Operator Knowledge Inclusion in Data-Mining Approaches for Product Quality Assurance using Cause-Effect Graphs

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Abstract: Product quality is one of the crucial factors influencing customer satisfaction and loyalty, and of course, a company’s reputation in general. A high quantity of non-conforming products increases risks and costs of production. For certain types of products, it is difficult to measure quality during production, therefore it is assessed afterwards in a laboratory. We propose to determine the relationship between process and quality parameters. The identified process parameters can then be used in future to estimate and predict quality. In this paper we present a method to develop a Cause-Effect Graph (CEG) based on expert knowledge (qualitative part) to provide visualization of the causes and effects to support machine operators. To validate the CEG we used data mining methods (quantitative part). We apply our approach to an industrial use case (stretch film production), collecting the expert knowledge through interviews and card-sorting techniques, and performing a logistic regression and decision tree analysis in the data-mining part. The validity of the proposed method is proven for continuous technical processes with certain important criteria of classification, e.g. availability of process variables, their amount, relationship between process and quality relevant variables. Thus, the main contribution of this paper is presented by the matching of experts’ knowledge with results of data mining in order to improve the production process understanding and visual support of causes and effects of production process for operators.

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1. INTRODUCTION

Increasing the Overall Equipment Effectiveness (OEE) is one of the core tasks in automation. To increase the OEE, three factors can be improved by companies: plant's availability, plant's performance and product quality. For the product quality assurance, it is necessary to produce a high quantity of conforming products and low quantity of non-conforming products. At this, the quality is a summary of several product related features. All features need to be within the specification limits for a confirming product. Non-conforming products consists of at least one feature, which exceeded a specification limit. In general, there are two approaches to identify a product as conforming or non-conforming (Gordon, 1996). On the one hand, quality inspections are made during plants’ runtime (online). Online quality assurance allows the plants’ process to be quickly adjusted in order to fulfil or restore the quality requirements. Nevertheless, online quality assurance is only possible if product features that influence the quality are measurable and comparable to specification limits under real-time constraints. On the other hand, the product quality is observed in laboratory inspections (offline) (Bernardy & Scherff, 1998). Several tests are applied to the product in order to identify conforming and non-conforming products. Beneficially, several test can be made even if they are time consuming. Disadvantageous, if there are a lot of non-conforming products, there may be a high quantity of product spoilage because no adjustments can be made to the process anymore. To overcome this drawback, expert knowledge and historical data can be used, predicting the products’ quality. (Vorne Industries (ed.), 2008)

In our contribution, we believe that the experiences of offline quality assurance in combination with the known production process, which leads to the observed quality, are used to identify the relationship of process and quality parameters. This supports the opportunity of quick modifications of the process and adjustments to the quality requirements, although the quality cannot be measured online. To illustrate the relationship of process and quality parameters, and to show the connection of causes and effects, a so called Cause-Effect Graph (CEG) is drawn. This graph is identified through the evaluation of expert knowledge and complemented by the analysis of historical data of the underlying process. In sum, the main contribution of this work is the development of better understanding of the production process, and development of the CEG for the visual support of the operators.

The remainder of the paper is structured as follows. In section 2 the problem statement is presented and section 3 covers the state of the art. Section 4 proposes the concept of CEG as well as the approach and constraints for its development. Section 5 evaluates the proposed approach using an industrial case study in the domain of automated production systems (aPS). Conclusion and Outlook is given in section 6.
Based on historic process and quality data (Research question RQ1). More specifically, the CEG can capture different types of relationships (RQ1.1), e.g. whether an increasing or decreasing process parameter of an aPS leads to increasing or decreasing product quality. In order to build the CEG, identification of the quality, process, intermediate and environmental (in case of necessity) parameters is required (Requirement R1.1.a) to describe the scope of the influencing environment. To do so, access to the operators’ manuals, troubleshooting reports and technological process description is required (R1.1.b). Moreover, it is necessary to illustrate types of relationship between the parameters (R1.1.c) to define the different relations between discovered process parameters, i.e. an increasing process value may have an increasing or decreasing effect of product’s quality. Also, knowledge acquisition from the experts (e.g. operators, technologists) is required in order to collect mental models (R1.1.d) and derive a comprehensive CEG representing causal relationships of process and quality parameters. Furthermore, additional information is identified by the data-driven methods. In particular, thresholds of process parameters leading to non-conforming products and the strength of the impact of specific parameters complete the information content of CEGs (RQ1.2). Consequently, an exclusively data-driven method is required which is independent of the expectations and knowledge of experts (R1.2.a). Furthermore, the data-mining method is supposed to not only quantify the relationship but also measure its strength (R1.2.b) and illustrate the range of optimal operation (R1.2.c.) to complement the CEG.
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