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Flexible Automation in Porcelain Edge Polishing Using Machine Vision

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Abstract

The first step in producing glazed porcelain dishes is molding of raw material granules. Then, the biscuit of the dishes is formed. This process is performed by press machines under high pressures. Dishes formed have usually burrs around the edges. To improve flexibility and increase product quality, robots are employed for dish polishing process for which the exact position of the dish is required. This paper deals with the problem in a real world manufacturing line. Machine vision technology and image processing techniques are employed, implemented and integrated with the current robotic system to detect the pose (position and orientation) of biscuits, hence guiding the robot arm to perform its polishing operation at correct and most efficient pose. The system and algorithms have been developed. The development has been done for two representative sample dishes of circular and rectangular shapes, both of which were developed and tested successfully.

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Keywords: machine vision; robot; image processing; position detection.

1. Introduction

The ever increasing demand for glazed porcelain products, significance of competition issue among manufacturers, increase in export, and customization have caused the manufacturers to resort to mechanization of

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various systems of manufacturing processes, control and inspection. One of the stages in production of glazed porcelain dishes is the molding of granules of raw material and, as a result, the production of the biscuit of porcelain dishes. The molding process of dish biscuits is performed by press machines under high pressures. Due to several production reasons, such as ensuring the complete filling of mold and the strength of dish biscuits, the injected amount of granules into the mold exceeds the empty volume of the closed mold. Therefore, burrs are created at edges of biscuit of dishes. All of the dishes are required to be polished through edges of dish biscuits before glazing. So, with regard to the production rate of related manufacturing line, the polishing process of edges is performed utilizing various robots, all of which need to have information about the location of direction of biscuits, which in traditional systems the positioning process of dish biscuits is carried out by mechanical methods. Most of robotic systems make use of sensors for position adjustment of manufactured product within the acceptable tolerance. In this study, the results pertaining to utilization of machine vision system in order to detect the position and direction of dish biscuits are presented. In principle, the entire machine vision systems are constituted of a camera, a computer equipped with interface card, lighting system, and sensors [1]. The system employed, in addition to interpretation of location and direction of dish biscuits to robot, is capable of the detection of faulty biscuits as well. Thus, it is possible to record the information and to do subsequent statistical analyses. Many studies have been conducted in the field of product positioning with use of machine vision in robotic processes. Machine vision system has been employed so as to calculate the position of robot's end effector in maintenance and inspection process of heat transfer system at a nuclear energy unit [2]. The mentioned system operates with use of images taken consecutively by a camera and online processing. To enhance the efficiency and precision of non-destructive tests such as the inspection of welding crack defect, robotic systems elevated by machine vision system has been used [3]. Also, machine vision system has been utilized as the most important section in fruit harvesting robots, e.g. apple and strawberry, and the quality of the development of a detective position-discovering system for robot guidance has been considered [4,5]. To position several non-industrial robots in an appropriate geometrical arrangement, it is required to have the relative locations of robots to each other and surrounding area. On that basis, machine vision system has been utilized and considered for positioning of robots [6].

In robotic polishing process of biscuit edge of porcelain dishes, sensors, mechanical systems and template vibrant have been used to locate and direct the dishes. See Fig. 1, to observing the template vibrant to positioning dishes. Hence, the manufacturing rate in that section has been significantly influenced. On the other hand, considering the output rate of factory, it is not possible to polish all of the output biscuits from the press, which inevitably involves some biscuits to be transferred by human to another section in order to perform the polishing of edge. In this research, the results from successful utilization of machine vision system for detection of position and direction of biscuits of glazed porcelain dishes in robotic polishing process of edges are presented.

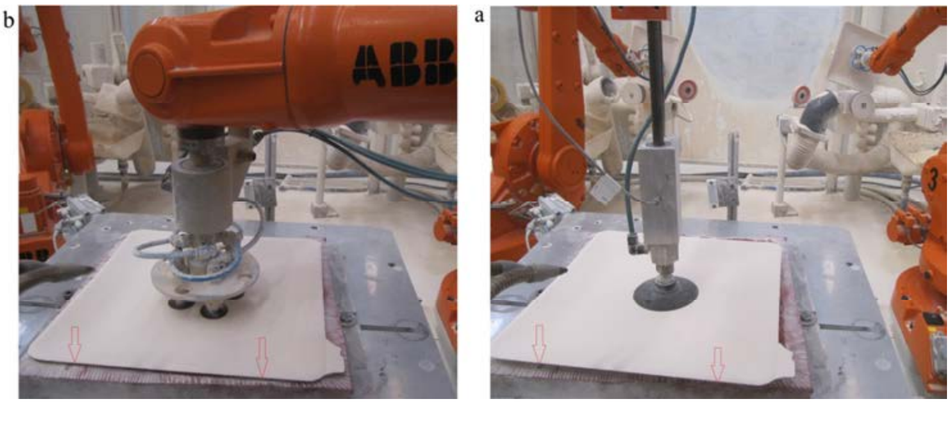

Fig. 1. Image of the positioned dish in template vibrant. (a) Before vibration; (b) After vibration.

2. The lighting condition

For different reasons, such as restraints in number of robots and Pressing machines, the production of each porcelain dish is in form of groups. The biscuits of 30 porcelain dish types are produced by four Pressing machines, and after that, the polishing process of edges of dishes are performed by 12 robots. Therefore, programming of presses and robots can be modified proportional with manufacturing process and polishing of biscuit edge of dishes. Also in each group of robots, dishes with more similarities to each other are processed by polishing. So, the vision system related to each group of robots is designed proportional with the types of dishes manufactured in that group. With regard to the fact that one of the most important sections of any machine vision system is the lighting condition, in this section we consider the lighting condition of porcelain dish biscuits. After the pressing process and the creation of burr at the edge of the biscuit of each dish type, proportional with its shape, edges and surfaces with different slopes are created. Also, during the falling of each biscuit from the press onto the conveyor and its movement toward the robots, it is possible that one or several burrs are separated from the biscuit.

Fig. 2 shows the images of quadrate biscuit selected out of the produced dishes. For lighting and separation of a dish type, directional lighting system can be utilized. On the other hand, regarding the variety of dish types as well as displacement of dishes on the conveyor as ±50 mm across the width of conveyor and the rotation of dishes at a maximum of 20° clockwise and counterclockwise from the camera scope, the differences of edges under directional lighting is high and so the fitting error of correct edge is high. Regarding that the nearest created edge to the dish surface is circular and that the surface exists in entire dishes, so the most appropriate lighting method is the use of intense light with appropriate intensity and angle.

3. Camera calibration

There are various factors in vision systems that might cause errors in obtained results, which generally can be mentioned namely as lens distortion, lack of precision error from electronic equipment of system, error from conversion to digital, mechanical assembly error, lighting error, environmental condition effect, software error, light refraction and calibration error. In most calibration processes, 12 parameters are specified during the calibration of camera, 6 of which are related to internal factors while the other 6 relate to external ones.

External factors include translation vector and rotation matrix of camera's origin relative to global coordinate origin. Internal factors include focus length, position of the center of image and distortion factors of lens. Regarding that the camera is fixed in positioning and directing of the dish biscuits during robot vision process, the camera calibration is carried out once. In this study, the calibration process used in [7] is employed and its results are presented in continuation. Fig. 3(a) shows pinhole camera model used for calibration process.

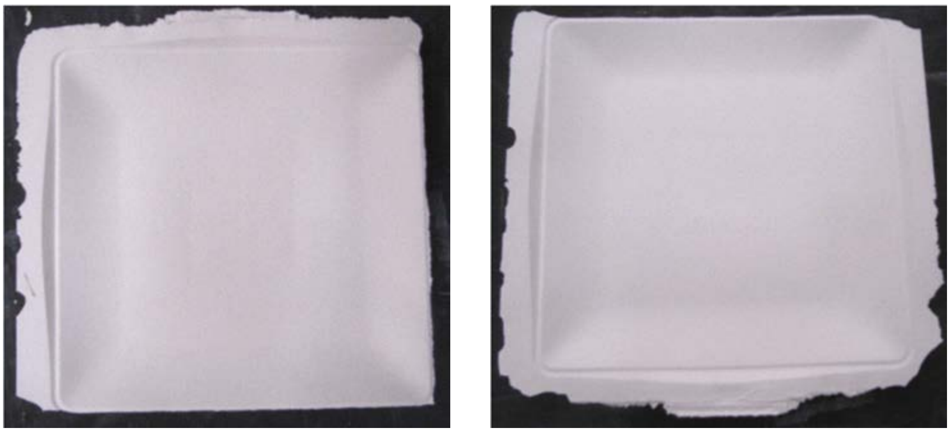

Fig. 2. Images of two square dishes with different burrs.

3.1. Camera Calibration Results

In order to do the calibration process, a checkered plane with each area size of 30×30mm is used, see Fig. 3(b). Items such as dimension precision, the quality of black and white colors, and flatness of the plane are among the features that must be taken into consideration. After placing the calibration plane on the conveyor and fixing the camera position in an appropriate place on the plane, image is taken and the process is iterated for different positions and directions of calibration plane. Eventually, making use of images taken by camera and MATLAB software, the calibration process completes.

Fig. 4 illustrates the pixel error in camera calibration. Tables 1 and 2 show the intrinsic and extrinsic parameters of camera calibration estimated using Heikkilä and Fabras method [7]. The calibration process includes the verification stage through position detection of a matrix of rectangular black objects with known position. During the verification process the robot arm ordered to move to controlled positions (minimum of three) and those positions are detected by the priorly registered camera-robot coordinate system.

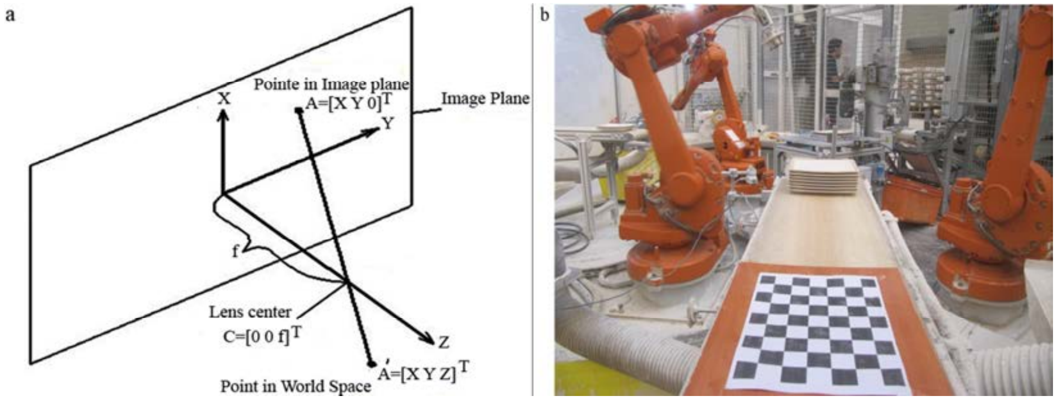

Fig. 3. (a) The geometry of a pinhole camera; (b) Target plane for calibration process.

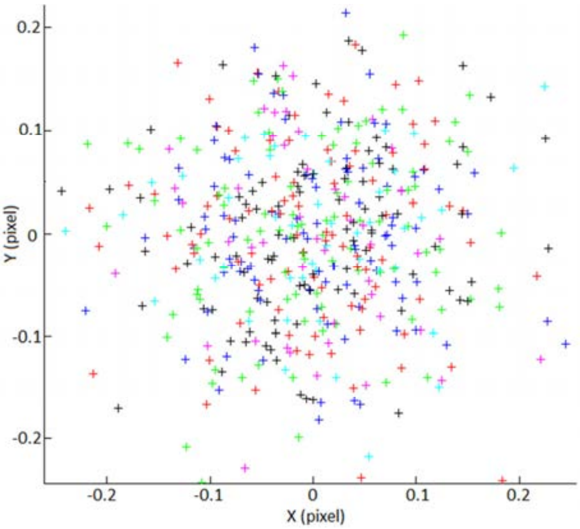

Fig. 4. Pixel error in camera calibration.

Table 1. Results of camera calibration (intrinsic parameter).

Calibration results after optimization
Fc = [4471.72712 4492.85555] ± [77.51219 75.42093]
cc = [214.03465 -1.13003] ± [0.00000 0.00000]
alpha_c = [0.00000] ± [0.00000]
Kc = [0.61713 -28.37477 -0.03627 -0.01239 0.00000]
±[0.35125 14.21774 0.01313 0.00472 0.00000]
err = [0.25277 0.17431]

Table 2. Extrinsic parameter of the last target position.

Extrinsic parameters:
Translation vector=[11.727874, 32.415968, 0.658586]
Rotation matrix: $= \begin{bmatrix} -0.056664 & 0.63834 & -0.767661 \\ 0.998130 & 0.05389 & -0.028863 \\ 0.022946 & -0.7678 & -0.640206 \end{bmatrix}$
Pixel error: = [0.36395 0.12371]

Fc: focal length, cc: principal point of image, alpha_c: skew coefficient of image, Kc: distortion coefficient of lens, err : pixel error.

4. Image processing

In this process, the aim is to position and direct the edge of porcelain dishes biscuit. In general, the produced dishes have various shapes which could be divided into four groups: circular, square, rectangular, and triangular. Out of the four groups, the positioning and directing algorithm relevant to two dishes with quadrate (square) and circular shapes has been presented. The images taken have a resolution of 1280×960 pixels, which were taken using the industrial camera (DFK23GM021).

In image processing of square dishes, straight edge detection algorithm has been used. To date, many studies have been conducted in regard with edge discovering of different products. To extract the crack defect in automation process of ceramic tile grading, edge-detective function and afterwards the morphological functions to increase the accuracy of algorithm has been applied [8]. To detect the edge of ceramic tiles, the Subble edge-detective algorithm has been used and the process of edge detection has been introduced as two stages: detection of pixels in which the occurrence of edges is probable, and integration of these pixels to describe the edge [9]. The first step in image processing is the improvement of images and elimination of noise afterwards. In noise elimination of images, the application of linear filters causes image dimming. For this reason, a linear filter has been used for noise elimination of the image, which includes the detection of each pixel of the image, classification of neighbor pixels according to their intensity, and eventually replacement of main pixel value with the middle value obtained through the classified pixels [10]. In this stage, to detect the edges of dish, straight edge detective functions have been applied on the images. The processing algorithm of images relevant to square dishes has been illustrated, see Fig. 5.

The results from the application of the algorithm on square dish image are demonstrated, see Fig. 6.

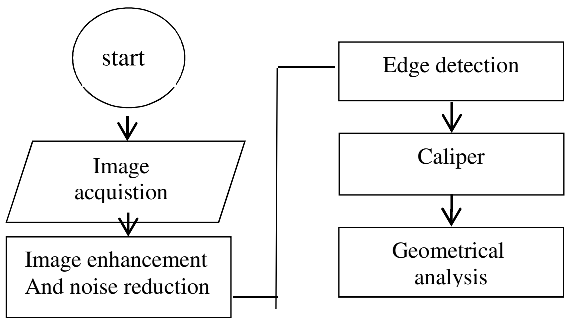

Fig. 5. Image processing algorithm.

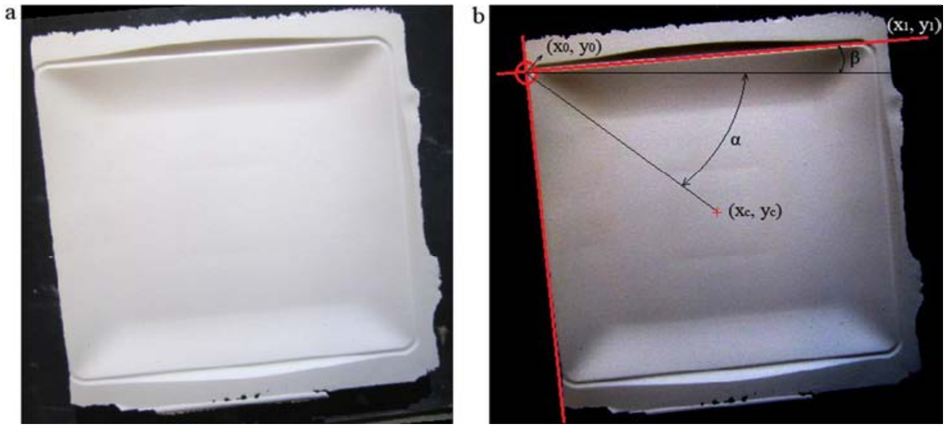

Fig. 6. Square dish biscuit: (a) before image processing; (b) after image processing (line fitting).

After the image processing and the lines fitting on at least two edges of the dish, three points are introduced as the output from this stage. One point relates to the intersection place of the two lines, and the other two points relate to the end points of fitted lines. Therefore, by geometrical calculations on the obtained three points, the direction of edge as well as the centre coordinate of dish relative to the vision system reference is resulted. With the assumption that the image can be divided into four equal areas from its centre; the intersection place of the two lines fitted on dish edge could be located on any of the four areas of image. Also, regarding that the rotation of dishes is possible clockwise and counter clockwise (from camera scope), generally there is the possibility of eight different conditions at the place of lines intersection point and edge angle. In continuation, one of the possible conditions is considered. According to the Fig 1(b), the condition presented in this research is the position of intersection point of lines fitted on edges in upper left area of the image and the rotation of dish is counter clockwise. So, to calculate the rotation angle and the centre of dish, we have the following relations:

$$\beta = \tan^{-1}\left(\frac{y_1 - y_0}{x_1 - x_0}\right) \quad (1)$$

Where β is the angle corresponding to the line fitted on latitudinal edge of biscuit relative to the horizon. x_0 and y_0 are the pixel coordinates of the intersection of the two lines where x_1 and y_1 are the pixel coordinates of the end point of the latitudinal line. So the coordinate of dish centre can be achieved by:

$$x_c = x_0 + \sqrt{a^2 + b^2}\cos\alpha \quad y_c = y_0 + \sqrt{a^2 + b^2}\sin\alpha \quad (\alpha = 45 - \beta) \quad (2)$$

Where $\sqrt{a^2 + b^2}$ is half of the dish diameter.

In positioning process of circular dishes, circular edge discovering method has been used. The edge zone of circular dishes, like quadrate dishes, also has edges and surfaces with different slopes. So, the lighting with appropriate intensity method is used in these dishes. In circular dishes, the aim is to calculate two numbers indicating the x and y position of their center. Fig. 7 shows the results obtained through the application of the algorithm on the image of circular dishes.

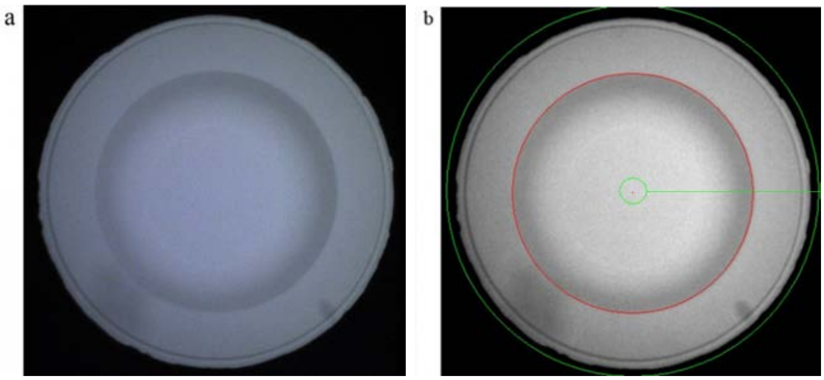

Fig. 7. Circular dish biscuit: (a) before image processing; (b) after image processing (line fitting).

In Fig 7(a) the part of edge which has distortion, is the same as burr of biscuit. The burr-related area extends (radially) to the first edge. In circular dish biscuits, the fitting of the entire edges except the burr-related edge, leads to the calculation of pixel coordinate of biscuit center point. This is obvious in Fig 7(b). In this condition, due to the software properties in detection of edge points from the center radially outward and from the dark edge towards the light one, the nearest edge to the center is fitted.

5. Result

In tables 3 and 4, the results from the positioning and directing of a number of biscuits are given. Fig. 8 shows detected dishes which have placed in five different positions and orientations. Sub-images a, b, c, d and e show the situations happened in the five first rows of table 3. To validate the results, the positions and orientations detected by vision system were given to the polisher robot in porcelain TAGHDIS Company. Fig. 9 shows the dishes after the polishing process. The quality control unit of the company approved the quality of polished dishes processed by the robot and vision system.

Table 3. Results of positioning and directing of square dishes.

horizontal edge angle	dish center x(Pixel)	dish center y(Pixel)	dish number
-22°	400	600	1
-3°	395	620	2
15.2°	380	590	3
8°	389	610	4
-20°	418	604	5
-10.6°	403	593	6
2.1°	386	612	7

Table 4. Results of positioning of circular dishes center.

radius (Pixel)	dish center x(Pixel)	dish center y(Pixel)	dish number
326	495	519	1
310	510	512	2
318	498	525	3
338	486	523	4
325	493	532	5
312	502	510	6
322	499	514	7

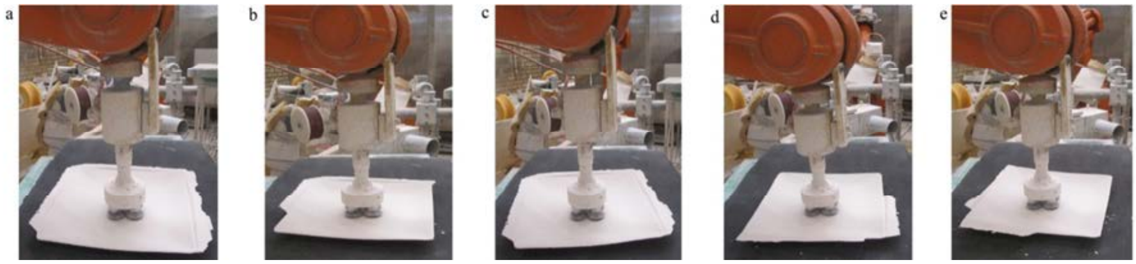

Fig. 8. Five detected dishes placed in different positions

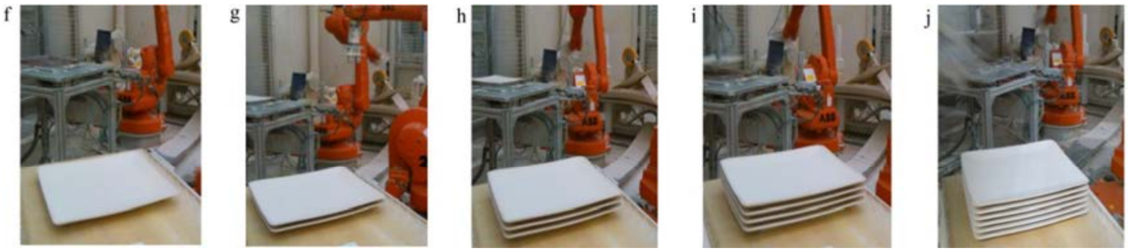

Fig. 9. Polished dishes processed by the robot and vision system.

6. Conclusion

In this study, the results obtained through successful application of machine vision in creation of a flexible automatic process for the polishing of the edge of glazed porcelain dishes are presented. The aim was to increase the uniformity and manufacturing rate of polishing process of dish edges. Owing to the application of machine vision in detection of position and direction of dishes online, there is no need for positioning and placing the dishes in robot-handled location using mechanical systems as well as the dish control by human. As a result, the pace of process is increased and the entire biscuits produced by press, are polished in the same section. The manufacturing rate of each polishing sections used to be 300 dishes per hour, which has reached to 360 dishes per hour through the application of machine vision and the elimination of mechanical systems.

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