GAS Journal of Engineering and Technology (GASJET)
Volume 2 | Issue 11, 2025 Homepage: https://gaspublishers.com/gasjet-home/ ISSN: 3048-5800

Dimensional Measurement of Large Size Ceramic Tiles Using 2 Low Resolution Cameras

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Received: *10.09.2025* | ***Accepted:*** *24.10.2025* | ***Published:*** *06.11.2025*

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DOI: *10.5281/zenodo.17543088*

Abstract **Original Research Article**

Dimensional measurement of ceramic tiles is critical for quality inspection in ceramic tile manufacturing enterprises. We describe a method of dimensional measurement of large size ceramic tiles using 2 low resolution cameras. In order to increase the measuring accuracy, two cameras placed just above the tile corners capture the detailed image of adjacent tile corners to calculate its sub dimensions. 3D approach is used to get the sub dimensions. The cameras capture the remaining corners of the tile after tile is moved by some distance to get the remaining sub dimensions. Then the sub dimensions with the dimensions of the background board on which the tile lies are used to calculate the dimension of sidelines and diagonals of the tile. The experimental results show that the proposed method is low cost, efficient and reliable. The measuring accuracy can reach 0.05mm. It can be easily introduced in in-line large ceramic tile inspection process.

Keywords: dimensional inspection, dimensional measurement, ceramic tile, visual inspection, machine vision, quality inspection.

1. INTRODUCTION

The increase in the production of ceramic tiles imposes the introduction of innovative solutions in the field of quality inspection systems. A person supported by sensor or vision systems in many manufacturing enterprises carries out the quality inspection of ceramic tiles. However, inspection by a person has many limitations in speed and accuracy. Recently the automatic inspection systems based on machine vision are replacing the traditional manual inspection by a person [1, 2, 3, 9, 10, 15]. In the early solutions, vision systems based on 2D image analysis were mostly used. Some authors presented the study of the measuring tile dimensions based on 2D approach using one camera [4, 7]. However, these solutions have low measurement accuracy due to their limited model, which is not taking into account the tile flatness, and arbitrary placing the tile is not allowed.

In recent years, a number of 3D reconstruction methods based on stereo binocular vision have been studied for ceramic tile inspection [5, 6]. The reconstructed third model is used to extract dimensions. Some authors presented a laser illustrating system with stereo binocular vision. The laser helps find the corresponding tile feature points such as corners and the center of the edges in both camera images, and then their world coordinates are reconstructed. These world coordinates are used for dimensional inspections. The stereo binocular vision approach can successfully extract the tile dimensions regardless of the irregular tile flatness. The shortcoming of this methodology is that the accuracy depends on the camera resolutions and stereo matching.

This paper presents the method of extracting the tile dimensions with 2 low resolution cameras. In order to improve the measuring accuracy, the cameras are located just above the tile corner so that they can capture the detailed images of tile corner region. The sub dimensions then are extracted from the images and the whole dimensions are calculated from the sub dimensions and background board dimensions. The objective of the paper is to develop and implement a dimensional inspection system with 2 cameras located just above the tile corners.

2. Measurement Principles

2.1 pinhole camera Model

For the pinhole camera model, the relationship between a 3D point $\mathrm{P} = [\mathrm{X}, \mathrm{Y}, \mathrm{Z}]^{\mathrm{T}}$ in world coordinates and its corresponding image point $\mathrm{p} = [\mathrm{u}, \mathrm{v}]^{\mathrm{T}}$ in image pixel coordinates is given by equation (1).

$$\binom{p}{1} = \gamma K[R \ \ t]\binom{P}{1} \quad with\ K = \begin{bmatrix} f_x & s & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

where γ is a non-zero scale factor. R is a rotation matrix, t is the translation matrix from the world coordinate system to the camera coordinate system. K is the intrinsic matrix. (c_x, c_y) is the principal point and $(f_x,\ f_y)$ is the focal length of the camera in u and v axis respectively. s is the aspect factor.

If lens distortion is not negletable, the camera model includes the radial and tangential lens distortion equations as follows.

$$\begin{cases} u_d = u[1 + k_1 r^2 + k_2 r^4 + k_3 r^6] \\ v_d = v[1 + k_1 r^2 + k_2 r^4 + k_3 r^6] \end{cases} \tag{2}$$

$$\begin{cases} u_d = u + [2p_1 uv + p_2(r^2 + 2 \cdot u^2)] \\ v_d = v + [p_1(r^2 + 2v^2) + 2p_2 uv] \end{cases} \tag{3}$$

Where (u_d, v_d) and (u, v) are the normalized distorted and undistorted image coordinates respectively, $r^2 = u^2 + v^2$, k_1, k_2, k_3 are radial distortion coefficients and p_1, p_2 are tangential distortion coefficients.

2.2 Tile dimension measurement principle

We can obtain measurements in world coordinates for objects that lie in a known plane for pinhole cameras. This task can be solved by intersecting an optical ray with a plane. With this, it is possible to measure objects that lie in a plane, even when the plane is tilted with respect to the optical axis.

The solution to equation (1-3) is not unique but a line (optical ray). The world point would lie on optical ray from image point through the optical center. If the world object point lies in a specific plane, it can be derived by intersecting the optical ray with the plane as depicted in figure 1.

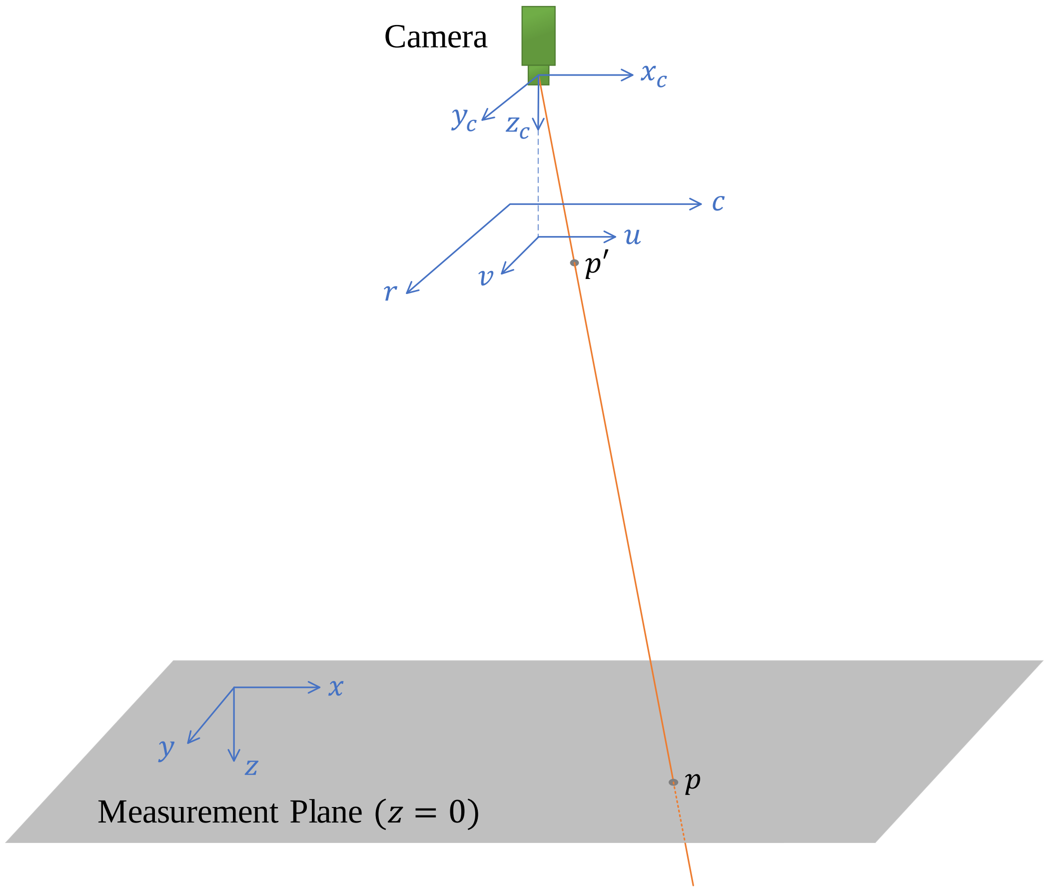

Figure 1. intersection of optical ray and measurement plane

In figure 1, (x_c, y_c, z_c) is the camera coordinate system, (r, c) is the image coordinate system and (u, v) is the image plane coordinate system, (x, y, z) is the world coordinate system.

In this way it is possible to measure objects that lie in a plane, even when the plane is tilted with respect to the optical axis.

If the plane is $z = z_0$, the world object point is derived as follows:

$$\begin{cases} \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \gamma K[R \;\; t] \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} \\ u_d = u + u[k_1 r^2 + k_2 r^4 + k_3 r^6] + 2p_1 uv + p_2(r^2 + 2u^2) \\ v_d = v + v[k_1 r^2 + k_2 r^4 + k_3 r^6] + p_1(r^2 + 2v^2) + 2p_2 uv \\ z = z_0 \end{cases} \tag{4}$$

In equation (4), camera intrinsic and extrinsic parameters can be estimated through camera calibration.

Equation (4) can be used measure dimensions of planar object. However, the manufactured ceramic tile is not planar as depicted in figure 2 and applying equation (4) for tile dimensional measurement could results in a measurement error.

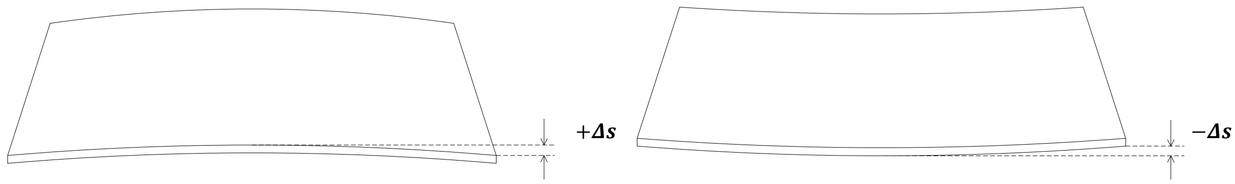

Figure2. ceramic tiles with surface curvature

So, a few errors are caused when applying equation (4) for measuring dimensions of ceramic tiles.

The errors are as follows:

- Error due to the incorrect tile corner detection caused by tile side curvature.

Tile corners must be detected in the captured images before calculating the tile dimensions using machine vision. In order to detect tile corners, the tile is segmented from the background. The segmented image is then used for extracting tile edges, and the feature points like tile corner are detected using the edges.

Edges can be detected by using edge detection methods such as Canny, Prewitt, Roberts, Laplacian and Log.

In figure 3(a) the blue dotted rectangular region is captured by the camera.

If the camera captures the image in perspective, the tile edges AB, BC, CD, DA is not a straight line due to the side curvature. Tile corner A can be extracted using number of methods. One method is intersecting the tangent line to edge AB and the tangent line to edge AD, which is more practical than the other methods when the tile has corner or edge defects. The intersected point would be A' which is not A obviously. Incorrectly detected corner A' would cause a dimensional measurement error. The same issue would happen when detecting corner B, C and D.

The solution to this issue is to capture the image in the position just above the tile corner. The captured images would be like figure 3(b). The edges would be straight lines and the detected corner would be the same as the actual corner point.

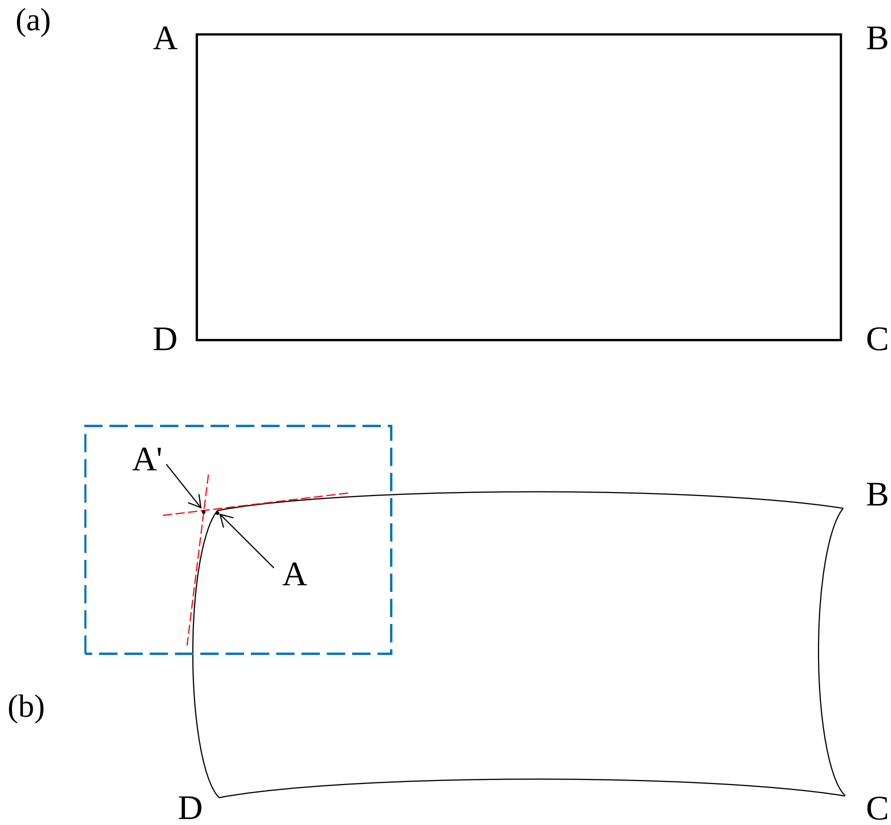

Figure 3. (a)- captured images in a position just above the corner (b)-captured image in an arbitrary position

- Error due to incorrect world coordinates calculation caused by tile surface curvature

The four corners of the tile would differ in height from the reference plane (e.g. z=0) due to tile surface curvature. If the height of four corners can be estimated, the world coordinates of four corners could be derived from equation (4) by substituting $z = z_0$ with $z = h_i$, where h_i $(i = 1,2,3,4)$ is the height of each corner. But the estimating the height of four corners is out of scope of this paper and it requires an additional equipment.

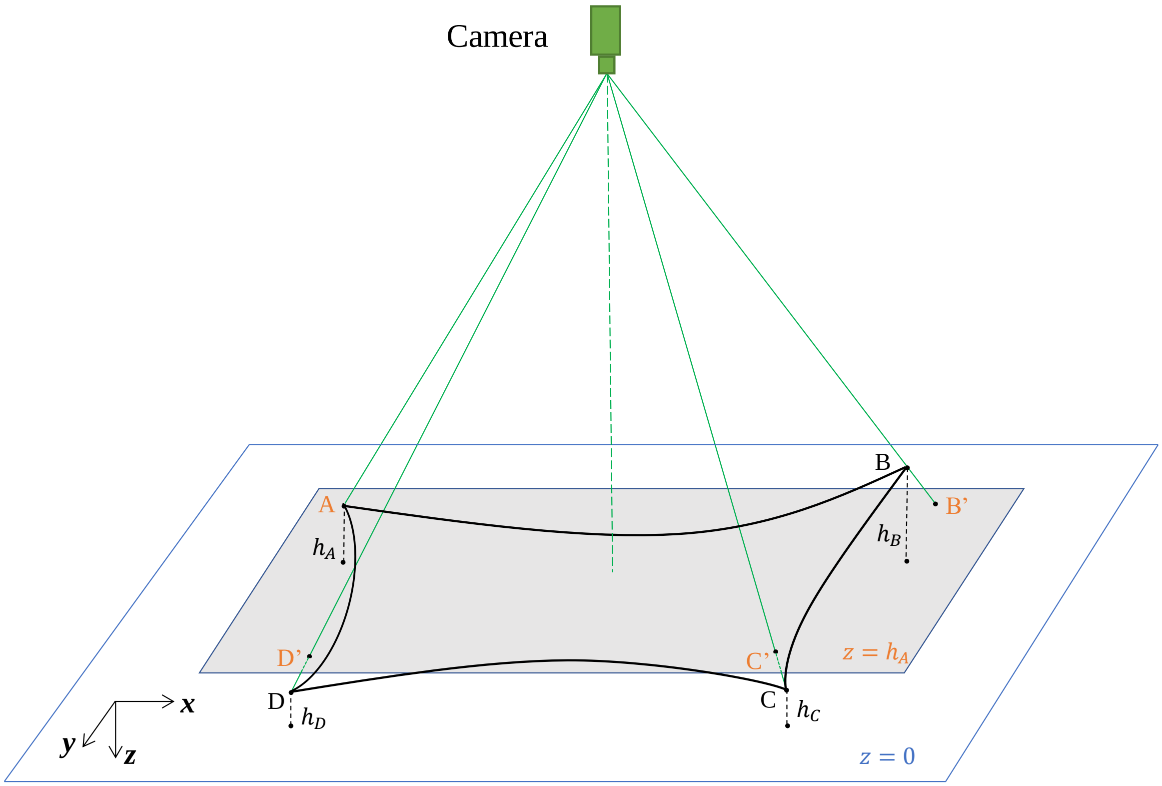

Figure 4. invalid corner calculation caused by irregular corner heights from the reference plane

If the reference plane (also called measurement plane) is set to be $z = h_A$, the solution of equation (4) for A will be A, but the solution s for B, C and D will be B', C' and D' respectively as illustrated in figure 4.

Obviously, $B' \neq B,\ C' \neq C,\ D' \neq D$

This will result in an error in dimensional measurement of tile.

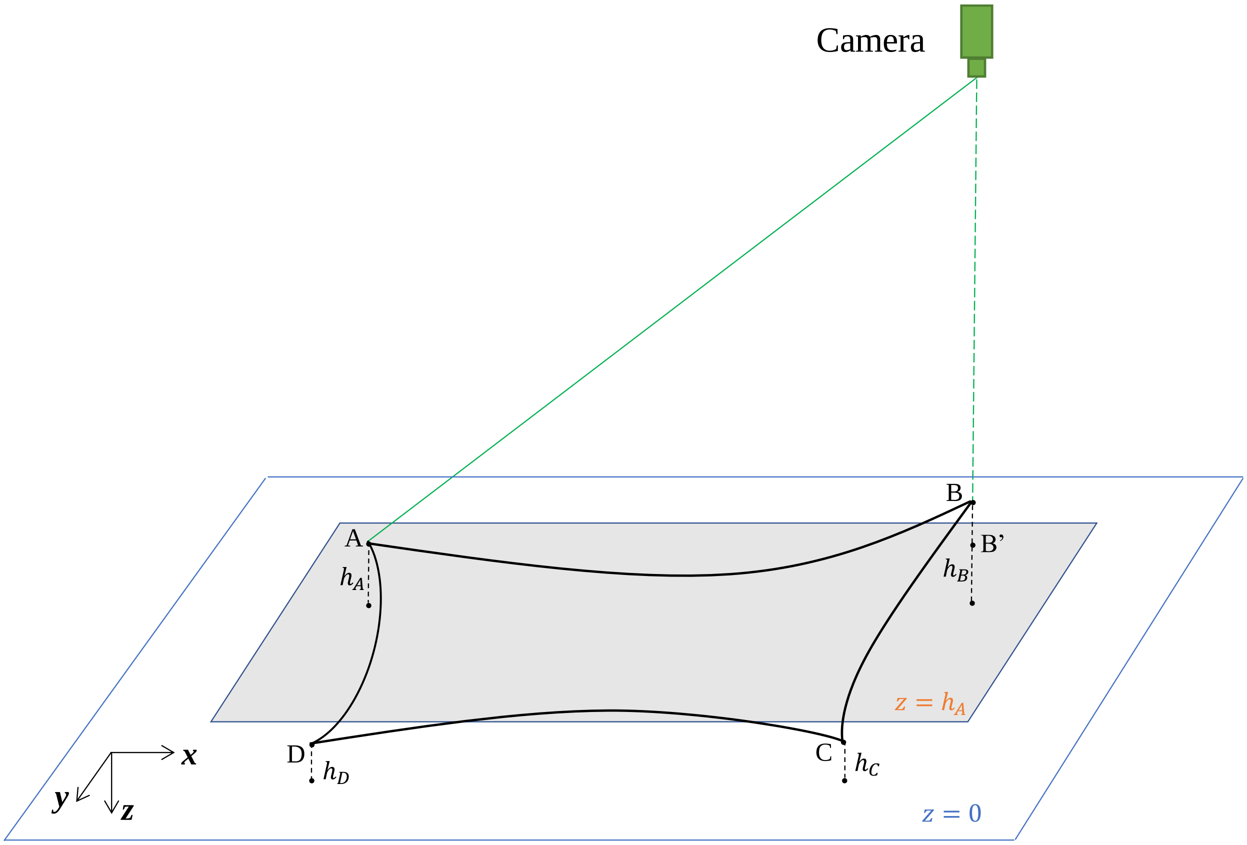

Figure 5. camera mounted just above the tile corner and the solution of 2-3

This issue can be solved by simply capturing the image from the position just above the tile corner.

Let's assume that the camera is mounted just above the tile corner B and capture the image. The solution of equation (4) will be B' which is the perpendicular projection of B onto the reference plane. Thus

$x_{B'} = x_B,\ y_{B'} = y_B,\ z_{B'} = z_A \neq z_B.$

Despite $z_{B'} = z_A \neq z_B$, B' would not result in any dimensional measurement error when measuring the dimension AB.

The same is true for C' and D' if C' and D' is the perpendicular projection of C and D onto the reference plane respectively. One camera cannot meet this setup requirement in which the camera is positioned just above four corners of tile.

2.3 Camera Setup

To fix the camera positioning issues discussed above, two cameras are used for tile dimensional inspection. The camera setup is depicted in figure 7.

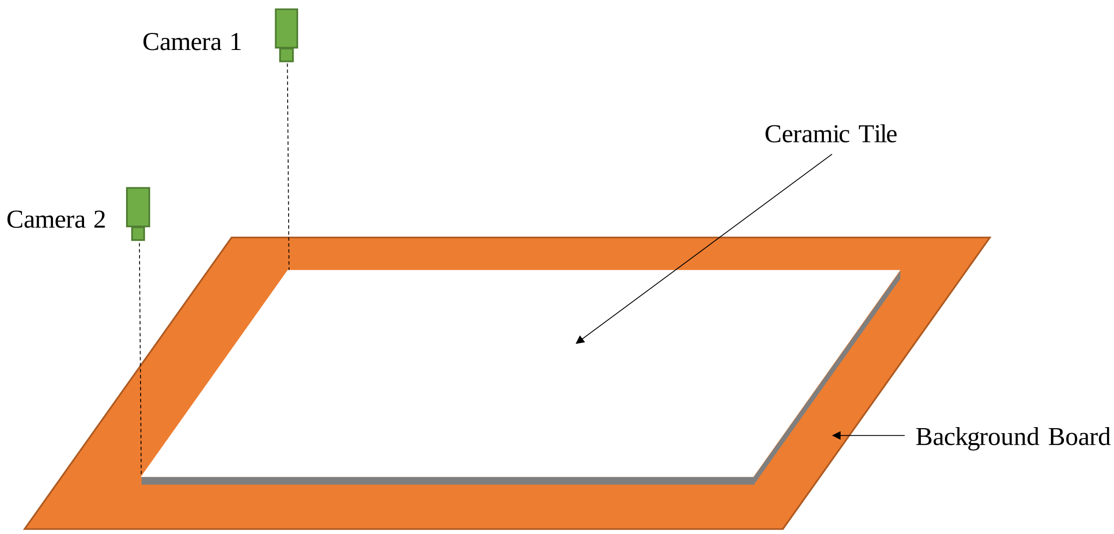

Figure 7. camera setup for dimensional inspection

Each camera is located just above the corner of the tile. The distance between the camera and the tile is calculated to make sure enough measurement resolution can be obtained.

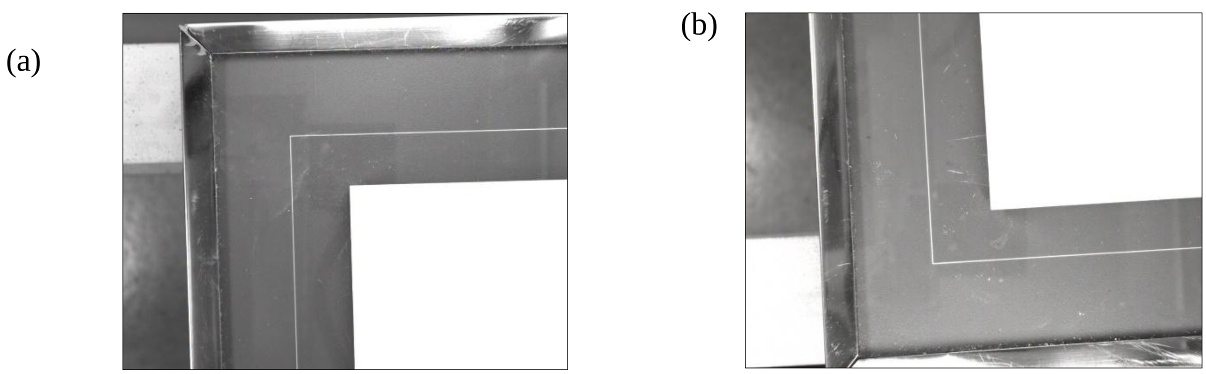

Figure 8. Captured images by cameras, (a) top camera image, (b) bottom camera image.

The cameras capture the corner image of tile as depicted in figure 8.

These images are used to calculate the sub dimensions.

2.4 Background coordinate system

In order to calculate the dimensions, a background table is used. The table is put under the tile and thin rectangle contour is engraved on its surface. The principle of calculating dimensions using background table and sub dimensions are as follows:

Let's assume that the background coordinate system (BCS) is set on the background table.

The origin of BCS is upper left corner of the rectangle contour of the background table, and the x direction of BCS is rightward and y direction of BCS is downward.

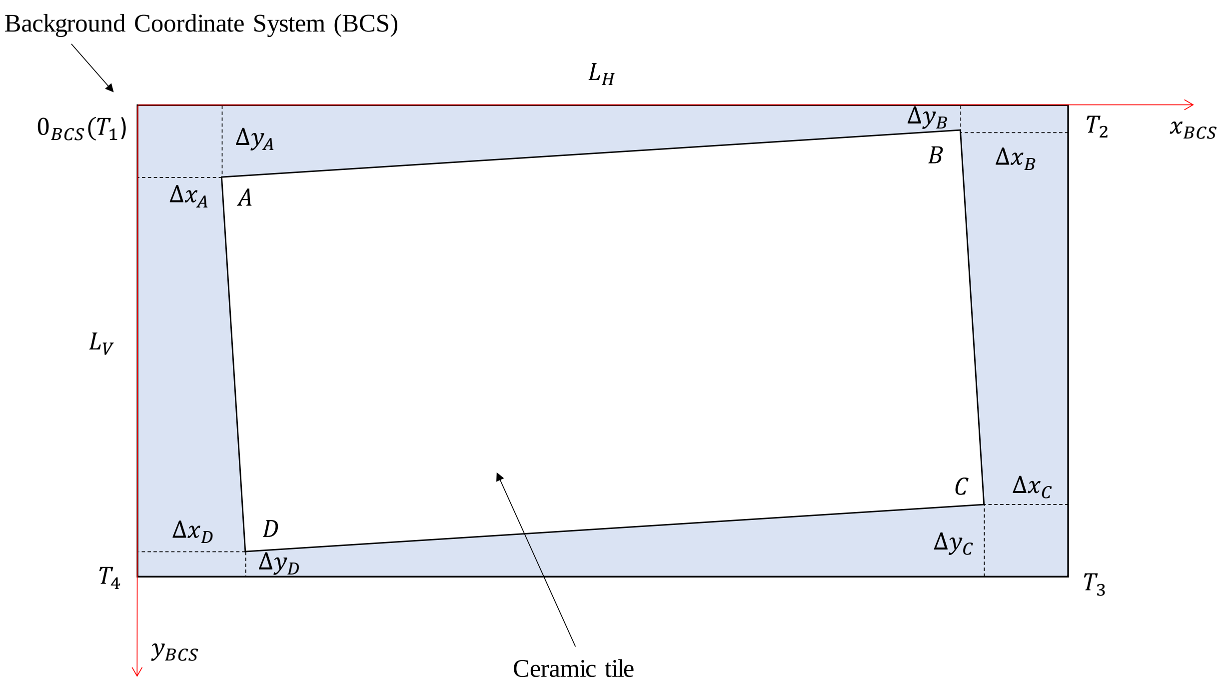

Figure 9. principle for calculating dimensions using background table and sub tile dimensions

Let L_H and L_V are the width and height of the background rectangle contour respectively.

The BCS coordinate of A is $(\Delta x_A,\ \Delta y_A)$, where Δx_A and Δy_A are the offset from rectangle corner T_1 in x and y direction respectively.

In the same manner, the BCS coordinates of B, C and D are $(L_H - \Delta x_B,\ \Delta y_B)$, $(L_H - \Delta x_C, L_V - \Delta y_C)$ and $(\Delta x_D, L_V - \Delta y_D)$ respectively, where $\Delta x_B, \Delta y_B$ are the offset from rectangle corner T_2 and $\Delta x_C, \Delta y_C$ are the offset from T_3 and $\Delta x_D, \Delta y_D$ are the offset from T_4 in x and y direction.

$$\begin{gathered} A(\Delta x_A, \Delta y_A) \\ B(L_H - \Delta x_B, \Delta y_B) \\ C(L_H - \Delta x_C, L_V - \Delta y_C) \\ D(\Delta x_D, L_V - \Delta y_D) \end{gathered} \tag{5}$$

Then the tile dimensions AB, BC, CD, DA, AC, BD can be calculated from the BCS coordinates of A, B, C, D.

2.5 BCS coordinates calculation principle

In order to calculate the BCS coordinates of the four corners of tile, the offset coordinates of the tile corners relative to every BCS rectangle corner must be calculated. The offset coordinates relative to every BCS rectangle corner can be derived from equation (4). The cameras are calibrated to determine the camera parameter at every corner for equation (4). The calibration is done by Bouget's method. After each calibration, the local coordinate system is defined as depicted in figure 10. The xy plane of every local coordinate system lies on the background table.

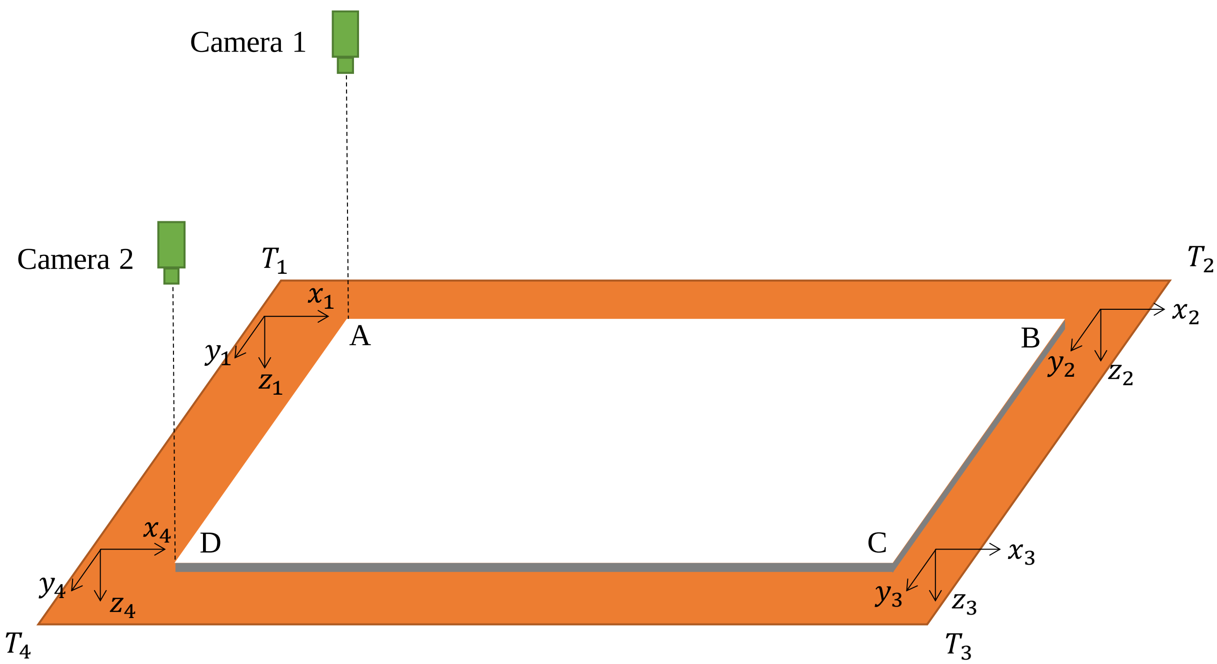

Figure 10. local coordinate systems

The local coordinate systems at $\mathrm{T_1}$, $\mathrm{T_2}$, $\mathrm{T_3}$ and $\mathrm{T_4}$ are $\mathrm{x_1y_1z_1}$, $\mathrm{x_2y_2z_2}$, $\mathrm{x_3y_3z_3}$ and $\mathrm{x_4y_4z_4}$ respectively. The coordinate of A $(\mathrm{x_{1,}y_1,z_1})$ relative to local coordinate system $\mathrm{x_1y_1z_1}$ can be derived from equation (4) with the calibration parameters at $\mathrm{T_1}$. Then BCS contours are extracted using image processing techniques to derive coordinate of $\mathrm{T_1}$, direction of axis x and y relative to the local coordinate system $\mathrm{x_1y_1z_1}$. The coordinate of $\mathrm{A(\Delta x_A, \Delta y_A)}$ relative to BCS is calculated from A $(\mathrm{x_{1,}y_1,z_1})$, $\mathrm{T_1}$, direction of axis x and axis y. In the same manner, the coordinate of $\mathrm{D(\Delta x_D, L_V - \Delta y_D)}$ relative to BCS is calculated from the coordinates of D, $\mathrm{T_4}$ and direction of axis x and y relative to the local coordinate system $\mathrm{x_4y_4z_4}$. BCS coordinates of A and D are calculated simultaneously. After the tile is moved by the mechanical transport system, the cameras see B and C, the same calculation process is repeated to get $\mathrm{B(L_H - \Delta x_B, \Delta y_B)}$, $\mathrm{C(L_H - \Delta x_C, L_V - \Delta y_C)}$ as described above. The coordinates of the four corners of tile relative to BCS are then used to calculate the tile dimensions.

3. Results

The tile dimensional inspection system includes 2 industrial cameras (DAHENG HV1351UM). The camera resolution is 1280*1024. The camera calibration is carried out by Zhang's method at four positions.

Table1
camera intrinsic parameters

parameter	Camera1	Camera2
$[c_x, c_y]$ [pixel]	639.5, 511.5	639.5, 511.5
$[f_x, f_y]$ [pixel]	3157.573, 3159.584	3130.441.30, 3133.416
s	0.84	0.83
p_1	0.00041	-0.00155
p_2	0.00094	-0.00172
k_1	-0.18963	-0.19895
k_2	0.29956	0.57156
k_3	-1.29563	-3.61738

The average reprojection error was 0.079.

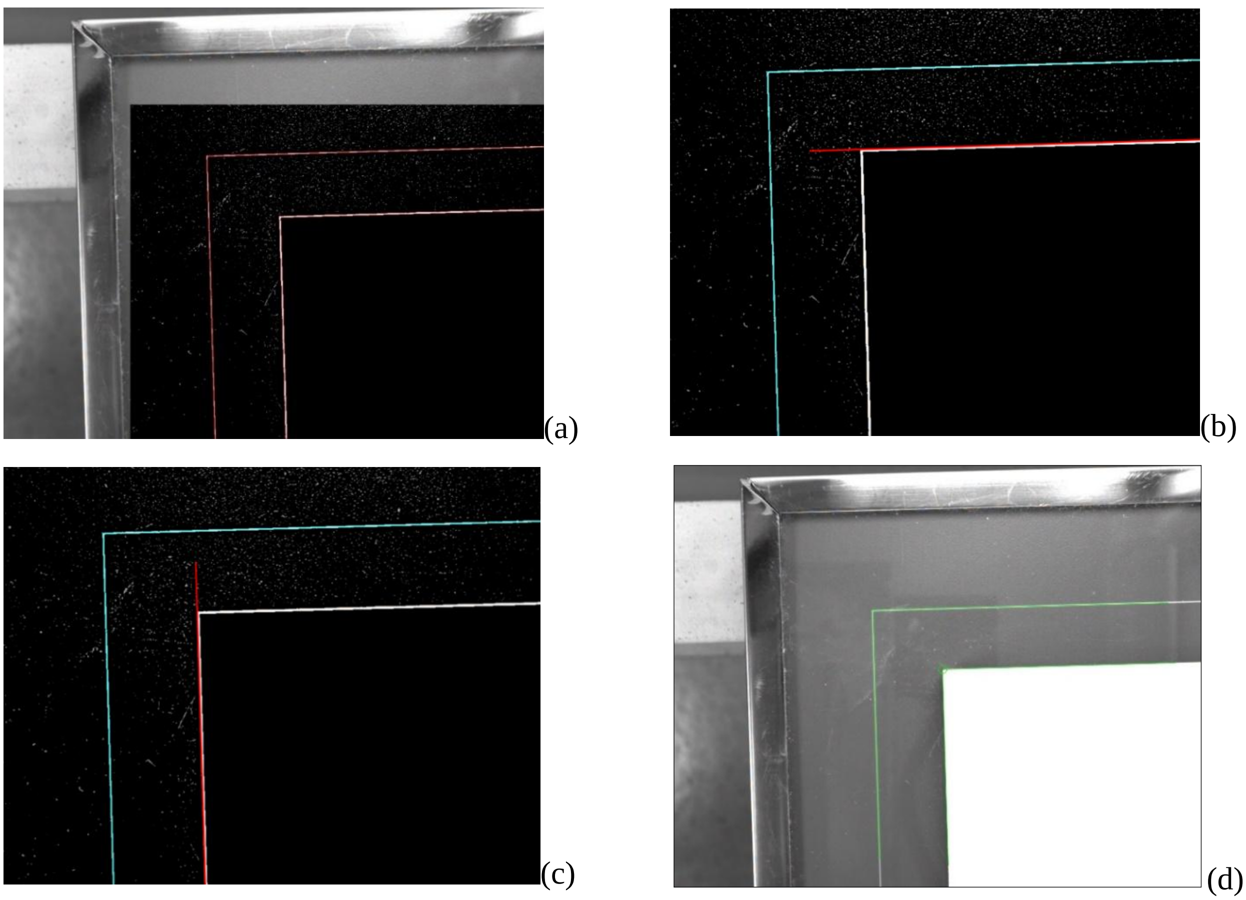

Figure 11. (a) Adaptively thresholded image, (b) tile horizontal edge (c) tile vertical edge (d) detected tile corner.

In order to extract the rectangle contours of BCS and tile, the image is rectified to compensate the lens distortion and the undistorted image is applied adaptive threshold approach. The horizontal and vertical tile edge is detected from the thresholded image as depicted in figure 11. In Figure 11, the black region is the region of interests (ROI). Then the tile corner is the interconnection of horizontal and vertical edge of the tile. BCS edges are extracted in the same way.

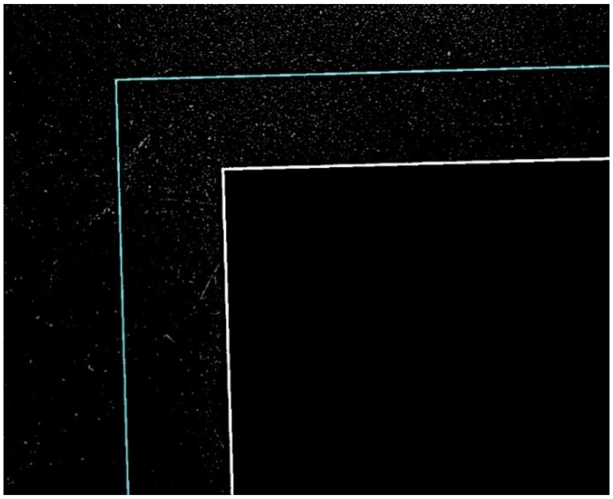

Figure 12. detected edges of BCS

We took 10 different 300mm*450mm tiles and measured the dimensions of each tile 20 times. Then we compared the measured dimensions with dimensions measured by standard gages.

The experiment result is as follows:

Table 2
experiment result (300mm)

No.	Our system ($\overline{d}$)	Gage ($\overline{d_g}$)	Standard deviation(σ)	Error ($\overline{d} - \overline{d_g}$)
1	300.03	300.02	0.04	0.01
2	300.04	300.01	0.04	0.03
3	300.03	300.05	0.03	-0.02
4	300.02	300.00	0.05	0.02
5	300.02	300.02	0.03	0.00
6	300.00	300.01	0.04	-0.01
7	300.04	300.03	0.05	0.01
8	299.95	299.98	0.04	-0.03
9	300.02	300.00	0.03	0.02
10	300.05	300.03	0.04	0.02

Table 3
experiment result (450mm)

No.	Our system ($\overline{d}$)	Gage ($\overline{d_g}$)	Standard deviation(σ)	Error ($\overline{d} - \overline{d_g}$)
1	450.10	450.05	0.04	0.05
2	450.05	450.02	0.04	0.03
3	450.03	450.05	0.03	-0.02
4	450.02	450.06	0.05	-0.04
5	450.08	450.10	0.03	-0.02
6	449.98	450.01	0.04	-0.03
7	450.04	450.03	0.05	0.01
8	449.95	449.98	0.04	-0.03
9	450.02	450.00	0.03	0.02
10	450.05	450.02	0.04	0.03

The standard deviation is within 0.05mm and the maximum error is±0.04mm. The bad results are occurred mainly due to incorrect BCS edge detection introduced by inconsistence ambient light condition.

4. Conclusions

This paper presents a ceramic tile dimensional inspection method using 2 low resolution industrial cameras. The cameras capture the detailed images of the tile corner. The sub dimensions from the tile corner images and background board are used to calculate the dimensions of sidelines and diagonals of the tile. The experimental results demonstrate that the method has high accuracy and efficiency.
In the future, we will continue to make a study to improve the measurement accuracy.

Acknowledgment

I would like to take the opportunity to express my hearted gratitude to all those who make a contribution to the completion of my article.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Declaration of conflicting interests

All data that support the findings of this study are included within this article.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data Availability

The data that support the findings of this study are available within the article.

Funding

No funding has been received for this article.

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