A Vision System for Detecting Paint Faults on Painted Slates

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Abstract: This paper is concerned with the problem of how to detect paint type defects on painted slates using machine vision. We begin by outlining the motivations for this research and present a review of research in related areas before proceeding with a process description and a categorization of typical paint defects. We describe the test bed built to replicate factory conditions and the testing of image capture techniques. We discuss problems we confronted such as getting a sufficiently strong signal level from the slate, the effects of the slate surface profile on image capture and how we dealt with these problems. The third principal challenge was to generate a strong signal to noise ratio for each defect type so that a computationally inexpensive image processing method becomes viable. We demonstrate how this objective was met in the laboratory environment and conclude with a discussion on the challenges to be overcome when a production prototype is assembled.

Keywords: Manufacturing process, painted slate, inspection, lighting, camera, depth profile.

1. Introduction

The painted slates are inspected manually by an operator who looks at the slates as they emerge from the paint process line. Inspection is considered to be satisfactory by the industrial partner. An automated approach must replicate the achievements of the human operators and offer convincing advantages if its adoption is to be seriously considered in this industry.

The aims of using automated visual inspection are to classify products for quality so that defective units may be rejected, to measure some properties of the product with a view to controlling the production process and to gather statistics on the efficiency of the production process for management purposes.

Tobias et al [8] list some of the key factors that influence the adoption of machine vision systems in industry. These include increased productivity, improved product quality, absence of human inspectors performing dull and monotonous tasks, high-speed inspection (matched by high-speed production) and reduced human labour costs.

No prior work was found on the inspection of slates whereas there is an abundance of research material on the subject of ceramic tiles, a product not dissimilar to slates in general shape and conveying requirements. All work in the field of ceramics inspection reviewed used different imaging sub-systems and processing techniques to detect paint and substrate faults.

Diffuse lighting methods are universally employed in conjunction with color cameras [1,2,3,4,5,6]. Peñaranda et al [2] use a fiber optic light guide placed directly above the tile to create a linear strip of light from halogen light sources. The light guide appears to be located 90º to the tile and the camera view angle is not specified. Boukouvalas et al [1] locate the camera directly above the tile and use diffuse lighting with halogen lamps as source. The tile is indirectly illuminated and a reflecting baffle is used to create diffuse illumination.

The minimization of spatial and temporal illumination variations is reported as being crucial to successful defect detection. Good results are reported when variations are less than 2% [2]. Boukouvalas et al [4,5] report that replicating human eye capability involves resolving gray scale data to less than one gray scale level. In experiments on the response of the human eye, Hubel [7] found that our eyes begin to respond to regions having intensity variations greater than 2% relative to background intensity levels. Absolute intensity levels are of little relevance since our eyes do not respond to absolute values of light intensity.

Spatial corrections of illumination variations are effected by curve fitting [1,3,4] or by pixel level multiplications with factors determined using a calibration pattern [2]. Line scan cameras are invariably used in an effort to reduce spatial illumination non-uniformities. This is motivated by the fact that it is easier to control the intensity uniformity of a long, narrow strip of light than that of an area large in two dimensions. Temporal variations are corrected by placing a reference surface in the field of view of the imaging system and correcting for variations using multiplication [3,4]. Ideally, we would wish to replicate the human eye invariance to gray scale illumination variations; no techniques to achieve this are reported in work concerning ceramics inspection.

2. Description of the Slate and Defects

The manufactured slates are painted on a high-speed paint line and are manually inspected as they emerge from the paint line. Human inspectors make a decision as to whether each individual slate is defect free and remove defective slates from the conveyor system.

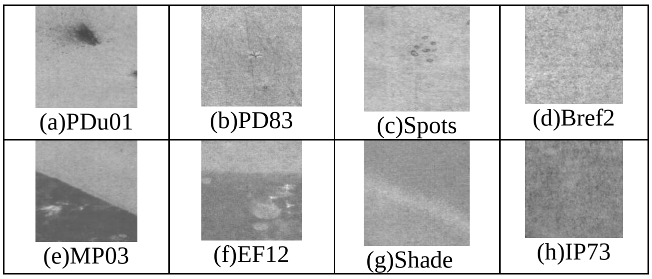

Figure 1: A selection of defects found on the slate. From top left, paint dust, paint droplet, spots, reference, no paint, efflorescence, shade variation and insufficient paint.

While a number of slate sizes, surface profiles and colors are produced, this research is focused on one slate size. The slate is usually colored black or gray and has a high gloss surface finish. One of a range of pantone colors is used in any single production run. The painted surface is nominally flat.

A description of the paint line process is as follows: Each item is pre-heated, spray-painted, post-heated and cooled prior to arrival at the inspection point. After inspection the slates are stacked and wrapped. The inspection is the only manual operation on this highly automated process.

Defects are broadly classified as being of type paint and substrate. Substrate faults are marks, dirt, lumps, depressions and edge faults. Paint faults are sub-divided into stains, nozzle and heating types: nozzle types include missing paint, insufficient paint, paint droplets, spots and paint dust. Heating types include shade variation and burn mark. Sizes range from sub-millimeter to hundreds of square millimeters.

No.	Defect Type	Defect Size	Description
1	Insufficient paint	20 mm < {W, L, ø} < all slate	Reduced gloss level
2	Missing paint	2 mm < {W, L, ø} < all slate	Paint missing from some areas
3	Droplet	2.0 mm < {W, L, ø} < 15 mm	Excess dried and cracked paint
4	Efflorescence	ϕ > 5.0 mm	Contaminant preventing correct adherence of paint
5	Paint dust	2 mm < {W, L ø} < 50 mm	Dried paint dust on surface
6	Burn mark	20 mm < {W, L, ø} < all area	Reduced gloss due to overheating
7	Barring	W = 10±5 & 20 < L < 600 mm	Shade variation by uneven heating
8	Spots	1 mm < {W, L ø} < 5 mm	Localized shade variation
9	Shade variation	20 mm < {W, L, ø} < all areas	Incorrect pre-heating of slate

Table 1: Definition of paint defects

3. Description of Image Capture Tests

Paint faults are typically inspected using diffuse lighting techniques [1,2,3,5,8]. This approach is impractical for slates because of the difficulties associated with obtaining a sufficiently intense response from the slate surface.

The strategy used to get sufficiently strong light intensity at the sensing device relies on using the strong reflecting properties of the glossy surface. The imaging system relies on specular reflections whereby the lighting and camera angles relative to the surface being imaged are equal. Light incident on the slate at angle, ø, will be reflected from the slate and into the camera at the same angle, ø, when the surface quality is acceptable. A collimated light source would be appropriate. Paint faults have reduced gloss levels and present a surface to the incident light that is more diffuse than that of an acceptable slate. A diffuse reflecting surface will reflect light in all directions and there will be a reduction in light levels arriving at the sensor. The diffuseness is dependent on defect type with stain type faults being slightly diffuse and burn mark type faults being very diffuse. A reduction in light arriving at the camera signifies the possible presence of a defect.

This imaging method is more commonly used to image surface irregularities such as the substrate faults found on the slate. The slate surface profile is specified as being uniform to ±0.1 mm. A smooth transport mechanism that maintains slate aspect with respect to light source and camera will be necessary for this method to be successful. Substrate faults are also likely to be detected using this imaging method.

3.1 Test Bed Description

A Basler Model L102 line scan CCD camera was used as the sensing device and the video data was captured and transferred to computer hard drive using a Eursys model Multi frame grabber card. An f28 mm lens was used with aperture set to 2.8. A micro-positioner was attached to the camera to facilitate fine adjustment of camera view line. The slate was illuminated using a fiber light guide illuminated by a 150W halogen bulb driven by a Schott-Fostec DC regulated lamp controller. No light intensity feedback sensor was used. A cylindrical lens was placed in front of the fiber light guide. This arrangement creates a very intense and collimated source. The camera was fixed in position 700 mm from the slate and lighting was separated from the slate by a distance of 84 mm. Camera control and frame capture was implemented using the Eursys Easygrab software environment.

A guide for slate conveyance was made from Bosch extrusions. The slate is inserted between slots in the extrusion and ensures the slate travels smoothly in the X and Y-axes. There is scope for 5 mm movement in the Z-axis. Slate weight will keep it on the lower edge of the slot and there should not be any Z-axis movement. Slates were pulled by hand along the extrusions and moved past the inspection point at relatively constant speed. Frames of width 2,000 pixels and length 600 pixels were captured and transferred to computer memory. Regions of interest were extracted from these frames and filed for later analysis. The Neatvision [10] image analysis software was used to implement off-line analysis.

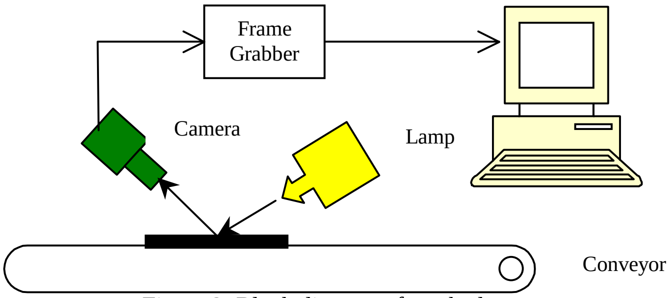

Figure 2: Block diagram of test bed.

3.2 Description of Tests

The industrial partner supplied approximately 60 samples for use in the tests. Most samples contained one or more defect types and the full range of defect types were contained within the samples. 10 samples contained no defects and were used as references.

Alignment of the camera onto the narrow band of light created by the fiber light guide was the first principal obstacle encountered. The focused band of light is only 5 mm wide. The typical laboratory tripods and easily adjustable positioning mechanisms turned out to be inappropriate as fine adjustment was extremely difficult. Furthermore, retaining a hard-won alignment proved to be an impossible task.

The mechanical rigidity of the supporting frame and slate transport mechanism established itself as a second major source of signal capture errors. The slate is relatively heavy and moving it along the conveyor introduces some vibration. The solution was to source solid, rigid brackets and to strengthen the mounting frame and transport mechanism. The light guide was mounted using fixed position, rigid brackets. The camera was mounted onto a rigid bracket with a micro-adjustor added to facilitate fine adjustment of view line.

At this point it became clear that the slates were not flat. These slates normally have some degree of concavity and convexity. The depth profile ranged from negligible to 5 mm over the slate length and up to 2 mm along the slate width. Though this does not impair slate functionality in any way, it does introduce a new level of difficulty to the image capture task. Initial feedback from the industrial partner was to the effect that the depth profile was caused by either uneven drying in the warm laboratory or inappropriate stacking conditions. Fresh samples were made available and it was noted that some of these also had significant depth profile variations.

The depth profile raises and lowers the absolute position of the band of light and the view position of the camera. When the slate position is elevated the band of light shifts to the left while the sensor view position shifts to the right. With incidence and reflectance angles of 45°, if the slate position rises 1 mm the band of light and camera view point move 1.25 mm in opposite directions. The higher the angle of incidence, the smaller the shift in location of the band of light. The lower the angle of incidence the wider the band of light so that the overall effect of altering the angle of incidence is cancelled. The depth profile also changes the angles of incidence and reflectance with respect to light source and camera. A change in the slate aspect alters the angle of incidence from ø to ø+α and the angle of reflectance from ø to ø-α.

Our initial consideration was to devise a method to force the slate into a uniform flat shape during inspection. The worst effects of depth profile variation were removed in the laboratory by pressing down on the slate and forcing it against the supports of the conveyor. Results were acceptable as the slate does have some elasticity. This approach is unlikely to be a solution on the production line.

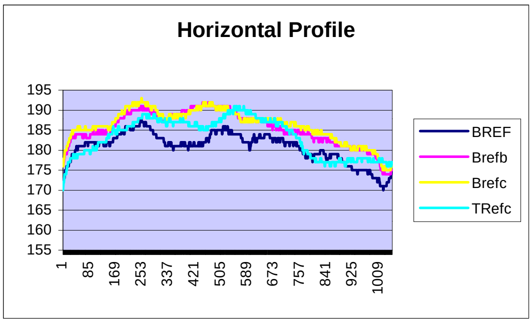

Figure 3

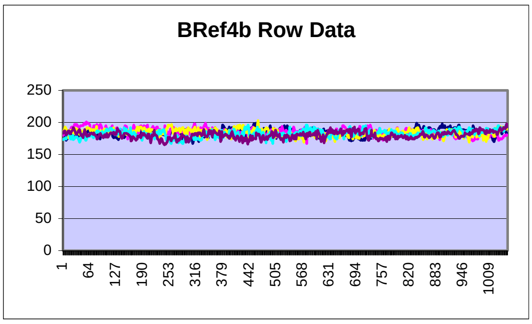

Figure 4

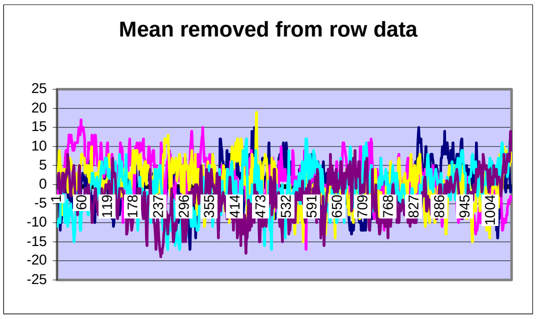

Figure 5

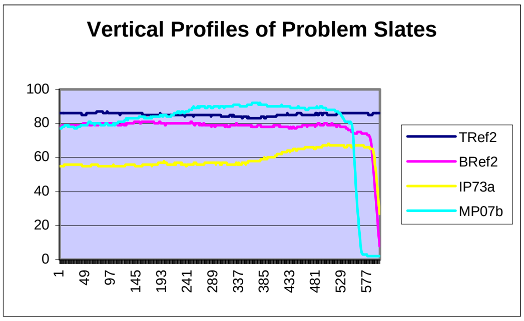

Figure 6

An alternative approach is to defocus the lens on the fiber light guide. This produces a wider band of light and reduces the collimation. The intensity is also reduced and was compensated for using spare capacity in the lamp controller. Tests were repeated with lens defocused sufficiently to produce a light band of width 13 mm making it relatively easy to align the camera when using the micro-adjustor. Though the effects of depth profile are still evident useful results were obtained. A noticeable difference in signal levels remains between slates having negligible and significant depth profiles. Light intensity is sufficient and even the smallest paint defects can be imaged.

The lamp angle of incidence was set up at 44° and the exposure setting was 1,000 microseconds. Grey scale mean values were 180 gray levels for reference samples at lamp intensity setting of 77%. The cross direction pixel resolution was 0.21 mm and the moving direction pixel resolution was 0.44 mm. Light levels are 2 times lower than required for production line speeds but there is sufficient spare capacity in the lamp controller.

3.3 Test Data and Results

A black slate, bref2, was used as the reference image. The image contains 600 successive lines of data representing a 264 mm length of the central 252 mm of the slate. A horizontal profile was calculated by averaging data in columns and has 20% non-linearity. The profile is shown in figure 3 for three successive scans and good repeatability can be observed. A compensation curve was generated to linearize the horizontal profile. The compensation profile reduces variation to 2.5%. Row data shown in figure 4 has a mean value of 181 gray levels. Mean subtracted from row data is shown in figure 5. Noise level due to slate texture is 15 gray levels.

Variation for the gray reference sample is reduced from 22% to 12% using compensation data from the black reference slate. Better results were expected from the compensation and it is an indication of the difficulties presented by depth profile. The measured variation of the vertical profile is 11% with noticeable drop in mean signal level close to slate start and end.

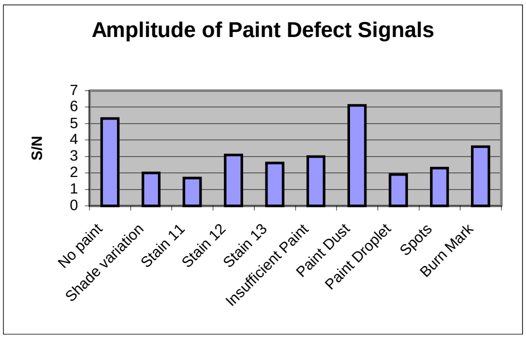

Figure 7: Fiber Light Guide Results

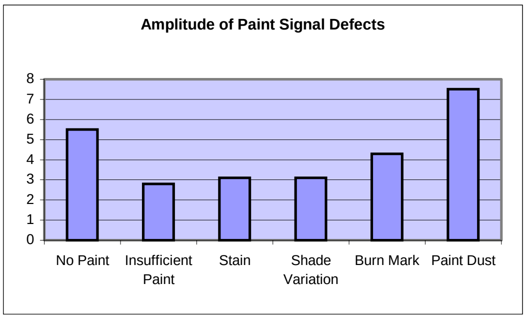

Figure 8: Diffuse lighting Results

4. Tests using a Diffuse Light Source

Tests were also conducted using an aperture fluorescent light system with integral cylindrical focusing lens (TSI Model AFL9000) as the illumination source. The test bed was identical in all other respects. This lighting method creates a wide band of partially diffuse and partially collimated light and provides easy camera alignment. The exposure setting was 2,000 microseconds and the gray scale mean values were 80 gray levels for reference samples. The cross direction pixel resolution was 0.28 mm and the moving direction pixel resolution was 0.62 mm.

Light levels are 4 times lower than required so that effective moving direction resolution will be 2.0 mm at production line speeds. Cross direction resolution is not influenced by production speed and will be set as considered appropriate. An advantage of this lighting method is that it is relatively immune to slate profile non-uniformities. An obvious disadvantage is that the smaller defects cannot be detected. A review of fault types and sizes shows that many of the paint faults are quite large[1] and can be inspected at a relatively low moving direction resolution of 2 mm. A less intense light source would suffice. The effects of depth profile do not impact negatively on large size defect detection.

5. Image Processing

All images were thresholded using a double threshold with lower threshold set at 150 and upper threshold set at 210. Any image data between these set points is deemed acceptable quality and any pixel data outside these set points is considered to be associated with a defect.

The image was inverted and subjected to a 4-connected erosion to remove noise. The balance of white pixels were counted and compared to a threshold. The common processing loop was applied to all images with good results. Defects with a signal-to-noise ratio larger than 2.0 will be detected using this threshold setting. All paint faults listed in table 1 were successfully detected. The erosion step was removed to successfully detect the small size paint defects of paint droplet and spots.

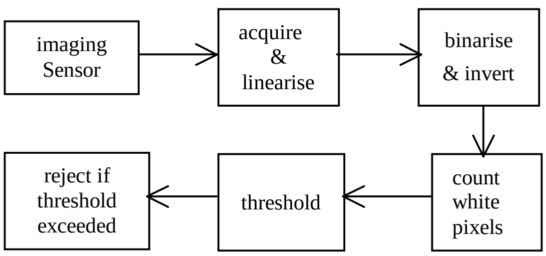

Figure 10: Common processing loop applied to slate images.

All image processing has been applied to subsets of the full slate. Methods to segment the slate image from the background, handle edge effects and non-uniformities over a complete slate have yet to be developed. Testing of the candidate image processing techniques of gray level difference method and local binary patterns did not produce conclusive results on the laboratory images. The irregularity of the conveying method is thought to have been a significant contributory factor to the inconclusive results for these methods.

6. Discussion

The collimated lighting method is preferred because light intensity levels are sufficient and all defect categories can be detected. It suffers from the disadvantage that signal level can be affected sufficiently by depth profile variations to render defect detection difficult and in extreme situations, impossible.

The effects of low-level depth profile variation can be removed by image pre-processing. A morphological white top hat is a candidate algorithm. This would introduce an additional level of processing carrying considerable computational overhead and should be avoided. Medium level depth profile variation causes considerable gray level shifts, which are difficult to distinguish from large area paint faults such as shade variation. Further testing is being carried out to determine if an optical or image-processing solution can be found for this problem.

The diffuse lighting method works very well for detection of gross paint faults. Defect detection is not adversely affected by depth profile non-uniformities of up to 5mm. The low pass filtering effect of the slow scan speed averages out much of the slate texture. This has the advantage of lowering noise levels and the disadvantage of removing useful information such as tiny defects. Small paint faults such as spots and paint droplets are not detected using diffuse lighting.

7. Conclusions

Laboratory test results demonstrate that automating the visual inspection of painted slates is a realistic target. An image capture technique has been tested which meets our objectives of obtaining a sufficiently intense signal level from the slate and obtaining a sufficiently strong signal-to-noise level for each paint defect type to make computationally inexpensive algorithms useable. Problems have arisen due to the unanticipated depth profile non-uniformities. We expect to minimize profile effects using optical or image processing means and to remove any remaining effects by suitable pre-processing. A production prototype inspection system will be built to investigate whether production line realities can be successfully overcome.

Acknowledgements

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References

[1] C. Boukouvalas, F. De Natale, G. De Toni, J. Kittler, R. Marik, M. Mirmehdi, M. Petrou, P. Le Roy, R. Salgari and F. Vernazza. “An integrated system for quality inspection of tiles”, Proc International Conference on Quality Control by Artificial Vision OCAV’97, (Toulouse, France), pp. 49-54, 1997.

[2] J. Peñaranda, L. Briones and J. Florez. ”Colour machine vision system for process control in ceramics industry”, Proc. of SPIE 3101, pp. 182-92, June 1997.

[3] C. Boukouvalas, J. Kittler, R. Marik and M. Petrou. “Automatic grading of ceramic tiles using machine vision”, Proc. of IEEE Intl Symposium on Industrial Electronics, pp. 13-18, 1994.

[4] C. Boukouvalas, J. Kittler, R. Marik and M. Petrou. “Automatic Colour grading of ceramic tiles using machine vision”, IEEE Transactions on Industrial Electronics, vol. 44, no. 1, pp. 132-135, Feb 1997.

[5] C. Boukouvalas, J. Kittler, R. Marik and M. Petrou. “Colour grading of randomly textured ceramic tiles using colour histograms”, IEEE Transactions on Industrial Electronics, vol. 46, no. 1, pp. 219-226, Feb 1999.

[6] C. Boukouvalas, J. Kittler, R. Marik, M. Mirmehdi and M. Petrou. “Ceramic tile inspection for colour and structural defects”, Proc. AMPT ’95, pp. 390-399, Aug 1995.

[7] David Hubel. “Eye, Brain and Vision”, Scientific American, 1988.

[8] O. Tobias, R. Seara, F. Soares and J. Bermudez. “Automated visual inspection using the co-occurrence approach”, IEEE Midwest Symposium on Circuits and Systems, pp. 154-157, Aug 1995.

[9] P. F. Whelan and D. Molloy, Machine Vision Algorithms in Java, Springer, 2000.

[10] Neatvision, An Image Analysis and Software Development Environment, www.neatvision.com.

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[1] Minimum size of $100mm^2$ though width or length dimension can be as small as 1.0 mm.