Journal of Research and Applications in Mechanical Engineering
ISSN: 2229-2152 (Print); 2697-424x (Online)
(2021) Vol. 9, No. 1, Paper No. JRAME-21-9-005
[DOI: 10.14456/jrame.2021.5]

Research Article

VISION-BASED AUTOMATIC LEAK DETECTION FOR SHORT PIPES IN WATERWORKS INDUSTRY

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Received 17 December 2020
Revised 26 February 2021
Accepted 9 March 2021

ABSTRACT:
One of the most common and widely used products in waterworks solution are short pipes. A number of manufacturing processes are involved in the production phase of these workpieces. Defection can be found in various forms in regard to the manufacturing processes, from the material forming to machining process. One of the most common defection found is related to the material porosity which leads to the leak problem. In this research, automatic leak detection system is designed and developed in order to inspect short pipes. The workpieces are submerged under water and bubbles will be detected by the vision-based detection algorithm to justify the leak. From the experiments, the inspection process took 15 seconds. The detection exhibited 0% false positive and 10% false negative. In addition, the production line has been transformed to a continuous line so that the the number of operators is reduced from 3 to 1.

Keywords: *Leak detection, Bubbles inspection, Waterworks*

1. INTRODUCTION

Short pipes are one of the common parts used in waterworks. They are used as connectors in pipelines that fluid, in this case, water, can pass through. Leakage of the pipes is a serious issue which is unacceptable in any case as it affects the efficiency of the system. In the manufacturing process, producing short pipes is involved various steps, i.e. die-pressing, molding, machining, surface finishing, and etc. Hence, the quality control (QC) process is required to ensure the quality of the workpieces. In this research, leak detection is performed as a part of the QC process.

Leak detection is usually conducted manually with an aid of testing equipment. In this case, we focused on the leak caused by porous and tiny holes occurred from the material processing, especially molding. The current leak detection procedure of the case-studied factory is improved. Originally, the bubble detection method is used to inspect the leak. The visual inspection is performed manually by the operators. The workpieces to be inspected are placed at the testing station consisting of a water bath and a gripper. The gripper secures the pipe at both ends, and then submerges the pipe underwater. The compressed air flows into the pipe. As a result, bubbles will be appeared in case the pipe leaks. This entire process has been improved by transforming to be a continuous production line. Consequently, the waiting time due to batch testing process is eliminated.

This article is organized as follows: available leak detection techniques are reviewed in Section 2. System architecture and mechanical setup are described in Section 3. Vision system is presented in Section 4. Experiments are presented in Section 5. Conclusion is in Section 6.

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2. REVIEW OF LEAK DETECTION TECHNIQUES

A number of leak detection methods are currently used in this industry. Compressed air or gas is normally used in the testing process. Commercially available methods are as follows:

(a) Vacuum test can be done by submerging the workpiece underwater. The machine will suck all the air inside the workpiece out. Water droplets will present at the leak positions on the workpiece [1]. (b) Helium test can be done by pumping Helium into the workpiece. The leak will be inspected by using Helium detector, e.g. [2-4]. This method provides accurate result but the cost is relatively high. (c) Halogen sniffer checks the leak from halogen gas which is used in refrigeration products [5, 6]. The concept is similar to the Helium test. (d) Pressure decay can be done by using compressed air pumping into the workpiece. A pressure gauge is installed on the workpiece to detect the pressure drop in case of leak [7, 8]. (e) Bubble test can be done by submerging the workpiece underwater. Compressed air will be pumped into the workpiece. In case of leak, the bubbles will be detected [7]. The bubble detection method is based on visual inspection in which can be done manually or automatically. The advantage of this method is low cost and able to present the quantity of leak; however, leak position may not be detected accurately [9]. Bubble detection algorithms can be developed based on various methods, e.g. optical flow [10] and edge detection [11]. However, in this case, the algorithm is developed based on the smart camera functions.

In summary, the advantage of (a), (b), (c), and (e) is the leak location can be determined visually, while (d) cannot locate the leaking point [5]. For the advantage of (d), it is an only method that can be showing numerically which is easy for being automated [5]. However, the pressure difference can be minor, e.g. 0.0001 mBar, if little leak is presented. Therefore, the pressure gauge with that level of sensitivity is required. The cost of equipment is expensive. In this research, bubble test is selected according to the best practice of the company. The leak of short pipes is generally little. Bubble still can be recognized by the operators.

3. SYSTEM ARCHITECTURE

3.1 Requirements related to short pipe manufacturing process

The production of short pipes consists of 16 steps as shown in Fig. 1. The process can be divided into four main stages: Molding, Machining, Checking, and Packing.

(a) Molding is between Step 1-5. The workpieces are Ø15 mm, Ø20 mm, and Ø25 mm × 150 mm. The workpieces are formed with sand molding process. Afterwards, the molded parts are sandblasted before entering the machining stage.

(b) Machining is between Step 6-9. A computer numerical control (CNC) lathe machine is used to machine the parts. The holes are Ø13 mm, Ø18 mm, and Ø24 mm, respectively. Next, the machined parts will be transferred to the QC station for checking.

(c) Inspection is between Step 10-15. The leak detection is conducted by using 6-7 bar compressed air and visual inspection of the bubbles underwater. The parts will be dried by blowing with hot air. The defected parts will be rejected while the non-defected parts will proceed to next stage.

(d) Packing is in Step 16. The finished goods will be packed and stored in the inventory.

A comparison between the current and the improved processes is shown in Fig. 1. In this research, the checking process in Step 10-15 is transformed to be automated. The improvement is as follows:

Step 10 - Transfer the workpieces to the leak detection station by using a conveyor;
Step 11 - Automatically Load-in to the leak detection station;
Step 12 – Detect the leak with bubble method;
Step 13 - Automatically Load-out of the leak detection station;
Step 14 - Reject the defected workpieces on the conveyor; and
Step 15 - Dry the workpieces by using a hot air tunnel.

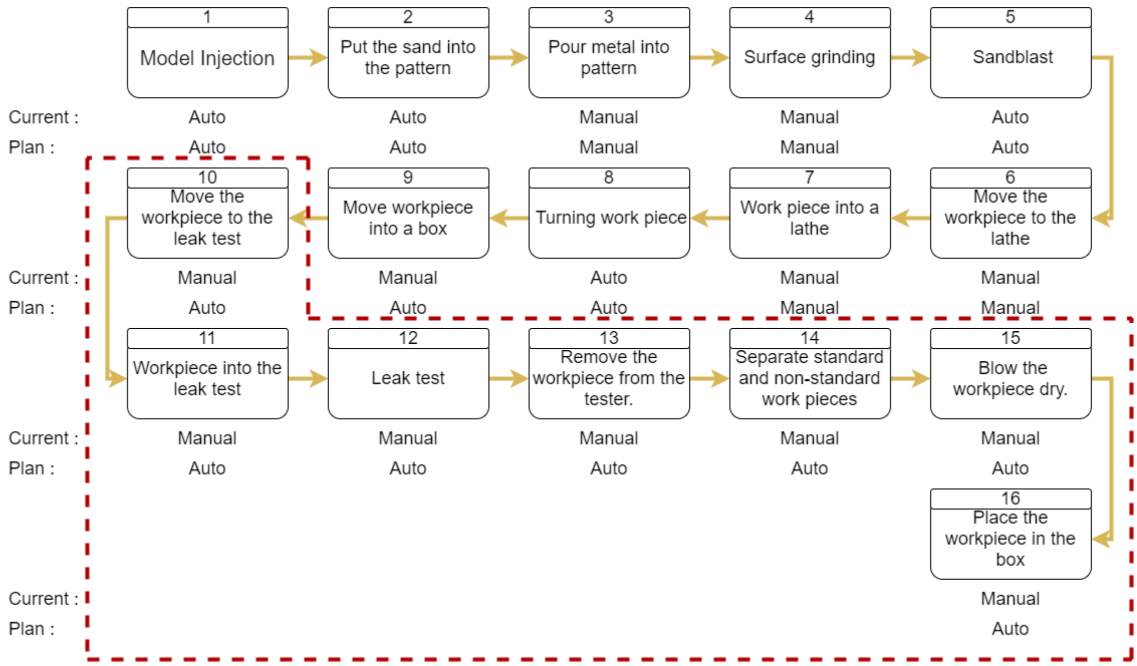

Fig. 1. Process flow diagram for short pipes

3.2 Machine components overview

To develop an automatic leak detection, the mechanical system is designed for transferring the workpiece and the vision system is designed for the testing process. The mechanical system consists of 5 parts, namely an input conveyor, a gripper, a rejection tray, a blower, and an output conveyor. The vision system consists of a smart camera installed next to the water bath for detecting bubbles (see machine layout, Fig. 2).

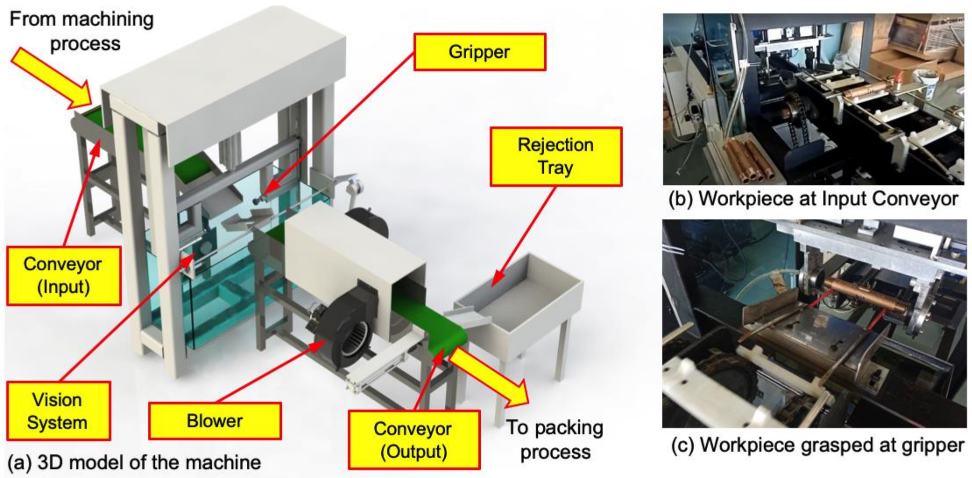

Fig. 2. Machine layout showing components of leak detection machine

For the system architecture (see system diagram, Fig. 3), (a) Programmable Logic Controller (PLC) is used for controlling process sequence. (b) The PLC controls the operation of the conveyor by controlling speed of the motors via an inverter. The inverter is also used for controlling the flow and heat of the blower for drying the workpieces. (c) The gripper is one of the main components of the system. The 2-finger friction gripper is used to grasp the workpiece in place [12]. The gripper operation and its position are pneumatic actuated. The signals are controlled by using solenoid valves controlled by the PLC. The rubber fitting with a hole is at an end of both fingers. The compressed air will be pumped into the short pipe through this hole. The air flow is controlled by a solenoid valve triggered by the PLC. (d) For the vision system, the smart camera is connected to the PLC, the bubble detection algorithm is run on the camera. Then, the result will be sent out for being processed by the PLC.

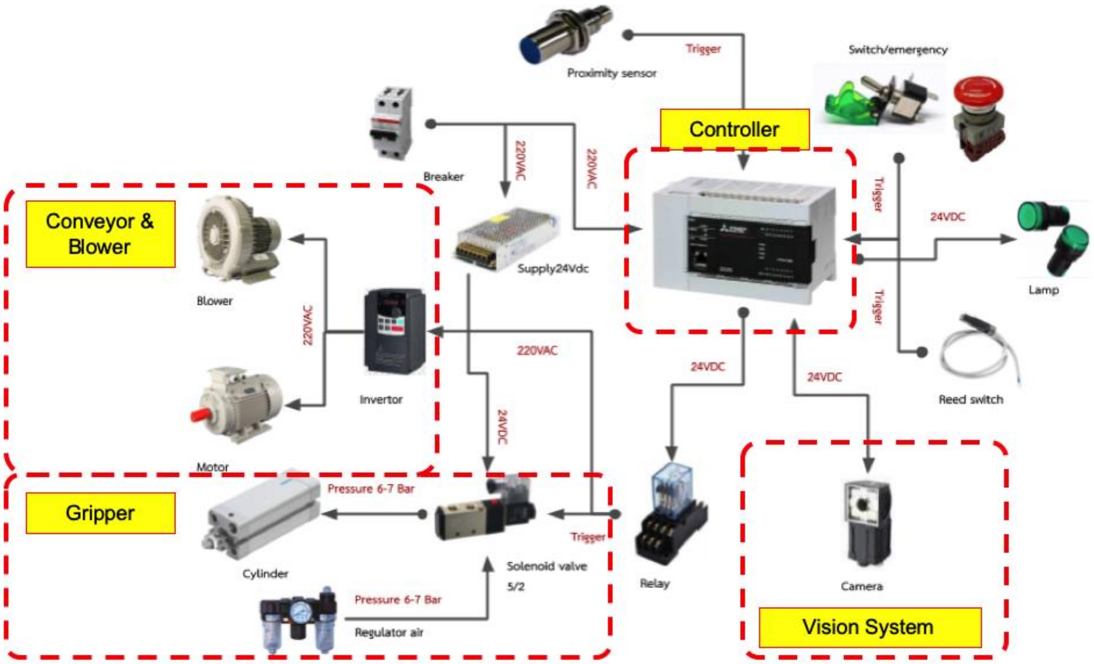

Fig. 3. System diagram

3.3 Machine components and process flow

The critical machine component part in this case is the "gripper". It needs to hold the workpiece underwater while the pressure inside the workpiece increases due to the compressed air. The pressure will rise up to 6-7 bar and stay for 10 seconds for testing. Pneumatic cylinders are used to actuate the gripper, i.e. vertical movement for submerging the workpiece and horizontal movement for gripping the workpiece (see Fig. 4a). The gripper is designed to support the workpiece with 3 different diameters (see Section 3.1). The Ø40 mm rubber fittings are mounted at the end of the finger for preventing the leakage while gripping, so that the air can be contained (see Fig. 4b). A Ø40 mm cylinder is selected for actuating the gripper. Hence, the gripping force is 7.06 kN. This satisfies the maximum force of 2.94 kN, occurred at the operational condition for Ø25 mm pipes.

In regard to the process flow, the operation steps are as follows (see Fig. 4):

Step 1 - The workpieces are transferred to the testing station with the input conveyor. In this case, the speed is synchronized with the production rate of the station before;

Step 2 - When the workpiece has arrived the gripping position, the gripper will secure the workpiece and dip into the water bath for the bubble testing;

Step 3 - The compressed air will be pumped into the short pipe for certain amount of time;

Step 4 - The camera is triggered. In case of defection, the bubbles will be detected;

Step 5 - The gripper will release the workpiece on the output conveyor;

Step 6 - The workpiece will pass through the blower in order to dry; and,

Step 7 - The defected workpieces will be rejected to the reject bin, while the non-defected workpieces will proceed to the packing station.

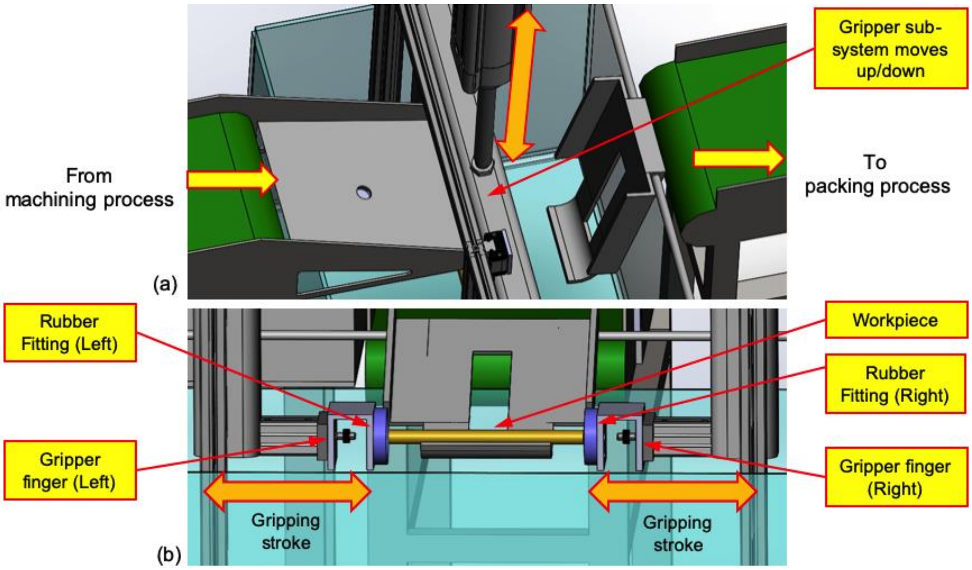

Fig. 4. Machine components and process flow

4. Vision System

4.1 Smart camera

The main concept of using vision system is to detect the presence of bubbles which can imply that the workpiece leaks. This research uses a smart camera (Omron FQ Vision Sensor: FQ2-S20100F) [13]. The camera uses Complementary metal–oxide–semiconductor (CMOS) as the image sensor and has built-in pulse lighting. It has a built-in processor that is able to process the data and communicate with the PLC via I/O and TCP/IP protocol. The machine vision algorithm for detecting bubbles is programmed by using FQ Touch Finder Simulation software.

4.2 Leak detection algorithm

First, images of the workpiece are obtained from 30 frames per second (FPS) video with 10 seconds duration captured (equal to 300 frames). The image size is 752 × 480 pixels and captured in real color. The images are processed in order to segment the bubbles from the background. The images are preprocessed with a set of functions, i.e. grayscale conversion, edge extraction, and background suppression [13] (see Fig. 5). For (b) the grayscale filter, it used for converted the original RGB image to a grayscale image. (c) Strong smoothing filter is applied for reducing noise in the image. The lower and upper limits of color are set. (d) The edge of the workpiece is extracted by using horizontal edge extraction function in which the edge is determined between light and dark pixels. (e) Background suppression is for extracting a specific range of brightness to increase the image contrast.

Afterwards, the bubbles will be detected by using (f) search functions, Shape Search 3. This function is used as it is robust to orientation, partial occlusion, various lighting condition, and background [14]. It is robust to the ripples that can be occurred due to the vibration while the workpiece is in the water. The images of bubbles are used as a template. False positive result may be occurred, for example some bubbles presented when dipping the workpiece underwater but the workpiece does not leak. To prevent the false positive result, the number of bubbles detected throughout 300 frames must be greater than the threshold level (count = 5). If count > 5, the result is "NG" meaning that the workpiece is leak. Otherwise, the result is "OK" (see examples of bubble detection in Fig. 6).

The bubbles presented will be counted and calculated. From the preliminary experiment, the detection rate is 95%. Eventually, the final result is sent to PLC to accept or reject the workpiece.

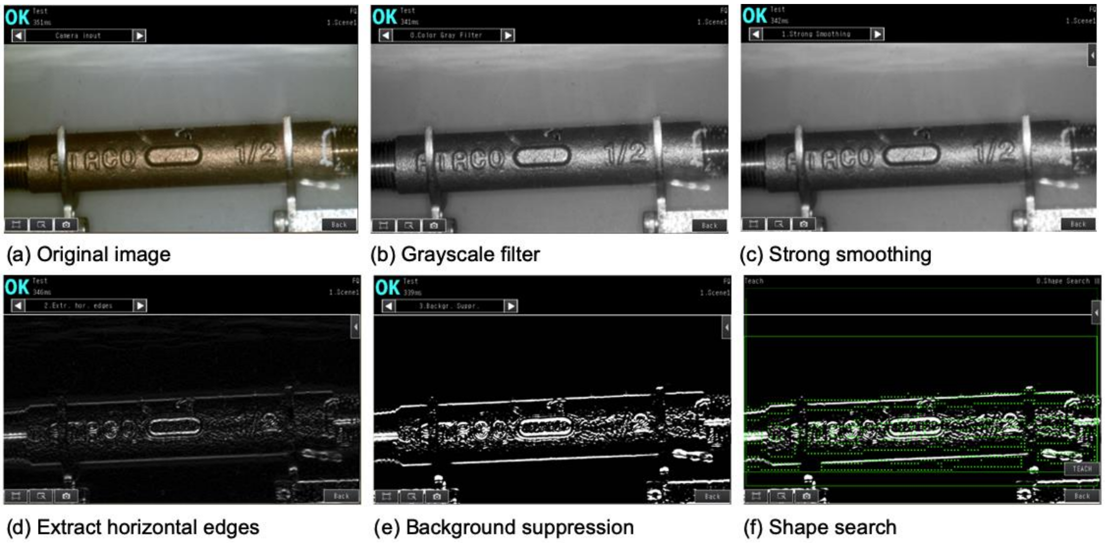

Fig. 5. Image at each stage of the bubble detection process

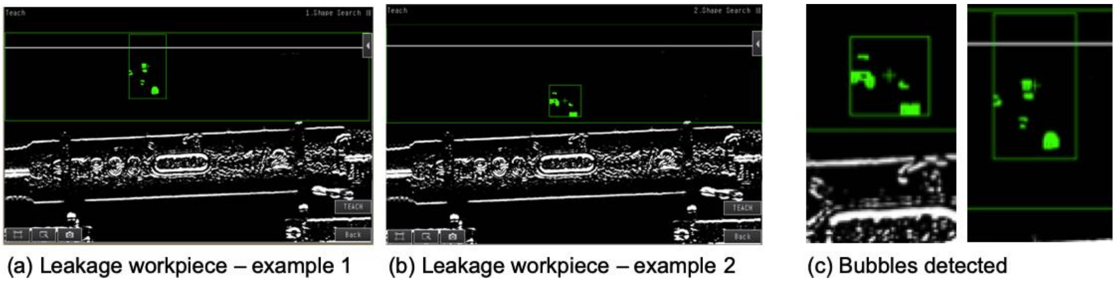

Fig. 6. Example cases of the workpiece with leak: TP and FN

5. EXPERIMENTAL PROCEDURE

5.1 Experiment procedure

The experiments were divided into 2 main parts to measure the performance of two parts: (a) mechanism and control and (b) vision system:

(a) Experiment 1 Mechanism and control - is to test whether the components of the machine perform and are able to carry out the operation properly. The tested components consist of (i) conveyor can transfer the workpiece to the target position; (ii) the gripper can secure the workpiece dropped from the input conveyor; (iii) the gripper can release the workpiece on the output conveyor; (iv) the gripper can grasp the workpiece tightly and no air leak at the rubber fittings; and (v) the output conveyor can reject the defected parts. Each test was repeated with 100 sample workpieces.

(b) Experiment 2 Vision system - is to test the performance of the bubble detection algorithm. The samples consist 10 workpieces: 5 good and 5 leak. The test was repeated 10 times for each sample. False Positive (FP), False Negative (FN), True Positive (TP), and True Negative (TN) were calculated. For detailed explanation, FP refers to the case that the workpiece does not leak but the system detected as leak. FN refers to the case that the workpiece leaks but the system cannot detect. TP refers to the case that the system can correctly determine the workpiece that leak. TN refers to the case that the system can determine the workpiece that does not leak correctly.

5.2 Experiment results

The experiment results are summarized in Table 1. For Experiment 1, success rates of individual steps (i)-(v) are higher than 84%. When considering continuous process, the overall success rate is calculated from individual steps *i-v* shown in Table 1. The overall success rate is 67.3%. The number is promising for the prototype. However, this rate can be improved if the system is commissioned properly which will be done in the future. The errors also resulted from inaccuracy of machined parts, e.g. rubber fittings. Improving components' quality will increase the success rate.

For *Experiment 2*, the accuracy of leak detection algorithm can be determined. FP rate is 0% while and FN rate is 10%. Even though the result is promising for prototype phase, it still cannot be used for the QC yet as the FN rate is too high. FN refers to the percentage that the system fails to detect the leak, so that the defected parts can be proceeded to the packing process (see example case in Fig. 6(c)). This can be improved by enhancing the training set of bubbles template and tuning the detection algorithm.

Table 1: Summary of experiment results

	Experiment 1 – Mech and Control (Success rate)						**Experiment 2 – Vision System**			
Test item	i	ii	iii	iv	v	Overall	FP	TN	TP	FN
%	100%	96%	87%	84%	96%	67.3%	0%	100%	90%	10%

Note : S_k is success rate of test item-*k*. Therefore $S_{overall} = S_{\text{i}} \times S_{\text{ii}} \times S_{\text{iii}} \times S_{\text{iv}} \times S_{\text{v}} = 67.3\%$

6. Conclusion

In this research, the automatic leak detection system for short pipes is developed. The system consists of mechanical parts to convey the workpieces throughout the process. The vision system is the key operation of the testing process. Bubbles detection algorithm is implemented to determine the defected workpieces. From the experiment, the overall success rate of the mechanical and control was around 67%. For the vision system FP rate was 0%, and FN rate was 10%. Improvement is required in the future.

Overall, the performance between manual (original) and automatic (improved) processes will be compared. (a) The process continuity is improved by converting from batch process to a continuous line. The waste due to the waiting time between machining process and leak detection process is eliminated. (b) The number of operators decreased from 3 to 1 operators. The remaining operator can also control and monitor another precedence process which is semi-automatic. (c) The testing rate is constant at 15 seconds/workpieces while the testing duration is used to be operator dependent, which varies between 15 and 25 seconds. (d) However, the testing accuracy decreased by approximately 10%. This need to be improved to be lower than 0.1% according to the standard. This improvement will be done in the future.

Acknowledgement

We would like to thank Asahi Thai Alloy Co,. Ltd., Thailand, for technical support, financial support, and the demonstration site. Also, this project is participated in Talent Mobility program, which is partially funded by National Science Technology and Innovation Policy Office, Ministry of Science and Technology, Thailand. In addition, we would like to thank NXPO Office of Higher Education Science Research and Innovation Policy Council as part of project "Promotion of Robotics for All & Development of Robotics Innovators, Researchers, Engineers, and Startups" for the financial support of publishing process.

References

[1] SciLution Co., Ltd. Leak Tester Automatic Machine TL Series, URL: https://www.scilution.co.th/product/leak-tester-tl, accessed on 03/12/2020, 2020.
[2] General Vacuum & Flow Co., Ltd. Helium Leak Detection, URL: https://www.vacuumthai.com/Helium_Leak_Detection, accessed on 03/12/2020, 2017.
[3] Li, B., Hou, D., Wang, X., Ba, D. Study on the influence of the position of precise detection port on the performance of helium mass spectrometer leak detector, Chinese Journal of Scientific Instrument, Vol. (11), 2020, pp. 58-65.
[4] Schnaidman, A. Leak detection using helium as a tracer gas and the primus line solution for pipe rehabilitation, paper presented in 37th International NO-DIG Conference and Exhibition, 2019, Florence, Italy.
[5] Vinogradov, M.L., Kostrin, D.K., Karganov, M.V., Tiskovich, V.Y. How to choose a leak detection method, paper presented in 2016 IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conference *(*EIConRusNW*)*, 2016, Petersburg, Russia.

[6] Shin, Y.H., Hong, S.S., Lim, I.T., Chung, K.H. The effect of the operational conditions on the quantitative leak rate of leak detectors, Key Engineering Materials, Vol. 321-323, 2006, pp. 1560-1563.
[7] Shu, X., Li, H., Qin, Z., Liu, L., Deng, M., Zhang, D. Leak detection by testing vapor in tank foundation, paper presented in 2014 IEEE Far East Forum on Nondestructive Evaluation/Testing, 2014, Chengdu, China.
[8] Garcia, A., Ferrando, J.L., Arbelaiz, A., Oregui, X., Bilbao, A., Etxegoien, Z. Soft computing analysis of pressure decay leak test detection, paper presented in 15th International Conference on Soft Computing Models in Industrial and Environmental Applications (SOCO 2020), 2020, Burgos, Spain.
[9] Gao, F., Lin, J., Ge, Y., Lu, S., Zhang, Y. A mechanism and method of leak detection for pressure vessel: whether, when, and how, IEEE Transactions on Instrumentation and Measurement, Vol. 69(9), 2020, pp. 6004-6015.
[10] Wu, C.L., Pan, H.F., Xia, Y.M. Air-tightness detection system based on optical flow method, Journal of Electrical and Electronics Engineering, Vol. 30(8), 2013, pp. 947-951.
[11] Gan, J.W., Qin, F.J., Cao, B. Design of FPGA image processing system for the bubble edge detection, Chinese Journal of Mechanical Engineering, Vol. 36(2), 2015, pp. 293-296.
[12] Gualtiero, F., Santochi, M., Dini, G., Tracht, K., Scholz-Reiter, B., Fleischer, J., et al. Grasping devices and methods in automated production processes, CIRP Annals, Vol. 63(2), 2014, pp. 679-701.
[13] OMRON Electronics Co., Ltd. Smart Camera FQ2-S/CH Series, URL: https://assets.omron.eu/downloads/manual/en/v4/z337_fq2-s_ch_smart_camera_users_manual_en.pdf, accessed on 03/12/2020, 2017.
[14] Vongbunyong, S., Archeewawanich, P., Akaratham, P., Martchan, C., Thamrongaphichartkul, K. Automatic handling for valves trimming system, IOP Conference Series: Materials Science and Engineering, Vol. 501, 2019, pp. 1-7.