Real-time parameter optimization based on neural network for smart injection molding

H Lee¹, Y Liau¹ and K Ryu²

¹ PhD Student, Department of Industrial Engineering, Pusan National University, Busan, Korea.
² Associate Professor, Department of Industrial Engineering, Pusan National University, Busan, Korea.
E-mail: hslee.yeeyeng85.kryu@pusan.ac.kr

Abstract. The manufacturing industry has been facing several challenges, including sustainability, performance and quality of production. Manufacturers attempt to enhance the competitiveness of companies by implementing CPS (Cyber-Physical Systems) through the convergence of IoT (Internet of Things) and ICT (Information & Communication Technology) in the manufacturing process level. Injection molding process has a short cycle time and high productivity. This features have been making it suitable for mass production. In addition, this process is used to produce precise parts in various industry fields such as automobiles, optics and medical devices. Injection molding process has a mixture of discrete and continuous variables. In order to optimized the quality, variables that is generated in the injection molding process must be considered. Furthermore, Optimal parameter setting is time-consuming work to predict the optimum quality of the product. Since the process parameter cannot be easily corrected during the process execution. In this research, we propose a neural network based real-time process parameter optimization methodology that sets optimal process parameters by using mold data, molding machine data, and response data. This paper is expected to have academic contribution as a novel study of parameter optimization during production compare with pre-production parameter optimization in typical studies.

1. Introduction

Injection molding is a manufacturing process for producing plastics parts by injecting material into a mold. A wide variety of products are manufactured using injection molding, which vary greatly in their size, complexity and application. Injection molding process has two most common problems of all. The first problem is the derivation of optimal process parameters for initial injection molding machine setting considering various process variables in order to implement effective manufacturing after product design. In order to derive the optimal process variables, there is a process of continuously adjusting the process parameters in a trial-error manner which causes considerable loss. The second problem is the difficulty to change the value of initial process parameter during injection molding process, especially when defects occur during manufacturing. Currently, there is not yet method for quality improvement of this dilemma, and it is challenging to response to the occurrence of equipment failure and sudden production problems. In this research, we present a methodology of neural network based real-time parameter optimization in injection molding process and propose the detailed neural network structure. This study is expected to facilitate establishment of smart factories for injection mold, and to suggest a guideline for manufacturing innovation toward the fourth industrial revolution.
2. Literature research

Injection molding is the most widely used fundamental manufacturing process for plastic products. It is ideally suited for mass production of plastic parts with complex shapes requiring precise tolerance. In this process, hot polymer melt is forced into a cold empty cavity of a desired shape and is then allowed to solidify under a high holding pressure.

In order to improve the injection molding system, various researchers conducted injection process innovation and analysis. One of the representative researchers is one by Tuncay and Hasan[1]. They have studied the quality and process problems according to the characteristics of injection products by using neural network, Taguchi method, and Meta-heuristic method. In addition, the control parameters of injection molding machine were derived on the main characteristics such as defects (moldability, appearance defects, distortion, warping) of the injection mold, and proposed method for deriving the optimal parameters [2]. Lu and Kim[3] studied the effects of injection molding conditions on surface contours of a molded polycarbonate lens. In order to systematically analyze the effects of various process parameters on the lens contours, statistical methods were used in conducting the experiments. Sadeghi[4] proposed a neural network model for predicting the quality or soundness of the injected plastic parts based on key process variables and material grade variations has been developed. The approach uses a backpropagation 4–2–3 net trained based on inputs/outputs data which were taken from simulation works carried out through a CAE software. In recent times, many techniques are being developed to solve multiple-input–multiple-output (MIMO) parameter- based problems, such as neural network, group method of data handling (GMDH) algorithm, fuzzy logic, etc. Nam [5] analyzed the temperature and pressure data inside the mold and controlled the process variables to optimize the quality using K-fold Cross Validation method. Gao [6] proposed a methodology for monitoring the quality of online produced products by using the Support Vector Regression method by utilizing the initial mold, melting temperature, and filling pressure values based on the design of experiments and simulation. Chen et al. [7] conducted a sequential analysis process using the Taguchi method, ANOVA, Response Surface Analysis method, and hybrid heuristic method (Genetic Algorithm + Particle Swam Algorithm) to derive manufacturing time, Many MIMO (Multiple Input and Multiple Output) studies have been conducted to optimize multiple quality levels. Taghizadeh et al. [8] derived initial process parameter settings for optimum quality by learning the mold temperature, melt temperature, settling value and degree of warping of the product using back propagation artificial neural network. The aforementioned researches focus on the reduction of defects by using historical data. However, we attempt to analyze the real-time data and to control the processing parameters in the real-time. The existing previous studies are mainly focused on the optimal process parameter setting right after product design. The studies are conducted on initial parameter optimization according to product and production characteristics by combining various statistical techniques and soft computing methods. It is essential to study the optimization in manufacturing field and shop floor by utilizing the technical factors and design principles of smart factory.

3. Real-time parameter optimization system

3.1. System framework

The proposed Smart injection molding system framework is shown in Figure. 1. The Smart injection molding system is a set of technologies that performs self-decision making, prediction, verification and control based on variable data generated during the process to optimize quality and production through data analysis, simulation, and control enhancement techniques. This system is able to conduct a self-learning of know-how and knowledge on characteristics of product quality and search the optimal initial parameter setting. Furthermore, this system can control the process parameters during production time using real-time data to prevent defects. The framework proposed in this study is inspired by six design principles of smart factory. The six design principles such as interoperability, virtualization, real-time capability, etc. are adapted in each module or functions. For example, interoperability is applied to communication between functions modules (Global decision maker and Local decision maker) and virtualization is applied to Digitalized factory model.
This framework is divided into three layers including planning layer, execution layer, and control layer. In this paper, we define and analyze the execution layer and the control layer of the injection mold system intensively.

In this paper, we focus on a data analysis framework for the control layer, which is a management area of the SCADA (Supervisory Control And Data Acquisition) system on the point of view of manufacturing support systems. The framework consists of four modules: Mold sensor, Machine controller, Vision sensor and Process parameter optimizer.

Mold sensor collects temperature data inside the mold. Machine controller acquires molding machine process parameter and internal cylinder temperatures. Vision sensor is constructed as a visual sensor system for collecting the shrinkage and warpage data of the final product produced. Process parameter optimizer derives optimal process variable values to minimize defects using the artificial neural network. First, the machine controller acquires control log data (melting temperature, packing time, etc) generated in the injection molding machine itself, and obtains the temperature (usually three or four zones) of the cylinder zone temperature inside the molding machine. This is replaced by the new setting value derived from the process parameter optimizer. The mold sensor acquires temperature data inside the actual mold to determine the difference between the control value of the actual equipment. A detailed description of process variable optimization is provided in the next section.

![Diagram of the framework of smart injection molding system](image)

**Figure 1.** Framework of smart injection molding system.

### 3.2. Process parameter optimizer

The injection molding process has a mixed data in which continuous and discrete data. It is necessary to synchronize the type of data in order to learn and predict through the artificial neural network. In this study, continuous data is transformed into discrete form using Self-organizing maps (SOMs). SOMs were developed by Kohonen(1982) and are a peculiar class of artificial neural networks based on unsupervised competitive learning which consists of iteratively modifying the synaptic weights [9]. In self-organizing systems, the output neurons of the network compete among themselves to be activated, and an output neuron winning the competition is called a winner-takes-all neuron or a winning neuron [10]. The neurons, selectively tuned to discrete input patterns, are located on a one or two dimensional lattice in a topographic map, and they have intrinsic statistical features.

In this study, SOM is applied to extract the dynamic process parameter characteristics as the network input. The proposed methodology uses a sigmoid function for the backpropagation artificial neural network (BPNN) structure. Figure 2. is Architecture of the BPNN model. Table 1. is input and output variables of the proposed BPNN model.
Figure 2. Architecture of the proposed BPNN model.

Table 1. Input & output variables of the proposed BPNN model

| Variables                        | Setting range | Data feature |
|----------------------------------|---------------|--------------|
| Mold temperature (°C)            | 20 - 80       | Continuous   |
| Packing pressure (MPa)           | 30 - 175      | Continuous   |
| Back pressure (MPa)              | 50 – 70       | Continuous   |
| Melt temperature (°C)            | 180 - 280     | Discrete     |
| Packing time (S)                 | 1 - 18        | Discrete     |
| Cooling time (S)                 | 7 - 25        | Discrete     |
| Warpage (mm)                     | 0 – 1         | Discrete     |
| Shrinkage (%)                    | 0 - 3         | Discrete     |

4. Conclusion
In this study, we proposed a system framework to optimize process parameters of injection molding system. The proposed system framework is divided into three categories. We focused on the function and data analysis methodology for the control layer. We proposed the artificial neural network structure of SOMs and BPNN based on the data obtained from the shop floor. The proposed artificial neural network is defined as a structure that supports learning of artificial neural network by discretizing continuous data. Furthermore, input and output variables of artificial neural network are defined based on existing literature. However, this study excluded the analytical process and the verification process of the experiment using real data. Therefore, it is expected that future work will be required to prove and verify the results of failure prediction and derivation of optimal variables using actual data.

Acknowledgments
This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MEST) (No. 2016R1A2B4014898).
References

[1] Erzurumlu T, Oktem H 2007 Comparison of Response Surface Model with Neural Network in Determining the Surface Quality of Moulded Parts Materials & Design 28 459-465.

[2] Ozcelik B, Erzurumlu T 2006 Comparison of the Warpage Optimization in the Plastic Injection Molding using ANOVA, Neural Network Model and Genetic Algorithm Journal of Materials Processing Technology 171 437-445.

[3] Lu X, Khim L 2001 A Statistical Experimental Study of the Injection Molding of Optical Lenses Journal of Materials Processing Technology 113 189-195.

[4] Pattnaik S, Karunakar D, Jha P 2012 Application of Computer Simulation for Finding Optimum Gate Location in Plastic Injection Moulding Process International Journal of Advanced Engineering Research and Studies 159-161.

[5] Nam J 2016 Injection-moulded Lens form Error Prediction using Cavity Pressure and Temperature Signals based on K-fold Cross Validation Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 0954405416654421.

[6] Gao R X 2014 Online Product Quality Monitoring through In-process Measurement CIRP Annals-Manufacturing Technology. 63 493-496.

[7] Chen W, Pen H, Shu C 2014 An Integrated Parameter Optimization System for MIMO Plastic Injection Molding using Soft Computing The International Journal of Advanced Manufacturing Technology 73 1465-1474.

[8] Taghizadeh S, Özdemir A, Uluer O 2013 Warpage Prediction in Plastic Injection Molded Part using Artificial Neural Network Iranian Journal of Science and Technology, Transactions of Mechanical Engineering 37 149.

[9] Chen W C, Tai P H, Wang M W, Deng W J, Chen C T 2008 A neural network-based approach for dynamic quality prediction in a plastic injection molding process Expert systems with Applications 35 843-849.

[10] Miller W T, Hewes R P, Glanz F H, Kraft L G 1990 Real-time dynamic control of an industrial manipulator using a neural network-based learning controller. IEEE Transactions on Robotics and Automation 6 1-9.