APPLICATION OF ARTIFICIAL INTELLIGENCE FOR THE IMPLEMENTATION OF INDUSTRY 4.0 CONCEPT

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Abstract: The paper deals with implementation of artificial intelligence method for diagnostics of technological machines. The deep learning as a method of AI seems to be a very good candidate for solving complex problem of technical diagnostics. The method is now implemented for diagnostics for concrete production enterprise.

Keywords: INDUSTRY 4.0, DEEP LEARNING, NEURAL NETWORK, IMAGE SEGMENTATION

1. Introduction

The current trend in mechanical engineering in the world and in Slovakia is to achieve maximum degree of automation in line with the aims of the 4th Industrial Revolution known as Industry 4.0. Automation of production process is one of the means to enable manufacturing companies to maintain their strong position in a growing competitive environment. It allows by the application of adaptable flexible production systems to reflect the trend of customization according to customer requirements (small batch production). Adaptable flexible manufacturing systems are group of autonomous elements that perform isolated tasks, but they have the ability to integrate and be fully managed by the central control systems. An integral part of meeting the requirements for the introduction of a higher level of automation is the processing and analysis of complex data flows in the production environment. Its role is not to summarize and to state the current state. This is in particular the process of optimization of the data collected, improvement of efficiency of data processing, and especially the transformation of the data to data structures to a form that can be processed, comprehended and autonomously managed by the central management system of the company. Based on the above requirements, we can state that the conditions for maximum automation are fulfilled by providing necessary hardware, process and data integration resources in the manufacturing process.

Data integration in a business can be divided into three basic types:

- horizontal integration
- vertical integration
- end to end integration

The detail of, scope and nature of the data to be included at the appropriate level of data integration must be determined by the needs arising from its purpose.

Horizontal Integration - represents the integration of data structures for corporate or multinational enterprises. It integrates independently operating and cooperating manufacturing entities.

Vertical integration - represents a comprehensive integration model of a manufacturing enterprise. It integrates the data characterizing individual units of the production enterprise (departments). Its elements include manufacturing control structures, actuators, sensory controllers and self-organizing systems. Software systems that implement the vertical integration are ERP systems.

End to end integration - it is characterized by product-oriented integration. It is the integration of data that is relevant to the product. It focuses on the product, the requirements defined by customer, the pre-production, manufacturing and post-production engineering, the quality management, maintenance and recycling, and on the other direct product-related tasks.

Our aim is to achieve the highest possible degree of automation of manufacturing process and is based on the assumption that the only accepted goal at the present is the maximum automation within the individual production plants, and therefore the achievement of the high level of vertical integration within the enterprise is a prerequisite for its achievement. To achieve the maximum adaptability of a manufacturing process from the point of view of incorporating changes resulting from customer requirements the successful implementation of End to End integration is desirable. After fulfilling these requirements, we can start activities that will increase the autonomy, adaptability and management flexibility of the manufacturing enterprises. We can say that our goal will be to achieve a higher degree of automation of manufacturing processes and thus the transformation of the manufacturing enterprise into a self-organizing and self-governing system. The tools we will use to achieve this goal will be mainly from the collection of artificial intelligence tools.

Automatization, self-organization, self-management is achieved by implementing computer aided control of systems for analyzing any device or phenomenon. For implementing computer control, it is required to create a robust digital image of all basic elements, processes and phenomena in the digital world that will represent the real word and thru that model we can then work by using computing methods. The aforementioned "digital image" is in fact as precise as possible mathematical model of a real-world elements (mathematical model of subject, process, phenomenon, ...) in which, besides its basic physical characteristics (dimensions, performance, consumption ...) also characteristics describing relationships and co-operation between elements in the given space or process are present. Of course, a successful modeling of the processes and tasks involved in the production process is needed.

Currently existing robotic or automated workplaces mostly cover automation of routine human activities. There are no comprehensive solutions for automating processes where a higher level of control and decision-making is needed, based on the principles of abstract thinking, cognitive thinking, self-learning processes, or on autonomous empiric-based learning systems. We can say that automated systems with higher levels of control and decision-making are absent. This is due to the fact that higher level control cannot be covered by simple mathematical models that describe the elements occurring in the automation process statically and incompletely. In order to be able to control the processes of automation at a higher level of control, we cannot work with the mathematical models of each entity involved in the automation process separately, but we must ensure modeling of the complex automation process by dynamic mathematical models of all elements occurring in the real automation process. At the same time, we must ensure that the managed system is able to dynamically respond to the input and output signals from the environment, and flexibly respond to unpredictable changes and, of course, having the ability of direct iterations with humans, and to react to actions of a collaborating person or device.

An important goal in the Industry 4.0 automation process is the ability of automated systems to respond to environmental stimuli by adapting the control processes to current conditions. Thus, we can say that we need to provide a certain set of tools that will provide the automated system with "self-learning" capabilities, or at least system must have the capability that allows the user to react to conditions that the system cannot process and afterward they will be handled by it autonomously (supervised learning). After we successfully create the aforementioned tools that do not exist sufficiently at present, we will significantly increase the efficiency of automated control, because in the event of similar phenomena, systems will have "reaction" schemes for optimal management of the phenomena in their knowledge databases. The techniques chosen by us to develop the automated system with “knowledge” are the Deep Learning techniques. Solved problems fall within the domain of artificial intelligence, by their very nature. Deep learning techniques will enable the systems to learn independently and allow them to be successfully applied in automated systems, thereby increasing the autonomy of management. Primary Deep Learning is group of tools simulating human brain function by technology. For its working it uses a specific software mimicking the propagation of signals among the neurons through synapses, which are known as the neural network. This system is formed by the introduction of multi-level neural networks with backward propagation and successful implementation of Big Data. It can be developed into a successful implementation for real world problem solving and searching for real world data connections.

2. Deep learning

Deep Learning applications are not programmed by using precisely defined algorithms that solve the problem exactly, but they are trained on real big amount of data to teach them how to behave in different situations, and how to find solutions to problems. This task is very complicated, however, because they are prone to bad data interpretation, and therefore team of experienced specialists needs to verifying and correct possible misbehaviors in the training process. Most used applications for deep learning systems are:

- Analysis of text information
- Analysis of the spoken word
- Image recognition
- Smart behavior simulation

From the above list, it is obvious that the application of Deep learning systems is mainly used to solve narrow focused problems. As we have already mentioned we plan to increase the degree of automation, because of that we must perceive the manufacturing enterprise as a complex and therefore a successful implementation of Deep Learning Systems must consist of data interpretation in its complex form.

A wide area of successful applications of Deep Learning Systems is their application in financial sector and recently in human-oriented systems (behavioral analysis, marketing analysis, predictions). Their application in the technical sector or in mechanical engineering is not yet widespread.

Therefore, many of the developed methodologies and tools for Deep Learning Systems need to be adapted in order to successfully use them in the technical sector. The internal principles of work of the systems will remain similar with existing applications. The modifications made by our research will focus on the way data is prepared on the input and interpreted on the output side of Deep learning systems.

In order to modify the existing successful applications of Deep Learning Systems in the field of mechanical engineering, specifically manufacturing systems, it is necessary to find analogies between the data from which and to what data we want to transform using Deep learning systems, in accordance with the aforementioned division into the four basic groups. We can declare the following analogies:

- Analysis of the spoken word - the analogy of the spoken word in the case of a mechanical engineering applications is in using an audio recording e.g. recording of production line (critical nodes). The performance of current hardware and the quality of available sound filtering algorithms have sufficient performance to obtain qualitatively sufficient data. Deep learning system can be deployed in the Condition monitoring and diagnostics of production lines. After, obtaining a sufficient number of input samples, we are able to create a sufficiently comprehensive database of samples with the help of expert in the field that can assess the current status of the production line and possibly predict potential malfunction. This database can then be used in supervised learning scenarios, followed by further implementation of reinforcement learning and adversarial algorithms, we can bring the system to the process of self-learning.
- Image recognition – as with the previous case we will use the analogies between data. Deep learning system will be deployed to evaluate images acquired by means of machine vision (cameras). The initial set of data will be subjected, as in the previous case to tagging by expert in the field, to allow us to use supervised learning to autonomous recognition of the known anomalies on the basis of the database of evaluated samples. This method can be applied in Condition Monitoring and Diagnostics of systems, and also for example, we can successfully apply the Deep Learning System in the process of self-alignment of the robotic device when handling products. Based on the comparison of image information in the "Knowledgebase", the system will be able to recognize the current state and make real-time corrections. Compared to other conventional image processing approaches, Deep Learning System has a significant advantage in its flexibility and accuracy in the evaluation process, and thus greatly enhances the flexibility of manufacturing and automation processes.
- Analysis of text information - in this case, it is only necessary to change the metric and data encoding of known machine learning algorithms. The reason that has hindered widespread usage of these techniques is the difficulty of creating evaluation algorithms and the unambiguous definition of metrics for the data evaluation process. The application potential is significant in this case, as existing systems only have predefined decision-making algorithms and, in the event of ambiguous or critical situations, most of them fail. Application of Deep Learning Systems allows us to increase the adaptability of control system to use iterative changes of parameters while increasing the resistance of control system to the occurrence of fatal failures.
- Smart Behavior Simulation - is the most challenging of existing applications. The control system that will use a Deep Learning will gain new adaptability abilities for its iteration with the surrounding environment. It will have a self-learning subsystem and will have the ability to autonomously react to new requirements. However, for a sufficiently good functionality, we will need a very extensive knowledge base, as well as a very precise and reliable data analysis, description of iterations between all possible potential actors, causal analysis and, of course, very detailed and precise interpretation of all the iterative elements and the algorithmization of all processes and

phenomena will be needed to be done. The obtained comprehensive input data will allow us to obtain an accurate, comprehensive digital model of the entire control process that will form the basic object for simulating intelligent behavior.

3. Application of Deep learning

Our research focuses on the implementation of Deep Learning System in the product quality assessment and management process. Requirements for the development of a system with sufficient agility in the field of autonomous production quality assessment have arisen from our cooperation with industry and are intended to replace the manual quality control used in industry. The reason for replacing the human labor is not only saving company resources primarily financial savings, but our intention is mainly to increase the accuracy of the quality assessment, exclusion of subjectivity brought into the assessment process by the human element and at the same time increasing the speed of the process.

From the group of well-known Deep learning algorithms, we chose for our application the image analysis algorithms, due to the nature of the task of visual quality assessment of the product. Today, an electromechanical inspection station is used to assess the quality of the product. For our needs, we need to extend the existing solution by equipment designed to address machine vision tasks - industrial cameras. The visual characteristics of the evaluated product can be by their nature described as extremely difficult to evaluate for the computer vision in production environment and thus our proposed implementation must be comprehensive in nature and the inspection station must be extended to include lighting technology forming optimal lighting conditions required to obtain the final image of adequate quality.

After the necessary modifications of the inspection station it will be possible to create an image database of the products being evaluated. After obtaining a sufficient number of samples, it will be possible to carry out the learning process by using supervised methods, where we will create a database of knowledge about the quality of the product being evaluated. The structure of the knowledge database will consist of the acquired image of the product, description of its condition and assessing the level of quality achieved, assessment if product meets or fails the quality requirements.

To successfully fulfill the required tasks in the implementation of the Deep learning system, we will have to perform the necessary algorithmic tasks that will build the definition and metrics for the evaluation process.

Finally, the individual elements of the system will be integrated into a complex system whose proper operation will ensure the fulfillment of the defined task.

This paper will bring to the reader the summary of the basic information needed for the successful implementation of Deep Learning Systems in mechanical engineering. At the end of the paper we described the task that aims to indirectly increase the degree of automation in the production process by applying the Deep Learning System by automating the quality assessment of the final product. Our research is currently focused on its implementation and we will keep you informed about the results of our research.

We will use semantic image segmentation with Deep Learning techniques using familiar approaches to image analysis and understanding. Task of understanding the will be realized through a deep convolutional neural network. These properties can cause unclear boundaries of objects, that will decrease accuracy of semantic segmentation and can cause incorrect object boundaries.

One way is to build a semantic segmentation is through a recurrent neural network using Conditional Random Field (CRF) postprocessing that trains the entire network by continuous smooth segmentation based on the underlying image intensities. For a more efficient use of Conditional Random Field postprocessing in recurrent neural networks we will use fully networks based on a combination of a convolutional neural network and the use of Conditional Random Field (CRF). Recurrent neural networks used with conjunction of Conditional Random Field have the ability to recognize non-distinctive details that can be hidden when using another architecture.

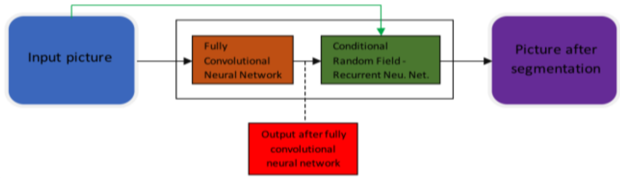

Fig. 1 *Block diagram of CRF segmentation Recurrent Neural Network*

Consider a random field X defined over a set of variables $\{X_1,...,X_N\}$. The domain of each variable is a set of labels $L = \{l_1, l_2, . . . , l_k\}$. Consider also a random field I defined over variables $\{I_1,...,I_N\}$. In our setting, I ranges over possible input images of size N and X ranges over possible pixel-level image labelings. Ij is the color vector of pixel j and Xj is the label assigned to pixel j.

A conditional random field (I,X) is characterized by a Gibbs distribution:

$$P(X|\mathrm{I}) = \frac{1}{Z(I)} \exp(-\sum_{c\in C_\varsigma} \phi_c(X_c|I))$$

where $\varsigma = (\nu,\varepsilon)$ is a graph on X and each clique c in a set of cliques $C\varsigma$ in ς induces a potential φ_c. The Gibbs energy of a labeling $x \in L^N$ is :

$$E(X|I) = \sum_{c\in C_\varsigma} \phi_c(X_c|I)$$

The maximum a posteriori (MAP) labeling of the random field is $x^* = \arg max_{x\in\mathcal{L}^N} P(X|I)$ For notational convenience we will omit the conditioning in the rest of the paper and use $\psi_c(x_c)$ to denote $\varphi_c(x_c|I)$

$E(x)$ is a Gibbs energy of labeling $x \in L^N$ and $Z(I)$ is proportion function. Probability that a pixel is correctly labeled is inversely proportional to Gibbs energy $E(x)$. Let G be a graph on X of each clique c in a set of cliques C_G then in fully connected pairwise CFR model G is the complete graph on X and C_G is the set of all unary and pairwise cliques. Energy of specific unary cliques $\psi_u(x_i)$ expresses the inverse of probability that the pixel will be assigned a specific label independently of other pixels. Energy of pairwise cliques $\psi_p(x_i, x_j)$ expresses the inverse of probability of assigning labels x_i a x_j, to depended pixels i, j. Corresponding Gibbs energy is then given as sum off individual clique energies:

$$E(x) = \sum_i \psi_u(x_i) + \sum_{i<j} \psi_p(x_i, x_j)$$

Unary components are obtained from the convolutional neural network, they express the probability of splitting pixels into classes, and are performed irrespective of the similarity between labels or their consistency. Pairwise components energy provides a way of smoothing dependent on image data, and contributes to the assignment of labels to pixels with similar properties.

The individual steps of the iteration algorithm are composed of and described as layers of the convolutional neural network. The iteration is based on the use of Gaussian filters (they are a type smoothing filters). The advantages of using them is their simplicity even though they can gain dimensions as high as the image resolution itself. The individual iteration steps represented by the convolutional neural network are:

1. Initialization
2. Message spreading
3. Statistical balancing
4. Reconciliation
5. Adding unary potential
6. Normalization

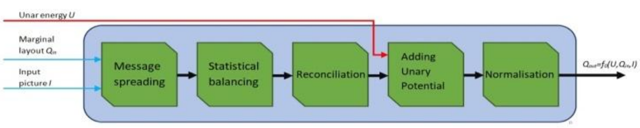

Fig. 2 *Iteration algorithm*

Minimalization of energy E(x) of neural network using Conditional Random Field gives us the best results when determining the probabilities that the pixel has a specific label. Because of difficult nature of the minimalization of distribution P(X) it is approximated by simpler distribution Q(X) that is a product of independent marginal distributions:

$$Q(X) = \prod_i Q_i(X_i)$$

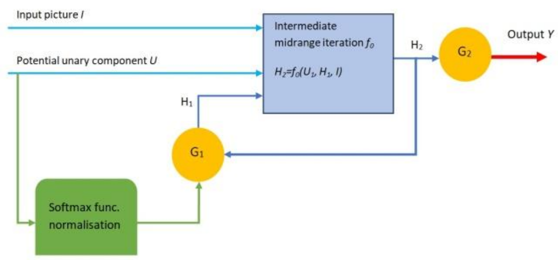

Fig. 3 *The principle of operation of the iteration algorithm*

Thus, we can conclude that the method of applying a recursive neural network with Conditional Random Field is applied by formulating as a recurrent neural network that can improve the quality of the overall output of the convolutional neural network in the area of forward propagation,

Our method is based on the ability to train the network, by combination of a convolutional and recurrent neural network using Conditional Random Field by application of a well-known algorithms. By this we combine the features of both deep learning and graphic modeling.

Our paper is designed to introduce the reader to the subjects we are working on in our applied research. The choice of selected methods and approaches has been carefully chosen according to the nature of our research projects carried out with our collaboration with industry. We can say that successful understanding of the entire multipart tasks presented here will allow us to create a device that will fully correspond to the concepts of Industry 4.0

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