An Intelligent Defect Detection Method of Small Sized Ceramic Tile Using Machine Vision

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Abstract: Quality control of small sized ceramic tile is an important part for manufacturing enterprise. To improve the efficiency and precision of ceramic tile defect detection, an intelligent detection method is proposed in this paper. Firstly, the noise is eliminated by image pre-processing，and the geometric primitive of ceramic tile is taken as benchmark. Meanwhile, the nearest neighbor algorithm is adopted to search measurement point, and the size parameters are calculated by Euclidean distance. Then, local defect feature of chromatism is obtained by patch strategy and composite contour mask. It is necessary to merge potential block to recover original appearance of defects. Finally, the optimized parameters from feature distribution and a discriminant function are utilized to achieve target defect detection. The experimental results show that the method has good detection effect and high real-time performance.

1 INTRODUCTION

With the development of automation and artificial intelligence, AVIS(Automated Visual Inspection System) for ceramic tile is becoming increasingly popular due to its low cost maintenance and high accuracy. However, most of assembly line of ceramic tile in China still adopt traditional manual detection method because of the limitation of automatic technology. It will inevitably bring about the inspection errors and visual fatigue during the process (Boukouvalas C, 1995; Karimi M H, 2014).

Generally, the defect detection of ceramic tile is an important step for the whole of assembly line, because it ensures the quality of product. In the AVIS, if a inspection task is accomplished automatically by computers, the efficiency and reliability of detection process are greatly improved. Specially, for small specification of ceramic tile which situate under the large FOV (Field of View), the detection system requires high-speed and real-time. Thus, designing an effective method based on a AVIS is very important for ensuring quality of ceramic tile.

In last few years, image processing has been widely applied in many aspects of manufacturing. However, few methods are applied in actual production, in particularly the defect detection of ceramic tile. H. Elbehiery proposed a method of quality control for ceramic tile by integrating a visual control stage. However, it only works well in the defect of textured surfaces (2005). Andrade utilized infrared images and Artificial Neural Network to solve the issue of automatic inspection of ceramic tile, and the performance of the technique has been evaluated theoretically and experimentally in laboratory, but the system has not been applied in practical production (Andrade, 2011). Ehsan Golkar proposed a model which allows ceramic tile companies to perform quality inspection without costly artificial measuring tools, and this method can be applied in different situations of manufacturing production line systems (2011). Cristina Costa presented a phase correlation based algorithm for the automatic surface inspection of ceramic tile for fault detection, and the algorithm can be used to register the reference and test images (2000). However, there are very few methods have been proposed for the defect detection of small specification ceramic tile.

In order to solve the aforementioned limitations, a defect detection method for ceramic tile based on the machine vision is proposed in this paper. The works of size measurement and chromatism detection are completed under the large FOV and complex environment, and the proposed method

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utilizes the techniques of gradient sharpening, nearest neighbor searching algorithm, parameters optimization, color space, geometric primitives and composite mask etc. In the experiments, extensive test data is provided for the subsequent quality evaluation.

This paper is organized as follows, the overall frame of both platform and algorithm is given in Section II. In Section III, the strategy of image pre-processing is illustrated in detail. The method of size measurement is introduced in Section IV and the chromatism detection is discussed in Section V. Finally, the experiment and conclusion of our work are summarized in the last two sections.

2 THE OVERALL FRAME

2.1 Hardware Platform

In our method, the locating and sorting system mainly consists of IPC (Industrial Personal Computer), CCD industrial camera, LED light, EPSON robot, image processing software etc. The overall platform is shown in Fig. 1, the whole assembly line is divided into acquire and grab region for the task. Firstly, the standard parameters are acquired and stored into the database offline through the feature model. When the visual system is initialized, the location packet is imported to system automatically. The center coordinates of the ceramic tiles are obtained by location system with the proposed algorithm, Subsequently, the coordinate datas through system calibration are sent to the each CSARA robot by network communication separately (Ashraf M A, 2011; Lan M I, 2007).

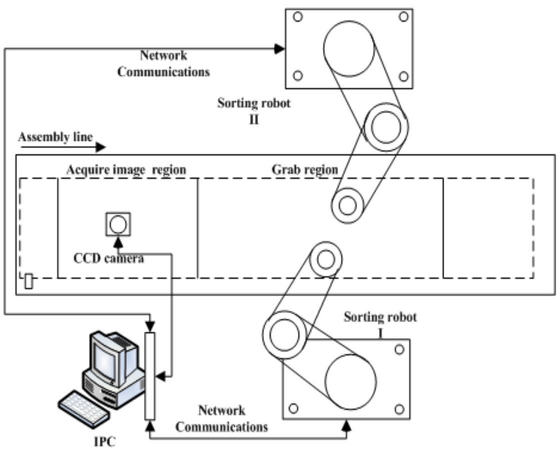


Figure 1: The platform of defect detection and sorting

2.2 The Algorithm Flow

The algorithm of defect detection is achieved by four steps in our work： image pre-processing, size measurement, chromatic aberration detection and parameter optimization, the main process is shown in Fig. 2.

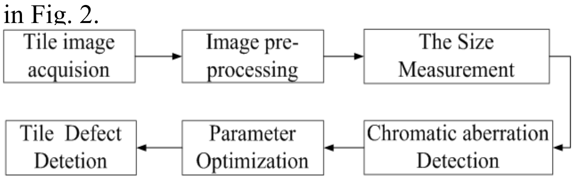


Figure 2: The algorithm flow of defects detection

(1) The image pre-processing consists of sharping the image and extracting the contour.

(2) The size measurement mainly adopts geometric primitives of contour and nearest neighbor algorithm to search segmentation points.

(3) Chromatic detection is conducted based on HSV color space, patch strategy and composite mask to obtain local defect features of color.

(4) Gaussian model is adopted to obtain the optimized standard parameters from the sample feature distribution.

3 THE IMAGE RFEPROCESSING

Due to the perturbation from environmental condition and noise of acquisition systems, the image quality of ceramic tile is inevitably degraded. It is necessary to highlight the concerned target and enhance image contrast. Related works of improving image quality have completed base on the both hardware and software in this paper.

Firstly, the annular LED light and obscura are adopted to construct the stable inspection environmental. Moreover, an improved gradient sharpening method is introduced to ensure that the targets edge will not be over-smoothed.

The conventional sharpening algorithms will not be discussed in this part (Lan M I, 2007). The contour of detection target is a fundamental task for subsequent detection algorithms, and the improved sharpening method for ceramic tile will be introduced later. For the image f(x,y), the gradient of pixel (x, y) indicates the maximum change in this location, and its magnitude $G_M[f(x, y)]$ is defined by

$$G_M[f(x,y)] = \sqrt{(\frac{\partial f}{\partial x})^2 + (\frac{\partial f}{\partial y})^2} \tag{1}$$

In order to reduce the computational cost, the absolute value is adopted to replace the traditional square operation, and the gradient modulus value is formulated as .

$$G_M[\mathrm{f}(\mathrm{x},\mathrm{y})] = |f(\mathrm{x},\mathrm{y}) - f(\mathrm{x}+1,\mathrm{y}+1)| + |f(\mathrm{x}+1,\mathrm{y}) - \mathrm{f}(\mathrm{x},\mathrm{y}+1)| \quad (2)$$

The pixel value is directly replaced by the gradient value in the traditional method, by doing so, it could result in some weaknesses with ? image original information. Therefore, the gradient sharpening has been improved by setting threshold judgment in our work, and the specific formula is

$$G'_M[\mathrm{f}(\mathrm{x},\mathrm{y})] = \begin{cases} G_M[\mathrm{f}(\mathrm{x},\mathrm{y})] + T_1 & G_M[\mathrm{f}(\mathrm{x},\mathrm{y})] \geq \mathrm{T}'_1 \\ f(\mathrm{x},\mathrm{y}) - \mathrm{T}_2 & f(\mathrm{x},\mathrm{y}) \geq T'_2 \\ f(\mathrm{x},\mathrm{y}) & other \end{cases} \quad (3)$$

$G'_M[\mathrm{f}(\mathrm{x},\mathrm{y})]$ is the final value after above mapping, and its maximum value is 255. T'_1 denotes a low threshold which is used to highlight the dark details. When the $G'_M[\mathrm{f}(\mathrm{x},\mathrm{y})]$ is greater than T'_1, its value is increased by T_1, which can enhance the object edge. Similarly, T'_2 denotes a high threshold, and it restrains light regions. Based on the above analysis, the regions in the original image with high pixel value are retained while its dark details are enhanced by equation 3. And the modified method increases the contrast between the edge information and backgrounds.

The image pre-processing is an essential step to obtain accurate target contour. The median filter is used to reduce the noise of image firstly. Both the Otsu algorithm and Canny edge detection (Jiao, 2007) are used in pre-processing step to highlight target edge, and also 8 Freeman chain code is adopted to acquire ceramic tile contour (Galba T, 2014; Keraudret B, 2014).

4 THE SIZE MEASUREMENT

The indicators of the target size measurement are defined as the upper width(UW), lower width(LW), left height(LH), right height(RH), integrity(IN) and edge straightness(ES), which cover the basic shape features of the ceramic tile. The steps of the measurement method mainly include two parts: acquiring segmentation points and calculating size parameters.

4.1 Acquiring The Segmentation Points

The most methods for ceramic tile size measurement are given which takes its corner as the theoretical segmentation points. However, it is difficult to acquire stable and accurate corner location by traditional algorithm in industry (Boukouvalas C, 1995; Karimi M H, 2014). Another strategy obtains the intersections between borders by fitting linear of target edges, and this method refers to these intersections as segmentation points which are obviously deviated from engineering practice.

Actually, the real tile corner is circle transitional region as shown in Fig. 3. A nearest neighbor algorithm based on the oblique external envelope is proposed to solve the problem of points segmentation. The oblique external rectangle is an ideal geometric primitive for ceramic tile, and the geometric characteristic changes with the fitting target. Furthermore, its shape property is not affected by the target rotation and translation.

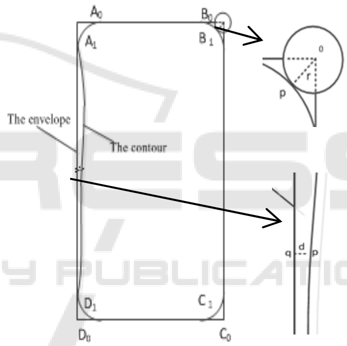


Figure3: The envelope and segmentation points of contour

How to break the closed ceramic tile contour is the core content in this work. Taking partial enlarged detail from upper-right corner of Fig.3 as example. B_0 is the benchmark of the oblique external rectangle, and B_1 is the corresponding segmentation point of B_0 on the closed contour. r is the minimum radius of the contour spatial neighborhood. The nearest neighbor algorithm used for point position segmentation is shown below.

Table.1: The nearest neighbor search algorithm

Nearest neighbor search algorithm
Intput：O(x_0, y_o), r=r_0, step=s , flag=false, discri{(p(r),C(i)};
Output: Return Flag{ true, false };
1. count=0;
2.for all r do
3.r=r_0+step;
4. if discri{(p(r),C(i)} satisfy T;
5. Flag=true;
6. else
7. Flag=false;
8. Break;
9. return Flag

The related Parameter description are illustrated below.

(1) O(x_0, y_0): Envelope reference point;

(2) r: Neighborhood radius,the value is initialized r_0=2;

(3) Step: Radius step represents the minimum precision of searching, and its value is set as 1;

(4) Flag :Test mark, it is initialized as false;

(5) discri{}: Discriminant function, it determines whether the point are within the setting neighborhood;

(6)T: Discrimination rules.

4.2 Size Parameter Calculation

The coordinates of segmentation points A_1, B_1, C_1 and D_1 on the ceramic tile contour are obtained according to the process discussed in the above section**.** Subsequently, the length of the line segments L_{A1B1} , L_{C1D1} , L_{A1D1} , L_{B1C1} are calculated as the ceramic tile parameters of the upper width, lower width, left height and right height by Euclidean distance respectively.

The contour edge of the ceramic tile is not the ideal straight line as shown in partial enlarged view of Fig. 3 . The p is the midpoint of the line, and q denotes the projection of p on the endpoint straight line. d denotes the edge straightness, and the least square method is adopted to fit actual ceramic tile edge. The system uses this method to fit the contour between the segmentation points. The maximum value of the ceramic tile straightness is defined as ES.

5 THE CHROMATISM ETECTION

The purpose of chromatism detection for ceramic tile is to sort products whose color differ from standard sample. Our method uses HSV color space, patch strategy and composite mask to obtain local defects of chromatism.

5.1 Color Space

Comparing with other color spaces, HSV is more closer to model of human visual cortex (Muhammad B, 2016). Moreover, the component of H and S is less affected by the environment. The color feature F is generated based on the weight of the HSV color space by .

$$F_t = (\lambda_1 \times H + \lambda_2 \times S) / \mathrm{N} \qquad (9)$$

F_t represents the color feature generated by the I block. H and S which represent hue component and saturation respectively. Similarly, λ_1 and λ_2 are the weight of corresponding component. N denotes the number of pixels traversed in the setting block, and the weight value λ_1=0.7, λ_2=0.3 in this paper after testing.

5.2 Image Patch

Traditional strategy describes color information of the whole region by evaluating statistic, such as mean, variance and entropy. However, this method can not perceive small change and it dilutes effect of local color information. So the patch strategy for ceramic tile is introduced to solve above problem.

The uniform block is adopted for local segmentation in ceramic tile image. It is difficult to guarantee that the image length and width are integer multiples of the patch step, so the four types of patch are produced during the process. The specific judgment rule is analyzed by equation (10), and g(i, j) is the discriminant function of boundary conditions.

$$g(\mathrm{i},\mathrm{j})=\begin{cases} 1 & \mathrm{i}<\mathrm{Width}\&\&\mathrm{i}+S_x>\mathrm{Width}\&\&\mathrm{j}<Height \\ 2 & j<Height\&\&\mathrm{j}+S_y>Height\&\&i<\mathrm{Width} \\ 3 & j<Height\&\&\mathrm{j}+S_y\&\&\mathrm{i}<\mathrm{Width}\&\& \\ & \mathrm{i}+S_x>\mathrm{Width} \\ 0 & other \end{cases} \qquad (10)$$

S_x , S_y are patch step in horizontal and vertical direction respectively. The smaller the value is, the higher the patch accuracy is, but the real-time of the algorithm will be depressed. In general, step value is adjusted by specific target dimension.

Through the above algorithm, the image patch for ceramic tile is completed. The problem of patch scale and surpassing boundary is solved effectivelly, which provides a new strategy for highlighting the local chromatic aberration.

5.3 Compound Contour Mask Operation

When g(i, j)={1, 2, 3}, it is shown that the patch situates beyond contour boundary of ceramic tile, and the segmentation ROI unit may not completely overlap with target boundary. So the feature statistic which involves external contour brings some errors in the calculation.

The biggest characteristic of contour mask is that the ROI of arbitrary shape could be dug, so that we only care about region strictly which is needed in image process, while other area will be shielded at the same time. Another detail which the filling color of contour mask may be same with the color of target defect will be focused on in this part. A composite mask method is used to acquire pure color feature Ft, and the specific operation is as follows.

(1) Two images which are the same size as the acquiring image are initialized and the pixel value of them is zero. We take images as the parent of the tiled composite contour mask which are denoted as M1, M2 respectively;

(2) The contour of ceramic tile is painted in the M1 and M2 mask images with pixel precision respectively, and the contour of M1 and M2 is filled with RGB(255,0, 0) and RGB(0, 255, 255) pixels.

(3) Then we perform "and operation" on HSV color space of the images with mask M1, M2 respectively. If the resulted values of operation of both M1 and M2 are equal to the original color, the value will be retained to generate F_t. Otherwise, they will be ignored.

While the patch situates beyond contour boundary of ceramic tile, step 3 will be implemented. The compound contour mask operation can help system to avoid interference from external contour pixel.

6 OCATION DISCRIMINANT

6.1 Parameter Optimization

If the standard parameters are obtained directly from the sample set off-line, the empirical errors are inevitable in the practical calculation. Thus, the Gaussian feature distribution is used to optimize the standard parameters in our method.

In order to ensure the accuracy of the standard parameters, the images of standard and defect-free sample sets are tested directly to obtain each parameter. Gaussian distribution is performed on each element of sample sets.

Mean μ_j and standard deviation σ_j of each parameter type are acquired by maximum likelihood estimation. The 3δ principle is used to remove the part of data which falls outside the model ($\mu-3\delta$, $\mu+3\delta$), and then the optimized standard parameters are obtained by averaging the processed data. From statistics point of view, the standard parameter obtained by distribution model can eliminate the bad samples, and the data are more stable.

6.2 Target discriminating

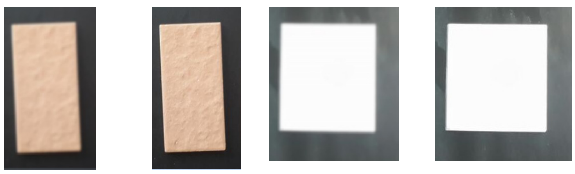
Once target does not meet the discriminantive requirement as shown in the equation 11, the system will terminate the judgment immediately to reduce the determination time.

$$g(f_{tj}) = \begin{cases} 1 & if \ \left| f_{tj} - f_{sj} \right| \le T_j \\ 0 & else \end{cases}$$

where j={0,1,2 $\cdots$ } refers to parameter types, $g()$ indicates the discriminant function. f_{tj} is the parameter of the test online. f_{sj} is the optimal standard parameter. T_j is the threshold which determines the tolerance capability of qualified product. When all the values of the corresponding $g()$ are equal to 1, it is identified as the qualified product. Otherwise, the program terminates the at once. The coordinate data is sent to each EPSON robot by network communication separately.

7 EXPERIMENT

1). In order to evaluate the effectiveness of the improved sharpening method for the ceramic tile image, we implement the image pre-processing by before and after sharpening modification under the same experimental conditions. Two types of ceramic tile are used for test. We visualize the performance improvement in Fig. 4.

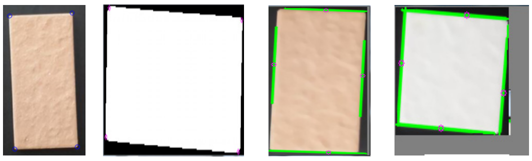


(a) (b) (c) (d)

Figure 4: The effect before and after of sharpening

It can be seen that the ceramic tile edge with modification is sharper and the contrast is stronger than before, which facilitates subsequent size measurements.

2).We test the stability and accuracy of measurement method which is provided by section III, and this method is adopted to measure some indication for different types of ceramic tile, such as segmentation points, fitting edges and the extraction midpoints. The specific effect is shown in Fig.5.



（a） （b） （c） （d）

Figure 5: The effect of size measurement

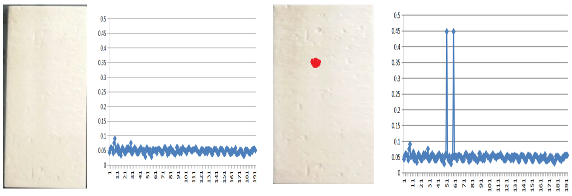
It can be observed that measurement indicators have a precise fitting effect and it can reflect the actual shape of the ceramic tile effectivelly. The indication data of ceramic tile (45mm ×95mm) is given in table 2, and the measure accuracy is 0.2mm per pixel .

As seen in Table 2, the indicator of 15 same type and qualified ceramic tiles are obtained, and the deviation of resultss is very small. It indicates that the proposed size measurement method has high accuracy and stable.

Table 2: The indication data of ceramic tile (mm)

Test order	UW	LW	LH	RH	IN	ES
1	44.6	44.6	95.2	95.0	0.959	0.2
2	44.8	44.6	94.8	94.6	0.965	0.2
3	45.0	44.8	94.6	94.8	0.958	0.4
4	45.2	45.0	94.6	94.6	0.940	0.2
5	44.8	45.0	94.8	95.0	0.950	0.4
6	44.6	44.8	94.2	94.4	0.954	0.4
7	44.6	44.6	94.6	94.8	0.956	0.2
8	44.4	44.8	94.6	94.8	0.962	0.2
9	44.8	44.6	94.4	94.6	0.965	0.2
10	44.6	44.8	95.2	95.0	0.945	0.4
11	44.6	44.4	95.0	94.8	0.974	0.4
12	45.0	45.2	95.2	95.0	0.978	0.2
13	45.2	45.0	95.0	95.0	0.985	0.2
14	45.2	45.0	95.2	95.0	0.982	0.4
15	44.8	45.0	94.8	94.6	0.965	0.2
Average	44.81	44.81	94.8	94.8	0.962	0.28
Variance	0.239	0.212	0.29	0.18	0.0120	0.09

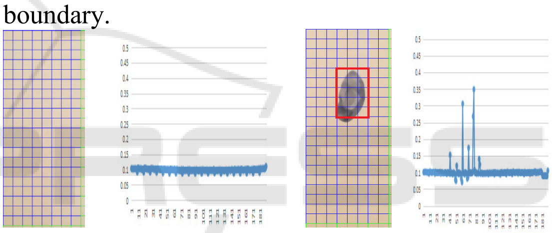
3). For validating the strategy of chromatism detection, the defect location detection from ceramic tile is conducted in this subsection. As shown in the Fig.6, c,d is the feature changes of a and b respectively, and the feature F_t of existing defect patch is obvious mutation than other patchs. The experimental result shows the validity of chromatism detection.



（a） （b） （c） （d）

Figure 6: The effect of chromatism detection

The work of merging potential block is done to recover original appearance of defects based on spatial information, and the feature distribution of patch is given in Fig. 7 . The region of green line represents that the patch situates beyond contour boundary.



（a） （b） （c） （d）

Figure7: The effect of patch and recovering original appearance

4).To verify the precision rate of the defect detection algorithm, 1000 ceramic tiles are used for detecting and sorting on assembly line. The result shows that the precision rate of the experiment with proposed method is 91%, and the detection time is 100 per second, which basically meets the needs of industrial production.

8 CONCLUSIONS

In this paper, an intelligent defect detection method of small sized ceramic tile using machine vision is proposed in AVIS, and the main works of the proposed method are summarized as follows.

1).An improved sharpening method is designed for the image of ceramic tile to improve the edge sharpness and the contrast.

2).The geometric primitive of contour is taken as benchmark. The size parameters are calculated by adopting the nearest neighbor algorithm and Euclidean distance. The measure accuracy is 0.2mm per pixel .

3).The local defect feature of chromatism is acquired by patch strategy and composite mask, and the experimental results show that the method has good detection effect and high real-time performance.

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