Automatic Handling for Valves Trimming System

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Abstract Shortage of workers in manufacturing industry has become one of the critical issues in every industry nowadays. Valves manufacturing process is involved forging and trimming process of brass workpieces which are hazardous and able to harm the workers. The aim of this project is to develop an automatic handling of valves in trimming system for replacing human workers. A 6-DOF articulated robotic arm is integrated with vision system for effectively picking the workpieces from the feeder and placing them to the rotating die for being trimmed. One of the challenging problems is the uncertainties of the shape of the forged workpieces related to flash. The specially designed impactive gripper and machine vision are developed to resolve those uncertainties. The gripper is a parallel jaws gripper designed to grip and hold an object with irregular geometries. For the selected model of valve, the system is able to work at 1,033 pieces hour at 96.67% success rate which is comparable to the capacity of the current human workers.

1. Introduction

Forging is one of oldest techniques in bulk material deformation processing. Yet, it is a very important technique used to make a variety of high-strength components nowadays. A large hydraulic press machine is generally used to generate force on a metal billet which is inserted between an upper and a lower molds. Three forging techniques, including (a) open-die forging, (b) impression-die forging, and (c) flashless forging, are used in metal deformation process [1]. For the impression-die forging, the shape of the final workpiece will be formed according to the surface of the molds. When the billet has been compressed within the cavity between the surfaces of two molds, some excess material will flow into the surrounding area and form flash (see Figure 1(a)-(c)). Afterwards, this flash must be trimmed off in order to obtain the forged workpiece with the desired shape. With die pressing method, impact force is used to trim off the flash by shearing at the cutting edge on the die (see Figure 1(d)).

These days, shortage of workers has become one of the most critical issues in many manufacturing industries. According to the operations performed in the factory that we study, the forged workpieces are transferred and inserted to the trimming dies manually at the rate of maximum 1,000 items/hour. Robotic system is considered to replace the human workers due to the high labor cost and safety issues. This manual operations is concerned high risk due to the size and accessibility of the trimming machine and the sharpness of the workpieces that can be harmful for the human workers while handling.

Development of automatic handling system with robot arm deals with 3 main areas of problems, including (a) motion control of robot arms, (b) design of grippers, and (c) vision system. A number of
research works with respect to this application were conducted in these areas. For example, Modi et al. (2015) [2] improved the performance of the CNC production line by using a robot arm picking and placing workpieces into CNC machine. Patil, G. (2013) [3] developed the visual-guided pick-and-place robot system with SIFT that is used for recognizing and locating the workpiece to be picked. SIFT is robust to work in low light condition and fast enough to operate real-time. Kumar et al. (2015) [4] developed visual-guided robot system that was able to work with various types and sizes of workpieces. The workpieces were able to be classified, recognized, and localized with higher than 80% accuracy.

Figure 1 (a-c) Impression-die forging and (d) Trimming processes (adapted from [1])

In conclusion, in this research, a vision-guided robotic system will be implemented in workpiece handling process. The workpieces with flash will be automatically transferred and inserted to the trimming die by the robot arm. This paper is organized as follows. The function requirements of the manufacturing process and system architecture are presented in Section 2. Details in gripper design and vision system are presented in Section 3. The experiments are in Section 4. Conclusion is in Section 5.

2. Methodology

2.1 Requirements related to forging and trimming process
CT-15 is a tail part of the valve (see complete product, Figure 2). CT-15 is made of brass JIS C3771 with the dimension of 44.6 mm x 27.0 mm. The flash is normally formed as a result of the forging process. The dimension of CT-15 with flash is around 60 mm x 40 mm in general.

The current operation related to the forging process of CT-15 consists of 7 steps (see Figure 2). The steps (4-5) are manual and (6) is semi-automatic operations. The workers pick a forged workpiece from the bin and then manually place in the mold in the trimming machine. The machine will be manually activated. The die will be rotated inside the machine and the workpiece will be trimmed. These steps will be converted to automatic operations by using a robot arm. Only (5-6) will be focused in this paper.

2.2 System architecture
The system that is developed in this research mainly consists of a robot arm with gripper and vision system. The system diagram is shown in Figure 3. CFD Controller is a robot controller used as a master of this system that the main program is running. CFD connects with the gripper via I/O and the machine vision module which is acted as a slave via TCP/IP protocol. The machine vision module is a smart camera module used to detect the workpieces, in which the information will be provided to CFD. This system is connected to the trimming machine and the part feeder through a Programmable Logic Controller (PLC), so that the CFD can command them according to the designed operation sequences.

In the operation, the forged workpiece will be fed to the robot picking position which is at one end of the part feeder. The vision system will detect the shape, position, and orientation of the workpiece. The robot will use the gripper to grasp this workpiece and transfer it to the trimming machine and placed on the mold. Next, the robot will activate the trimming process by sending the command through the PLC. The workpiece that has been trimmed will be loaded out automatically by the mechanism in the trimming machine. The details of each main component are explained in the following section.
3. Implementation

3.1 Mechanical Components: Robot arm and Gripper

3.1.1 Robot Selection

A small size 6-axis articulated robot (Nachi MZ04) [5] is used in this system. This model is selected due to specification of the high speed movement, high accuracy with ±0.02 mm position repeatability, workspace with 541mm reach, and 4 kg payload. The 6-axis robot is selected due to the position and orientation requirements of the pick-and-place process. The gripper is mounted on the robot’s end effector for grasping valves, CT-15 model, from the feeder to the rotating trimming die.

3.1.2 Gripper Design

For the gripper, impactive gripper type (jaw and friction grippers) [6] is used in this application. The friction grippers are impactive mechanical grippers that holding objects by using the friction force acting...
between active surfaces of the object and gripper’s jaw. The jaw grippers use the friction force together with the jaws’ geometry to support the object [7].

The impactive gripper type is chosen over the suction gripper type due to the availability of active surface to be gripped. For the suction grippers, the active surface must be the top side of the workpieces that contain numerous curve surfaces, which is challenging for the selection of proper vacuum pads. However, regarding the impactive gripper, the challenging issue is to specifically design the geometry of the jaws to match the contact surface and uncertain shape of flash (see Figure 4). From preliminary experiments, the special designed friction gripper achieved 99% success rate.

![Figure 4 Possible active surface for impactive grippers and suction grippers](image)

3.1.3 Jaw design

The shapes of possible contact surfaces are taken into account to design the active surface and the jaws’ geometry. In order to secure the position and orientation of the objects, sufficient points and areas of contacts are necessary. From Figure 4, the possible contact surfaces for impactive grippers are (a) top surface of the body, (b) in the holes, (c) shoulders, and (d) flash.

Regarding the prehension strategy, firstly the gripper is at the open position (Figure 5(a)). The gripper is approaching the workpiece from the top and body supporter lightly presses on this area to secure the pose of the valve relative to the gripper. Next, the jaws will close (Figure 5(b)), then the fingers will contact with the holes and other surfaces. As a result, the pose of the workpiece will be fully secured and ready to transfer. However, flash is not consider for being an active surface since the geometry of flash is uncertain. Therefore, there is no common geometry that the jaws can be designed to match.

Two versions of jaws geometry set were designed as follows:

![Figure 5 Impactive Gripper: position – open and close (demonstrated with 2 versions of jaws)](image)

(a) Open position (use jaw version 1)  (b) Close position (use jaw version 2)

For the first version (see Figure 6(a)), each side of the jaw is designed to match with three areas of contact surface which are 1 hole and 2 sides surface. The workpieces can be secured effectively at the desired position and orientation by the center finger, two supporting fingers on both sides, and the body
supporter. However, it was occasionally found that the two supporting fingers collide with some forms of flash. As a result, this issue is resolved in the second version of design. For the second version (see Figure 6(b)), the two side fingers are removed to prevent the collision. Only the center finger is used to insert into the hole for supporting and the body support that pressed the valve in the secured position.

From the two versions of design, the gripper is selected according to the gripping performance which is justified with the success rate of grasping process. The experiments were done on 27 cases which are the combination of 3 position variations (-5,0,+5 mm axial offset) and 9 flash shape variations. As a result, the success rate are 77.78% and 100.00%, respectively. Hence, the gripper-2 is selected.

![Figure 6 Impactive gripper jaws design](image)

(a) Jaws design set – version 1.  
(b) Jaws design set - version 2

**3.2 Vision system**

3.2.1 Detection algorithm development

This research use the smart camera (Omron FQ Vision Sensor: FQ2-S20100F) has a built-in processor that is able to process the data and communicate with other parts of the system via I/O and TCP/IP protocol. The machine vision algorithms for detecting the workpieces are programmed by using FQ Touch Finder Simulation software. The algorithm is designed with region-based and contour-based features detection on the significant features of the CT-15. To disregard the effect of uncertainties from the flash, the features are determined from the images of the workpiece without flash. The features that are manually marked are presented in Figure 7(a). Primarily, the data in regard to position (x, y, z) and orientation (yaw angle and up/down) will be calculated and sent to CFD.

![Figure 7 Examples of valves detection in various situations](image)

(a) Detection template  
(b) without flash  
(c) with flash and rotate

The algorithms are developed based on the functions available in FQ software [8]. The functions are the integration between region-based and contour-based detection algorithm. The capability of each search algorithms are summarized as follows:

(a) “Search” – simple and fast features matching algorithm. However, it is ineffective to handle complex situation, for example variations in lighting condition and shape.
“Shape search 2” – able to detect multiple objects presented in the image. It is robust to orientation, partial occlusion, and various lighting condition. It was found that this function was sensitive with the color variation in which lighter tone can be occurred in the production.

“Shape search 3” – is similar to Shape search 2 and also robust to the object with background. It is also capable of detecting the samples in various orientations. Example results are shown in Figure 7(b-c). From these key features, this function is selected to be used for this application.

3.2.2 Verification

The experiment was conducted with 50 random samples with flash. They were tested on the feeder in the actual production line. Each sample was tested with 4 posture variations (front/back and 0º/180º yaw). For the result, the samples was able to be detected with 98.77% correlation on average.

4. Experiments

4.1 Setup and testing procedure

The prototype system primarily consists of a robot arm, vision system, part feeder, and trimming machine are placed in the factory shop floor. The experiment was designed to evaluated the performance of the entire system. The setup is shown in Figure 8.

![Experimental working area setup](image)

The robot arm movement is set to 100% speed with 2 modes of smoothness function (with / without). In general, the smoothness function modifies the motion profile by adjusting acceleration constant in order to smoothen the movement at the beginning and the end of moving paths. Consequently, enabling smoothness function should help reducing vibration of the platform due to the robot movement and increase accuracy in gripping process but the time consumption might increase.

4.2 Experiment results

The experiment was conducted on 100 random samples. The workpiece was fed by the feeder. The experimental result is shown in Table 1. The smoothness function was enabled in Experiment 1-3 (3.92 sec/item, 899 items/hour) and disabled in experiment 4-6 (3.33 sec/item, 1034 items/hour).

Around 4-5% of the samples were missed due to the geometrical error of the part feeder. The part feeder used in this experiment is designed for feeding numerous models of valves. Small gap between workpiece and the guide rail of the feeder is presented. This gap leads to the orientation and position error of the sample when approaching at the end position. As a result, the vision system was able to detect these errors and the system rejected the workpieces.

| Experiment | Smoothness Function Enabled | Smoothness Function Disabled |
|------------|----------------------------|-----------------------------|
| 1-3        | 3.92 sec/item, 899 items/hour | 3.33 sec/item, 1034 items/hour |

Table 1 Experiment result – robot pick 100 samples at 100% speed
5. Conclusions
In this research, the robotic system for transferring the forged workpieces to the trimming machine is developed. The 6-axis robot arm equipped with special designed gripper is used together with the vision system to precisely pick and place the workpieces. One of the challenging issues is the uncertain shape of the forged workpiece regarding the flash which is uncontrollable in the manufacturing process.

The gripper and the vision system work together to resolve this problem in pick-and-place process. (a) **Impactive gripper**, two holes in the body and top surface of CT-15 are chosen to be active surfaces, in which the shape of the jaws and other supporting parts are designed specifically. The gripper achieved 100% success rate within ±5 mm position deviation. (b) **Vision system**, “Shape search 3”, working based on contour-based and area-based detection algorithm, achieved 98% detection rate. However, when the gripper and vision system components are integrated in the complete system, the overall performance little dropped from the individual tests.

About the final system configuration, the robot system without smoothness function can perform more efficiently. The system can handle the samples at the rate of 3.48 sec/item with less than 5% of unsuccessful picking. The performance is comparable with the working capacity of human workers.

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