International Journal of Control and Automation
Vol. 11, No. 3 (2018), pp.55-66
http//dx.doi.org/10.14257/ijca.2018.11.3.06

Development of Take-out Robot Integrated Control System for Automation of Injection Molding Process by Using Mold Inspection Module

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Abstract

In this study, a take-out robot integrated control system for the automation of injection molding process required for the construction of smart factory is proposed. Integrated operating module, take-out robot controller, mold inspection module, and process and peripheral data acquisition interface module are developed and assembled to make a take-out robot integrated control system. Experimental test is conducted to verify the performance of the mold inspection module with developed take-out robot integrated control system, take-out robot, and standard mold. Developed take-out robot integrated control system has performances such as 5 in number of motor control, 8 in number of sensor interface, 0.112sec in time of defect measurement, 1.3mm by 1.3mm in minimum size of defect measurement, and 5% in minimum relative brightness difference of defect identification. By the adoption of a take-out robot integrated control system, the injection molding process can be simplified and the cost for the construction of smart factory can be reduced.

Keywords*: Take-out robot, integrated control system, automation, injection molding process, mold inspection module, defect identification*

1. Introduction

Goods made from plastic are used in the various areas of living and industry. The injection molding process is used for production of plastic goods [1]. The injection molding machine used for the injection molding process consists of hopper for supplying the plastic chip, heater for heating, screw for transferring melted material, and mold for shaping as shown in Figure 1 and Figure 2. This injection molding process has been conducted by a manual.

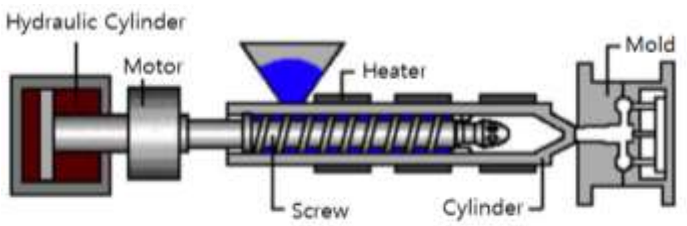


Figure 1. Configuration of the Injection Molding Machine

Recently, efforts for saving of production cost by using the process improvement in the injection molding product, which can be achieved by the adoption of a smart factory, have been increasing [2]. Automation of the production process, gathering of process and

Received (December 28, 2017), Review Result (February 4, 2018), Accepted (February 23, 2018)

ISSN: 2005-4297 IJCA

peripheral data, and transferring to manufacturing execution system (MES) are required for the construction of a smart factory.

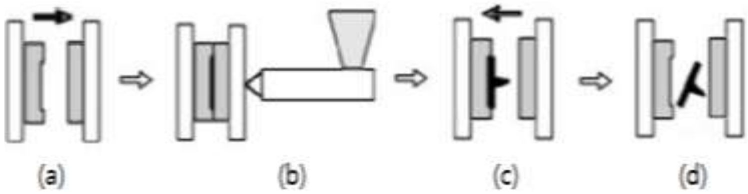


Figure 2. Injection Molding Process: (a) Tool-Close, (b) Injection, (c) Tool-open, (d) Take-out

Several methods, which use the various sensor systems for the monitoring of the process parameters in the injection molding process, have been proposed by many researchers such as Chan [3], Gao [4], Park [5], Marinelli [6], Ono [7], Park [8], Mao [9], and Peng [10]. Woll [11] used the pattern-based part quality monitoring method for the prediction of the part quality by using the pressure sensor. Kang [12] and Rhee [13] proposed the method for the optimization of the molding process by using the monitoring of the molding process. Hong [14] and Park [15] proposed the method for management of the molding process by using the monitoring of the molding process. Quality control plays an important role in injection molding process control to meet stringent tolerance requirements and to facilitate automation. Chen [16-17] proposed direct quality feedback control system having a cascade structure and a combined feedback and feedforward control using part weight as an important quality index. Park [18] and Chen [19] proposed the process control-based injection molding system to improve the quality of products such as accuracy of dimension and surface quality of plastic parts. Kruppa [20] and Zhou [21] proposed the quality prediction model based on the polymer melt properties for monitoring the product weight variation online and the dynamic control method for the improvement of product quality stability. Cui [22] used the ARM controller as the slave computer of injection molding control system to realize the on-site control for the injection molding machines and to provide distributed remoted control services for the host computer. Kim [23] applied embedded controller to the injection molding system to provide information and communication technology (ICT) such as programmable intelligent functions, communication, various interfaces, amplifier functions, and mobile device connection to application. Bu [24] applied a sliding mode controller to control a 4-DOF take-out manipulator in the injection molding machines. Take-out robot, robot teaching pendant and robot controller, mold inspection device having camera and controller, peripheral devices, and human and machine interface (HMI) hub are used in the injection molding process to construct a smart factory as shown in Figure 3. Process and peripheral data generated in the injection molding process are transferred to MES via HMI hub. By using the various peripheral devices such as dehumidifier, grinder, and refrigerator, the injection molding process is complex and the cost for construction of the smart factory is expensive. Chung [25-26] proposed the configuration of the take-out robot integrated control system for smart factory construction by the automation of the injection molding process. In this study, take-out robot integrated control system, which consists of integrated operating module, take-out robot controller, mold inspection module, and process and peripheral data acquisition interface module, is proposed, developed, and verified to simplify the injection molding process and to reduce the cost for the construction of smart factory.

In Section 2, the configuration of a take-out robot integrated control system is proposed. After which, a take-out robot integrated control system is developed in Section 3. Experimental test is conducted in Section 4.

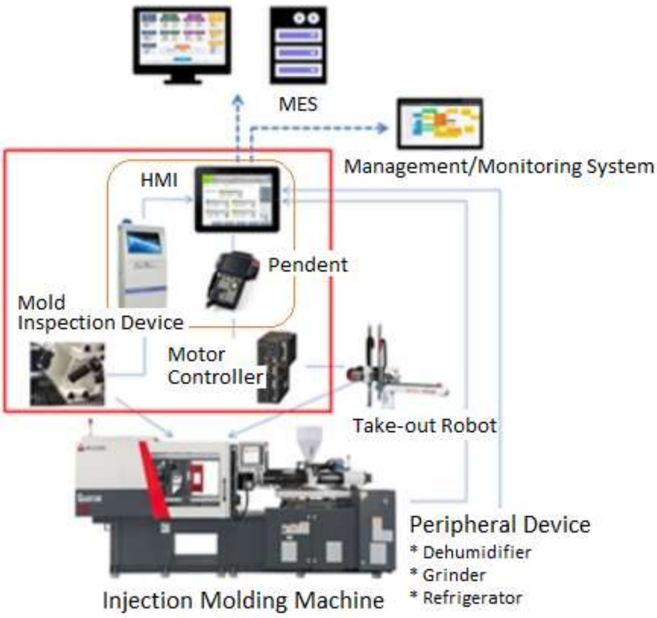


Figure 3. General Configuration for the Construction of a Smart Factory in an Injection Molding Process

2. Configuration of Take-out Robot Integrated Control System

Take-out robot integrated control system consists of integrated operating module, take-out robot controller, mold inspection module, and process and peripheral data acquisition interface module as shown in Figure 4.

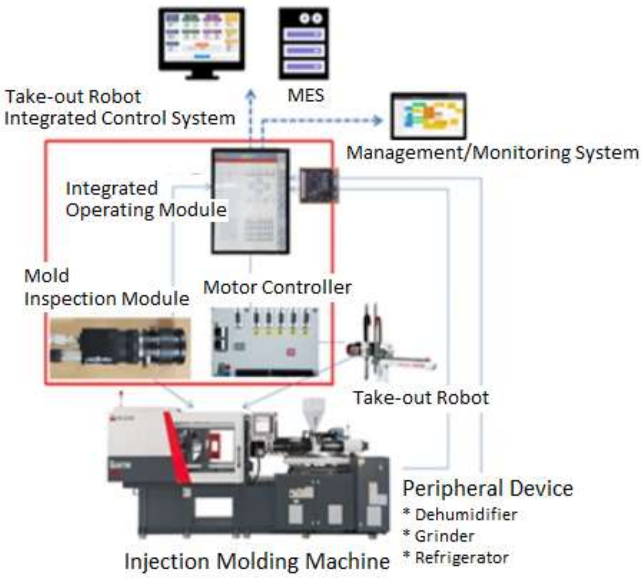


Figure 4. Proposed Configuration for the Construction of Smart Factory in an Injection Molding Process

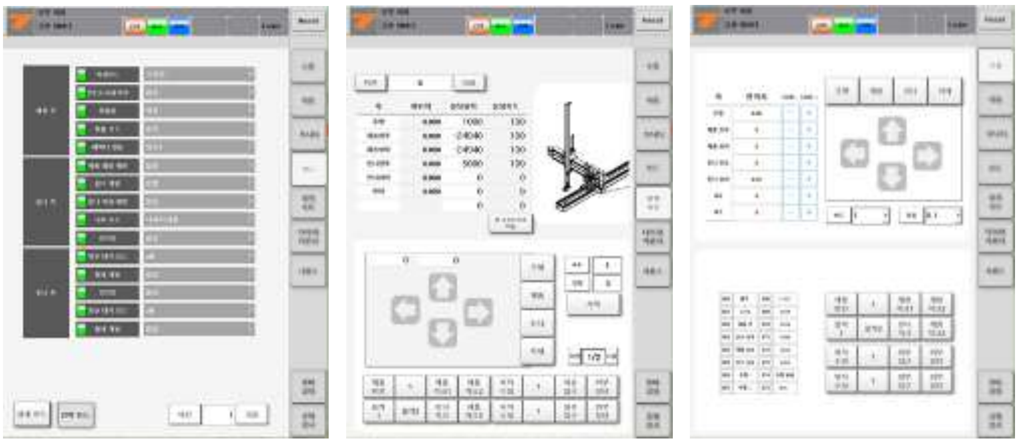
In the proposed configuration, an integrated operating module can conduct the functions of the HMI hub, mold inspection controller, and robot teaching pendant shown in Figure 3. By using the integrated operating module shown in Figure 4, the injection molding process can be simplified and the cost for the construction of the injection molding process can be reduced by the elimination of hardware such as the mold inspection controller and robot teaching pendant. The process and peripheral data generated by the mold inspection module, take-out robot, injection molding machine, and peripheral devices are saved in the integrated operating module and transferred to the MES and process management and monitoring system. By using the process and peripheral data acquisition interface module, the injection molding process can be simplified and the cost for the construction of smart factory in the injection molding process can be reduced by the elimination of hardware such as sensor interface and analog to digital converter.

3. Development of Take-out Robot Integrated Control System

Take-out robot integrated control system is developed to simplify the injection molding process and to reduce the cost for the construction of a smart factory.

3.1. Integrated Operating Module

Integrated operating module has functions such as MES communication for the transmission of production and process management data, robot operation for the programming of robot job mode, and vision operation for the programming of inspection job mode and condition as shown in Figure 5.



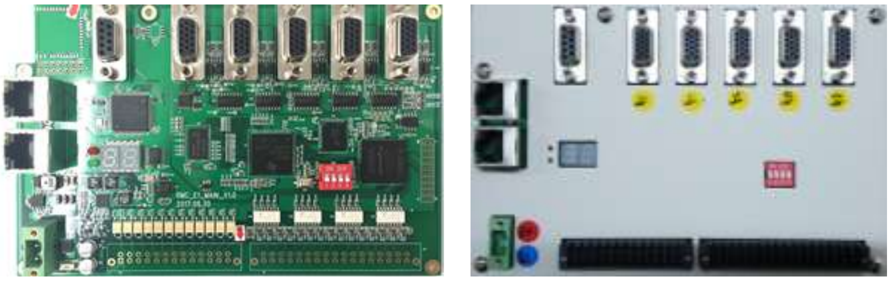
(a) (b) (c)

Figure 5. Functions of Developed Integrated Operating Module: (a) MES Communication, (b) Robot Operation, (c) Vision Operation

The hardware of integrated operating module has Window10 as operating system, Intel Celeron N2930 SoC processor having quad-core and 1.83GHz as CPU, 15” TFT LCD having touch panel as display, and QT having OpenCV vision library as programming tool.

3.2. Take-out Robot Controller

Take-out robot controller has functions such as control of 5 motor by pulse output, control of 32 peripheral device by digital output. Figure 6 shows the developed take-out robot controller.



(a) (b)

Figure 6. Developed Take-Out Robot Controller: (a) Board, (b) Case

3.3. Mold Inspection Module

Mold inspection module consists of vision image processing algorithm and IP camera having zoom lens. IP camera has an image pixel of 1280x960 and image data transfer rate of 100Mbit/sec as shown in Figure 7.

Figure 7. IP Camera Used in Mold Inspection Module

Vision image processing algorithm has functions such as pattern matching, application of Gaussian filter, measurement of image difference, and decision. Figure 8 shows the developed mold inspection module having the IP camera and the integrated operating module, where vision image processing algorithm is installed.

Figure 8. Developed Mold Inspection Module

3.4. Process and Peripheral Data Acquisition Interface Module

Process and peripheral data acquisition interface module has 8 analog interfaces using independent analog to digital converter (ADC) of parallel interface method, 32 digital inputs and outputs, and serial port. ADC has a resolution of 14bit and a maximum sampling rate of 32MHz. Figure 9 shows a developed process and peripheral data acquisition interface module.

Figure 9. Developed Process and Peripheral Data Acquisition Interface Module

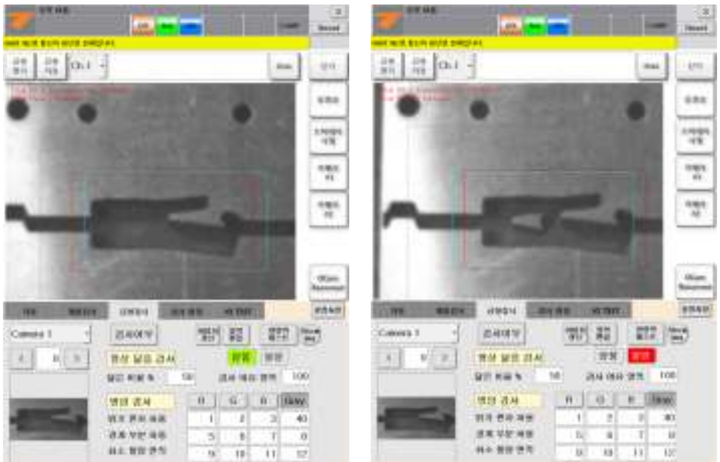
4. Experimental Results

The developed take-out robot integrated control system consists of integrated operating module, take-out robot controller, mold inspection module, and process and peripheral data acquisition interface module. Figure 10 shows the experimental setup for the performance test of a developed take-out robot integrated control system. In this setup, a take-out robot integrated control system, take-out robot, and standard mold are used to measure number of motor control, number of sensor interface, time of defect measurement, minimum size of defect measurement, and minimum relative brightness difference of defect identification. Figure 11 shows the standard mold used in the experimental setup.

Figure 10. Experimental Setup for the Performance Test of Developed Take-out Robot Integrated Control System

Figure 11. Standard Mold used in Experimental Setup

Figure 12 shows the mold image processed by mold inspection module. Figure 12(a) shows the mold image having no defect and Figure 12(b) shows the mold image having defect. When defect is measured in the mold image, the mold inspection module warns that mold has a defect with red color box. Figure 13 shows the processing time, which is 112msec, used by the mold inspection module for the measurement of defect.



(a) (b)

Figure 12. Mold Image Processed by Mold Inspection Module: (a) Mold Image Having No Defect, (b) Mold Image Having Defect

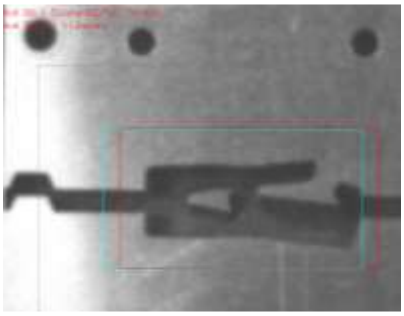
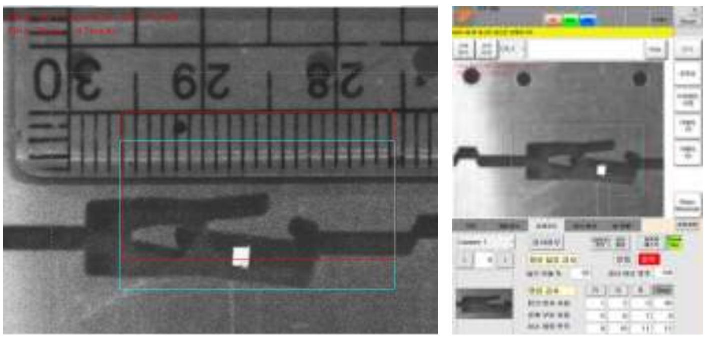


Figure 13. Processing Time Used by Mold Inspection Module for Measurement of Defect

Figure 14 shows the minimum size of defect, 1.3mm by 1.3mm, which can be measured by a mold inspection module.



(a) (b)

Figure 14. Minimum Size of Defect Can Be Measured by Mold Inspection Module: (a) Defect Size, (b) Measured Defect

Figure 15 shows test molds having defects with a relative brightness difference of 85%, 45%, and 5% compared with mold base.

(a) (b) (c)

Figure 15. Test Mold Having Defect with Relative Brightness Difference Compared with Mold Base: (a) 85%, (b) 45%, (c) 5%

Figure 16, Figure 17, and Figure 18 show the performance of defect identification by mold inspection module according to a relative brightness difference of 85%, 45%, and 5%, respectively. The image difference of standard mold and test mold is measured as shown in Figure 16(c) and Figure 16(d). The test mold has more pixels at the bright region compared with standard mold as shown in Figure 16(e) and Figure 16(f).

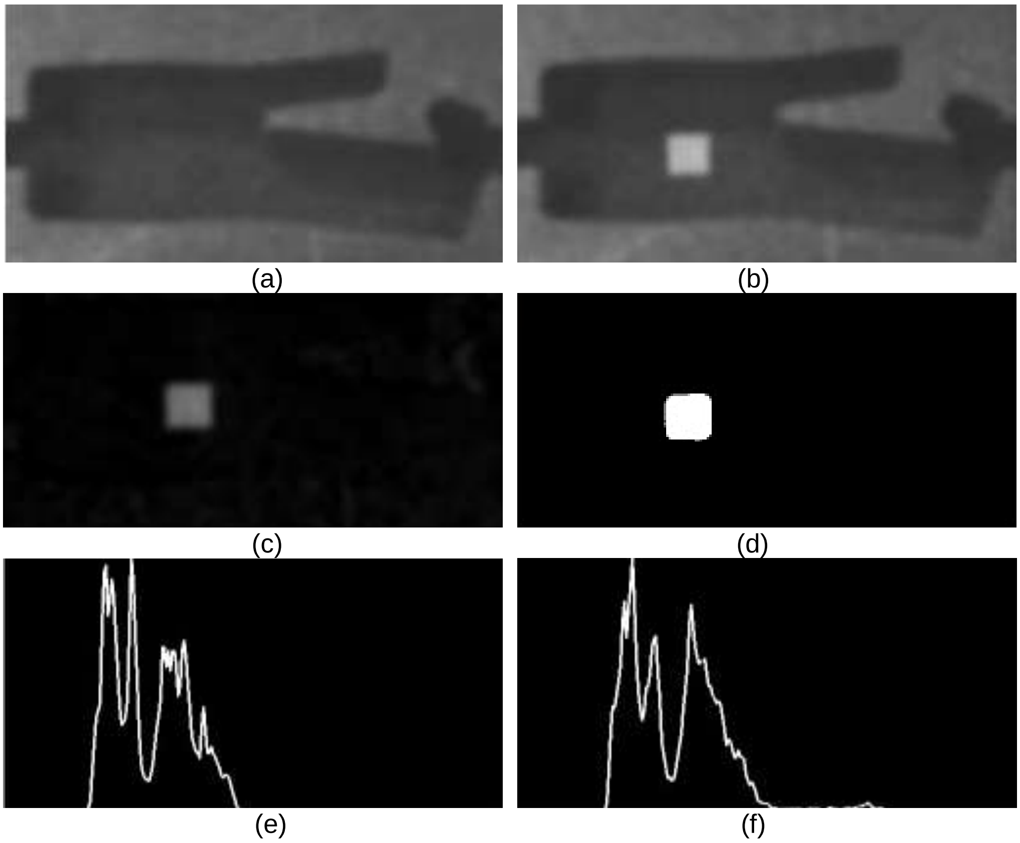


Figure 16. Defect Identification for a Relative Brightness Difference of 85%: (a) Image of Standard Mold, (b) Image of Test Mold, (c) Real Image Difference, (d) Binary Image Difference, (e) Pixel Distribution of Standard Mold, (f) Pixel Distribution of Test Mold

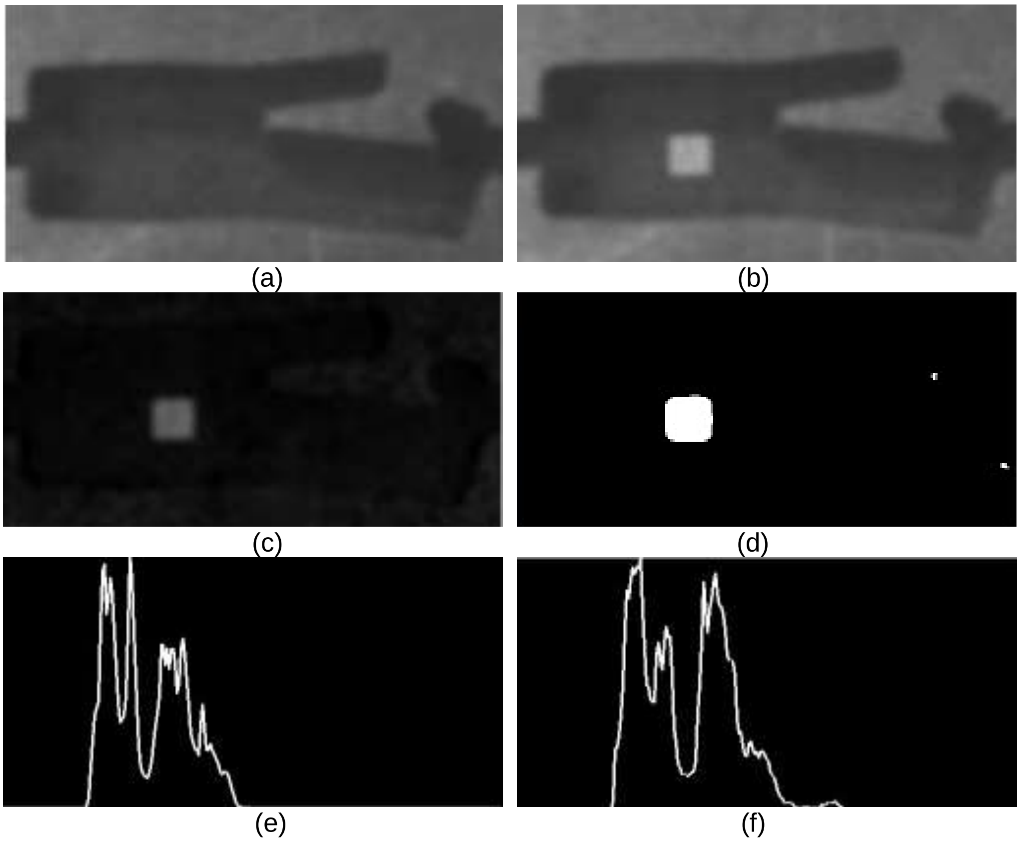


Figure 17. Defect Identification for Relative Brightness Difference of 45%

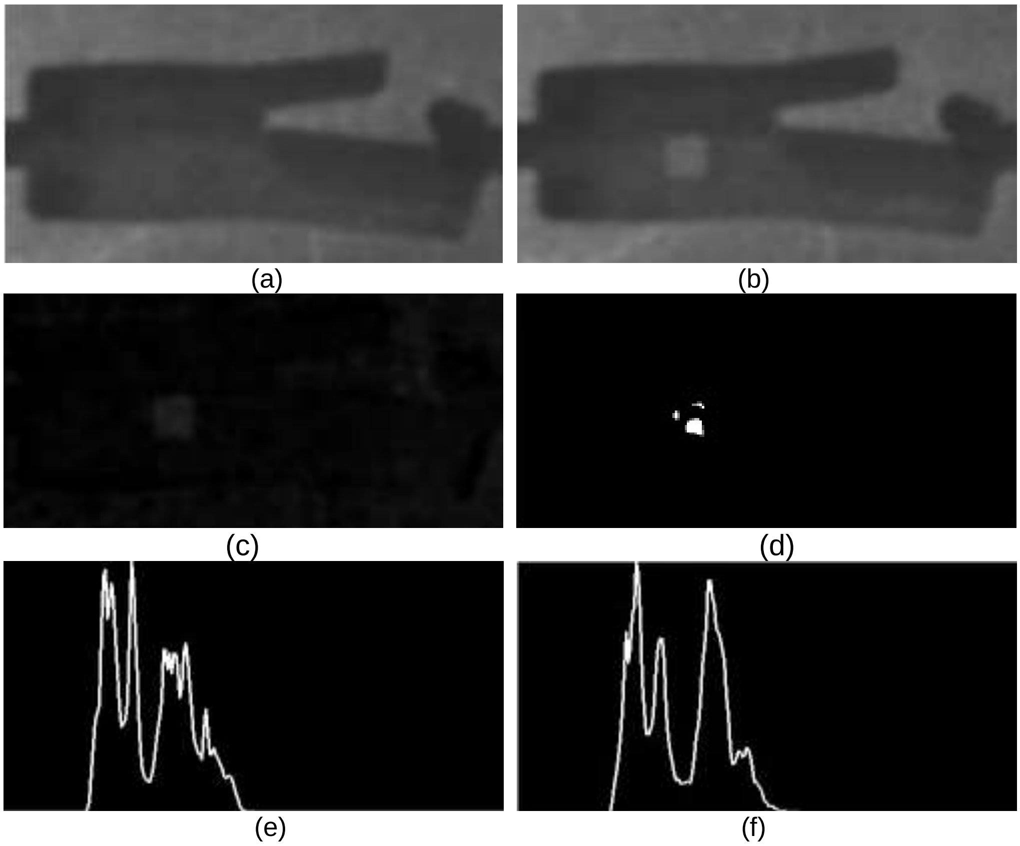


Figure 18. Defect Identification for Relative Brightness Difference of 5%

Although binary image of image difference of standard mold and test mold as shown in Figure 18(d) is distorted compared with that of Figure 16(d) and Figure 17(d), defect having relative brightness difference of 5% is identified by mold inspection module. Table 1 lists the performance of developed take-out robot integrated control system.

Table 1. Performance of Developed Take-out Robot Integrated Control System

Parameter	Value	Unit
Number of Motor Control	5	EA
Number of Sensor Interface	8	EA
Time of Defect Measurement	0.112	sec
Minimum Size of Defect Measurement	1.3x1.3	mm^2
Minimum Relative Brightness Difference of Defect Identification	5	%

5. Conclusions

In this study, a take-out robot integrated control system for the automation of injection molding process required for the construction of smart factory is proposed. Integrated operating module, take-out robot controller, mold inspection module, and process and peripheral data acquisition interface module are developed and assembled to make a take-out robot integrated control system. Experimental test using developed take-out robot integrated control system, take-out robot, and standard mold is conducted to verify the proposed take-out robot integrated control system. From the verification test, developed take-out robot integrated control system has performances such as 5 in number of motor control, 8 in number of sensor interface, 0.112sec in time of defect measurement, 1.3mm by 1.3mm in minimum size of defect measurement, and 5% in minimum relative brightness difference of defect identification. From this study, it is expected that the injection molding process can be simplified and the cost for the construction of the smart factory can be reduced by the adoption of a take-out robot integrated control system.

Acknowledgments

Following are results of a study on the “Leaders in INdustry-university Cooperation +” Project, supported by the Ministry of Education and National Research Foundation of Korea.

This paper is a revised and expanded version of a “Take-out Robot Integrated Control System for Smart Factory Construction by Automation of Injection Molding Process” presented at 1st International Workshop on Cultural and Technological Exchange and Mutual Development of The Pacific Rim Countries (CuTEMD2017), Pyeongtaek, Republic of Korea, December 16-17, 2017 and a “Development of Integrated Control System for Smart Factory in the Injection Molding Process” presented at 5th International Conference on Machine Design and Manufacturing Engineering (ICMDME2018), Jakarta, Republic of Indonesia, January 22-23, 2018.

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