Abstract of the doctoral thesis

Methods for efficiency and quality analysis of discrete production processes using technological templates and selected data mining techniques

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The aim of the thesis was to prepare a set of methods based on a selected data mining techniques, which would enable analysis of efficiency and quality of work of production installations used in discrete production. In addition, the process data, as well as the results of analyses, would be combined with the technology information related to those installations. The research was conducted in the field of preventive and predictive maintenance of production stands and in the field of knowledge discovery using analytical and informatic techniques.

The author of the thesis has concentrated his works on three main aspects. The first aspect was related to the combination of process data delivered by process controllers with the information about the technology. This combination enables the enhancing of knowledge about processes not only through the use of expert knowledge related to the technology, but also through the data analyses based on data mining techniques. The use of classical model information used in nowadays industry is insufficient for building of dynamic knowledge of processes, especially short-series and multivariant ones. Therefore, a set of research was conducted, which resulted in a definition of a model, which was based on OPC UA address space and AutomationML language. This model combines the data and technological aspects and was used in further steps of author's research. The author's input for the scientific field was a formulation of possible connection between informatic systems used for data processing and analyzing with the technological knowledge of physical construction, its design and maintaining of industrial installations. The results of the research are presented in the following papers: [2], where a conceptual approach for binding technology with process data was presented, and which used ISA-95 information model along with OPC UA communication; [3], where AML language was additionally used for modelling of physical assets and which enabled the results of analytical methods to be used for efficiency and quality management of the production stand; [9], where OPC UA address space was used as a tool for implementation of Information Layer of RAMI4.0 for elastic and mobile automation assets; [10] and [11], where research of OPC UA address space for data exchange between mobile automation assets was presented.

The second aspect was related to the automatic detection of manufactured production variants through the determination of author-defined technological templates. The templates allowed to represent a fragment of production process (namely: production cycle) in a form of finite set of features, which characterizes the single instance of a manufactured product. Those features are: cumulative energy consumption during the production of a single product, cumulative activity time of the installation during the production or cumulative activity times of single end-point devices used during the manufacturing. The detection of technological templates was prepared using a developed method for the detection of significant states of the installation, methods for the detection of production cycles, the clustering using k-Means method and the clustering using modified k-Means for automatic determination of k using hyperballs in multidimensional feature space. The author's input for the scientific field was the development of a new method for automatic determination of k

for k-Means algorithm and the approach for analysis of universal production stand in discrete production through the commonly used signals such as total energy consumption or activity signals of single end-point devices. The results of the research are presented in the following papers: [1], where an approach to production data using technological templates is described, as well as methods for constructing of those templates using the selection and aggregation of those features; [4], where a method for significant states selection method for technological templates is introduced; [5], where research and methods for aggregation of stream data is presented, and which can be used for further analyses and detection of various states of industrial installation; [6], where an approach to the analysis of process data is described and which assumes the use of clustering methods for selection and identification of various states of work of the production stand; [7] and [8], where methods for constructing and automatic determination of new technological templates was introduced, and which bases on the modified k-Means method using hyperballs in a multidimensional feature space.

The third aspect was the classification of a selected fragment of an industrial process in order to detect anomalies in the work of industrial installation. The method uses technological templates developed in the previous aspect: they are treated as a reference models which are then used by statistical methods and which allow to assess the efficiency and quality of work of industrial installation. This approach allowed to reduce the amount of data used for the analyses and enables the implementation on a process controller level, e.g. Programmable Logic Controllers. The author's input for the scientific field was the method for assessing efficiency and quality of work of industrial installation which can be applied to real-time process controllers. The results of the research are presented in the following papers: [1], where mechanisms for anomaly detection in the work of industrial installation was presented, and which uses technological templates, also for the identification of sources of those anomalies; [7] and [8], where the modified k-Means algorithm based on hyperballs in multidimensional feature space was used for the detection of anomalies and outliers in technological variants.

The research results obtained by the author expand the knowledge presented in current state of the field described in scientific publications and papers and provide a new approach to analyses of complex industrial installations using data mining techniques. This is enabled by the following factors: significant reduction of the amount of data used for analyses; possibility to be used on a process control level; analysis of the quality and efficiency of industrial installation without the knowledge of the technology give *a priori*; possibility to bind process data with technological databases which can contain information about physical assets, e.g. project files; ability to support the complex industrial installation through the commonly used process signals such as energies and activity statues; possibility to support the analysis of complex installations instead of a single end-point devices.

The results of author's research and the potential for their use are presented and published in the following papers and scientific publications:

1 *Determination of the machine energy consumption profiles in the mass-customised manufacturing*, Cupek, R., Ziebinski, A., Zonenberg, D., & Drewniak, M, 2018, International Journal of Computer Integrated Manufacturing, 31(6), 537-561.

2 *"Digital Twins" for highly customized electronic devices–Case study on a rework operation*, Cupek, R., Drewniak, M., Ziebinski, A., & Fojcik, M., 2019, IEEE Access, 7, 164127-164143..

3 *Knowledge integration via the fusion of the data models used in automotive production systems*, Cupek, R., Ziebinski, A., Drewniak, M., & Fojcik, M., 2019, Enterprise Information Systems, 13(7-8), 1094-1119.

4 *Online energy efficiency assessment in serial production-statistical and data mining approaches*, Cupek, R., Drewniak, M., & Zonenberg, D., 2014, June, 2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE) (pp. 189-194). IEEE.
5 Data Preprocessing, Aggregation and Clustering for Agile Manufacturing Based on Automated Guided Vehicles, Cupek, R., Drewniak, M., & Steclik, T., 2021, June, International Conference on Computational Science (pp. 458-470). Springer, Cham.
6 Data mining techniques for energy efficiency analysis of discrete production lines, Cupek, R., Duda, J., Zonenberg, D., Chłopaś, Ł., Dziędziel, G., & Drewniak, M., 2017, September, International Conference on Computational Collective Intelligence (pp. 292-301). Springer, Cham.
7 *Improving KPI based performance analysis in discrete, multi-variant production, Cupek, R., Ziębińsk*i, A., Drewniak, M., & Fojcik, M., 2018, March, Asian Conference on Intelligent Information and Database Systems (pp. 661-673). Springer, Cham.
8 *Estimation of the Number of Energy Consumption Profiles in the Case of Discreet Multi-variant Production*, Cupek, R., Ziębiński, A., Drewniak, M., & Fojcik, M., 2018, March, Asian Conference on Intelligent Information and Database Systems (pp. 674-684). Springer, Cham.
9 *Information models for a new generation of manufacturing systems-a case study of automated guided vehicle*, Cupek, R., Drewniak, M., & Ziebinski, A., 2019, October, 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC) (pp. 858-864). IEEE.
10 *Application of OPC UA Protocol for the Internet of Vehicles*, Cupek, R., Ziębiński, A., Drewniak, M., & Fojcik, M., 2017, September, In International Conference on Computational Collective Intelligence (pp. 272-281). Springer, Cham.
11 *An OPC UA server as a gateway that shares CAN network data and engineering knowledge*, Cupek, R., Ziebinski, A., & Drewniak, M., 2017, March, 2017 IEEE International Conference on Industrial Technology (ICIT) (pp. 1424-1429). IEEE.