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Hierarchical decision making for proactive quality control: system development for defect reduction in automotive coating operations

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Abstract

Product quality control (QC) in manufacturing usually relies solely on inspection. Once a quality problem is found, a solution is sought usually based on experience, which is basically ad hoc. A new generation of QC requires the integration of both quality prediction and inspection. Automotive coating is a typical example. In the paint shop of an automotive assembly plant, topcoat filmbuild quality on vehicle surface has been a major concern. In production, defects are frequently generated in the very thin coating layers, which can degrade severely both coating appearance and durability. Trial and error in troubleshooting is a usual practice.

In this paper, we introduce a proactive QC approach by resorting to artificial intelligence and engineering fundamentals. The approach is developed for solving a class of engineering problems for which conventional reactive QC approaches are feeble due to system complexity and uncertainties, such as that in paint applications. The main focus of the approach is on-process, rather than post-process. Thus, the domain knowledge about a process is fully explored and correlation of the process to product quality is established in a systematic way. In this approach the knowledge is expressed either symbolically or numerically, and structured in a hierarchy as reasoning progresses. Decision making is performed by a fuzzy MIN–MAX algorithm for heuristic knowledge and optimization for fundamental knowledge. To demonstrate the efficacy of the methodology, an application to QC of automotive topcoat is illustrated through developing an intelligent decision support system. This system is capable of evaluating process performance, and providing various valuable decision supports for defect prevention in different stages of a topcoat application process.

Keywords: Quality control; Intelligent decision support; Artificial intelligence; Fuzzy logic; Automotive coating

1. Introduction

Most quality control (QC) techniques used in the manufacturing industries today are post-process based (Kane, 1989). In plants, QC engineers and process verification engineers inspect final products. The identified quality problems are usually statistically analyzed, and solutions are then derived frequently based on experience. Process engineers are responsible for taking actions, such as fixing equipment, re-adjusting operational parameters, educating operators for good operational practice, and reworking on the returned products. Methodologically, inspection-based QC techniques are reactive to the product quality, since the premise of applying them is the generation of quality problems. Note that in some manufacturing industries, such as automotive painting and electroplating industries, once a quality problem is identified on a final product, it has already appeared on many other products. Even if a correct action is immediately taken at one stage of a multi-stage process, there will be still a certain number of products coming out with the same problem because those products have already been manufactured in the process after that stage. On the other hand, experience-based solution identification is not systematic and always consistent. For the same type of quality problem, engineers in different shifts may have different views and thus take different actions. Conceivably, the effectiveness of QC can be very different.

Due to increasing economic pressure and more stringent environmental regulations, the product quality standard becomes much higher, and process operation

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much more difficult. Traditional inspection-based QC alone is no longer sufficient. Nearly a decade ago, Wu et al. (1989) introduced a new QC concept called New Generation Quality Control. The focal point of the concept is process control. Needless to say, if product quality can be appropriately modeled into a process control scheme, then product quality can be significantly improved. Nevertheless, in the automotive coating industry, for example, such a QC approach is yet to be developed at the both theoretical and practical levels.

Recently, Lou and Huang (2001) introduced a process control-optimization-based, proactive QC approach for enhanced automotive coating. They suggested adding quality-bearing process optimization to the conventional regulatory control. This permits the adjustment of process operational settings when a quality improvement is justified. The approach can be generalized as a hierarchical process control scenario for proactive QC in any manufacturing processes. As shown in Fig. 1, the lower layer is for both the servo control and the regulatory control. The former is to allow the system to track set point changes. The later is to ensure smooth operations through rejecting disturbances. In this regard, the feedforward control is for rejecting more effectively measurable disturbances, while the feedback control is mainly for unpredictable disturbances. Usually, this control system is already implemented in plants. The newly introduced upper layer is designed for quality-bearing process optimization that consists of four components:

(a) A quality analyzer that evaluates the information about the final product. It transmits the quality information to the component, quality controller, when the product is found out of specification.
(b) A quality controller that identifies the root cause(s). If a quality problem is caused by improper process settings, relevant process parameter(s) will be identified and sent to the component, process optimizer. If it is due to equipment malfunction or failure, management or operator's improperness, or other than process setting related reasons, then the quality controller will send the information to engineers for off-line treatment.
(c) A quality predictor that predicts product quality using process information. This information may come from different operational stages in the process. The correlation between a set of process variables and a set of quality variables will be the key for the predictability of this component.
(d) A process optimizer that optimizes process operation so that product quality can be ensured. Optimization decisions will be made based on the information from the quality predictor and the quality controller.

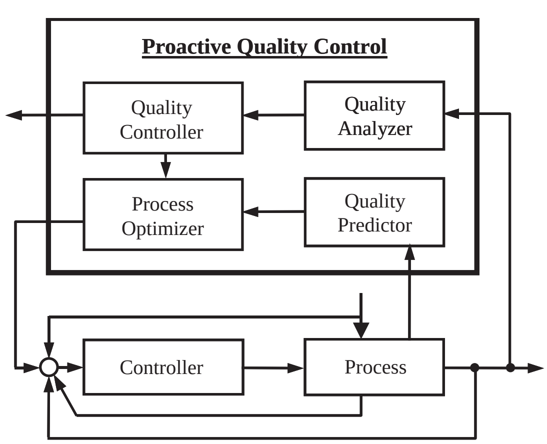

Fig. 1. Hierarchical process control for proactive QC.

While the hierarchical process control promises quality assurance using both process and post-process information, the effectiveness of the proactive QC is determined by the functionality of components and their integration. The development of these four components requires the use of all types of acquirable knowledge and available information that can be either numerical or symbolic, and either structured or unstructured. This renders the use of different modeling and decision-making techniques, depending on the type of industrial problem to be investigated.

This paper focuses on hierarchical decision making for proactive QC in the manufacturing industries. A specific application is for the defect prevention of vehicle coatings during automotive paint spray and drying operations. Due to process complexity and information uncertainties, adequate domain knowledge and pertinent data need be fully utilized. This requires the knowledge to be represented either symbolically or numerically, and structured in a hierarchy. A hybrid decision-making method is also introduced to derive the best possible problem-solving solutions. These developments are resorted to artificial intelligence, engineering fundamentals, and optimization techniques. The developed approach is adopted as the core of an intelligent decision support system for defect reduction in automotive coating operations. This system is capable of evaluating process performance and providing various valuable decision supports for defect prevention in different stages of a paint application process.

2. Automotive coating operation and quality concern

2.1. Process

A typical flowsheet of an automotive paint shop is depicted in Fig. 2. In the shop, vehicles one by one on a conveyor move through about 20 processes where five layers of thin coatings, such as phosphate, e-coat,