

APPLICATIONS OF COMPUTER VISION ON TILE ALIGNMENT INSPECTION

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ABSTRACT: Due to a lack of standard operation procedures for tile alignment acceptance in Taiwan, subjective visual inspection becomes the main quality measure. Without quantitative specifications for tile alignment, inspectors can easily manipulate the outcome so that fine craftsmanship is not valued, resulting in great quality variation in tile installation works. This paper proposes an automated tile installation quality assurance prototype system, utilizing machine vision technologies. The system receives digital images of finished tile installation and has the images processed and analyzed to capture the geometric characteristics of the finished tile surface. The geometric characteristics are then evaluated to determine the quality level of the tiling work. Application of the proposed automated system can effectively improve the tile alignment inspection practice, and at the same time reduce improper manipulation during acceptance procedures.

Keywords: *Computer Vision, Tile Installation, Acceptance Procedure, Quality Assurance, Corner Detection*

1. INTRODUCTION

In Taiwan, tile is one of the most common materials for floor and wall finishing in residential and industrial buildings. However, we can easily find flawed tiling works with poor alignment and/or uneven surface in many buildings. One of the major reasons of flawed tile quality is the lack of quality assurance standard. According to Section 09310 ceramic tiles of the Standard Construction Specifications and Codes by Public Construction Commission, finished installation of tiles shall be trued to a tolerance of $\pm 1/8"$ in a 10 foot radius, which complies with TCA standards (Tile Council of America). This specified tolerance has been used as the typical acceptance standard for most tile installation works. However, this standard applies only for the levelness of tile surface, and the accuracy of the tile alignment is out of its scope. In most specifications, alignment requirement is described as a qualitative manner but not a quantitative way, such as "Lay tile in grid pattern. Align joints when adjoining tiles on floor, base, walls and trim. Keep consistent spacing between the tiles for straight, uniform grout lines." This lack of detailed quantitative standard in tile alignment results in subjective judgment of fine craftsmanship.

Quality acceptance of tile alignment relies mainly on expert witness inspection and the inspection outcome can easily be manipulated. Some skilled masonry craftsmen have used spacers to improve tile alignment, but it has not become a common practice. Quality variation in tile installation works has always been a big problem in Taiwan's building industry.

To improve current tile acceptance in Taiwan, this paper propose a prototype tile alignment inspection system, utilizing machine vision technologies. Machine vision is the use of optical non-contact sensing to automatically acquire and interpret images, in order to obtain information and/or control machines or processes. Machine vision has been successfully applied to many industrial inspection problems, allowing faster and more accurate quality control. Machine vision allows the manufacturing industry to detect defects, calibrate and control the manufacturing process, which leads to more reliable products and better customer satisfactions.

Semiconductor manufacturing is one of the major industries that make the best use of machine vision. Machine vision-based inspection systems have been introduced and applied in various stages of IC

manufacturing [3][11].

In construction industry, machine vision has also been applied widely in many fields. In construction robot development, machine vision has been an integrated part in automated pavement crack sealing [1][2], bridge inspection [5], concrete surface grinding [4], sewer pipe inspection and tunnel inspection [10]. Other researchers use machine vision technologies for automated construction progress monitoring [7][12]. Machine vision and related video technologies are also becoming increasingly popular in intelligent transportation systems (ITS) applications. For example, Rabie et al. used a Mobile Active-Vision Traffic Surveillance System for incident detection and management [6]. In the field of geotechnical engineering, Suaw et al used machine vision for debris-flow monitoring [9].

2. JUDGING TILE ALIGNMENT QUALITY

To use machine vision for tile alignment inspection, we first have to figure out a mechanism that can tell the differences between a good alignment and a bad one. Figure 1 shows the comparison between an aligned tile surface and an unaligned tile surface. Aligned tiles lie in a straight line while unaligned tiles zigzag along a straight line. The straight line is the regression line of all the corner points which are supposed to be on the same alignment. The larger the corners deviate from the straight line, the poorer the quality is. This paper uses the corner “deviation” from the regression line as the alignment quality indicator, and since the finished surface is two-dimensional in terms of alignment, each tile work can be assessed with “horizontal deviation” and “vertical deviation” to represent its horizontal and vertical alignment quality respectively.

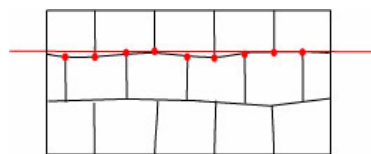
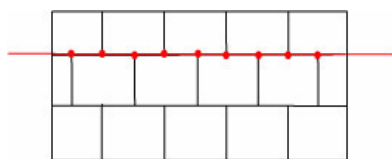


Figure 1. Aligned Tiles vs unaligned tiles

Aiming at a quantitative standard that can be apply to different tile sizes and tile areas, we propose the following alignment control mechanism considering Section 09310 standard for ceramic tile levelness:

“Finished installation of tiles shall be tried to a total deviation of 0.2 cm in alignment within a 3 m radius.”

“Total deviation” is defined as the total amount of deviations of all corner points in a line, by summing the distance from each corner point to the regression line within a certain length.

3. AUTOMATED TILE ALIGNMENT INSPECTION

The steps to automated tile alignment inspection using machine vision are described as follows:

1. Capture tile image

This research team uses an entry level Nikon coolpix S1(5.1 Megapixel) digital camera to capture tile images. The camera is mounted on a tripod to minimize image blurring.

2. Image preprocessing

The team uses two commercialized image processing software packages (Photoshop® and Inspector ®) to prepare the captured images for further analysis:

- (a) Calibrate image distortion: Distortion is the effect when there is a straight line running near one of the edges and it is bowing inward (pincushion) or outward (barrel). All camera lenses today have some level of distortion, especially super-zooms. To allow accurate image presentation, we let the captured image go through a distortion correction process from Photoshop® to restore the image back to a true horizontal and vertical alignment.
- (b) Gray scale image transform: Color images are transformed into gray scale using Photoshop® since later analysis requires only gray scale images.

- (c) Image enhancement and noise reduction: Image processing techniques such as median filtering, contrasting, brightness, edge sharpening by Inspector ® are applied to enhance the quality of interested points, and remove noise.

3. Corner Detection

Corner detection is an approach used within computer vision systems to extract corners for subsequent processing, and a corner can be defined as the intersection of two edges. Since we use tile corner deviation to judge tile alignment quality, it is important to extract tile corners from the image. We use a heuristic corner detector “FAST” developed by Rosten [8] as the extracting tool, and store the corner coordinates in a text file (Figure 2).

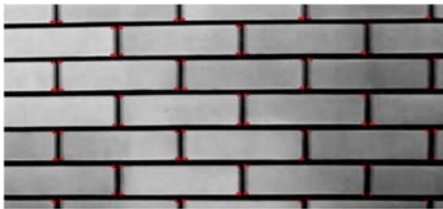


Figure 2. Corners detected by Rosten’s FAST

4. Corner Convergence and Corner Clustering

There should be only one point at each tile corner. However, motion blurs from inevitable camera shake result in hazy corners so that corner detection usually yields multiple points at each corner (as in Fig. 2). It is necessary to converge these multiple coordinates into one single point to represent the exacted corner. We write a Visual Basic subroutine and run all points extracted from corner detector through it to obtain a single set of corner coordinates. This corner convergence subroutine collects all neighboring points surround each corner and converges all into one single set of coordinate representing the corner. This routine also purges the noise away from the corners. Next step is to classify all corner points into sub groups by each horizontal and vertical line, and this step is called “corner clustering”. The points that are supposed to be aligned to the same horizontal line have adjacent y -coordinates and the points that are supposed to be aligned

to the same vertical line have adjacent x -coordinates as the image has been corrected from distortion from previous procedure and are true to global coordinates. Since the points on the same line should not separate by more than half of the grout width, half of the grout width is the threshold for classifying the group.

5. Scoring:

To determine if a tiling installation work comply with the quantitative standard, total tile deviation on each image is analyzed and converted to the corresponding total deviation in a 3m radius. The total deviation is then normalized to a 0~100 scale to represent tile alignment quality. A 100 score represents a perfect aligned tiling work, and 60 represents tiling with a total deviation of 0.2 cm (in 3m) and barely meet the requirement. Tiling works assessed below 60 are deemed failing the quality procedure, and a rework is mandatory. Assessing quality score requires the following:

- (1) Calculate regression line for each sub group:

The points in one sub group are fitted to a regression model relating Y to the function of X .

$$Y = \alpha + \beta X ,$$

where

$$\alpha = \bar{Y} - \beta \bar{X}$$

$$\beta = \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sum (X - \bar{X})^2}$$

- (2) Calculate average total deviation in one direction

$$D_i = \frac{\beta X_i - Y_i + \alpha}{\sqrt{(\beta^2 + 1)}} \quad (\text{point distance to } Y = \alpha + \beta X)$$

$$TD_p = \sum D_i \quad (\text{Total Deviation of one line})$$

$$\text{Ave.TD}_p = \sum TD_p / m \quad (\text{Average Total Deviation in one direction})$$

- (3) Calculate total deviation in 3m

$$\text{Ave.TD}_{\text{mm}} = \text{AveTD}_p \cdot \frac{\text{image.length (mm)}}{\text{image.length (pixel)}}$$

(converting total deviation from pixel into mm scale)

$$TD_{mm \text{ (in 3m)}} = AveTD_{mm} \cdot \frac{3000 \text{ (mm)}}{\text{image length (mm)}}$$

(calculate total deviation in 3m)

(4) Normalize the score

According to the said specification, a total deviation of 2mm is assessed a score of 60, and 0 deviation receives a perfect score of 100. Using interpolation, we can convert the calculated total deviation in 3m into a normalized score *X*.

$$\frac{TD_{mm \text{ (in 3m)}} - 0}{X - 100} = \frac{2mm - 0}{60 - 100}$$

$$X = 100 - 20 \times TD_{mm \text{ (in 3m)}}$$

Table 1 summarizes the devices and tools used in the system.

Table 1 Tile Alignment Inspection System Components

Procedure	Devices/tools	Description
Image Capture	Nikon® S1 CCD camera	- Digitize image
Image preprocessing	Adobe® Photoshop® CS4	- Correct distortion - Transform image into gray scale
	Inspector® 2.1	- Enhance image - Reduce noise
Corner detection	FAST detector	- Extract tile corners
Data processing	Visual Basic® Routines	- Corner Convergence - Corner Clustering
Scoring	Microsoft® Excel®	- Calculate total deviation - Normalize score

4. SYSTEM VERIFICATION

To verify the accountability of the proposed system, the research team conducts a series of real jobsite tests. Our tests include two major parts: computer scoring, and expert scoring. The research team collects images of seven tile installation works and have the images processed and analyzed by the system to obtain their quality scores of

alignment (computer scoring). For comparison purpose, we also organize an expert panel of 10 experienced professionals, including 2 jobsite managers, 7 masonry foremen, and 1 architect, to perform expert witness inspection. Experts are asked to mark their assessment on fuzzy scaled expert assessment charts of all seven works as shown in Figure 3. Mathematic average of 10 experts' assessment represents the witness inspection result (expert scoring). Table 2 summarizes the computer scoring and expert scoring results of the seven works.

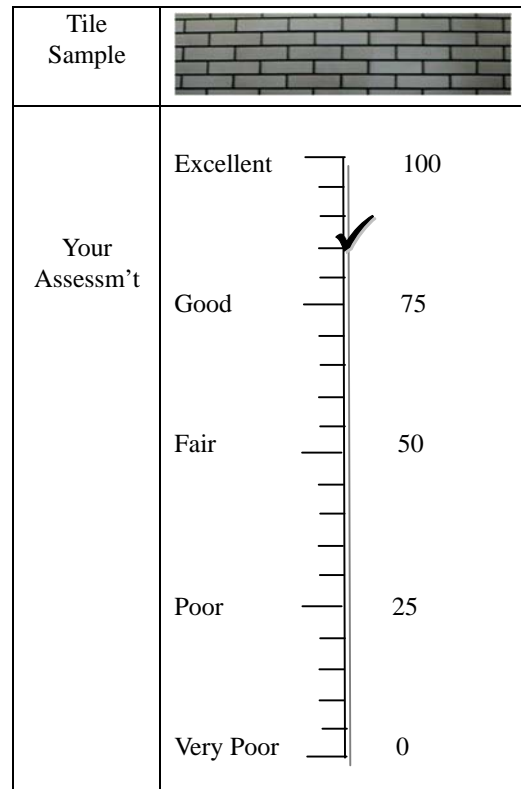


Figure 3. Expert Assessment Chart

A simple Pearson's Correlation test shows that the two scorings are highly correlated (Table 3), meaning computer scoring tends to yield a comparable result to expert scoring. These tests have proved that the proposed system has the potential to replace expert witness inspection for the scope of tile alignment.

Table 2. Computer Scoring vs Expert Scoring








Location	No. of Tiles	No. of Lines	Total Deviation (mm)	Ave. T. Deviation (mm)	3m T. Deviation (mm)	Accessed Score	Final Computer Scoring	Expert Scoring
Japan A airport 	34	X-22 lines	1.179	0.054	0.445	91	90.5	86.75
		Y-12 lines	2.924	0.244	0.484	90		
Kaohsiung B bank 	28	X-18 lines	1.357	0.075	0.754	85	84.5	73.25
		Y-18 lines	2.448	0.136	0.817	84		
Taiwan C comapny 	50	X-22 lines	2.392	0.109	0.725	86	84.5	72
		Y-12 lines	2.976	0.248	0.827	83		
Kaohsiung Farming Bld. 	50	X-22 lines	4.686	0.213	1.417	72	70.5	60.75
		Y-12 lines	5.592	0.466	1.554	69		
Kaohsiung Chi-Yu Rd. 	70	X-22 lines	7.574	0.344	1.639	67	67	60.5
		Y-16 lines	7.788	0.487	1.623	67		
Kaohsiung SunMing Rd. 	25	X-12 lines	4.306	0.359	2.153	57	56	38.75
		Y-12 lines	4.514	0.376	2.257	55		
Kaohsiung Ta-Hsin Rd. 	25	X-12 lines	4.518	0.377	2.259	55	53.5	32.75
		Y-12 lines	4.796	0.399	2.398	52		

Table 3 Pearson Correlation Test

		Computer Scoring	Expert Scoring
Computer Scoring	Pearson correlation	1	.977(**)
	Sig. (2-tailed)		.000
	N.	7	7
Expert Scoring	Pearson correlation	.977(**)	1
	Sig. (2-tailed)	.000	
	N.	7	7

** Correlation is significant at the 0.01 level (2-tailed)

5. CONCLUSIONS

This paper presents a machine vision-based inspection system for tile alignment. The system uses various image processing technologies for image enhancement, noise reduction, and corner detection. The authors successfully

develop a mechanism for measuring tile alignment quality level by involving total deviation. The system is tested again expert witness inspection and appears to deliver reasonable and accountable results. We believe that application of the proposed system can effectively reduce improper manipulation of tile acceptance procedures, and in the meanwhile prompting jobsite management to focus on promoting fine workmanship of tile installation.

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