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Image Processing Based Quality Measurement System for the Manufacturing Process of Porcelain Plates

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Abstract – *This paper aims to introduce an Image processing-based non-contact diameter and thickness measuring system for the manufacturing process of porcelain plates.*

The proposed system is designed to replace the manual process of quality assurance with a non-contact design that is more precise, time-efficient, and has effortless control. Seeing that the verification of acceptable tolerance levels in quality parameters (foot diameter, outer diameter, centre thickness & edge thickness) manually is time-consuming and erroneous, a more satisfactory system is designed to meet the stipulations.

Here in this design, the laser displacement method, triangulation principle and pixel scaling methods used to provide the necessary basis for the image processing analysis for thickness measurement, and edge detection algorithm for diameter calculations.

This system provides an improved error percentage variance of 0.01- 0.13 in outer diameter, 0.01-0.52 in the foot diameter and 0.18-1.38 in centre thickness measurement. Regardless the system can be used for similar applications where non-

Keywords *–Non-contact measurements, pixel scaling, CCD*

1 INTRODUCTION

This paper analysed the manufacturing process of porcelain products and identified the areas that can improve by applying vision-based measuring techniques to enhance to quality of products by reducing the drawbacks of the existing manual process.

The analysis is based on the data collected from the Dankotuwa Porcelain (Pvt) Ltd with the prime focus on **TYPE 520** plate model. From the statistical data, plate type 520 is the most defective plate item in the manufacturing process. According to company reports, the number of quality products versus the total production of porcelain varies between 60-75 % at the final production stage. At present, they employ a manual process where plates are selected on a random basis every ½ an hour where workers cut the plate (Refer Fig.1) through diameter axis and check the Outer diameter, Foot diameter, Centre thickness and Edge thickness of the plate using a vernier calliper. Further, the weight of the plate is measured using an electrical balance. The manual process does not yield a meticulous output as the process is time-consuming, inefficient and observer-dependent.

On the other hand, in the manual process quality parameters measurement take place in the biscuit stage (Fig.2). At this stage, it is impossible to recycle raw materials. By introducing an alternative approach to measure the quality parameters in, forming stage promotes easy recycling of defective products.

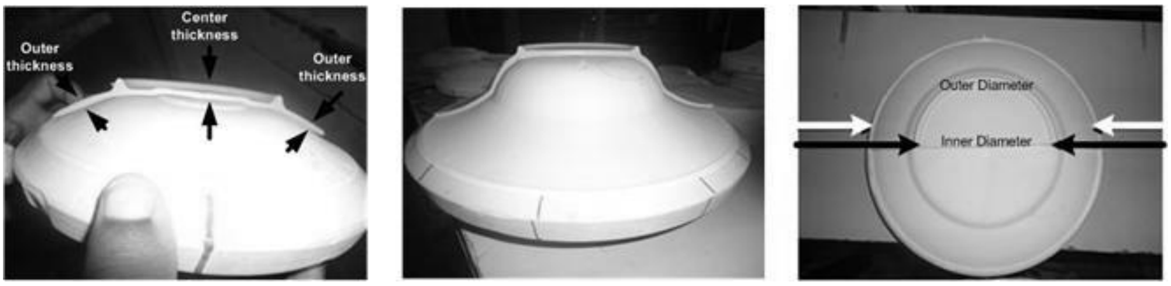

Fig. 1. Quality Parameters of Plates

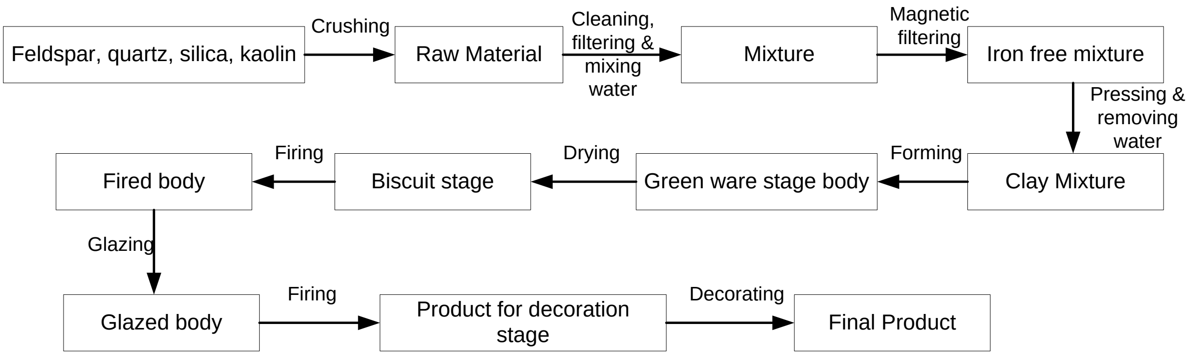

Fig. 2. Manufacturing steps of porcelain plates

Before the biscuit state, the product is extremely fragile. Therefore, the non-contact-based measurement system is required to do the quality parameter measurements. Vision-based systems widely used technology in many industrial applications. Even though is it established technology, the specific application needed to investigate and come up with unique solutions. Let us discuss few vision-based measurements application and research work.

Chenu-Chung (Chen *et al.*, 2008) explaining how CCD camera used for an area measuring while recording images simultaneously. It used the relationship between the pixel number and the distance to measure the area in large. Paper explain how to build the relationship between pixels and distance using the triangular method. Similar approached used in our proposed approach.

Chih Lu et al. (Lu, Wang and Chu, 2006)introduced a novel measuring system using a scan counter method via a CCD camera. In this method, measuring system, measure the distance between a CCD camera and an object, and to measure the projected area of the object. Two laser projectors are set on either side of a CCD camera and produce two parallel rays that project two bright spots on the object on the CCD. An external clock, which is generated by an extra oscillator, is used to measure the time interval between the two bright spots as the CCD scans the image. A circuit for counting the number of external clock pulses between the two bright spots is employed to calculate the interval between them in the video image. The most significant advantage of the proposed system is, it does not require highly complex hardware to process and processing time is less. It is an essential requirement for real-time application. Our approach using image processing techniques and required high processing power, and it takes considerable time to process.

The proposed system in (Lu, Wang and Chu, 2006) output distance from the CCD to image and calculate the surface area of the object. In our system, it is required to get the necessary measurements like the diameter and thickness of the plate.

To measure the thickness of a cable subpixel based image processing techniques has been introduced in(Wang and Zhao, 2011). The proposed method is more focused on the accuracy of the measurement as it used to take the precision measurement. Overall computational complexity is high in the proposed method. The proposed method not suites for our requirement as considered application requires a less complex computational algorithm for measuring parameters.

There are many vision-based measurements systems in the various application explain in (Wang and Wang, 2015),(Wang and Zhao, 2011),(Borkowski, 2002),(Wang *et al.*, 2007) and (Hwang, Park and Kim, 2010). In all these research work trying to solve application-oriented practical issues, which is needed to investigate case by case. Even though the same base principle is using, application-specific challenges require a novel approach to solve the problem. Hence, there are new research opportunities in vision-based applications.

Similarly, this study focused on an application-specific problem in the porcelain manufacturing process. The objective of this study is to replace the manual process of measuring quality parameters with a preeminent, efficient, automated system design to minimise the production wastage, time wastage and improve quality of production. The primary approach of the proposed methodology is a combination of Laser triangular method and image processing techniques.

2 METHODOLOGY

According to the quality targets, the details of the Plate **TYPE 520** with an acceptable range of variation in measurements are as follows.

Table 1 Manufacturing product details of Plate model: 520

Measuring detail	Design value	Tolerances
Foot diameter	187mm	+/- 1mm
Outer diameter	300mm	+/- 1mm
Centre thickness	5mm	+/- 0.5mm
Edge Thickness	3mm	+/- 0.5mm

Image processing approach is used to measure the quality parameters as the accuracy can maintain in the tolerance values, and it is proven techniques in non-contact measurements over ultrasonic systems—considered application required two types of measurements to be taken; Diameter and thickness.

2.1 Parameter Calculations

2.1.1 Calculation of Plate Thickness

For thickness measurements, Laser displacement method is used. If the angle between the Camera, laser and the line displacement is known, the component height calculated using simple trigonometric formulae (right-angled triangle).

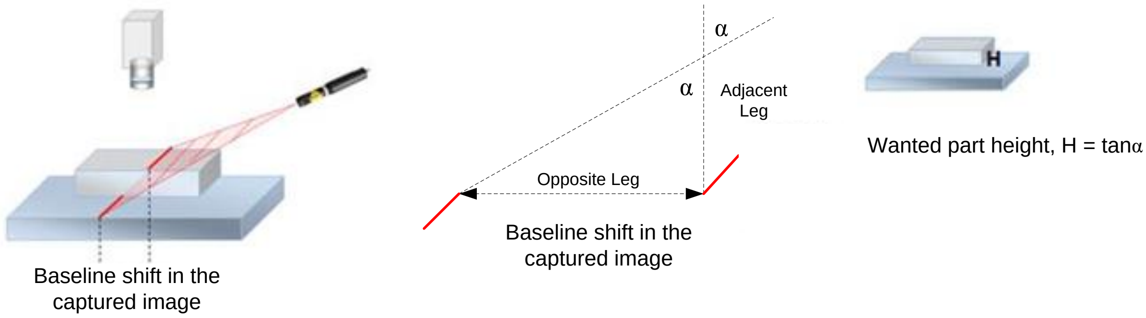

Fig. 3. Thickness measuring & Calculation using the laser triangulation principle

If the laser project on the object with a shallow angle (As shown in Fig. 3), even small differences in height cause a substantial displacement of the lines, even differences of tenths of millimetres can be detected easily without special effort, Fig. 4 shows a sample image of such displacement of the laser beam.

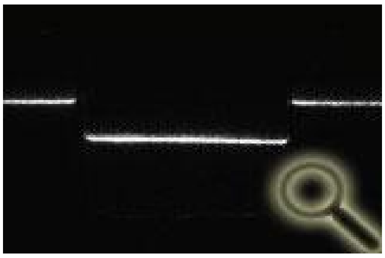

Fig. 4. Image of a projected laser beam for thickness measuring

The line displacement can be found by simply multiplying the pixel distance between two lines with a fixed constant. As the projection angle of the laser pointer (ϴ) is already known, plate thickness derived as a product of the tangent of the projection angle and line displacement.

$$Thinkness(Y) = X\ Tan\theta\ (1)$$

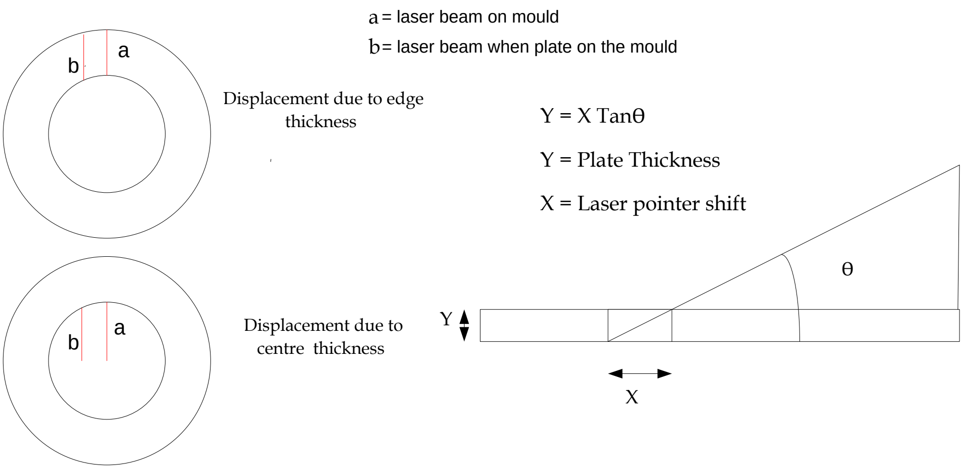

Fig. 5. Thickness calculations using a laser pointer

With this method, it is possible to find the centre and edge thickness of the plate. To find the edge thickness, it is needed to apply the laser beam parallel to the angle plate surface. Displacement of laser beams is appearing after adding two images taken mould only and mould with the plate. Plate thickness causes the displacement of the laser beams. In the practical setup, we are considered only centre thickness as the procedure is the same for the edge thickness.

2.1.2 Calculation of Plate Diameter

The edges of the captured images are detected by applying the edge detection algorithm(Canny, 1986) to the smoothened greyscale image. The relevant outer diameter & foot diameter are filtered out from the received set of diameter values (pixel values) procured using OpenCV inbuilt libraries. Similar to thickness measurement, outer diameter & foot diameter is obtained by multiplying the diameter values (pixel count) with a fixed constant.

2.1.3 Calculation of the Focal Length of the Camera

Even though the focal length of the Camera is specified, it is needed to find it experimentally in an application like image processing-based measurement calculations. As shown in Fig. 6, an object is mapped of the CCD chip through the camera lens. Since the CCD chip is two dimensions, we can find the value for focal length considering object height and width. Focal length can found using known parameters like object height, working distance and size of the CCD chip.

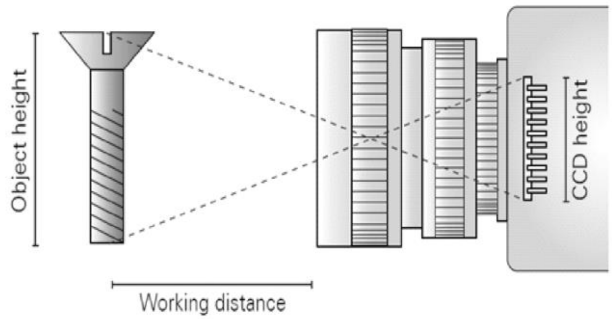

Fig. 6. Method of calculating the focal length

$$\text{The focal length of the height} = \frac{(\text{working distance} \times \text{CMOS height})}{(Object\ height + CMOS\ height)} \quad (2)$$

$$\text{The focal length of the width} = \frac{(\text{working distance} \times \text{CMOS width})}{(Object\ height + CMOS\ width)} \quad (3)$$

2.1.4 Pixel Calibration for Distance Measurement, Calculation Technique

Calibration involves determining the correspondence between pixel units and physical units. It allows measurements made in pixel units to converted to physical units by scaling factor. Four parameters need to measure in two dimensional CCD; pixel height, h; pixel width, w; the aspect ratio $r = h/w$; and pixel area, $a = h \times w$.

Furthermore, there are two methods of pixel calibration techniques; Length and Area-based measurements. Length based calibration technique has been used in this process as the measurements are the length of an object [15].

In the proposed method, the Camera is mounted perpendicular to the object in a fixed position. Fig. 7 shows how the object image focuses on the CCD sensor area. It is needed to find the relationship between pixel size and the object size. CCD pixel size and the calculated size is not necessarily the same. Therefore, let us define a new parameter, scaling factor. Since CCD is a two-dimensional, scaling factors should find for both x and y directions.

2.1 Calibration procedure – Length

In the calibration process, dimensions know objects needed to use as reference objects. Then no. of pixels will be counted using the algorithm. After that, the relationship between object dimensions and pixel count can found.
A circular-shaped object of known diameter has chosen. Let the known diameter of the calibration object to be *D,* and *W* is the pixel count.
The calibration parameters can then calculate as:

$$\textit{Pixel Scaling factor\_X (Px)} = Dx / Wx \quad (4)$$

$$\textit{Pixel Scaling factor\_Y (Py)} = Dy / Wy \quad (5)$$

x and y denote x-direction and y directions, respectively.

These equations valid only when H is the fixed and same type of plates.

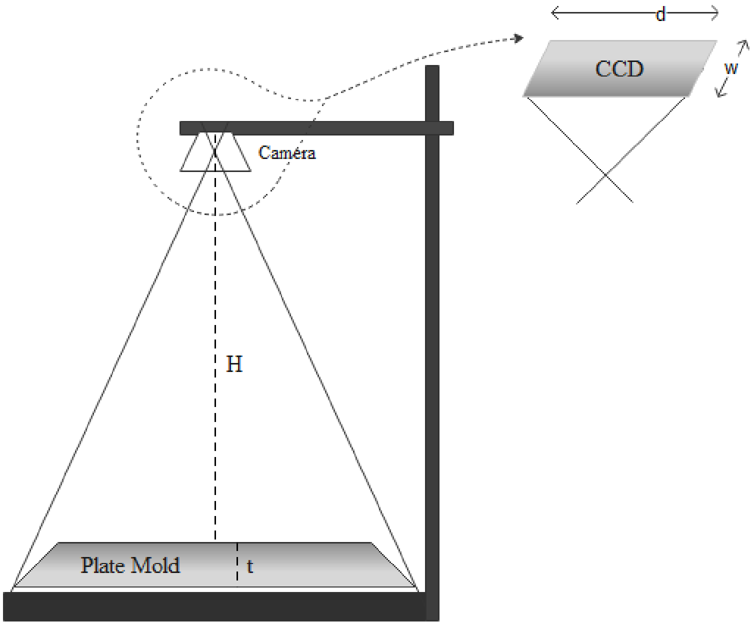

Fig. 7. Scaling the object on the CCD plane

The distance of Camera to foot diameter - (H+t)
The distance of Camera to outer diameter – H

i. ***Pixel to real values Conversion***

Plate Outer diameter – D0
Plate Foot diameter - Df

Measured values,

The pixel count of Outer diameter - NpixO

Pixel of foot diameter - NpixF

For a camera with a known pixel value mounted in the distance H from the object, the relationship between the number of pixels that represent X mm=N pix/L (mm).

$D_o = NpixO \times Px$ or $D_o = NpixO \times Py$ (6)

$D_f = NpixF \times Px$ or $D_f = NpixF \times Py$ (7)

From equation (5) and (6), plate outer diameter and foot diameter can find.

2.2 Image processing-based diameter, thickness detection and calculation Algorithms

Next, let us focus on image processing algorithms used in the proposed method.

2.3.1 Quality Parameter Measuring Process

The first step of the process is to capture images of the mould. Then apply mixed on the mould and capturing an image with the plate by applying two laser sources described in 4.1. From these two images, we can apply the image processing algorithm to calculate the thickness measurements and diameter measurements. These data stored in a database, and it will compare with the given specification. If it is in the acceptable range plate is moved to the next steps, and if not, it will reject, and raw material will be recycled.

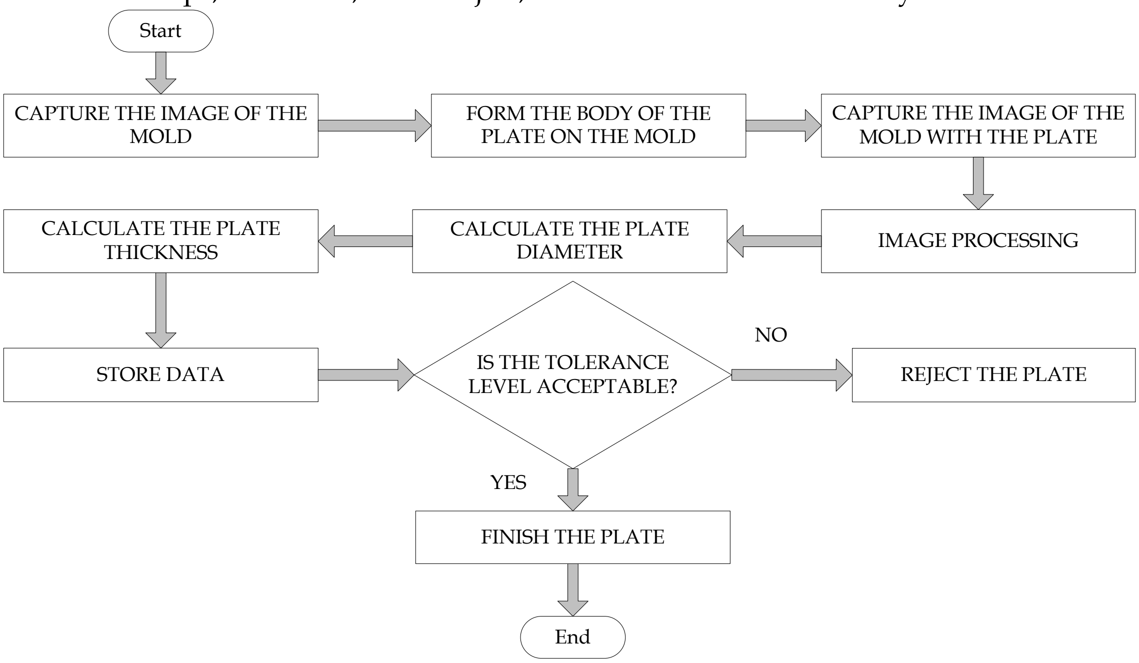

Fig. 8. Flow Chart for Quality Parameter Measurement Process

2.3.2 Image Processing Algorithm for Diameter Measurement

For diameter measurements, contours of outer and foot diameters need to need to identify. As the first step, the algorithm threshold the image to filter the unwanted details. Then, it converts to black and white image to make the edge detection process easy. Edge detection and centre identifying algorithm explained in the next sections.

After identifying the centre, the diameter can calculate. Fig. 9 shows the process of calculating the diameter of the plate.

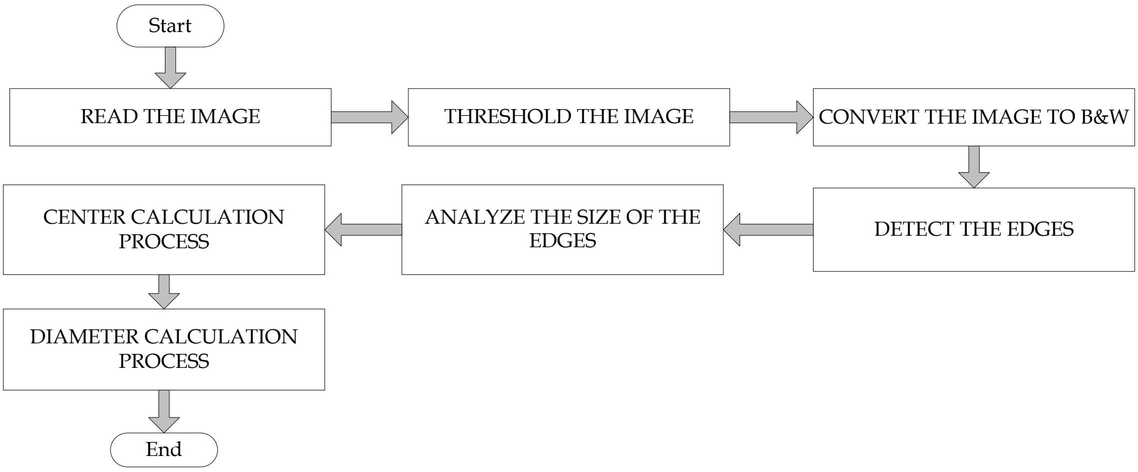

Fig. 9. Flow Chart for Diameter Measurement

2.3.3 Edge Detection Algorithm

The edge detection algorithm is based on the Sobel operator. The algorithm is calculating the gradient of the intensity of the image. At each point, it finds the direction of the change from light to dark. It also finds the magnitude of the change. This magnitude corresponds to how sharp the edge is.

The algorithm can break down into its constituent steps.

a. Iterate over every pixel in the image.
b. Apply the x gradient kernel.
c. Apply the y gradient kernel.
d. Find the length of the gradient using Pythagoras' theorem.
e. Normalise the gradient length to the range 0-255.
f. Set the pixels to the new values.

2.3.4 Centre Calculation Algorithm

The algorithm counts no. of pixels from left to right and right to left in the x-direction of the circle. The same procedure applied in the y-direction. From these values, it can calculate x and y coordinates of the centre.

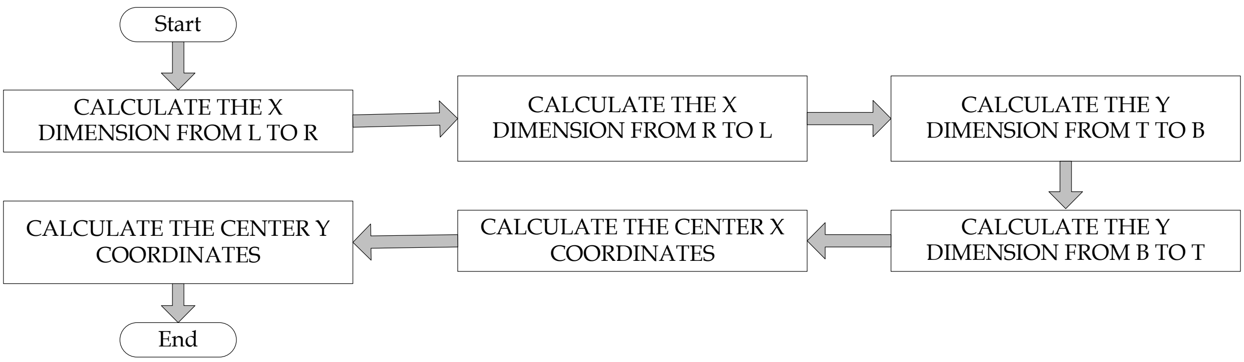

Fig. 10. Flow Chart for Centre Calculation

2.3.5 Diameter Calculation Algorithm

Once edges are detected, and centres of circles are known, diameters of circles can be calculated easily. The diameter calculation process is shown in Fig. 11.

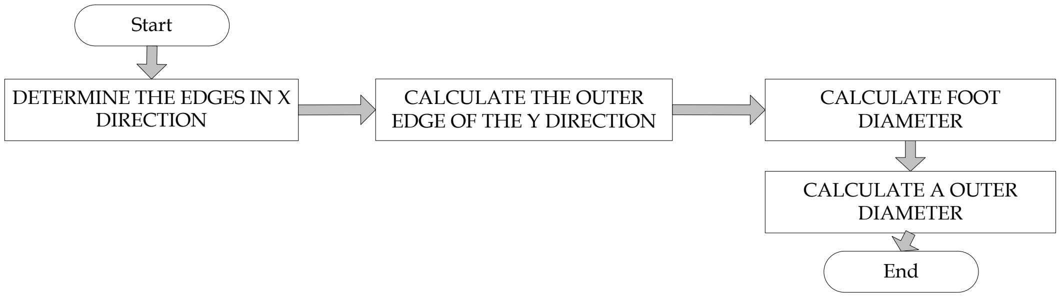

Fig. 11. Flow Chart for Diameter Calculation

3 IMPLEMENTATION AND TESTING

Implementation is being done in three steps.

1) Hardware implementation
2) Software implementation
3) Pixel scale conversion and System calibration

3.1 Hardware Implementation

The main components of the proposed system are CMOS camera and a single-board computer. A light source is applied to the Object (Porcelain plate on the mould) to capture uniform images by eliminating effect from background light sources. A laser light source is used to get the plate thickness using the triangulation principle. The single-board computer process images and results are shown in the LCD.

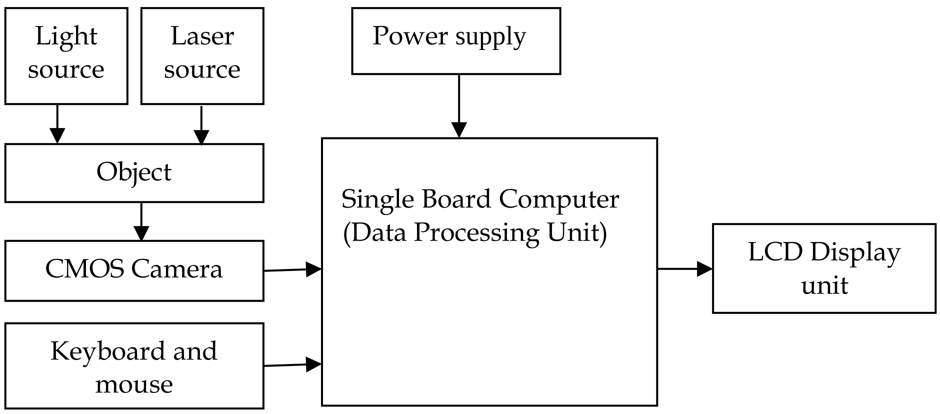

Fig. 12. Block Diagram of the Proposed hardware setup

Raspberry Pi Model B - ARM1176JZFS Processor is used as the central processing unit in the design. A 5-pixel camera module is used for detection, and a laser pointer of 532nm and 1mw power is employed.

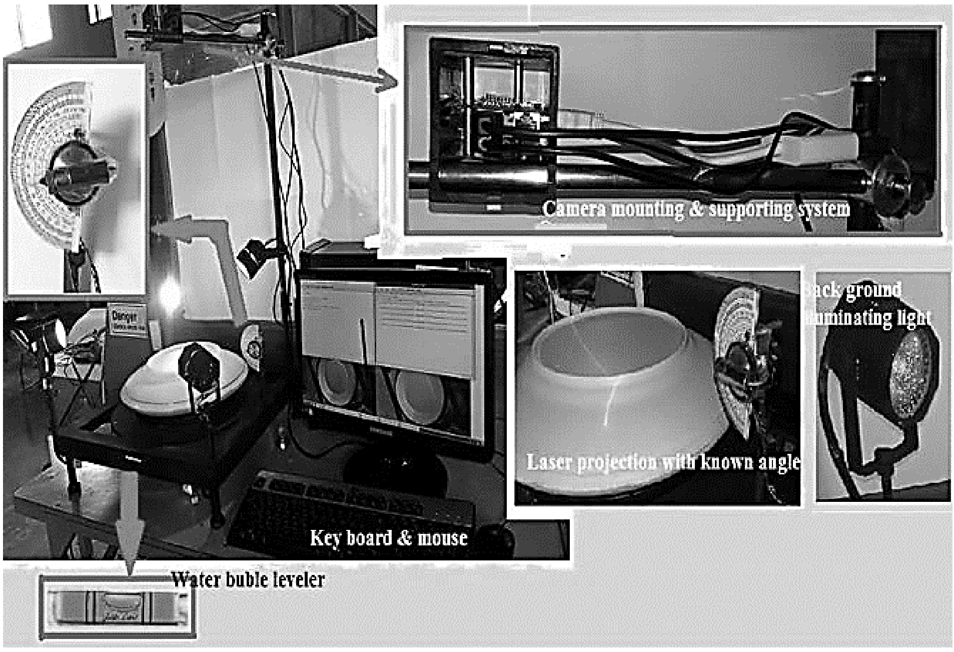

Fig. 13. The hardware setup of measuring unit

Hardware implementation is shown in Fig. 13. Setup equipped with a 1) lighting system to illuminate the object, 2) laser projectors with known angles to find the thickness of the plate using the pixel drift method, 3) camera module with Raspberry Pi board as the processor, 5) display and keypad. Water bubble leveller has been included to frame to adjust the frame to the horizontal level. Frame level affects the accuracy of the measurements.

3.2 Software implementation

Open-source computer vision and machine learning software library, OpenCV (Open-Source Computer Vision Library) are used for developing algorithms through Python programming language.

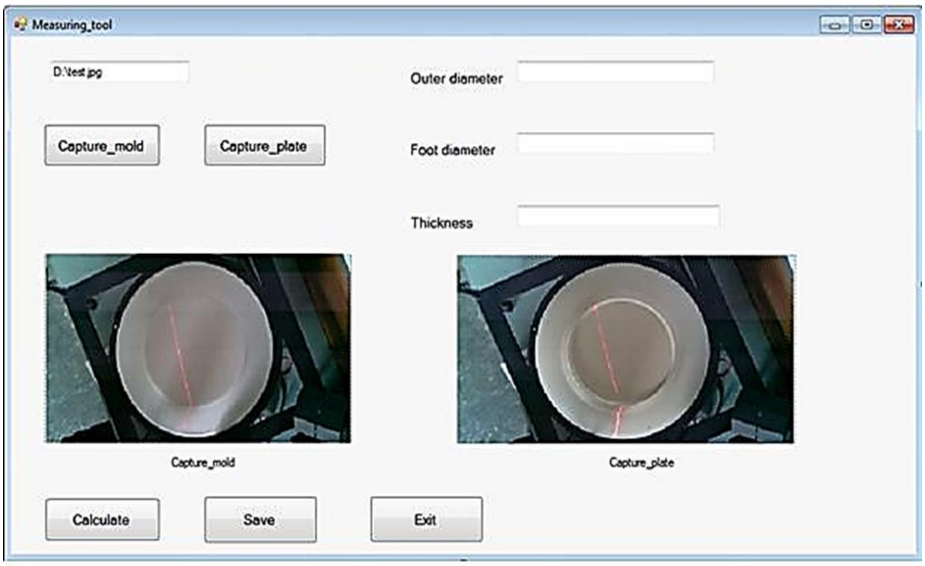

Fig. 14. Laser pointers shift after adding two images

Fig. 15. Implementation of thickness calculation

Fig. 16. Implementation of diameter calculation

Fig. 14 shows the software interface for the system. It shows the laser beam applied to mould and the plate. These two images added, and displacement of laser beams is calculated.

Laser displacement is shown in Fig. 15. Laser implement first calculated from pixel mapping, and after that, it converts to real object measurement by multiply by scaling factor. Fig. 16 shows the processed images for contour detection hence calculate the diameters of out and the foot diameter of the plate. These data are stored in the system for later analysis.

3.3 Pixel Scale Conversion and System Calibration

3.3.1 Pixel Calibration calculations

Reference objects were made in a two-dimensional plane to find the scaling factors according to equation 4 and 5. Table 2 shows the scaling factors obtain for x and y directions—the average value selected as the scaling factor.

Table 2 Pixel calibration

Length of Specimen (*Dx*) in mm	Pixel count (*Wx*)	The scaling factor (*Px*) in mm	Width of the specimen (*Dy*) in mm	Pixel count (*Wy*)	The scaling factor (*Py*) in mm
400	947	0.4224	400	932	0.4291
300	711	0.422	300	699	0.4291
310	735	0.4218	310	723	0.4287
320	759	0.4217	320	745	0.4295
200	474	0.422	200	466	0.4291
250	593	0.4216	250	582	0.4295
Average value		0.422	Average value		0.4292

TYPE 520 plate has been used to verify the results.

Outer diameter – measurements taken on x directions,

The relationship between pixel value with real distance = 300.96mm / 712pix

Px = 0.422 mm

Foot diameter – measurements were taken on y directions,

The relationship between pixel value with real distance = 187.78mm / 437pix

Py = 0.429mm

In both approaches, nearly the same scaling factor values obtained.

4 RESULTS AND DISCUSSION

The results of the testing phase are as follows. These values obtained according to the equations (1),(6) and (7).

Predominantly measurement of distance and displacements is categorised into two as contact method and non-contact method. However, designing a quality measurement system for the manufacturing process of porcelain plates at the forming stage seek a non-invasive method with no external effect on the product. We have proposed a quality measurement system that employs Image processing. The primary purpose of this system is to replace the existing manual process with a low cost, efficient, automated system that requires minimal supervision.

In the design, the pixel dimensions of captured images are directly converted to the real scale of the plate, and measured values are displayed via an LCD and stored for further analysis. The results of the system show that developed design works with acceptable accuracy. However, for accurate analysis of the captured image, elimination of unnecessary noises, maintaining of a proper lighting system and precise surface levelling is crucial.

Table 3 Observation from the proposed system

Plate number	Actual Reading (mm)			System Reading (mm)		
	Outer diameter (mm)	Foot Diameter (mm)	Centre thickness (mm)	Outer diameter (mm)	Foot Diameter (mm)	Centre thickness (mm)
1	300.5	188	5.58	300.46	187.90	5.56
2	302	187.5	5.06	301.73	187.47	5.13
3	302	187.5	5.30	301.73	187.47	5.27
4	301.5	188.5	5.30	301.30	187.68	5.27
5	300.5	189	5.58	300.46	189.18	5.56
6	303	188.5	5.06	303.41	187.68	5.13
7	302	187	5.54	301.73	187.04	5.55
8	302.5	187.5	6.02	302.15	187.47	5.99
9	301.50	189	5.54	301.30	189.18	5.55
10	303.5	188.5	5.06	303.8	187.68	5.13

Table 4 Error vs measuring distances

Plate No.	Absolute Error Percentage (%)		
	Outer Diameter(mm)	Foot Diameter(mm)	Centre Thickness(mm)
1	0.01	0.05	0.35
2	0.08	0.01	1.38
3	0.08	0.01	0.56
4	0.06	0.43	0.56
5	0.01	0.10	0.35
6	0.13	0.43	1.38
7	0.08	0.02	0.18
8	0.11	0.02	0.49
9	0.06	0.10	0.18
10	0.08	1.43	1.38

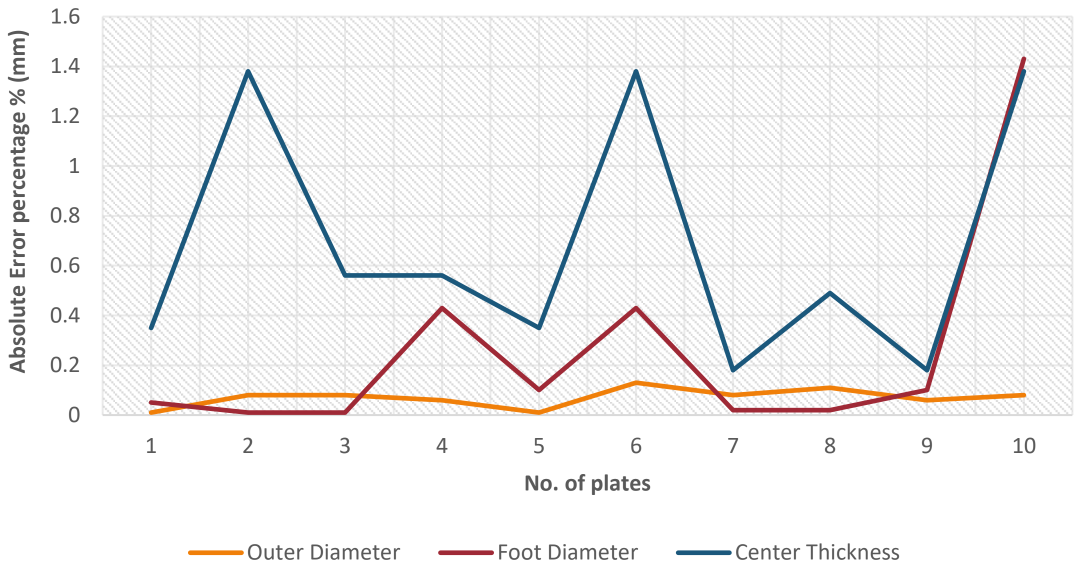

Fig. 17. Error vs. measuring distances

5 CONCLUSIONS AND RECOMMENDATIONS

With the help of the proposed design to the production line, product quality can be improved while reducing the energy loss and material wastage. In the proposed system, the main focus was the keep the accuracy of the system in the acceptable quality range and the keep the computation complexity minimum as possible. In the proposed system, we have used simple mathematics, and image filtering techniques to keep the computation simple. Hence, the processing time can be reduced. Processing time plays an important role in the industrial environment as it directly affects the production rate. However, the proposed system is a standalone system where plates should take off from the production line to do the measurements. Still, it saves time comparing to human measurements and saves the production cost as the testing in forming stages.

By use of a high-resolution camera, measuring accuracy can be increased as the pixel density of the image depends on the resolution of the Camera. Electro-Magnetic Interference caused by the vast amount of inductive load present in the factory environment must be avoided with the use of shielded cables for data communication. Raspberry pi and other electronic circuits should be covered in IP66 enclosure to prevent dust and moisture.

This system is tested only for plate type 520. In order to test with other plats, it is required to modify the base structure as the measuring plate is kept on the plate mould. It is a disadvantage of the system, and it can be improved by changing the mechanical structure where it supports different plate moulds. However, in this study, it was only focused on mechanical design.

Measurements are affected by the environmental lighting condition. In this study, an open mechanical design with a lighting system was used due to limited resources. It is recommended to use covered design with controlled lighting environment for minimising errors.

According to the error percentages, it is apparent that measurements accuracy is in the acceptable level of the factory quality standard. In addition, the following recommendations can be made for further improvements of the system

- The system should improve as a fully automated online system which can apply with the production line.
- System configuration with the network line to allow remote monitoring and access.
- Improvements in the user interface for smooth operation.
- Real-time isolation of defective products

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