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VISUAL INSPECTION BASED ON MACHINE VISION SYSTEM FOR SMART INJECTION MOLDING

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Abstract. *A machine vision system is widely used in industry for visual inspection, process control, parts identification and robotic guidance. This paper presents the application of a machine vision system in injection molding production and injection mold making stage. Development of visual inspection during injection molding production focuses on real-time automated inspection to achieve higher accuracy quality inspection of molded parts and assist real-time process monitoring and control. Application of Human-Robot Collaboration (HRC) system is proposed in injection mold making stage to improve performance of mold making processes by tackling ergonomic issues. The machine vision system plays important roles in HRC systems for part identification and inspection as well as human movement detection. In order to implement these applications in smart injection molding, Internet-of-Things (IoT) and Cyber Physical System (CPS) are necessary to enable real-time data collection, communication and analytics to achieve flexibility in the process and improve production efficiency.*

Keywords: Machine vision, Smart injection molding, Human-robot collaboration (HR-C) system

1. **Introduction.** The automated manufacturing is shifting towards smart manufacturing concept and intelligent systems with the introduction of Industry 4.0 strategy. A review report about the state of manufacturing conducted by General Electric (GE) in 2017 mentioned that the lack of skilled people in manufacturing factories motivates the industry to shift towards smart manufacturing in order to fill manufacturing jobs and keep up with demand [1]. Injection molding as one of the important manufacturing processes to produce plastics parts needs to make a breakthrough and survive in this industrial revolution. This can be achieved by integration of smart manufacturing concept into injection molding. Smart manufacturing can be defined as collaborative manufacturing system that integrates sensors, communication technology, computing platform for the purpose to respond in real time to meet fluctuation of demands and condition in factory [2,3].

Injection molding industry consists of three main stages which are mold design, mold making and injection molding process. In this paper, we focus on application of machine vision systems in mold making and injection molding process. 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 productivity of mold making production. In addition, the manual handling of heavy mold components and requirement of high accuracy in handling tight tolerance in mold assembly process motivated us to develop human-robot collaboration system in mold industry.

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In common practice in injection molding production, the molded part inspection is done in-line by human inspector or after production, referred as off-line inspection by sampling or sorting. It is difficult to guarantee accuracy and consistency of manual inspection result because the decision on defects in injection molding is subjective based on skill and experience of the inspectors. In addition, human inspector is incapable of inspecting every part especially for the parts which are produced in short cycle time. Delay in detecting the defects on time will occur and cause production of defect parts which is a waste in production. During injection molding process, a defect usually starts occurring at less apparent stage and becomes more serious gradually as production continued. Once a defect occurred, the subsequent parts produced will have defects, too. Defect detection in real time under the environment of unstable condition and diverse disturbance is important to improve the productivity [4].

Machine vision is one of the key technologies for automation and Industry 4.0. Machine vision system benefits manufacturing industries in the field of industrial robot guidance, inspection and part identification. In order to solve the above problems, this paper presents the application of machine vision system for human-robot collaboration system in injection mold making process and how automatic visual inspection provides real-time inspection during injection molding production and the needs of understanding data flow between mold design, mold making and injection molding production to benefit real-time process control in injection molding industry.

2. **Literature Review.** A machine vision system consists of camera, illumination unit, main processor with image processing software and manufacturing process control systems [5]. The basic component is the industrial camera with lens. The ability of camera to capture a focused and clear illuminated image of the inspected object depends on lens and image sensor of the camera. Position and number of the cameras to be fixed depend on the point of interest and dimension of object to be inspected. Illumination unit or lighting is a key to capturing desired image feature and this affects the accuracy of image analysis result. A lighting technique includes a light source, commonly LED light, and its placement with respect to the part and the camera. Types of lighting techniques are back lighting, front lighting, structured lighting and others. A computer is employed for processing of the acquired image by using image processing analysis and classification software [6]. To achieve the objective of the application, the image captured needs to undergo a few processes which are image acquisition, image processing, feature extraction and decision making.

The development of physical components such as sensors and industrial camera and software for machine vision increases the flexibility in application of machine vision system and leads to better quality, efficiency and sustainability in the manufacturing industries. Machine vision systems enable flexibility in automation by providing the machine capability of "see" and think. With these capabilities, machine can work like human workers to identify different parts without additional setup and facilitate quick changeover when part changes. In terms of safety, robot integrated with machine vision system captures image and delivers to the control system to perform operation from hazardous environment. Besides, machine vision systems support workers by accomplished dull and repetitive tasks and ensure perfect human-machine interaction which leads to safety workplace. The current well-developed industrial camera and lens able to capture up to 1000 frames per second. Integrating these cameras the effective image processing and analysis algorithm can scan for defects in short time and perform real-time inspection. Visual inspection system has been applied in various types of manufacturing industries [7,8] such as pharmaceutical industry to scan the color and printing on pills [9], food packing industry to inspect the roundness of bottles [10], and textile manufacturing industry to inspect on-line fabric inspection [11]. This system provides the industry with high accuracy and high consistency for the quality inspection process. The selection of capability of industrial camera that fits the objective's requirements of the application determines the cost and performance of the system. Cost for machine vision system dropped almost 75% compared to past decade due to development of advanced technology to produce the lens and camera components. Thus, application of machine vision with lower cost and better performance that reduce the inspection error cost and labor cost gives the manufacturing industry high savings potential due to the high return on investment.

3. **Machine Vision System for Human-Robot Collaboration (HRC) System in Mold Making.** Human-robot collaboration is one of new trends in the field of industrial robots as a part of strategy Industry 4.0. Human-robot collaboration is a system in which a robot and a human are collaborating on a same task which combines benefits from both human and robot in a joint task [12]. Humans with cognitive skills are able to adapt to any changes in task and understanding of the task. Meanwhile, robots are good in handling repetitive task, reduce ergonomics issue on human workers in handling heavy work piece and can operate for long working hours without fatigue. Thus, a human-robot collaboration system in mold industry is proposed to solve these issues in the mold making process.

Figure 1 shows the proposed framework focusing on developing HRC systems for material handling, processing and assembly operation and inspection operation in mold industry. All the HRC systems in each section controls by the production central control. Each section has its own production control system to receive the assigned operation from central control and generate the corresponding human-robot collaborative task sequences. Communication interface between the section allows information flow between operations and ensures the right operation is performed on right product. In this paper, we will focus on the assembly and inspection section. The operation in assembly and inspection section includes receiving parts from external section such as machining section or maintenance section, identification of parts for mold that to be assembled, assembly of the mold and inspect the functionality of the mold and finally transfer the assembled mold to testing and storage.

Machine vision system plays important roles in this human-robot collaboration system to ensure the accuracy and flexibility of the collaborative tasks with human workers. Situations where mold assembly is required are production of new mold and maintenance of

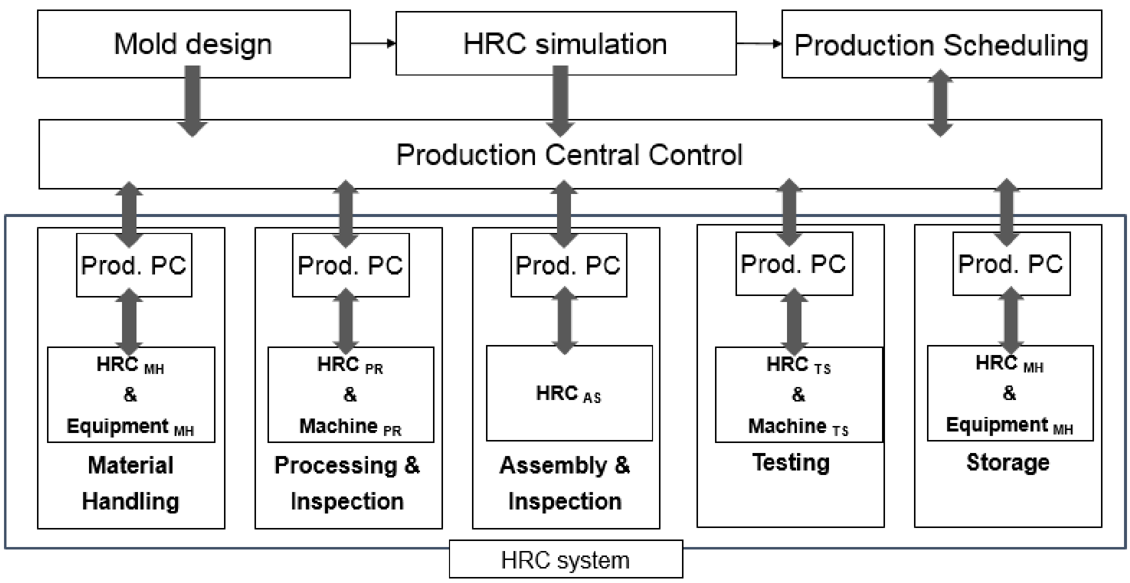

FIGURE 1. Mold manufacturing with human-robot collaboration

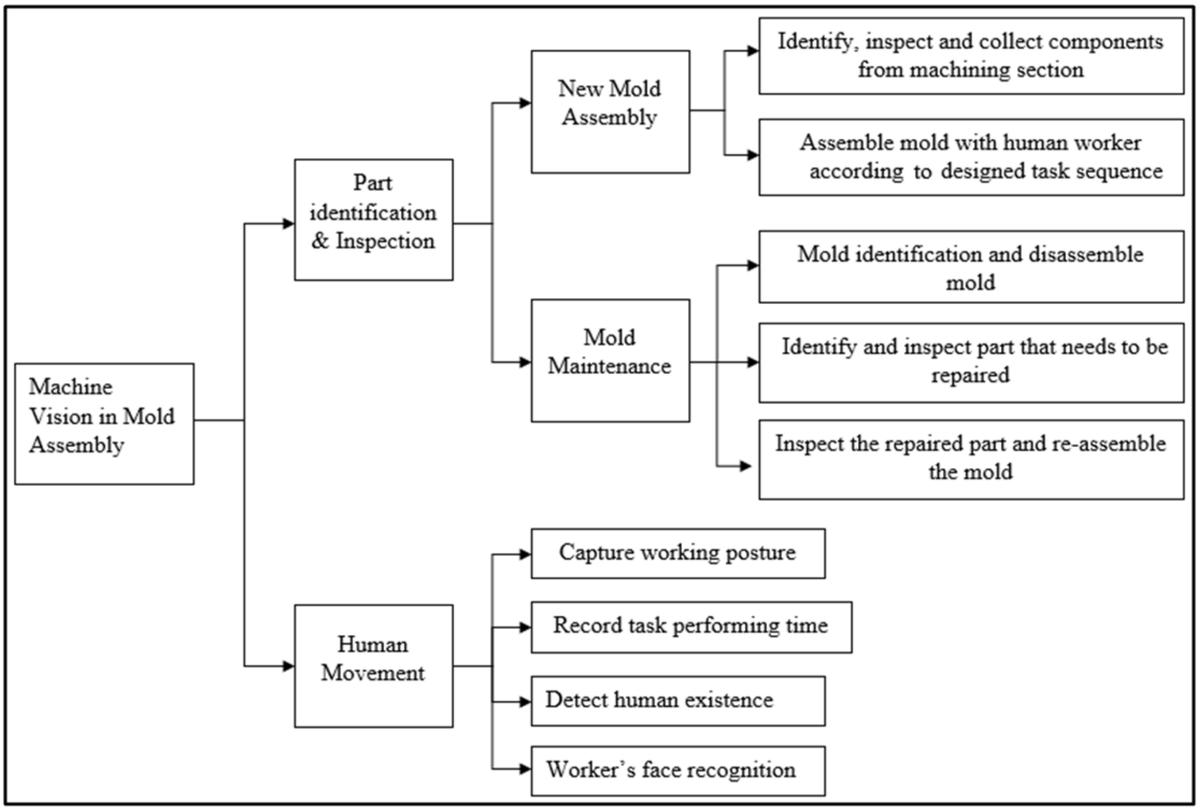

Figure 2. Application of machine vision system in HRC mold assembly

existing mold as requested from injection molding production. Figure 2 shows functions of machine vision systems in the mold assembly with human-robot collaboration system. Two types of machine vision systems are proposed in the human-robot collaboration system. One is attached to the robot which does collaborative tasks. The machine vision system attached to the robot performs tasks such as mold components identification and inspection and human existence detection. For the situation of production of new mold, components in the mold and structure of the mold to be assembled will be loaded into the robot. The robot identifies and inspects the mold components from machining section by using the machine vision system attached to it. If the quality and dimension of the parts meet the requirement, the robot will collect and transfer the parts to assembly section. Whereas, the part will be sent back to machining section for rework. At the assembly workstation, robot positions the mold components according to the assembly sequence at the specific position as in the designed work layout. Then, robot collaborates with human worker to perform the assembly task. During the assembly, robot picks up and assembles the component while human worker adjusts position and inserts screw as necessary. This kind of collaboration can reduce the mistake done by human worker such as misplacement of components and the precision position adjustment performed by human worker can reduce the complexity in the robot programming. Safety collaboration is the most important consideration when implementing human-robot collaboration system [13,14]. Hence, the assembly process is recorded by the camera attached to the robot to detect the existence of human's body part to avoid collision and injury on the human worker. The robot inspects the assembly process from time to time to ensure all the parts are assembled. Finally, an identification code is engraved on the mold and recorded in the mold database. The application of machine vision on the robot for mold maintenance is similar. When a mold is received, the robot scans the identification code on the mold and downloads the mold structure and components that need to be repaired. Then, the robot disassembles the mold and places the components accordingly as the same in the assembly process. Image of the worn part is captured and sent to maintenance section to decide on the repair work or replacement of the part. After the part is repaired or replaced, the robot collaborates with human worker to re-assemble the mold. Every image captured by the machine vision system is stored in the production database for job tracking and improvement as well as the analysis of product cycle of the mold for predictive maintenance.

Another one is machine vision system located at the workstation to capture and analyze the movement of human worker. Adaptive capability of robot to human working condition is one of the important issues in HRC systems [15]. Machine vision system is proposed for human worker's face recognition. Every worker has its own motion trend and posture while performing a task. Hence, face recognition is needed to identify the worker and loaded the specific robot motion programming to collaborate with the worker. With the machine vision installed at the workstation, we are able to capture the motion of the human worker in the aspect of working posture and task performing time. Figure 3 illustrated concept of using machine vision to analyze human worker's motion from time to time. In future application, an algorithm as well as decision making model to determine the adjustment of robot motion will be developed to analyze the posture of the workers to improve the assembly workstation from aspect of ergonomic. The images will be analyzed and simulated to predict the human worker's condition with the continuous input of human-robot unit data. The results are then sent to robot for motion adjustment, action change or role switching to adapt with the human worker's condition from time to time.

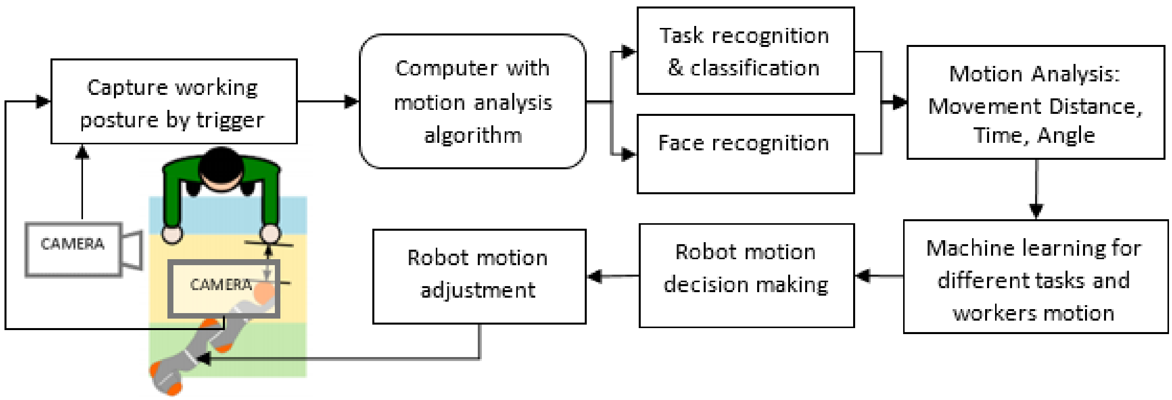

Figure 3. Machine vision to analyze human's motion in HRC mold assembly

4. **Machine Vision System in Injection Molding Production.** The main objective of machine vision system in injection molding production is to perform inspection of the molded parts. We characterized the defects in injection molded parts to physically measurable defect and unmeasurable defect. Unmeasurable defects are defects that cannot be measured by physical measurement tool and usually do not have defined tolerance for inspection. Examples for unmeasurable defects are burn mark, bubble, contamination, sink marks, discoloration, etc. Physically measurable defects are defects that are measurable using measurement tool, such as dimension, shape, flash, brittleness, and warpage. Measurable defects are usually inspected through off-line sampling because tools are required and it takes time to do the measurement; hence on-line inspection will cause stacking of parts at the station. Meanwhile, unmeasurable defects are inspected on-line by human workers. The problems with the human visual inspection are misdetection and inconsistency of the inspection result. Hence, a real-time automated visual inspection system is proposed to inspect both types of defects effectively in-line.

As shown in Figure 4, the real-time automated inspection process starts with the starting of the injection molding cycle. Once the injection of plastic molten into the mold, solidifies and then ejected out from the mold, the sensor positioned at the exit of the part on the conveyor senses the coming of the part and the orientation of part. The signal to the positioning tool will be sent if the orientation of the part is not at the right angle. The positioning tool corrects the angle of the part, and then the camera is on via frame grabber. Camera captures the image of the part molded and image processing algorithm starts defect detection algorithm. If a defect is detected, a signal to reject the defective part will be sent and the production personnel will be alerted. At the same time, the defect is classified into defect types by neural network. The cycle number that produced the part defined as c will be recorded. Besides, the processing parameters of the cycle of the defect occurred, c, the cycle before defect, $c-1$ and the cycle after defect, $c+1$ will be retrieved from the machine controller system. The proposed real-time automated inspection is not only aimed for real-time inspection, but the result can also be analyzed for real-time monitoring and machine prognosis purpose.

Figure 5 shows the overview of data flow in the injection molding industry. Implementation of Internet of Things (IoT) that can ensure the efficiencies of data collection, data flow and data analytics are the main keys for the realization of smart injection molding. As we can see in Figure 4, 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

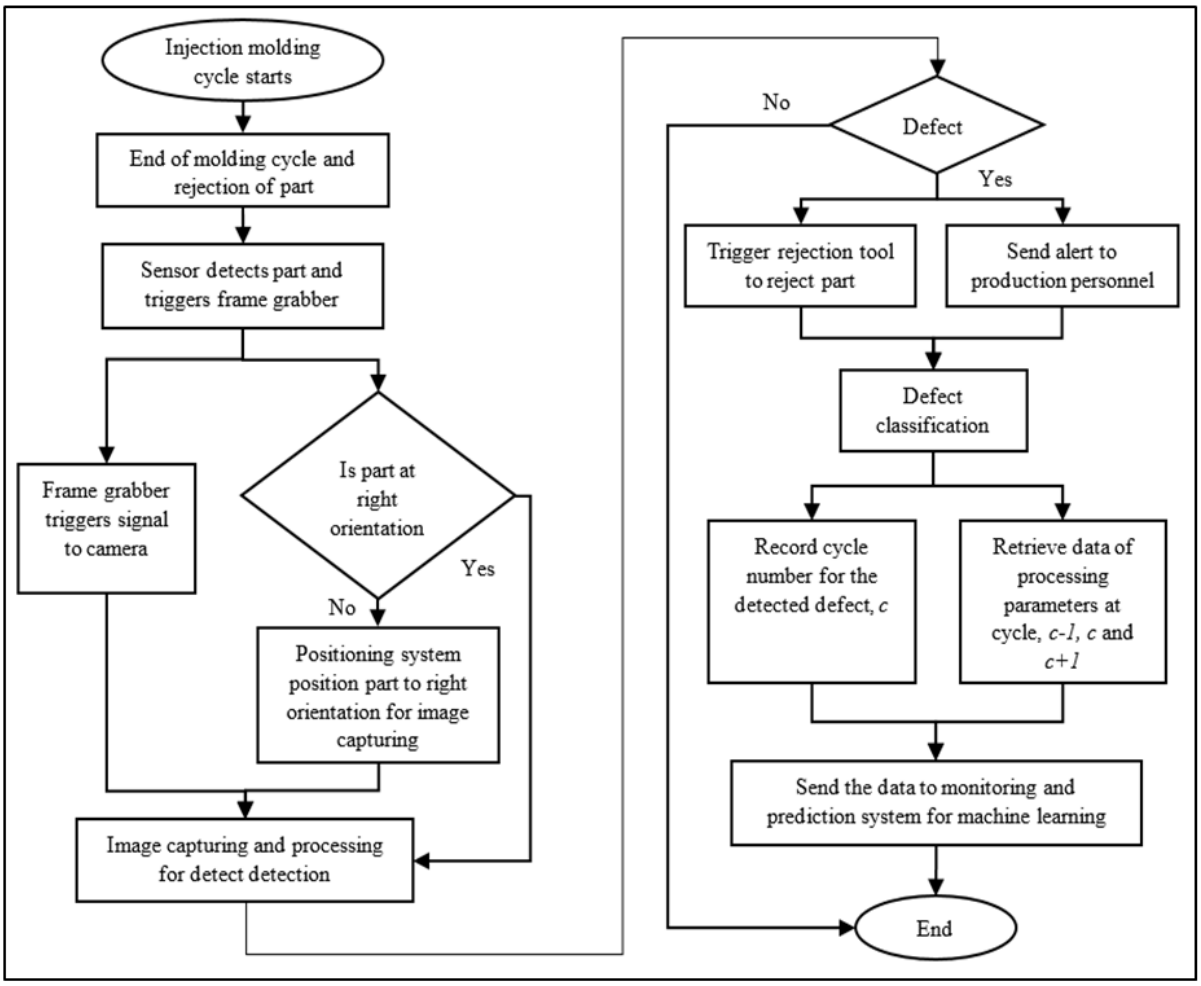

FIGURE 4. Real-time automated visual inspection process

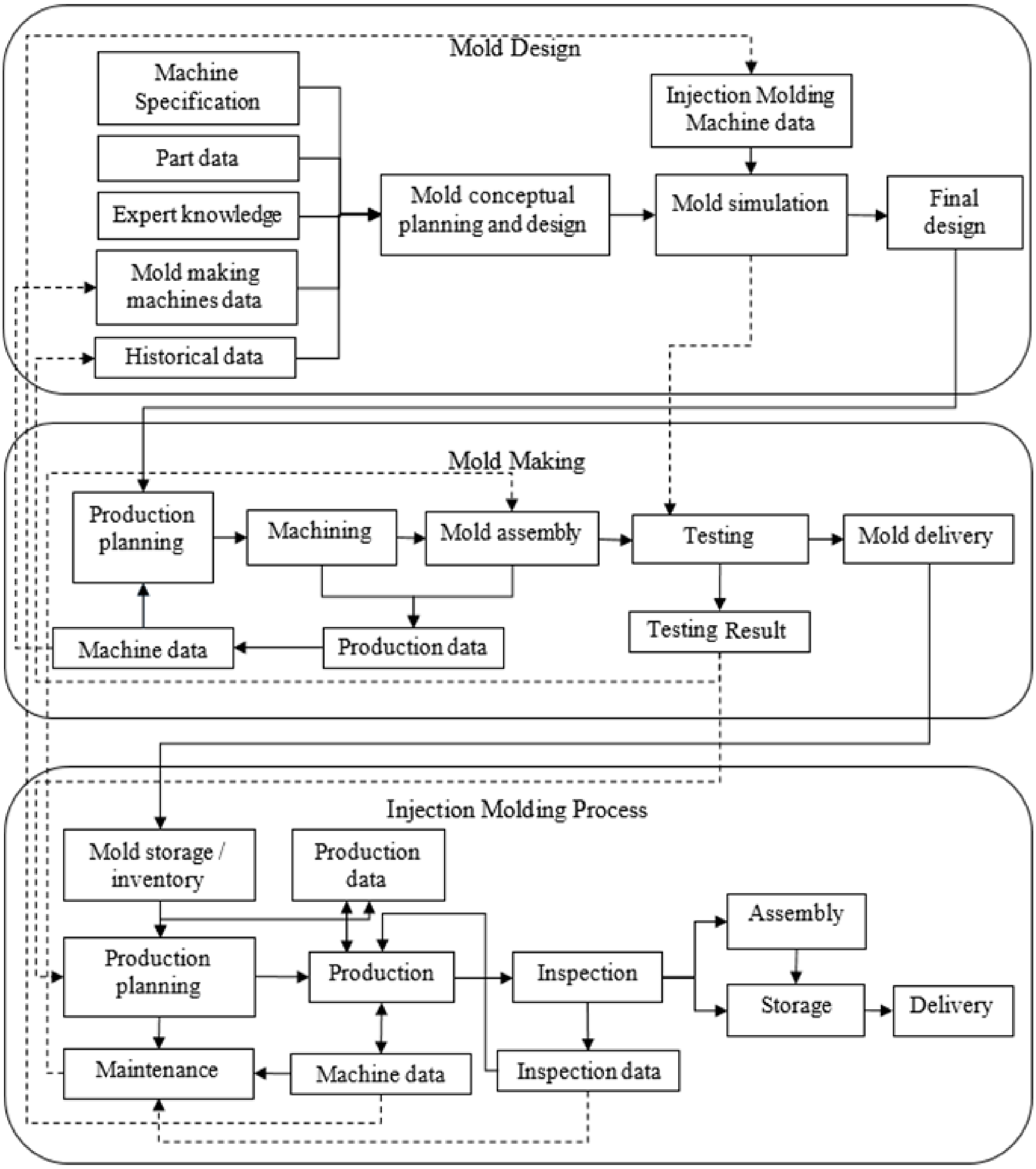

Figure 5. Overview of information flow in injection molding industry

process need to be linked from physical production to virtual production such as analytics model to achieve more efficient, smart and sustainable manufacturing environment [16,17]. The connection and communication of data are important especially when the mold design and mold making are outsourced to mold manufacturer. In such case, IoT plays an important role to link the mold manufacturer and injection molding production to obtain the details of machine specification and current condition of the injection molding machines. Continuous data input of machines for mold making process helps mold designers to gather the updated information on the machine condition and adjust mold design accordingly. The combination of machine vision systems and sensors distributed in the injection molding plant that enables collection for wide range of types of data and real-time bidirectional information flow within and between these stages is crucial to improve the performance from the aspect of quality, time and cost.

The data combination of the processing parameters and the analysis of defect will send to the monitoring and prediction system for further analysis. The data set can be stored as database to study the relationship between significant processing parameters that affect the specific defect. Once the identification of significant parameters is known, the relationship is useful to develop prediction model to predict the defects and abnormality of the process parameters. With the continually input of data on defect versus processing parameters from inspection to the self-learning prediction model, the accuracy of the prediction model can be improved. Meanwhile verification of the prediction result can be done by comparing with the result of the automated visual inspection during the production. Besides, the image of molded part defects captured by automated inspection system can be used to monitor the condition of the mold and machine from time to time for predictive maintenance scheduling. Machine or mold breakdown during the production can be avoided and hence improves the performance of the whole process. The result of predictive maintenance analysis will then send to the mold assembly section to perform disassemble of mold and identification of parts for repair using proposed human-robot collaboration system. Images of molded parts before and after maintenance of mold have to be recorded to trace back the maintenance performed. The image captured from time to time which is stored in the database can be retrieved by the mold designer to improve the mold design and hence increase the life time of the mold.

5. **Conclusion.** This paper presented the application of machine vision systems in smart injection molding industry for mold assembly with human-robot collaboration system and injection molding process. Technologies such as Internet-of-Things (IoT) and Cyber Physical System (CPS) play important roles in smart manufacturing concept. Some problems in realization of the smart 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. The integration of machine vision systems into smart injection molding enables visualization of the whole process and the data acquisition and analysis of assembly workplace and injection molding process are expected to be more effective.

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