

Automated Quality Inspection on Tile Border Detection using Vision System

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Abstract: Most of the ceramic tile industry still doing the quality control by manually. The accuracy of the manual inspection by human is lower due to the harsh industrial environment with noise, extreme temperature and humidity. A camera should replace the human eyes to recognise the defect tile effectively. Thus, a suitable method have to investigate for implementing this function. This project aim to design and develop an automated quality inspection in ceramic tile industry using vision system. The performance of the system is analysed. An Imaging Source CMOS industrial camera is use to capture the tile border. Image processing with edge detection technique is use to analyse the captured image of tile border and identify the defective tiles. The image filtering and intensity of the light are adjust to evaluate the performance of the system. The overall automation process involves image capturing, image processing, and decision making. The defect detection algorithms are develop to differentiate the defective tile based on the edge detection technique. The system using background subtraction method has achieved 50% accuracy in identify the status of tile since it consist of many limitation. By evaluate the gradient variation on the tile border edge, the accuracy of the defect detection has achieved 80% in identify the tile condition.

Index Terms: border defect detection, ceramic tile, crack, vision, visual inspection

I. INTRODUCTION

In this industry 4.0 era, automated system is indispensable to a modern manufacturing industry. The need of the mankind has demanded increase in productivity with the improved quality of the products. This has led to innovations, and these innovations have transformed the traditional manufacturing to advanced manufacturing. Quality control is a step in manufacturing to ensure customers receive a good product that meet their needs and free from defects. Consumers will face the risk if the quality of product is done in the wrong way

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[1]. There are several methods of quality checking. Each method has its own advantages and disadvantages. Contact type equipment consumes more time for quality check than non-contact type [2]. The conventional quality checking of a component is made by taking one sample out of a lot to ensure the quality of the particular lot. Such quality checking method may lead to rejection of the whole lot or even acceptance of defective parts. In order to ensure the quality of the product, each component has to undergo quality check, which raises the need of in-process inspection. In-process inspection ensures successful control over the quality of the component, reduces the quality check time, ensure inspection of each component and reliability as well as the efficiency of the system [3]. To fulfil the automated and in-process inspection, machine vision can be applicate. A machine vision system is a type of technology that enables a computing device to inspect, evaluate and identify still or moving images. The main problem in developing efficient machine vision is to translate the human visual perception into sequential and logical operations. In purpose to find some other ways for defect detecting the image processing methods are developed [4]. Edge detection is an image processing technique to find the boundaries of objects in images by detecting the discontinuities in brightness. In the ceramic tiles industry, the tile border can be found out using this method to identify the defect condition. There are many object analysis functions in MATLAB which are detect edges, circles and lines. MATLAB which developed by MathWorks is a multi-model numerical computing environment and possessed own programming language [5]. Image processing and computer vision is one of the product in MATLAB. Algorithm development is medium for image processing and computer vision due to each situation is unique and good solutions require many kinds of iterations on design [6]. It provided an Image Processing Toolbox contains many kinds of set of reference algorithms and workflow apps that can be applied for image processing, analysis, visualization, and algorithm development. It able to carry out image processing such as image segmentation, image enhancement and noise reduction. Many visualization functions and applications to explore images and produce histograms as well as manipulate regions of interest (ROIs) [7].

Most production process is automated in ceramic tile industry, yet the final step which is quality inspection still monitored manually. Failures on ceramic tile always causing by human error. The manual inspection on detecting the defect is based on human decision. Inspectors may feel eyes fatigue and tired causing the fail in inspection [8]. The failures in product will make customer on risk and the vendor, installer and some implicated person have to take responsible on it. Failure in quality inspection will cause the defect product shipped out to customers. Customer will complain and ask for recalled which will cause the company loss of money. Besides, customers not only ask for the product that failed specifications or had to be recalled but the company's operations in general also will be question for the quality. The product may not be accepted if the company under excessive warning letter. The image and reputation of the company will be destroyed and cause loss in customers' trust and business in this competitive field. Associated the financial impact due by lost sales, lower production with increased production costs and material cost increased. Company will suffer tremendous loss for failing in quality control so that a proper solution should be implemented to solve the error in inspection of defect product [9].

II. RELATED WORKS

A. Methods for Defect Detection

Ceramic tile defect can be detected by many methods. The more traditional method is detected by human eyes. A research is conducted by F. Ozkan [8] using an eye-tracker to assess workers when detect the surface defect of ceramic tile. The workers will mark a straight line on a surface of tile when they realise the defect occur. The marked tile will be sorted automatic by sensor detected. The research found that an expert worker have shown a systematic pattern when inspect the ceramic tile on conveyer. A good inspectors are evaluated by accuracy and speed are relatively high and make many brief eye fixations during the time they have to inspect. For a novice worker, the accuracy and speed will relatively low. Human eyes can detect some obvious defects but not all recognizable by human eyes. Human resources also expensive to use and sometime they are not accurate enough for visual controlling [10]. Time of Flight Diffraction (TOFD) technique using ultrasonic sensor is one of a non-destructive testing in the quality control of ceramic tile. It used to do the mapping of edges position. Ultrasound is transmitted and reflected in a normal direction if the tile is perfect. Diffracted wave will emitted with a wide angular range when a crack is detected. This method saving production cost but may affected by temperature, dust, vibration, humidity, roughness and movement of tile [11]. A laser speckle photometry also applied in ceramic industries for detection of micro-cracks on the surface of ceramic. A speckle pattern will varies based on the thermal and mechanical excitation of object. Heat will be distributed on the surrounding of defect area. Camera is positioning above the object act as a detector of the pattern change to recognise the defect such as crack [12].

There are many research of defect detection on ceramic tile with automated visual inspection system based on image processing method. The detection speed and accuracy rate are high which extremely improves the accuracy, stability and efficiency of product detection [3]. Image processing can be done within production line process. The cameras scan the tile quickly without stalling it and fixing position [10]. Image processing required less time to do defect detection and many algorithms have available to classify different type of defect [13]. In the research of Y. C. Samarawickrama by using Matlab image processing technique to detect the surface defect of tile, the accuracy have reached 96.36% from 110 sample and the rate of perform image processing and result delivering are just consumed 2 seconds [14].

B. Edge Detection Algorithms

Edge detection is the first step in image processing. Its function is to identify the discontinuities intensity in the boundaries of a homogeneous regions in an image. It is important for the next step which is edge extraction. Edge detection make the discontinuities apparently for the edge extraction. There are many edge detectors developed to produce edges that provide for faster and precise recognition of object from an object greyscale image [15], [16].

One of the most practical and frequently used edge detection algorithms is Canny edge detector. Canny operator can be said as an optimal detector. It function as make the image smoothly and find the gradient to eliminate insignificant edges with thresholding. This method obtained very good results in detected cracks, scratches, spots and blobs defect on tile [16]. Matlab software have the Canny edge detector library which can apply to do the image processing purpose. The automated ceramic tile surface defect detection system achieve an higher accuracy of 96.36% with using this technique in Matlab [14]. An automated visual inspection system of ceramic tile border defect also applied Canny technique to focus the line gradient for histogram subtraction with the aid of morphological filter for eliminate noise [10]. Laplacian of gaussian operator is a second derivative edge detector can be used for edge linking method [13]. Other kinds of gaussian edge detectors such as canny is more complex. The operator could find the proper edge location and test wider areas around the pixel. In a study of real time defect detection method for high speed bar in coil from S. H. Choi et al. [17], they used laplacian filter to isolate image according to gray levels. By using this technique, they unable to recognise the orientation of the edge. It show where the gray level intensity function changes, the orientation of edge is not finding. Thus, this kind of technique inaccurate for detect corner and curves [15]. Sobel and Prewitt operator is the first stage of edge detection to evaluate the derivatives of image intensity. The operators are simple and used to detect the edges and orientation but they do not have accurate sensitivity to noise [15]. The study from E. Golkar et al. [10] have conducted an algorithm of ceramic tile length and width defect detection by using Prewitt and Sobel techniques in beginning step of vertical line extraction. The study found that the fluctuation of Prewitt's method is almost same with the

real size changes measured by digital caliber. An approximate deviation of 1.44% is shown on the maximum relative-error of both techniques. M. Roushdy [15] have found that Canny edge detector are better than Laplacian of Gaussian while Laplacian of Gaussian is better than Prewitt and Sobel based on noisy image.

C. Type of Defect

Ceramic tile will face some defect cause by the mechanical damaging during the production line. Researchers have found few patterns of defects from the existing defect detection methods and are shown in Table 1.

Table 1 Type of ceramic tile defects [16,17]

Type of Defects	Description
Cracks	Break down, slit of tile
Pinhole	Scattered isolated pinpoint spot, craters, small bubbles
Corner	Break down of tile corner
Edge	Break down of edge
Blob	Water drop spot on tile surface
Dirt	Dust or glaze residue
Scratch	Scratch on tile surface
Size	Incorrectly length, width, thickness of tile

Corner and edge defect have detected by obtained angle change using thresholding and contour tracing algorithm and dot product formula to identify the tile corner and edge defect [18]–[20]. Edge crack, curvature and size defect can be detected by edge extraction techniques with looking pixels in the image where edges are likely to occur by looking for discontinuities in gradients and edge linking to produce descriptions of edges [10], [17], [20], [21].

An abnormal reflected light used to detect the cracks defect. A normal tile is expected to reflect light at the same angle. For a defects from an uneven surface like cracks will reflect light in a different direction to the rest of the surface. It can be detected by placing the camera at where the abnormal reflected light occur, any light reflect to the camera considered as defect tile [22].

III. RESEARCH METHODOLOGY

A. Detection Algorithms Based on Background Subtraction Method

A good tile border is taken as a reference for the defect detection afterward. The tile border is acquired and the ROI is found and set as constant. The image is first change to a binary image. Threshold level is adjusted to obtain a high performance image. Canny edge detection is applied to segment and extract the edge. Threshold level is adjusted to filter the disturbance around the edge. Morphologically dilate operation is performed to link the edge [23-25]. Then, morphologically filled operation is done to fill the region in the edge. Camera focus and iris as well as light are adjusted again if the edge is not extract nicely. Step from image acquired until morphological operations are repeated. The coordinate of the edge is obtained. The reference image is created. The process is presented in Figure 1.

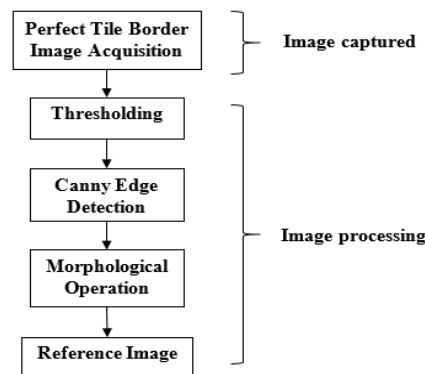


Figure 1 Reference image flowchart

After the reference image is processed successfully, 10 testing tiles are taken to conduct the defect detection. A testing tile is acquired with the same ROI as reference. The tile is go through the process of image acquired until morphological operation as reference. Detection algorithms is designed to detect the crack by comparing with the reference image as background. After the morphological operation, the coordinate of the edge of the image is obtained and then the image is resized to reference size and translated to move to the reference image position. Both reference and testing tile border image are compared. The differences between the images are obtained. The unused narrow line and tiny dot in the image are eliminated by adjusted the range of the pixels numbers to left only the data which needed to conduct the identification [26-28]. The crack area is highlighted and the condition is identified. The steps are repeated to test the other 9 testing tiles as presented in Figure 2.

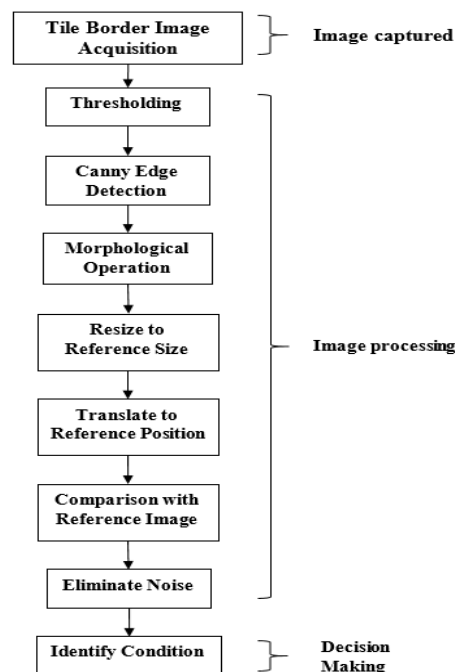


Figure 2 Testing image flowchart

The system is identified whether the tile is good or defected. The accuracy of the defect detection system is analysed and calculated as shown in (1) where a is the number of correct detection while b is the total number of sample tiles.

$$Accuracy = a / b \times 100\% \quad (1)$$

B. Detection Algorithms Based On Edge Gradient Variation

First, a tile border image is acquired and the edge detection is processed as previous experiment. The difference is that no reference sample is required in this experiment. All sample tiles which include 3 good and 7 crack tile are go through the same detection algorithms. The morphologically filled operation is skipped to save processing time and only the edge is obtained for the defect detection. After the edge detection, the edge coordinate is found by taking all the first and last value 1 pixels along the column of the image pixels for the top and bottom edge respectively. Both top and bottom edge coordinate graphs is plotted. Then, polynomial curve fitting method is applied on the graphs to perform the best fit line on every 20 interval points. The best fit line on every 20 interval points are drawn using the linear equation. To improve the numerical properties of both the polynomial and the fitting algorithm in the MATLAB, centering and scaling values which are the mean and standard deviation are found to apply the standard normal distribution in the linear line equation. It centers x at zero and scales it to have unit standard deviation. Mean and standard deviation for each of the 20 points in the edge coordinate graph are found by using equation as shown in Eq. 2 and Eq. 3 respectively. Standard normal distribution is obtained from equation as shown in Eq. 4. These values are substituted to the linear equation that exhibit in Eq. 5 to draw a straight line. Where μ represents the mean, x is the value of x-axis, n is the number of value of x-axis, σ represents the standard deviation, z is the standard normal distribution, y is the value of y-axis, p_1 represents the slope or gradient of the line and p_2 represents the y-intercept point. The flowchart of the process of detection algorithms is shown in Figure 3.

$$\mu = \sum x / n \quad (2)$$

$$\sigma = \sum (x - \mu) / (n - 1) \quad (3)$$

$$z = (x - \mu) / \sigma \quad (4)$$

$$y = p_1 z + p_2 \quad (5)$$

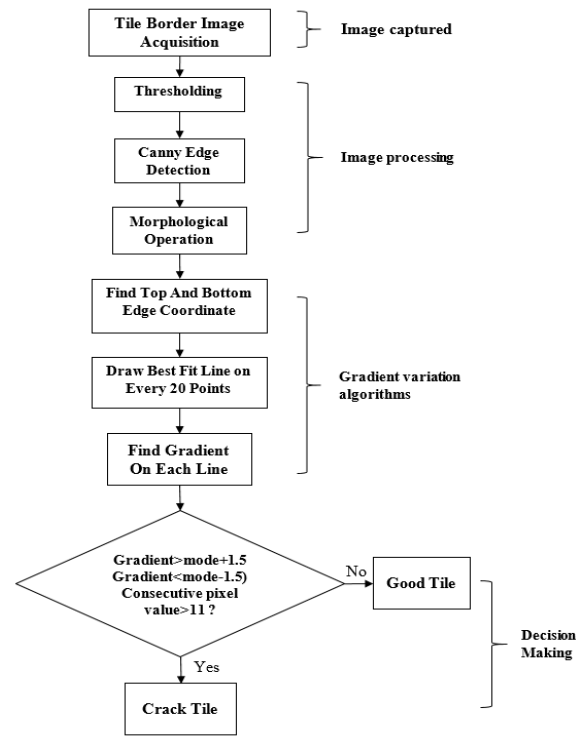


Figure 3 Detection Algorithms Based on Edge Gradient Variation Flowchart

C. Analysis of Both the Defect Detection Algorithms

From the both methods, the tile border cracks are detected. The accuracy of the both system are compared. Although both system can detect the cracks, the result obtained from them have some different. Since the sample used are the same, the performance in term of defect detection accuracy are compared and the ability to detect the type and size of the crack are determined.

IV. RESULTS

A. Experimental Setup

The experiments are carried out which involve testing the detection algorithms based on background subtraction method, detection algorithms based on edge gradient variation and analysis of both the defect detection algorithms. The experiment setup is shown in Figure 4.



Figure 4 Experiment setup



B. Detection Algorithms Based on Background Subtraction Method

The detailed explanations of the process to obtain the results are presented in subsection.

1) Reference Image Detection

The results from reference image detection are show in Figure 5. A good and perfect tile border is taken as a reference for the defect detection afterward. The region of interest (ROI) of the image is acquired as shown in Figure 5(a). Firstly the image need to change to a binary image is shown in Figure 5(b), then by apply the Canny edge detection the edge of tile will be extract and segment. The disturbance around the edge is filtered after the operation. The edge segmentation results is shown in Figure 5(c). By using morphological operation that is dilation, the edge become smoother can see in Figure 5(d). Than the edge is filled for the comparison in the defect detection afterward. Therefore, the reference image is created as shown in Figure 5e and it will apply in the defect detection system.

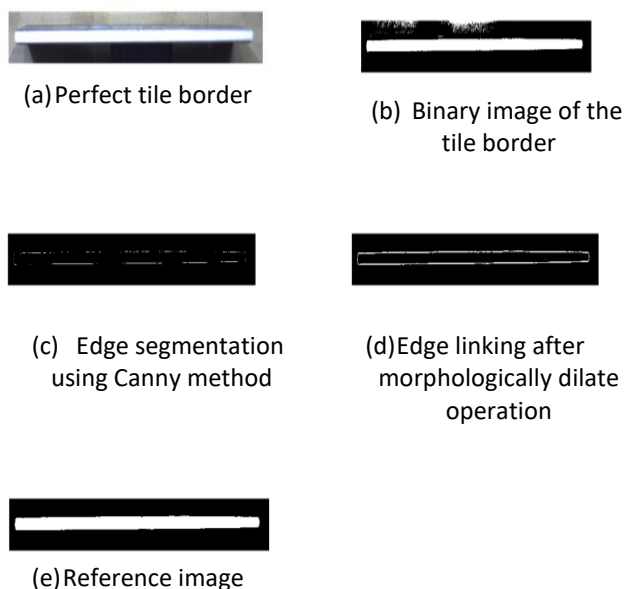
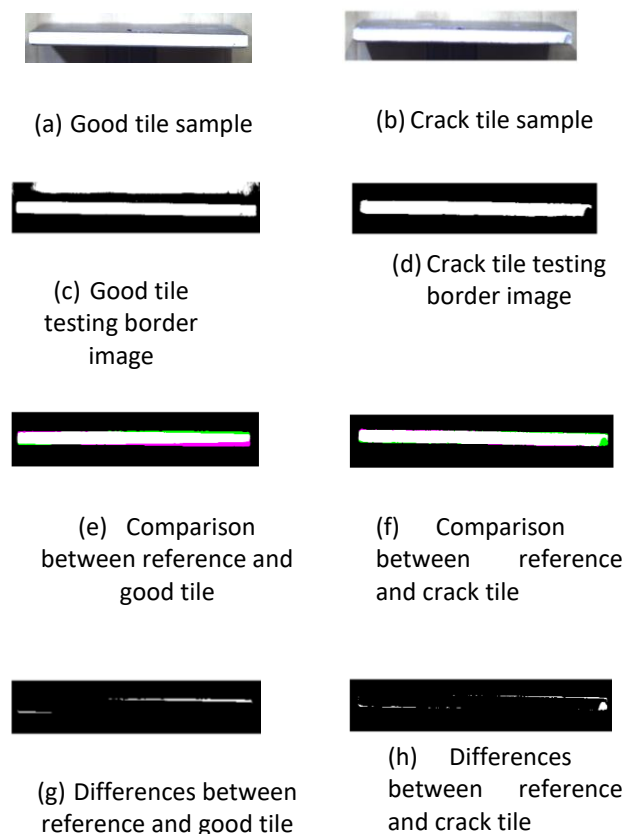


Figure 5 Reference image detection

2) Defect detection

The tile border defect detection system is conduct on 10 samples. A good tile sample and a crack tile sample are shown in Figure 6(a) and Figure 6(b). The samples undergo the same edge detection process as the process to obtain the reference image. The good and crack for testing tile image is obtained and shown in Figure 6(c) and Figure 6(d). The sample image is resized and translated to move to the reference image position for facilitating and reduce the error of the comparison afterward. After the dimension of both reference and sample image is adjusted to be the same, the both images are compared and shown in Figure 6(e) and Figure 6(f). The differences between the images is shown in Figure 6(g) and Figure 6(h).

It can be seen that is some narrow line and disturbance occur on the image. After eliminate the unused line and dot, the image left only the pixels that needed to conduct the identification. The results are shown in Figure 6(i) and Figure 6(j). The accuracy of the defect detection obtained high after remove the noise. The crack area will be highlight in pink easy to identify. Figure 6(k) and Figure 6(l) are shown the results of both good and crack tile. The results of all the sample tiles are recorded in Table 2.



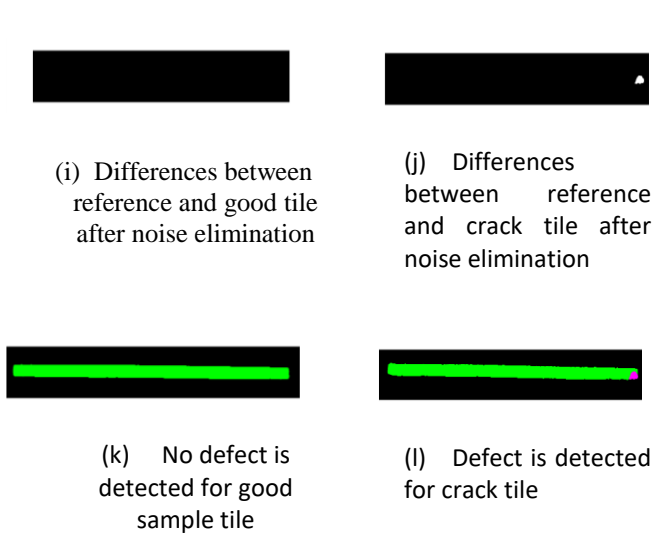


Figure 6 Defect detection

Table 2 Detection results

Sample Tile	Real Condition	Detection Result	True/False
A	Good	Good	True
B	Good	Good	True
C	Good	Good	True
D	Defect	Defect	True
E	Defect	Good	False
F	Defect	Good	False
G	Defect	Defect	True
H	Defect	Good	False
I	Defect	Good	False
J	Defect	Good	False

The accuracy of the defect detection for good tile, defect tile and overall system are calculated using equations shown in Eq. 1 and recorded in Table 3.

Table 3 Accuracy results

	Good	Defect	Total
Number of tested tiles, b	3	7	10
Number of defect tiles obtained	0	2	2
Number of correct detection, a	3	2	5
Number of wrong detection	0	5	5
Accuracy (%)	100	28.57	50

From the result of detection shown in Table 3, the good tile is always in correct detection while the defect tile is only obtained 28.57% accurate in the detection which 2 out of 7 testing tiles are in correct detection. Overall, the accuracy of the system is 50%.

C. Detection Algorithms Based on Edge Gradient Variation

A good and crack sample tiles results are presented in this section. The tiles acquired are undergo the edge detection to extract the tile border edge. The sample tile used as shown in Figure 7(a) and Figure 7(b) while the edge obtained of the border tiles are shown in Figure 7(c) and Figure 7(d).



(a) Good tile sample



(b) Crack tile sample



(c) Good tile border edge

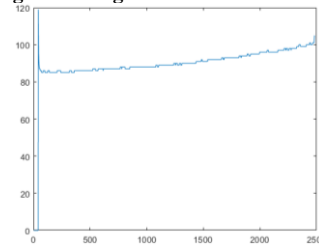


(d) Crack tile border edge

Figure 7 Detection Algorithms Based on Edge Gradient Variation

The top and bottom edge coordinate graph are plotted as shown in Figure 8 and Figure 9. The x-axis of the graph is the number of pixel column along the image while y-axis show the first and last pixels value 1 along each column of the image for obtain the top and bottom edge coordinate respectively. From both of the good testing tile edge coordinate, the line is almost constant across the graph. From the top edge coordinate of the crack testing tile, the variation of the slope is considered constant while the bottom edge coordinate have a big variation of slope at the end of the graph.

Graph of top edge coordinate for good testing tile



Graph of bottom edge coordinate for good testing tile

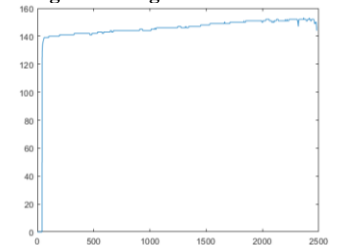
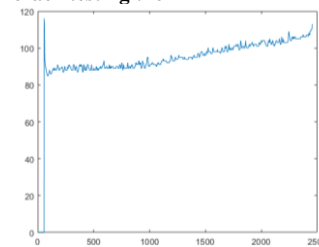


Figure 8 Graph of edge coordinate for the good testing tile border

Graph of top edge coordinate for crack testing tile



Graph of bottom edge coordinate for crack testing tile

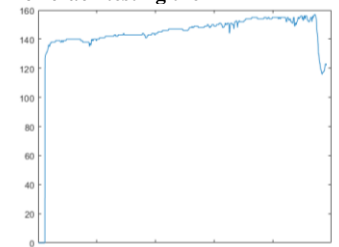


Figure 9 Graph of edge coordinate for the crack testing tile border

The best fit lines are obtained from the equation shown in Eq. 2 to Eq. 5. The lines are drawn on every 20 intervals of each point in the edge coordinate graph as shown in Figure 10 and Figure 11.

Graph of best fit line of the top edge coordinate for good testing tile

Graph of best fit line of the bottom edge coordinate for good testing tile

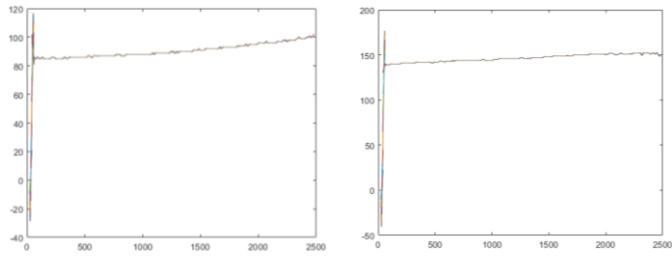
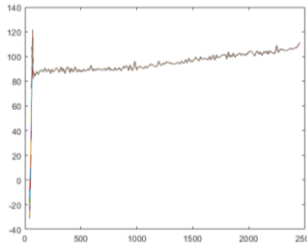


Figure 10 Graph of best fit line of the edge coordinate for the good testing tile

Graph of best fit line of the top edge coordinate for crack testing tile



Graph of best fit line of the bottom edge coordinate for crack testing tile

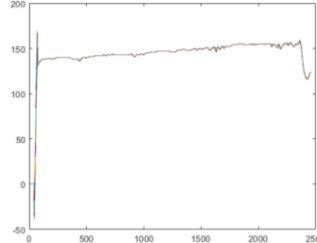


Figure 11 Graph of best fit line of the edge coordinate for the crack testing tile

From the line equation, the gradients of each line are obtained. The graph of gradient variation for every 20 points in top and bottom edge are plotted as shown in Figure 12 and Figure 13. The lines of the range are drawn on the gradient graph. It is facilitated to observe the gradient that out of the range. From the good testing tile, the gradient are inside the range. While the crack testing tile, there are some points that out of the range. The gradients at the starting points are always high and out of the range. This is because the corner of the tile have detected like a curve since the edge detection is not extract the edge in 90 degree perfectly. These gradients are become higher due to the curve and are ignored although they are out of the range.

Graph of gradient of the top edge coordinate for good testing tile

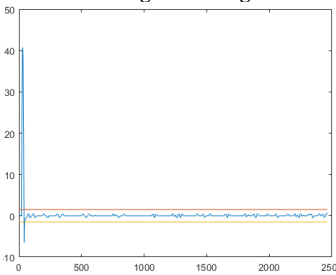
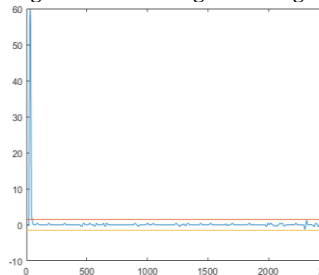


Figure 12 Graph of gradient of the edge coordinate for the good testing tile

Graph of gradient of the top edge coordinate for crack testing tile



Graph of gradient of the bottom edge coordinate for good testing tile



Graph of gradient of the bottom edge coordinate for crack testing tile

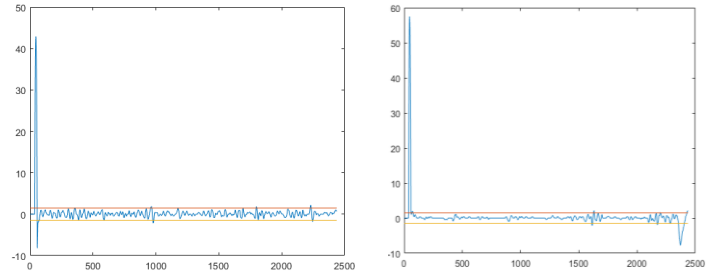
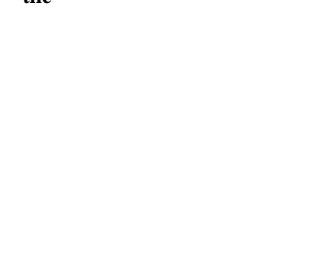
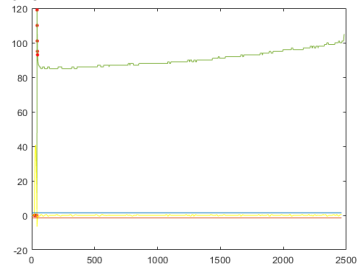


Figure 13 Graph of gradient of the edge coordinate for the crack testing tile

The points that are out of range are labelled as red dot at the edge coordinate graph as shown in Figure 14 and Figure 15. The below is the gradient graph for easily to view.

Graph of top edge coordinate with the gradient out of range for good testing tile



Graph of bottom edge coordinate with the gradient out of range for good testing tile

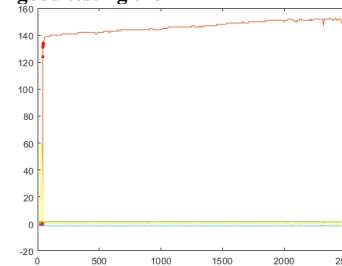
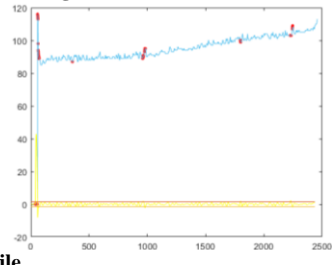


Figure 14 Graph of edge coordinate with the gradient out of range for good testing tile

Graph of top edge coordinate with the gradient out of range for crack testing tile



Graph of bottom edge coordinate with the gradient out of range for crack testing tile

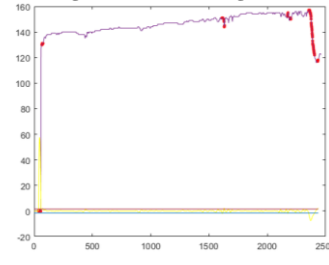


Figure 15 Graph of edge coordinate with the gradient out of range for crack testing tile

By filtered the gradients that consecutive points are less than 11, the area of the points are circled in the tile border image and are shown. In Figure 16 and Figure 17. The circled area is the crack area on the tile border. There is no circle on the tile image represent that it is a good tile.



Figure 16 Output of good testing tile



Figure 17 Output of defect testing tile

The output data of all the sample tile are recorded in Table 4. Based on the defect detection algorithms in MATLAB, the mode of gradient of all the testing tiles are found which always 0 along the top and bottom edge. Thus, the range of no defects for the gradients are less than 1.5 and more than -1.5 and vice versa.

Table 4 Detection results

Tile	Real Condition	Gradient out of range (gradient > 1.5) (gradient < -1.5)	No. of consecutive pixels (coordinate)	No. of crack found	True/False
A	Good	Top :- Bottom :-	-	0	True
B	Good	Top :-1.60 to 4.09 Bottom :-	13 (2416 to 2428)	1	False
C	Good	Top :- Bottom :-	-	0	True
D	Defect	Top :-7.70 to -1.61 Bottom :-1.60 to -8.15	14 (52 to 65) 48 (2365 to 2412)	2	True
E	Defect	Top :- Bottom :-1.61 to 2.34	- 14 (224 to 237)	1	True
F	Defect	Top :- Bottom :-3.61 to -1.58	- 16 (2451 to 2466)	1	True
G	Defect	Top :-3.74 to -1.53 1.58 to 3.39 Bottom :-5.75 to -1.52 1.56 to 2.75 1.64 to 2.93	18 (823 to 840) 18 (959 to 976) 30 (1256 to 1285) 24 (1311 to 1334) 16 (1365 to 1380)	5	True
H	Defect	Top :-1.57 to 2.80 -2.51 to -1.64 1.77 to 2.77 Bottom :-1.51 to 9.31	13 (1064 to 1076) 12 (1162 to 1173) 13 (2231 to 2243) 16 (106 to 121)	4	True
I	Defect	Top :- Bottom :-	-	0	False
J	Defect	Top :-1.61 to 12.64 Bottom :-1.68 to 3.33	12 (2465 to 2476) 17 (123 to 139)	2	True

The accuracy of the defect detection for good tile, defect tile and overall system are calculated using equations shown in Eq. 1 and recorded in Table 5.

Table 5 Accuracy results

	Good	Defect	Total
Number of tested tiles, b	3	7	10
Number of defected tiles obtained	1	6	7
Number of correct detection, a	2	6	8
Number of wrong detection	1	1	2
Accuracy (%)	66.67	85.71	80

V. CONCLUSION

The vision system that automated conduct the quality inspection on ceramic tile border has been developed. The system applied the defect detection algorithms based on the background subtraction method and edge gradient variation are designed and developed successfully. The characteristic of crack patterns are obtained based on the tile border line. From the detection using background subtraction method, the cracks found are represented by the large area of differences with the reference image. The small area is not considered as a crack and is filtered. The gradients variation that dropped or rose significantly along the edge with group of consecutive points are considered as the cracks' area occur on those points. The accuracy of background subtraction method is achieved 50% while method 2 achieved 80% of accuracy in the detection of 10 good and crack sample tiles. This method contains many limitations such as unable to determine the small cracks, top edge and corner edge. In edge gradient variance method, it is only failed in detect the unclean tiles

and crack that with lower gradient. The background subtraction has ability in removed the unwanted lines or dots in an image. An unclean tile with stain on the border can be ignored by using this method.

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