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Online quality optimization of the injection molding process via digital image processing and model-free optimization

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ABSTRACT

Injection molding is a widely used polymer processing technology that transforms plastics into products of various shapes and types. Defects may occur on molded products during production under improper settings. Online process optimization is a kind of systematic method that handles such problems by investigating the correlations of process variables and the quality of final products. However, this method requires accurate measurement of the quality index, which is challenging for some defects, such as shrinkage and flash. This study proposes a systematic method that combines digital image processing (DIP) and model-free optimization (MFO) to solve such problems. DIP technology is used to monitor the magnitude of surface defects. MFO uses online measurement as feedback to determine the optimal settings. The proposed method is successfully implemented on an injection molding machine. Experimental results show that it can effectively determine optimal solutions to eliminate defects of molded parts.

1. Introduction

Injection molding is a major plastic processing technique to convert thermoplastic into different products through an injection molding machine. Currently, a large ratio of all plastics is processed by injection molding, and almost all industries use injection molded parts to manufacture products. The entire process comprises three sequential stages: filling, packing-holding, and cooling (plastication). In the filling stage, a screw moves forward and pushes the melt through a runner, then a gate, and finally into a cavity. The cavity pressure gradually increases during this period until the cavity is completely filled, and then the pressure rapidly increases, and the process moves to the packing-holding stage. In this stage, additional materials are packed into the cavity at a high pressure to compensate for the material shrinkage caused by cooling. This process continues until the gate freezes. Subsequently, the melt can no longer be pushed into the mold. The cooling stage continues, accompanied by a gradual reduction in cavity pressure, until the material solidifies enough to eject the molded part from the mold without any damage. As the polymer cools in the mold, the polymer in the barrel undergoes plastication to prepare the melt for the next cycle.

Although it appears simple, injection molding is a rather complex nonlinear and time-varying dynamic process during which machine parameters, material properties, and process variables interact with one another to determine the quality of the final products. The quality of an injection molded part can be roughly divided into three categories: (1) dimensional properties, such as weight, length, and thickness; (2) surface properties, which are represented by the appearance of surface defects, such as sink marks, shrinkage, and flash; and (3) mechanical or optical properties, such as tensile and impact strengths.

Quality optimization is the ultimate goal for injection molding industries, where optimal process settings are determined to meet quality product requirements while saving on materials and energy. Zhao et al. reviewed three types of methods commonly used in optimization of the injection molding process (Zhou, 2012), including non-iterative methods like expert systems and fuzzy systems, intelligent optimization algorithms like genetic algorithms and particle swarm algorithms, and surrogate model-based optimization (MBO) methods. According to the authors' understanding, the second one, intelligent optimization algorithms, is more like a type of gradient-free algorithms used for optimization, as a comparison to gradient-based algorithms commonly used

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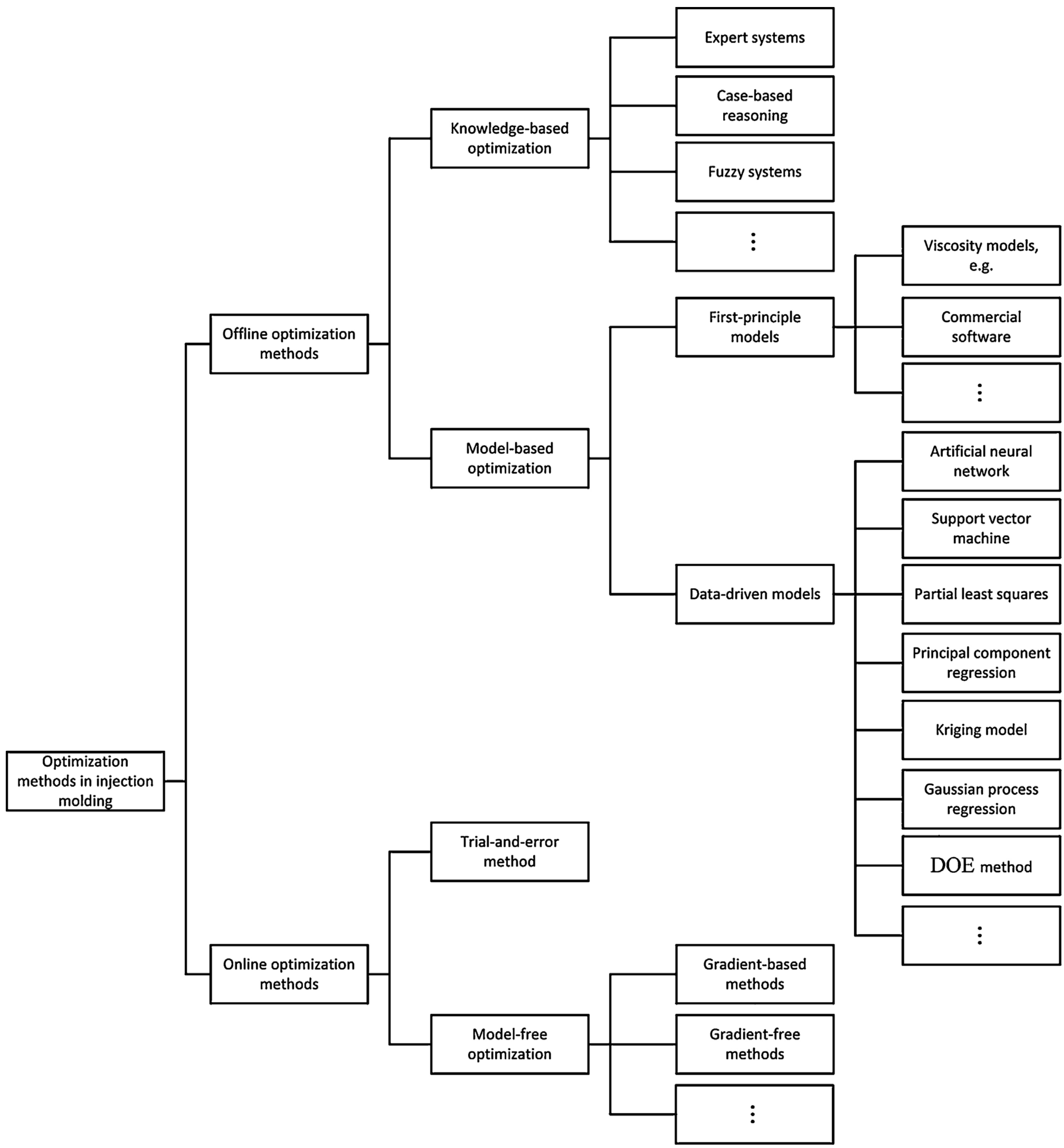

Fig. 1. Categorization of optimization methods in injection molding.

for MBO. Therefore, it may be more appropriate to divide them into two types, knowledge-based methods and model-based methods according to the key difference in building a relation between inputs and outputs. On the other hand, the optimization may also be categorized into the offline and online types according to the implementation difference. The different quality optimization methods in injection molding processes can thus be summarized with different levels and types as shown in Fig. 1. At level 1, the methods are categorized into offline optimization and online optimization. The offline optimization methods for injection molding can be divided into two groups, namely, knowledge-based methods and model-based methods. The knowledge-based methods include expert systems (Tucker, 1989), fuzzy systems (Zhou et al., 2007), case-based reasoning (Kwong et al., 1997), etc. Decisions are made based on the accumulated knowledge to search for the operating conditions. Normally, it is not easy to find the best solution by using these methods due to the lack of the accurate correlation between inputs and outputs. The MBO method, as a comparison, could be more efficient for the process optimization. The key of the MBO method is to develop a model to correlate the process variables and the quality of final products; based on the model, optimization algorithm is then used offline to search the best operational settings.