rather weakly touch on the topic of working directly with x-rays and the results of short-wave electromagnetic radiation and do not take into account their specificity, limiting themselves to an analysis of computer vision techniques and selecting objects for monochrome images.

2. Material and research methods
As research methods, methods of system analysis, methods of processing big data, ANN, methods of object-oriented programming were used.

The choice and application of neural networks is due to the fact that the neural network is a mathematical model of a parallel processor that accumulates experimental data and presents ample opportunities for their further processing [3].

Materials for the study are control processes and x-rays of spot-welded joints of engineering products. An example of a radiograph is shown in figure 1.

This x-ray was obtained using the hardware-software complex of "FOSFOMATIK" computer radiography and subsequent scanning of the obtained analogue image.

![Figure 1. Example of a radiograph.](image.png)

Technological control of spot welded joints based on electromagnetic radiation is based, as a rule, on the use of various radiation equipment: X-ray machines, gamma-ray machines, linear accelerators, betatrons.

Radiation flaw detection is based on the conversion of the radiation image of the inspected object into a radiographic image or the recording of this image on a storage device with subsequent conversion into a light image. In practice, this method is widespread due to its simplicity and documentary evidence of the results. In places where there are pores, slag inclusions, lack of fusion, large cracks, dark spots appear on the film. The type and size of defects is determined by comparing the film with the reference images.
Moreover, the main disadvantage of the electromagnetic control method is that the scattered radiation, depending on the energy of the primary radiation, changes the quality of the visual control result, reduces the contrast and clarity of the image, and, consequently, the sensitivity of the method itself; due to this phenomenon, small defects are difficult to distinguish without the use of automation.

3. Control automation
The developed methodology for the automated control of critical products by the methods of short-wave electromagnetic radiation includes:

- automation control algorithms and software based on them;
- description of the generated sequence of automation control;
- software application techniques, including end-to-end examples of automation control.

The synthesized sequence of automation control consists of the following steps:

- collection and formalization of data on the object of control, the equipment used and the requirement for the final product;
- transfer of formalized data to an artificial neural network;
- fixing the output values of the ANN;
- application of values obtained on the basis of a neural network for monitoring.

The most widely used approach to pattern recognition is the use of artificial neural networks (ANNs), since pattern recognition tasks are essentially discrete analogues of the problems of finding optimal solutions (discrete programming). These include a wide class of problems in which, according to some usually heterogeneous, incomplete, fuzzy, distorted and indirect information, it is necessary to establish whether the objects, situations or phenomena being studied have a fixed finite set of properties that allows them to be assigned to a certain class.

Let us consider in more detail an artificial neural network. ANN is designed in a high-level language in an interactive environment for programming and visualizing MATLAB results. To develop a neural network, the Neural Network Toolbox module was used, which provides functions and applications for modeling complex nonlinear systems that are difficult to describe by equations. The Neural Network Toolbox supports learning with a teacher and direct distribution, with radial basis functions and dynamic networks [4]. There is also support for learning without a teacher with self-organizing maps and competitive layers. With this tool it is possible to create, train, visualize and model neural networks. The Neural Network Toolbox can be used for tasks such as data approximation, pattern recognition, clustering, time series forecasting, modeling of dynamic systems and their management.

A feature of the ANN application is that when building an IMS, it is not necessary to know in advance absolutely all the laws of the studied area, but it is necessary to have a sufficient number of examples to configure the developed system, which after training will be able to obtain the required results with a certain degree of reliability.

Thus, having a properly composed and trained network, the control operator will have the opportunity to automate the most complex and monotonous task - recognition of the received radiographs.

The network diagram is shown in figure 2. Input neurons represent two classes: object data and equipment data.

The hidden layer includes 18 neurons, in accordance with previously generated data from the database. Three subsequent layers form three parameters: a filtering algorithm, a pasteurization algorithm, and a recognition algorithm. As a function of activation, a sigmoid function is used [5].

The programmer can, together or independently of the operator, train the neural network with up-to-date data on non-destructive testing. In this case, the main task of the programmer is to write and
support a software module for the recognition of radiographs, based on the recommendations of the ANN for given conditions.

Figure 2. Neural network diagram.

In case of changing the conditions of the control operation (equipment replacement, changing the type of objects being checked), the programmer needs to use the ANN to determine the necessary algorithms for preparing, segmenting and recognizing data. The choice of language and development environment remains at the discretion of the programmer. The program implemented in accordance with the proposed algorithms must be checked with test examples and passed to the operator.

The following recommendations may be an example of network output:

- data preparation algorithm: Median filtering;
- data segmentation algorithm: Pasteurization;
- identification method: binary trees.

4. Conclusion

In the course of the work, an analysis of the automation processes of electromagnetic control and a practical implementation in the form of techniques and software were performed. The modeling of the processes of automated control of welded joints by the methods of short-wave electromagnetic radiation is carried out. A model of a multicriteria approach to the control of welded joints has been synthesized. An approach has been developed that is based on a model for the synthesis of solutions for designing control processes for welded joints, a feature of which is a multi-criteria approach to the generality of the structures and properties of many methods of short-wave electromagnetic radiation in the production of critical products.

The proposed role of the ANN is to provide the programmer with data on the required structure and algorithms of the software for recognizing welded roentgenograms for current conditions, since approaches to preparing, segmenting, and classifying the results can differ significantly depending on the equipment used, the type of controlled products, and other technical conditions. This will avoid the long stages of scientific or experimental research, translating the task into a less laborious, engineering solution, which will increase the productivity of the control operation as a whole.

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