Augmented Reality Implementation for Comfortable Adaptation of Disabled Personnel to the Production Workplace

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Abstract

The paper presents the results of augmented reality system development and implementation for labour rehabilitation and adaptation of personnel with disabilities at modern manufacturing enterprise. Primary main attention is given to the production quality control using the computer vision system based on an artificial neural network. Simulation is used to produce the mixed reality for partially disabled personnel to provide comfortable adaptation of the production workplace. The research results were deployed and probated at a specialized enterprise that produces automobile cables and wires.

Keywords: smart manufacturing systems, intelligent simulation environments, neural networks, augmented reality, computer vision, rehabilitation

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Implementación de Realidad Aumentada para la Adaptación Cómoda del Personal con Discapacidad al Puesto de Producción

Resumen

El artículo presenta los resultados del desarrollo e implementación de un sistema de realidad aumentada para la rehabilitación y adaptación laboral del personal con discapacidad en una empresa manufacturera moderna. Se presta especial atención al control de calidad de la producción utilizando el sistema de visión artificial basado en una red neuronal artificial. La simulación se utiliza para producir la realidad mixta para personal parcialmente discapacitado para proporcionar una adaptación cómoda del lugar de trabajo de producción. Los resultados de la investigación se implementaron y probaron en una empresa especializada que produce cables y alambres para automóviles.

Palabras Clave: Sistemas de Fabricación Inteligente, Entornos de Simulación Inteligente, Redes Neuronales, Realidad Aumentada, Visión Artificial, Rehabilitación

通过增强现实让残障人士舒适适应生产工作地点

摘要

针对在现代制造企业工作的残障人士的劳动康复和适应，本文提供了增强现实系统开发和执行的结果。主要聚焦于通过计算机视觉系统（基于人工神经网络）进行的生产质量控制。使用模拟技术为残障人士制造混合现实，以期提供舒适的生产工作地点适应。研究结果在一家专业化的汽车电缆制造企业中加以应用和检验。

关键词：智能制造系统，智能模拟环境，神经网络，增强现实，计算机视觉，康复

Introduction

Modern simulation technologies implemented by the computer vision and augmented reality systems become an efficient facility for rehabilitation of people with disabilities. This subject refers to a vocational counseling, whose goal is to assist and empower individuals with various disabilities to achieve their career goals in the most integrated setting possible. This problem is particularly topical for modern production enterprises that are removing manual operations with robotic devices and artificial intelligence, but that are able to introduce new job opportunities.

In the sphere of labour rehabilitation, information technologies are used to reduce routine and physically taxing work conditions or support the personnel by providing them with additional visual or audio information. However, a complete replacement of humans by robots still remains an inefficient measure. Human staff is more adaptive and reliable to fulfill the casual work or outstanding services. Therefore, efficiency of a modern manufacturing enterprise depends on an optimal balance between the personnel and Artificial Intelligence.

In this paper we present a solution of rational application of Artificial Intelligence in a modern production enterprise, considering an additional parameter of employing the staff with the impairment of visual performance. This additional requirement necessitates a review of the optimization problem of modern enterprise automation to find a solution in the balancing of humans and robots.

State of the Art

Medical rehabilitation (Aramaki, 2019; Cao, 2016; Ivaschenko, 2021; Tieri, 2018) using the full stack of modern information technologies is a growing and promising area of computer science. Labour rehabilitation is comparatively less frequently discussed, but nevertheless an equally important area of scientific research reflected in a number of papers (Bell, 2013; Rehabilitation 2003).

The goal of social and labour rehabilitation is the comfortable adaptation of a disabled person to the workplace in production conditions and the development of an active life position. This problem remains salient for modernized enterprises that actively implement new information technologies. According to the concept of Industry 4.0 (Lasi, 2014), smart manufacturing enterprises reorganize their production processes on the basis of new technologies including robotics, the Internet of Things, Computer Vision, Augmented Reality, etc.

Technologies provide new opportunities for comfortable adaptation to production workplaces, including the improvements required by the personnel with disabilities. In particular, nowadays vision disabilities can be compensated for with modern hardware and software solutions for computer vision and image processing

(Sonka, 2008; Wiley, 2018) supplied with adaptive user interfaces capable of developing the mixed reality.

Related works of modern information technologies implementation of rehabilitation of people with visual disabilities are presented in (Bhandari, 2019; Kumar, 2014; Rajendran, 2020; Suresh, 2019). However, the problem of comfortable adaptation of disabled personnel to the production workplace is more specific and requires additional study.

Considering the requirements of a modern enterprise that employs the personnel with vision disabilities, the intelligent solution is designed to be built on the basis of a combination of artificial neural networks and knowledge bases (ontologies) used for logical reasoning (Egmont-Petersen, 2002; Goodfellow, 2016; Ivaschenko, 2020; Staab, 2009). Such integration allows consolidating the capabilities of pattern recognition and decision-making support for better adaptation of workplaces.

Below we present a new solution to apply Artificial Intelligence in a modern production enterprise considering an additional parameter of employing the staff with the impairment of visual performance.

Problem Statement

The problem of modern digital technologies implementation was stated by a unique production enterprise Samaraautozhgut. It is a producer of wires and accessories for automotive wiring harnesses in Samara region in Russia and employs persons with vision disability. Considering this factor, the systems of computer vision are hardly required at such an enterprise to help disabled employees increase the production efficiency and quality. At the same time the stated problem considers automated help of employees but not removing them by robots.

Typical stages of the production process are illustrated by Fig. 1.

Figure 1. Wire Assembly and Testing Process.

In this context comfortable adaptation of the personnel means supplementing them with additional interactive user interfaces based on sound notifications and Augmented Reality that provide additional information and thus helping them to reduce the errors caused by disability.

To solve this problem there was proposed an original hardware and software solution implementing the modern technologies of computer vision. The expected system features include automatic sorting, defect recognition and quality control. Quality control of products and production processes in turn provides for the implementation of photo / video processing of the results of monitoring e.g., assembly of parts and components, and control of the facts of operations performed.

The module for photo / video control of production processes should be implemented at a high level of usability and take into account all the features, advantages and disadvantages of a particular camera from which the video stream is captured and should be an application that works in full screen mode.

Additionally, the interface of the photo / video control module of production processes should provide for content management – pause / resume, fast forward / rewind, and also provide the ability to switch between several alternative screens for visual display.

The module for controlling the fact of performing operations based on the video stream in real time should recognize and control the steps actually taken in the production process and indicate the mistakes made, thereby correcting the process executor.

In this regard, the computer vision system is intended to:

- recognize the production process of assembling / testing harnesses;
- control the production process of assembly / testing of harnesses;
- inform the contractor about errors made during the assembly / testing of harnesses.

Solution Results

To implement the control of the fact of performing operations, the configuration of a convolutional neural network (CNN) was used. CNN provides image recognition and identifies the objects involved in the production process.

Experimental studies have shown that this is the optimal solution for working in real time, which makes it possible to accurately process the input data from the video stream and perform the assigned tasks.

In order to automate the finding and classification of images, the Tensor Flow framework was used, which is a library for machine learning. The OpenCV computer vision library was used for preliminary image processing. To accelerate the training of the neural network, a server with a GPU was used.

To train the neural network, five classes of recognition objects were defined:

- assembly gun;
- corrugated tube;
- clamp (wire fastening);
- operator assembling the wire;
- hands of the operator performing the assembly.

The first step was to prepare the data. A test video was originally created. The video showed various stages of the wire assembly from different positions and viewing angles (5 assemblies in total, there was only one assembly in the frame). For each class there were 4,000 images of the training dataset (the exception was the class of people: 2,000 images).

Since CNN was chosen as the architecture, further it was necessary to determine:

- dimension of the input image and output layers of the neural network;
- number and dimension of neural network convolution layers;
- number and dimension of down-sampling layers of the neural network.

After that, its markup was carried out, which was necessary for training the neural network. A total of 9,437 images were obtained. The dimension of the training and test images corresponded to the dimension of the CNN input layer. The training of the neural network consisted in optimizing the weight matrixes $W = \{W1, W2, \ldots, Wn\text{-}1\}$, where n is the sum of the number of convolutional layers and subsampling layers. Gradient descent and back propagation algorithms were used as learning algorithms for the CNN. During the training, a subset $S' \subset S$ was used.

For this video, a CSV file was created, where at every tenth frame it was noted which recognition object was presented on the screen. The final data were reflected in the table, where the average probability was marked for 5 objects and the final average value of the entire neural network for this set was calculated.

As a result, the CNN consisted of one input image, two convolutional and two down-sampling layers (subsampling layers). The dimensions of the layers and the input image are presented in Table 1.

Layer	Dimension	Feature maps number
Input Image	416x416x3	5
First convolutional layer	208x208x3	5
First layer of subsampling	13x13x1024	5
Second layer of convolution	104x104x64	5
Downsampling layer	13x13x2048	5

Then, by varying the number of epochs and testing the neural network on the test sample, the optimal number of epochs was determined (the minimum number was 25, corresponding to the number of epochs). Ultimately, after 20 000 steps, the probability exceeded 0.93, after which it did not change much (see Fig. 2).

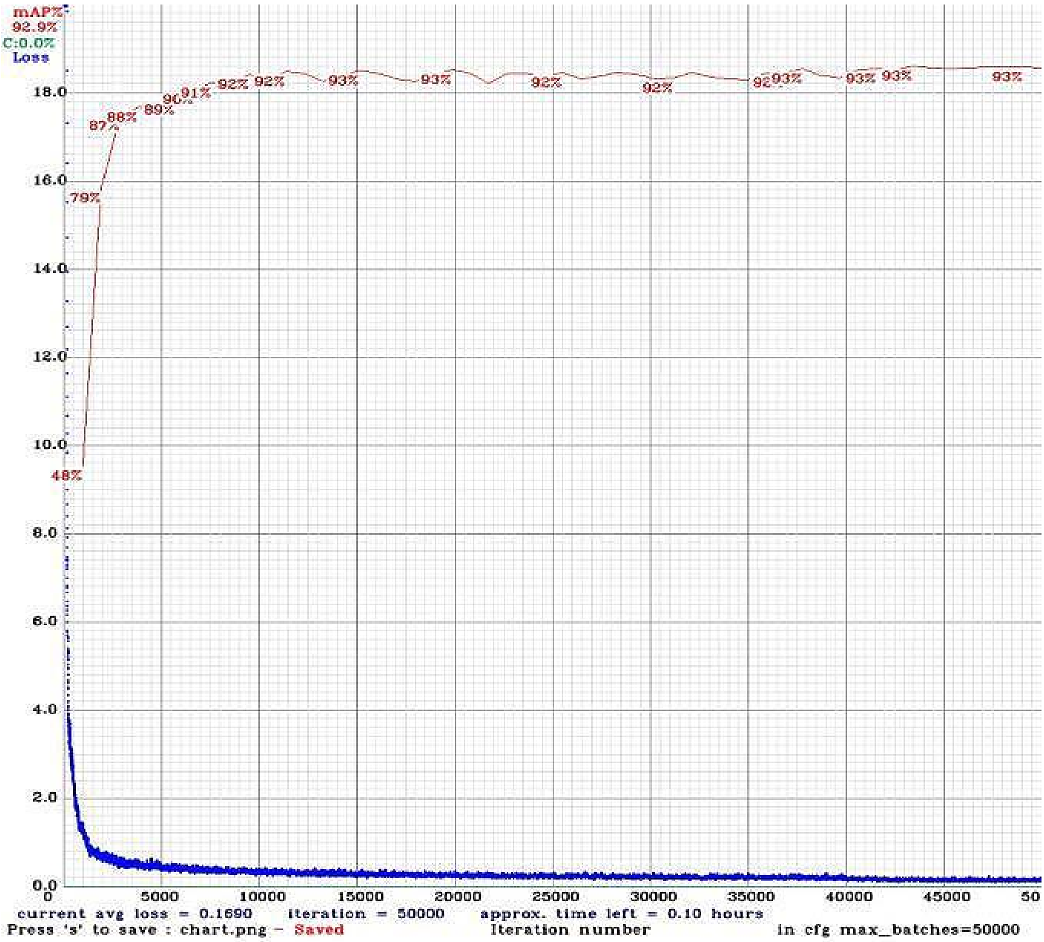

Figure 2. Probability of recognition (red line) and loss function (blue line).

An ontological approach was applied to describe the characteristic information about recognition objects (classes of objects used in the assembly of an automobile harness), as well as information about the production process, including technological operations of assembling and testing the wires in accordance with production and route maps.

The projected knowledge base provides:

- creating, editing, and deleting objects, and attributes;
- creating, editing, and deleting relations between the objects;
- navigation between objects of the subject area based on named relations in the knowledge base;
- description, binding, and implementation of existing rules without restarting the system;
- semantic search and knowledge visualization.

Using the specifically designed software called "Ontology constructor" allows you to add new information to the knowledge base without changing the program code. This feature, implemented in the manual operations control system, allows you to enter information into the knowledge base when making changes to the technological process during the assembly and testing of automobile wires, as well as describe a new production process for assembling and testing.

The generated semantic network accumulates the acquired knowledge of the manual operations control system in the form of recognition objects and links between them. In the future, this knowledge can be used to form logical onclusions and a text description of the operations performed.

Combination of the Ontology and CNN allows selection of image recognition method and setting of intelligent algorithms in accordance with the requirements for a given workplace.

Implementation

The software implements the following main functions:

- recognition of the production process of assembly / testing of wires based on video filming in real time;
- control of the production process of assembly / testing of wires based on video filming in real time;
- informing the contractor about errors made during the assembly / testing of wires;
- saving data about the contractor's mistakes made during the assembly / testing of wires.

To control the assembly and test the wire, you must first create in the system a standard with marked recognition areas for wires of each type (number) to be checked. To do this, in the opened form "Create a wire" on any of the cameras, select a square area with the mouse cursor, and go sequentially to each field for entering data and creating a list of stages and operations of the technological process for the selected wire (see Fig. 3).

The functions performed by the operator allow him to:

- receive informational messages (hints) on the order of the wire assembly;
- receive informational messages about errors made during the build process;
- control modes (control of modes of technological operations);
- manage recognition modes.

The operator assembles the technical product. The system prompts the assembly order, highlighting the structural elements involved in the assembly process, signaling the errors if they occur.

At the next step the system checks the performance of cameras for the presence of a video signal. If a malfunction (lack of signal) is detected from any of the cameras, the system will inform the user with a corresponding message.

Upon successful completion of the camera health check, the System is

Figure 3. Setup of the wire production process.

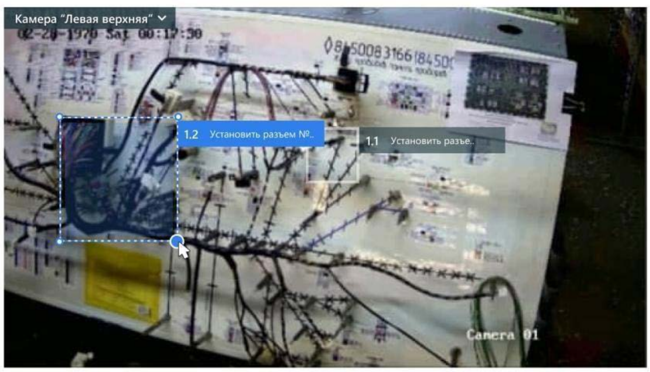

Figure 4. Production operation recognition and control in augmented reality.

ready to perform control over the operations. Then the user proceeds to the execution of the stages, according to the production process.

The user at the workplace performs the steps and actions, according to the technological process of assembling and testing the wires, namely:

- installing the wire;
- installation of the elements;
- fastening elements;
- removing the wire.

In case of erroneous actions of the user at any stage of the process, the system displays an informing window about the error he made with sound notification. The system shows at what stage the user skipped a certain action, thereby controlling the production process.

As presented in Fig. 4 the additional notifications are introduced in the form of simulated elements that are visualized above the real ones in a mixed reality scene. Their appearance can be supplemented by corresponding sound alerts.

In the exceptional case when the system incorrectly determines the user's action, it provides the ability to perform visual control instead of automated one. In this case, the user can use the "Skip" button to force confirmation of the operation. Information about its action is reported into the "Defect log" for further analysis.

Therefore, additional visual elements are added to the user interface helping the personnel to overcome the problems caused by the lack of visual information and thus provide comfortable adaptation of the workplace.

Let's consider an example of the functioning of the system using the example of assembling the typical wire. To check the quality of recognition of manual operations and to receive contextual instructions on the assembly order, the wire was assembled with and without making an error: inconsistency of the operation with the route map with the assembly of the automobile harness.

After choosing the harness number and checking the cameras for operability, the harness assembly began. To check the quality of recognition by the system, an error was simulated when performing the stages of installing the harness elements (see Fig. 5).

Information about an error (violation of the wire assembly sequence) appeared on the left side of the screen and on the main screen. In this case, the fact of the error was determined by means of a neural network. At the same time, contextual information about the error and information on actions to eliminate the error and continue the correct assembly of the harness was obtained from the knowledge base of characteristic information.

Figure 5. Experimental stand of the dual-fuel engine.

All information about the mistakes made during the assembly of the harness goes to the "Defect log" with the entry of the information into the knowledge base. The "Defect log" window receives information about the errors recorded by the user, made at the stages of assembly and testing, and also contains filter controls for displaying data in a convenient form.

As a result, 20 assemblies (identical technological operations) were carried out. Out of 20 processes carried out, the System in 1 case could not recognize the error. The recognition process exceeded 95%, which indicates a high rate exceeding the probability of an operator making a mistake, without using a manual control system.

Conclusion

Implementation of modern intelligent technologies allows not only reducing the personnel but also providing comfortable adaptation of the production workplace. The proposed solution based on computer vision does not remove the human worker but helps him by identifying and reporting the errors, caused by the disability. Additionally, it provides instructions on which step in the production process is the next one, i.e., it can support the human worker by reminding him of the general production process.

Therefore, the presented results illustrate the efficiency of quality control at the manufacturing enterprise employing personnel with visual disabilities. Next research steps are concerned with deep study of adaptation of disabled personnel to the production workplace considering the human factor and features of modern technologies of Artificial Intelligence.

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