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# Knowledge-Based Deriven Manufacturing System (KDMS) for Injection Molding

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***Abstract*—The global manufacturing development faces the new challenges including waste of resources, short delivery time, labor cost increase, short of labor, etc.. As a result, the overall industry environment of plastic materials manufacturing turns to focus on automatic production that enables manufacturing industry entering into the next phase so that production efficiency, man-made errors, and labor shortage can be improved. In this study, a cloud based platform of knowledge-driven manufacturing system integrates science bases and practical experience of injection molding with remote control technology that can enhance traditional production efficiency in several aspects such as production guidance in design/tooling/molding phases, production scheduling for all working members and equipment and processing monitoring via internet. More important is that during each working stage, sufficient knowledge are provided and guiding/driving the design/manufacturing work. The new knowledge/data are accumulated, preserved, reused. The system has been test in Jabil Green Point and Techmation, the efficiency is more than 50% improvement as compared with traditional human operation.**

***Keywords*—Intelligent, Knowledge-driven, Cloud**

## I. Introduction

Injection molding is one of the effective processes in manufacturing industry, which plays an essential role for mass production of plastic products. Currently, the industry around the world are all challenged by the same issues, that is, absence of labor, energy consumption, unstable product quality, and profit reduction. If there are no organized management system and standardized processing, it is hard to withstand the high product requirements and shortening delivery time. In order to improve those challenges and enhance the traditional molding efficiency, Industry 4.0 based on the concept of Internet of Things (IoT) and cloud service, big data collection, has first been proposed in Germany. By this new concept of industrial revolution, it gives a new thinking of making products through integrating with other technologies to enhance production flexibility, standardize production processing, and optimize molding conditions.

Operational experience and professional knowledge are the most valuable possessions of a company for their production. However, these usually lost when the employees left their jobs. The traditional way for plastic production is highly depending on the labor adjustment and experienced workers. How to preserve those knowledge and experiences greatly, and reuse it effectively comes as a vital issue. Following with the informatization generation, traditional manufacturing industry need to be transformed to highly automatic molding shop like eFactory by integrating with other technologies such as Information Technology (IT), Monitoring, Automation and Digital Manufacturing. The technologies synergy results in the greater integration and management ability for currently high requirement on the precision, fast, and complex molding processes and manufacturing apparatus, further improving the production efficiency and cost reduction.

In the past decades, injection molding process is based on the operators who adjust the molding machine parameters, designated as trial and error manner, to obtain the stable molding conditions got molding fine products. However, this operation manner, although workable, can result in numerous issues like waste in energy consumption, materials usage, cycle time and not enough high yield. Since trial and error is highly depending on the practical experiences and professional skill of the operator, it is hard to preserve the molding data and operational experiences, and the molding condition differs from each operator even for the same product.

Based on attributed adjacency graph, Ye [1] proposed the extended attributed face-edge graph (EAFEG) solid model representation method, which is unlike traditional graphbased methods using graph matching for feature recognition, the author used EAFEG and summarized rules to search the cut-set subgraphs and effectively recognize the undercut features. Ran [2] used the geometric solid topology and parting direction to recognize internal and external undercut features and automatically design the internal pin structure. Bassi [3] conducted accessibility analysis according to given mold parting directions to classify model solid curved surfaces in order to recognize features that cannot be molded by cavity or core molds. Kumar [4] divided undercut features by level of visibility into completely and partially visible undercut features, by proposing the polyhedron face adjacency graph for the recognition of undercut features. Unlike traditional graph-based methods, this method uses a Bezier surface coupled with the undercut visibility concept. In addition, the author proposed a rule for automatic production of the optimal parting surface of a model.

On the other hand, in order to solve various molding problems and optimize parameters, a number of researches [5-6] devoted on the computer aid engineering (CAE)

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technology with algorithm optimization process such as Taguchi method, cellular neural networks (CNN), and genetic algorithm. Chang [7] used genetic algorithm with CNN to optimize warpage and shrinkage problem, further verified with moldflow simulation. Lin [8] provided a self-adjustment system called ANFIS in order to optimize the molding parameter. This system combined fuzzy control with cellular neutral networks, and using Taguchi experiment method for testing and collecting diverse defect parameters as an intelligent integration database; furthermore, verifying with Moldex 3D commercial simulation software. However, there are more unpredictable instability during practical molding process. Hence, intelligent injection molding guidance [9] has been developed for obtain the optimum molding condition by analysis the relationship between parameters and product quality. Wang [10] provided an optimum parameters predictable module which used Taguchi experiment method, and using genetic network for achieving self-adjustment during real molding. Gao [11-12] developed a real-time close-loop quality control system by collecting the real-time sensor data to compare with the set up parameters, and further input to CNN algorithm to stabilize the product weight. For industrial requirement, an intelligent control system of injection machine needs to connect with not only executive level but operation side as well in order to control molding problems and cost for each product. Because of the similarity of product design, which is usually operate with the same experience, or the new challenge of product development, it is necessary to create a full database for preventing double work and fast regaining the historical data. The guidance of rationalized molding parameters is able to reduce the professional requirement of operators, and can stabilize molding quality in a short time. This sort of intelligentized control systems are the major development direction for manufacturing industry, and bringing about several advanced in creating new value of molding industry, decreasing the defect occurred, shortening cycle time, and cost reduction. This study employed strip model, and calculating the optimum filling time (injection speed), injection pressure/ clamping force, packing pressure, packing time, and cooling time through nominal shear stress as viscosity under different melted/ mold temperature. By using the parameters calculated above, we further optimize the molding process by different levels of Taguchi experiment method.

## II. System Structure

Knowledge-driven manufacturing system for injection molding is a full functional vertical integration platform from the beginning of mold design, tooling stage, and the end of molding (Fig. 1).

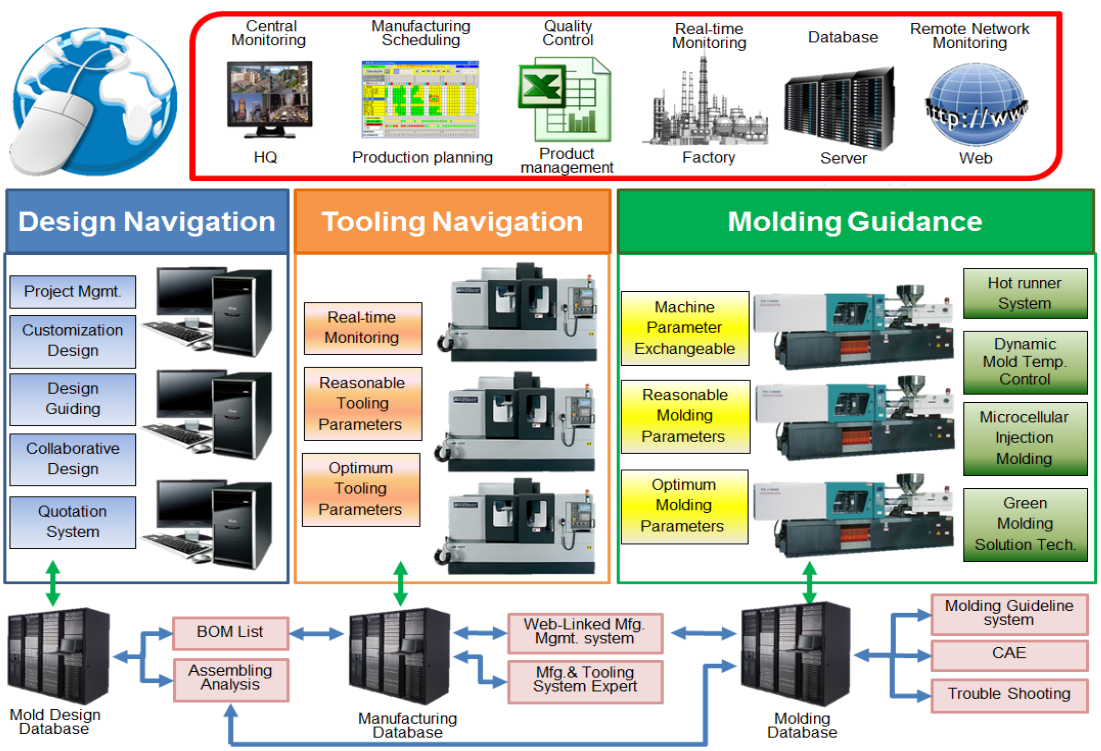


Figure 1. Structure of knowledge-driven manufacturing system for injection molding

Within the system, it is consisted of four essential elements, which are production guidance, professional database, human machine interface (HMI), and Internet cloud based structure. All of them are linked with each element to bring about the maximum profit of its value. Moreover, this manufacturing system possesses several significantly features. One of the features is open structure that can share data and information with other commercial software like PLM and ERP system, which was originally used, as well as secondary development on CAD software. On the other hand, it is developed numerous versatile modules like automatic recognition product features, mold design, rationalized parameter, and optimization, and so on. Those serve as a guidance to assist user for shortening process time by the professional database.

Production guidance is an innovation function to enhance the traditional efficiency on product development, which can show the guideline during production process. Those guides are composed of a number of theoretical algorithms and practical experiences so that it is able to provide reliable and feasible standard lists of guideline. For those three sections (design, tooling, and molding), they have their own particular navigator presented as below:

- Design navigation is a guidance for two parts which are mold design and mold manufacturing, and mainly leading user how to design a mold in reliability effectively. In mold design, whole the procedures of mold design have been separated to several navigator modules including mechanism design, concept design, mold design, mold base design, and 2D drawing (Fig. 2). By completing the navigator modules step by step, it can obtain the 2D drawing of mold eventually. Moreover, mold manufacturing comprises numerous useful guidance modules to strengthen connection to the tooling stage like manufacturing planning, electrode design, NC code, and tooling scheduling, etc..
- Tooling navigation is basically to make mold in automation technology. All the apparatuses such as CNC machine, electrical discharge machining (EDM) machine, wire cutting machine and all the relevant fixtures are connected to central surveillance office. It is possible to deliver the NC code received from design navigation directly into machine, and further to retrieve the tooling data for monitoring. In order to maintain the mold precision, some remote controlling modules can adjust the tooling progress immediately from surveillance office if the issues occurred like chatter, cutter breakage, and build up edge.
- During the first mold trial, molding guidance can provide molding parameters in a short time by simply input requirement information. Rationalization parameter module is the one that can give reliable parameter by material and machine selected as well as product dimentional data inputted. Furthermore, if there is defect on the product produced by rationalized parameter, optimization module could give advanced parameter for specific defect.

All of the production navigators are reliable standard lists of guideline, and depending on the professional database as core to support the data giving.

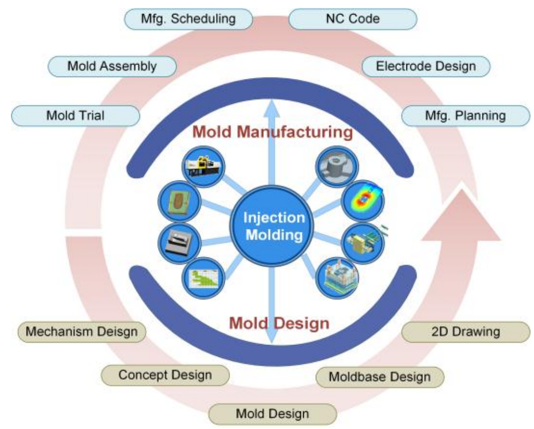


Figure 2. Architecture of design navigation

For mold design/tooling/molding sections, there are their own professional database which collects their associated data like standard mold parts, tooling information, material, and apparatuses data, and so on, for production guidance supported. On the other hand, because of database supported for knowledge management, it is able to accumulate all the historical project experiences to enrich itself as well as referring next time when the similar project started. By those characteristics, the database support sorted by three sections as Fig. 3 which are pro-production, production, and post-production. Moreover, in order to enhance the efficiency of database application, it could be consolidated with intelligentized machines for retrieving data immediately by HMI, and preserving know-how in their customization database in the factory of different places (Fig. 4).

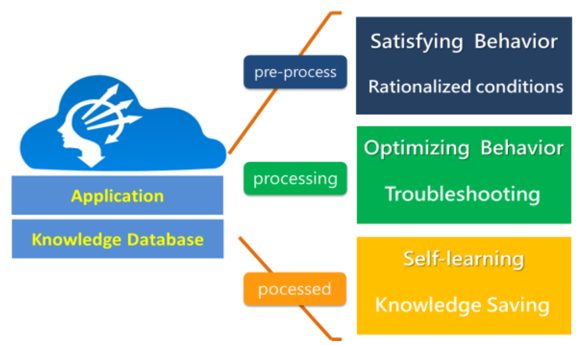


Figure 3. Database support process

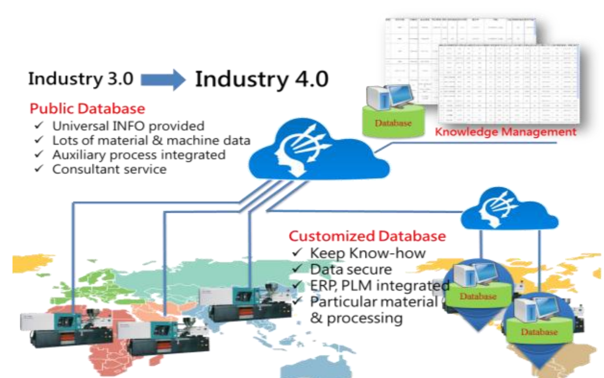


Figure 4. Integration service model of database, cloud, and injection machine

HMI system serves as a bridge for information delivering from central surveillance office to intelligentized machines. Based on Internet connection, surveillance office is capable to not only monitor real-time and on-line processing status but also contact with all working groups for further fulfilling remote controlling management. The big data collected from machine will finally send to cloud for sharing with each of section. There are three levels for the application of knowledge-driven manufacturing system, which are assistance, optimization, and cloud service, showed as Fig. 5.

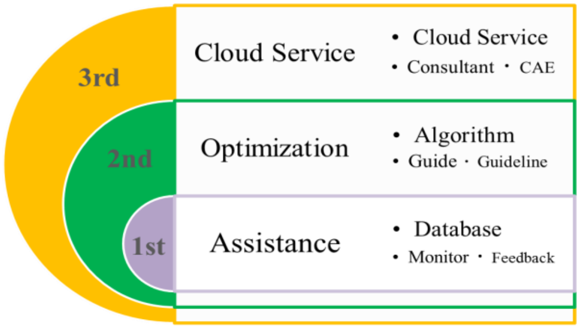


Figure 5. Three levels structure of knowledge-driven manufacturing system

## III. Results and Discussion

Our system collects theoretical algorithm, operational experiences, and simulation data, and being able to provide adequate mold design guideline, tooling database, and practical molding conditions as well as integrating into the workflow to meet the actual molding progression. All the data and information organize into professional database as support to apply in connecting to different software and controllers. Therefore, the connection efficiency between central surveillance and factory can be improved that upgrades the industrial automation capability.

This system has now been built as cloud based that is readily to login anywhere with Internet, and obtaining workflow information for whole working group members. Moreover, it is further able to pass retrieving parameters directly into controllers of tooling machine and injection molding machine as achieving the way of remote control of manufacturing line. The features of this cloud based knowledge-driven manufacturing system are: 1) assisting start to mass production rapidly, 2) enhancing process stability, 3) 100% real-time synchronized with apparatuses, 4) cost management, 5) and experience preservation. Furthermore, standard data output makes sure that the stable processing without the discrepancy of operator' s adjustment. Based on the features above, user can save all the conditions been changed as well as transferring between different machines for future producing. For the machine suppliers, the molding conditions given from the system can be the standard that to test machine and check the problem comes from.

In order to test the system feasibility and accuracy, we prepare two case studies for design navigation and molding guidance testing each. In the design navigation case study as shown as fig. 6, design navigator is able to save 76% design time for entire design work from model import to the end of feature design details. Design navigation simplifies numerous complex procedure into one mouse click. Therefore, it is significantly efficiency improvement. On the other hand, fig. 7 shows that the efficiency improved of molding guidance utilizing. Three operators with different levels of experience are employed to adjust the molding parameters artificially, and comparing with the one given by molding guidance. The result shows that the system parameters is capable to get qualified product with the least trial period and times, and saving cooling time dramatically compared to the others.

| | Without Design Navigation | Design Navigation |
|---|---|---|
| Model import | 1(hr) | 0.1(hr) |
| Feature design | [illegible] | [illegible] |
| Feature design Details | 96(hr) | 24(hr) |
| Total | 102(hr) | 24.6(hr) |

76% Time Saved!!

Figure 6.Case study of design navigation

| | System-A | Operator-B | Operator-C | Operator-D |
|---|---|---|---|---|
| Trial Time (min) | 3 | 26 | 36 | 33 |
| Trial Times | 1 | 29 | 32 | 25 |
| Filling Time (sec) | 0.5 | 0.74 | 0.87 | 0.65 |
| Velocity (mm/s) | 111 | 67 | 67 | 85 |
| Injection P. (MPa) | 100 | 60 | 100 | 80 |
| Packing Time (sec) | 6 | 3 | 6 | 5 |
| Packing P. (MPa) | 80 | 85 | 70 | 70 |
| Cooling T. (sec) | 15 | 30 | 30 | 30 |
| Metering (mm) | 70.2 | 70 | 78 | 70 |
| Switch Point | 10 | 15 | 15 | 10 |
| Back P. (MPa) | 3 | 3 | 3 | 3 |
| Weight(g) | 57.8 | 56.1 | 57.1 | 56.4 |


Figure 7. Case study of molding guidance

## Conclusions

According to the market research, the plastic application keeps growing in the future, and will reach 38.7 million tons at 2017. During the soar market potential, the enterprise should stay in the high competition. Therefore, this study is successful created a knowledge-driven manufacturing system for injection molding based on the industrial demand. The cloud based manufacture system can provide not merely knowledge guidance during production progress, which decreases not only the laborious mistakes and daily routine jobs, but also the greater management on production scheduling and experience saving. Moreover, the most valuable is that it is capable to reduce the total cost for higher revenue and, eventually, achieving the fully automation factories.

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