Digital Twin concept for smart injection molding

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Abstract. Injection molding industry has evolved over decades and became the most common method to manufacture plastic parts. Monitoring and improvement in the injection molding industry are usually performed separately in each stage, i.e. mold design, mold making and injection molding process. However, in order to make a breakthrough and survive in the industrial revolution, all the stages in injection molding need to be linked and communicated with each other. Any changes in one stage will cause a certain effect in other stage because there is a correlation between each other. Hence, the simulation should not only based on the input of historical data, but it also needs to include the current condition of equipment and prediction of future events in other stages to make the responsive decision. This can be achieved by implementing the concept of Digital Twin that models the entire process as a virtual model and enables bidirectional control with the physical process. This paper presented types of data and technology required to build the Digital Twin for the injection molding industry. The concept includes Digital Twin of each stage and integration of these Digital Twin model as a thoroughgoing model of the injection molding industry.

1. Introduction
Injection molding is one of the most important and common manufacturing process to produce plastic parts in high volume and low cost. Products that manufactured using injection molding vary widely in the geometry complexity, size, materials and application in varies industry. Integration of smart manufacturing concept into injection molding known as smart injection molding which implement the Internet-of-Things (IoT) in injection molding that enables data collection, communication and analytics to achieve flexibility in process and improve production efficiency. Injection molding industry covers three main stages, i.e. mold design, mold making and the injection molding process. The design of injection mold is an important stage because it is costly to do re-design and modification of mold in the future mass production. In current practice, mold design and making are perform either in-house or outsourcing. Mold designer gathers information on part, material and machine to determine the type of mold, layout of the mold in mold design. Once the design is completed, the mold designer will conduct the simulation using mold simulation software and the final design will send to mold making stage. Mold making stage consists of electrode design and manufacturing for mold insert, machining of mold components, assembly of mold and testing of the mold in machine. Tight tolerance and wide variety of processes involved increase the complexity of production planning. An efficient production planning is necessary in order to ensure the completion of mold on time. Finally, the production of plastic parts in injection molding process. It begins with production planning based on
demands, machine and mold availability. During the injection molding process, personnel in the operation perform the control and monitoring as well as optimization of machine parameters setting and the inspection on molded parts. The production data such as parameter setting, machine and mold condition, and rejection will be input and updated from time to time to production planning for adjustment of schedule and maintenance schedule. Real-time control and monitoring is almost impossible because of the large volume of processing data required and difficulty to perform real-time inspection.

Every stage in injection molding industry affects each other on the performance of the production of molded parts. Various data in the entire injection molding industry, including mold design, mold manufacturing and the injection molding process need to be linked to achieve more efficient, smart and sustainable manufacturing environment. Hence, the real-time bidirectional information flow between these stages is crucial to improve the performance from the aspect of quality, time and cost. In addition, a review report about the state of manufacturing conducted by General Electric (GE) in 2017 mentioned that there are not enough skilled people in manufacturing factories to fill manufacturing jobs and keep up with demand. This situation motivates the industry to shift towards smart manufacturing. The merging of Internet-of-Things (IoT) and the concept of Digital Twin enables the real-time data-driven manufacturing in various stages via convergence between physical and virtual production system. Therefore, this paper presented the application of Digital Twin concept in every stage of injection molding industry and the integration of each Digital Twin model that brings all the experts and data from each stage together to achieve complete and powerful insight in injection molding industry.

2. Concept of Digital Twin

Digital Twin plays important role in the 4th Industrial Revolution because it enables the combination of information technology and operation technology to create new value by link the preparatory production stage with real production. The Digital Twin concept model introduced by Dr. Michael Grieves contains three main parts: physical products in real space, virtual products in virtual space and the connections of data and information that connects the physical and virtual space. Digital Twin can be defined as a replication of real physical production system in digital model, which are used for system optimization, monitoring, diagnostics and prognostics using integration of artificial intelligence, machine learning and software analytics with large volume of data from physical systems.

Digital Twin model has five enabling components – sensors and physical assets from physical system, integration, data and analytics in the digital model. Data consists of data from enterprise and operational and environmental data from physical system obtained using sensors distributed in physical system. The sensors allow bidirectional data communication in real-time between physical system and virtual system using integration technology, which includes communication interface and security. Then the Digital Twin uses the analytics techniques to analyze the data for defined purposes and provides responsive action based on simulation result to physical asset for further action. With the Digital Twin, the operation in a single machine as well in the interconnected system are visible to everyone who has authority to access the system, i.e. manufacturing, procurement, warehousing, transportation and logistics. Digital Twin allows the manufacturers to see how the physical system is performing by looking all the data in the manufacturing execution system. The analytics techniques in the Digital Twin model include what-if analysis and predictive analysis to simulate the real-time conditions in the physical system and predict the future state of the systems. The conceptualization, comparison and collaboration capability of Digital Twin enables us to conceptualize the manufacturing process visually, compare the option and outcome, and then finally collaborate with other manufacturing section.

General Electric (GE), Siemens and ANSYS introduced a series of platform to build the Digital Twin. Currently, this technology has been implemented in aerospace industry, wind-turbine power plant and automotive industry for performance improvement and operational inefficiency prediction. For example, GE has built Digital Twins of jet engine that can achieve power optimization, monitoring and diagnostics of jet engine. DXC Technology built a Digital Twin for hybrid car manufacturing process to predict the performance of car before committing the changes in the manufacturing process.
3. Application of digital twin in injection molding mold design and manufacturing

This section presents the needs of Digital Twin at every stage in injection molding industry and how the Digital Twin connects with each other to build, operate and enhance the performance at each stage. Figure 1 shows the overview of information flow in the injection molding industry.

3.1 Injection mold design

Input information of part drawing and specification of material, molding machine specification and other tool specification such as type of mold, runner system, gate, use of robotics and estimated cycle time are necessary when design the mold. Mold designer has to be experienced enough to take all these considerations and the capability of mold making production to produce the designed mold. Mold design and simulation software such as Moldflow enables designer to design, simulate and analyze the mold designed and the part produced. The data input to simulation is based on the technical specification provided by the material supplier and machine manufacturer. However, in practice, the condition of a specific machine in production varies over time and this will cause the result from simulation differ from the real production. Therefore, in order to obtain accuracy and reduce resetting time during mold testing, the simulation has to be conducted using data from current condition of injection molding machine which to be used. These data can be obtained from the database of the Digital Twin model of the machine in the injection molding production. In addition, lead-time of mold design and making determine the lead-time of product to market. Continuous data input of machines for mold making process helps mold designers to gather the updated information on the machine condition and adjust design accordingly with the capability and availability of machining machines to avoid production delays due to the tool or machine breakdown during mold making. The final design of the mold will act as Digital Twin model.
of the mold and can be virtually installed in Digital Twin model of injection molding machine for future production planning and real-time process simulation.

3.2 Injection mold manufacturing

Once the mold design is completed, the detailed drawing of the mold will save in the database and mold-making production will retrieve the drawings for mold making process. Mold making mainly consists of machining of the parts, assembly and testing. Machining of mold components start with cutting of raw material, milling and lathe, wire-electrical discharge machining (WEDM), EDM and polishing. Each of the machine and tools has its own Digital Twin model. With the Digital Twin models of the machines, the overall physical production of mold making process can be visualized and simulate the production for production planning. During production, sensors distributed at each machine will send real time data to the Digital Twin models for production monitoring, quality prediction and prediction of machine condition for preventive maintenance scheduling. These data will update and store in each Digital Twin model and will be used for future mold design process.

In current practice, the production of mold making are done manually. However, because of the heavy weight of the mold, high variety number of components to be manufactured and assembled, application of human robot collaboration (HRC) systems is proposed in mold making process. Figure 2 shows the proposed framework of HRC systems in mold making. Simulation of the HRC systems is required to determine the collaborative task sequence, robot model selection and robot effector selection. Hence, the integration of the Digital Twin models of the human workers and the robots into the Digital Twin models of machines are necessary. Adaptive capability of robot to human working condition is one of the important issue in HRC systems. The Digital Twin models can analyze, simulate and predict the human worker’s condition with the continuous input of human-robot unit data, and then input the result to robot for motion adjustment to adapt with the human worker’s condition from time to time.

4. Application of digital twin in injection molding process

Many research related to injection molding process focus on the optimization on process parameter and quality, but the trend of research is moving towards real-time process optimization, process monitoring, and prediction of quality defects. Application of Digital Twin concept in injection molding can help to achieve these objectives. Figure 3 illustrates the concept of Digital Twin in injection molding process.

Virtual production consists of the Digital Twin model of every single machine and equipment includes mold, material handling equipment and automated visual inspection system. Each of the machine is unique although they have the same machine specification and model because the machine condition will change when the production proceeds from time to time and this will cause instability in the performance of the molding machine. Besides, it is difficult to ensure the consistency of material supply. These problems lead to the inconsistency in quality of molded part. Before the production, the
initial parameters are set according the result from mold testing in mold making stage. The Digital Twin models of automated inspection system also used to determine and select the corresponding image-processing algorithm and inspection equipment setup before the production starts. During the production, sensors distributed in each physical machine provides updated production data to manufacturing execution system and virtual models. The virtual model feedback the responsive action to physical production for production plan adjustment. The measurement of machine condition such as pressure and temperature corresponding to the machine parameter setting and the real-time result from automated inspection system are input to computational model of Digital Twin for the purpose of process optimization and quality prediction. These data can further analyze and generate maintenance schedule for mold and injection molding machine.

![Digital Twin of injection molding process](image)

**Figure 3.** Digital Twin of injection molding process. (Inj m/c: injection molding machine; AVIS: automated visual inspection system)

### 5. Conclusion

This paper presented the application of Digital Twin concept in injection molding industry from mold design to mold making and finally injection molding process. Technology such as Internet-of-Things (IoT) and Cyber Physical System (CPS) play important role in Digital Twin concept. Some problems in realization of the Digital Twin in injection molding such as manual acquisition of data, implementation of sensors in injection molding machine, development of real-time automated visual inspection systems, optimization and prediction analytics model are yet to be solved to complete the Digital Twin application in injection molding industry.

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