Exploring the effects of a factory-type test-bed on a painted slate defect detection system.

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SYNOPSIS

This paper is concerned with the problem of how to detect visual defects on painted slates using an automated visual inspection system. The inspection work cell of the manufacturing process was replicated by mounting the inspection system on an industrial conveyor and operating at production line speeds. Laboratory test bed proven image sensing methods and inspection algorithms were subjected to robustness testing in an environment similar to that found in the factory. The additional challenges introduced by a factory-type test-bed are discussed in detail.

1 INTRODUCTION

Factory conditions are quite different to those encountered in a laboratory environment and we considered it necessary to test our methods in a manner, which took account of the difficulties introduced by a manufacturing environment. We describe the production prototype built to replicate factory conditions including mechanical, optical and software components. We discuss problems we confronted such as the effects of the slate surface profile and conveying non-idealities (vibration and slate drift) on image capture and how we dealt with these problems.

2 DESCRIPTION OF THE FACTORY-TYPE TEST-BED

A conveyor was built to replicate factory conditions. Slates are transported past the inspection line at factory line speeds. A fibre optic line light illuminates the slate and the camera captures a digital image of the slate and transfers this image to a PC located underneath the conveyor. The camera used was a 2K-pixel line-scan type from Basler operating at a scan frequency of 2.5KHz. A Eursys frame grabber was used to interface the camera to the PC. A 30” light-line illuminated with two 150W halogen lamps allows us to image the slate with either the 300mm or the 600mm edge facing forward. Software development was carried out on a 600 MHz Celeron processor having 128 MB RAM. The developed algorithm was ported to the MS Visual C++ environment and modified to automatically detect slate edges and nail holes.

The effects of vibration are reduced by using a belt-driven conveyor and by careful selection of the belt material. A guide is located on one side of the conveyor to reduce slate lateral drift and rotation and to ensure relatively constant slate CD position with respect to the camera and lighting.

Figure 1: Conveyor and slate inspection system.

2.1 Image capture method
The imaging system used in this implementation relies on the strong reflecting properties of the glossy surface and captures specular reflections whereby the lighting and camera angles relative to the surface being imaged are equal (Carew et al, 2001). 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. Variations in the light intensity reflected from the slate indicate the possible presence of a fault.

2.2 Image processing algorithm
A four component, image processing loop is applied to all images to check for defects (Carew et al, 2002). Each component is designed to identify a specific image feature indicative of the presence of a defect. These components are global mean threshold method, adaptive signal threshold method, labelling method, edge detection and labelling method.

The grey level mean threshold method is an intensity test. The adaptive signal threshold is set relative to the grey level mean of the region under inspection. This approach is necessary because of acceptable variations in intensity across the slate. The threshold is set outside the typical noise margin of the image.

The labelling method begins with a binarisation of the local region using an adaptive threshold set relative to the mean and with the threshold set well within the typical noise margin of the image. This method is used to identify low contrast defects such as shade variation, efflorescence and some template marks. The edge detection and labelling method is used to identify thin structures such as some types of template marks.

2.3 Segmentation of slate image from background
Slate edge detection was facilitated by cutting slots in the conveyor base and ensuring the belt width is less than that of the slate. The camera signal from these slots is close to the camera black level when no slate is present and there is a sharp signal transition when a slate arrives in field of view. A threshold operation is sufficient for edge detection. Corners are located by

tracking the horizontal and vertical edge lines to their end positions. These end positions will be in the same location and define the corners. The exception being when the corners are damaged and the slate is classed as defective.

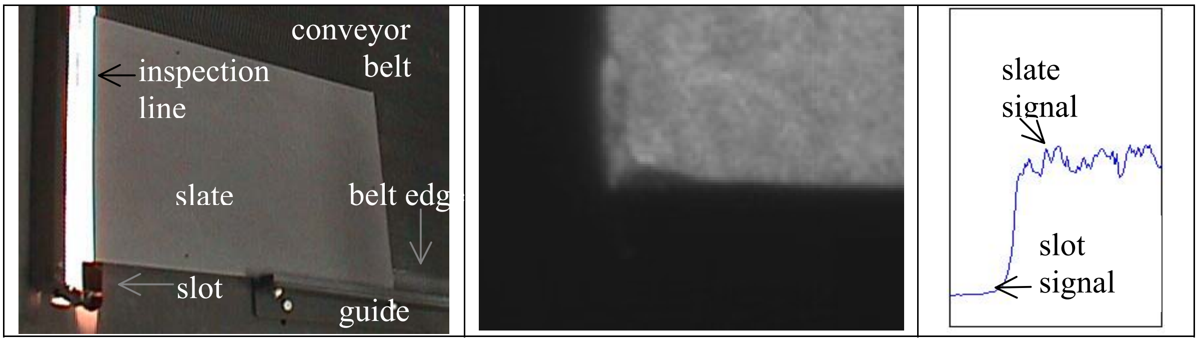

Figure 2: Conveyor belt detail, typical slate corner image and typical slate to belt transition signal.

To verify the slate edge is defect free, we initially drew a straight line between the detected corner positions and set the inspection start locations relative to this line. Rotation is accounted for using the equation[1] for a straight line. Nail holes are detected by a threshold operation in the image section where the holes are expected. When present, neighbouring image data is transferred to cover and completely eliminate the hole from the image. The slate is now segmented from the background and the four component algorithm can be applied. An edge fault such as a bit of missing material will be detected using the adaptive signal method.

3 CHALLENGES INTRODUCED BY THE FACTORY-TYPE TEST-BED

System engineering of the conveyor system and its interaction with the inspection equipment simplified the inspection task. However, some non-idealities caused problems and these are described in this section. Slate lateral drift and rotation, slate depth profile variation and conveyor vibration and speed variations are the sources of the problems.

3.1 Effect of slate lateral drift and rotation on shading compensation.

The horizontal profile of the captured image contains non-linearities caused by the non-uniformities in the light line, lens and image sensor. It is usual to compensate for these non-uniformities using what is termed a shading compensation table. Many researchers (e.g., Peñeranda et al) calculate a compensation factor for each pixel and multiply each image pixel by the computed factor. Our compensation table is computed using images captured from reference slates as training data. A typical compensation curve is shown in Figure 3a. The rate of change in compensation values rises sharply close to the slate edges.

Even small lateral shifts or rotation of the slate will cause the wrong pixel to be compensated by the wrong factor (cross-direction imaging resolution is 0.2 mm). This is a problem close to the slate edges because the compensation factors can be large and over-compensation can occur resulting in bright lines at left or right edges. Modifying the slate edge guide or the method of generation of the compensation factors would be difficult to implement. The

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[1] $m = \frac{y_2 - y_1}{x_2 - x_1}$, where m is slope of line and (x_n, y_n) is the corner location. (Fanchi).

solution was to modify the compensation factors close to slate edges so that large changes in neighbouring pixel locations cannot be generated. While this still leaves room for error, it is sufficiently negligible that the image processing algorithm effectiveness is not compromised.

3.2 Effect of depth profile variation and vibration on edge detection

The devised edge checking method worked well for flat slates but resulted in false triggers for slates having significant depth profile variation. Particularly troublesome were slates having a curved profile whereby the slate rises at either end. The captured image follows the curve of the slate and false triggers occur when there is too much error between the assumed straight edge and the imaged curved edge. An example of false defects caused by the edge checking method is shown in Figure 3b.

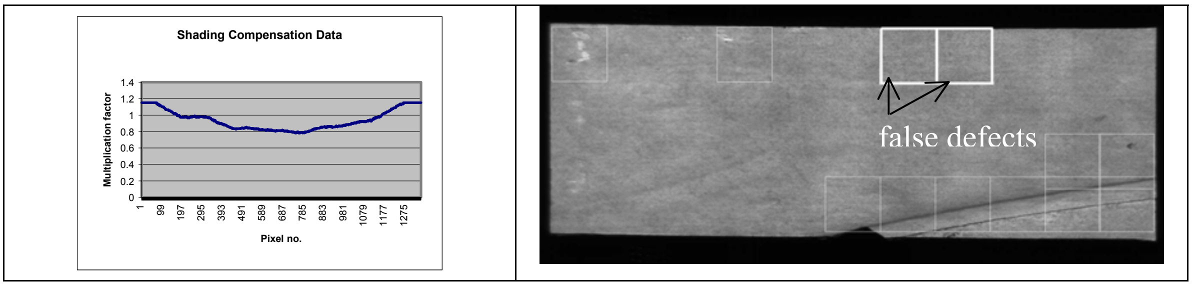

Figure 3: Typical adjusted compensation curve on left and false edge defect generation example on slate image on right. Left corner was at row 39, right corner was at row 50 and slate edge at false defect image sections began at row 53.

The devised solution was to divide the edge into short line lengths of 30mm length and to verify the exact edge location for these short segments. This necessitates segmentation of the slate image from the conveyor belt material and a simple threshold is effective for most slates. However, the threshold method is unreliable for unpainted slates as the signal response of unpainted slates is not significantly different to that of the conveyor.

3.3 Effect of depth profile variation and vibration on algorithm and threshold settings

Uniformly flat slates adhere well to the conveyor belt material and are transported past the inspection line in the position at which they are placed on the belt. The belt material was chosen to have a suction effect on the slates. A significant percentage of the slates are not flat and have a depth profile. The shape of the profile, in combination with the conveyor vibrations, can result in some z-axis movement of the slate as it progresses along the conveyor. The z-axis movement modifies the reflection profile and appears in the captured image as localised intensity variations.

The width of the light band was increased to accommodate the z-axis movement and ensure the inspection line is always illuminated. Increasing the width of the light band is achieved by defocusing the line light lens, thereby diminishing the intensity of the specularly reflected light component while simultaneously increasing the influence of the diffusely reflected light[2] component. The specular reflections produce the image information that enables defect information extraction and the diminution of their contribution lowers the discrimination capability. The increase in magnitude of acceptable light intensity variations was

[2] $R = R_0 \cos i + R_1 \cos^m \theta$ where R = surface reflectance, $R_0 \cos i$ represents the diffuse reflections and $R_1 \cos^m \theta$ represents the specular reflections. (Davies)

accommodated by relaxing the various threshold settings with a view to avoiding the false classification of acceptable slates as defective.

3.4 Effect of variation in speed profile

The constancy of conveyor speed was measured by imaging the same slate several times and by imaging 16 reference slates in succession. The timing of image capture is under digital control and is repeatable. Measurements for the repeatedly imaged slate ranged from 298.3 to 300.7 mm. Measurements for the 16 slates ranged from 295.9 to 300.1 mm. These variations are assumed to be due to conveyor speed variations and preclude the use of image data for accurate slate width measurement. Another effect of the speed variation is to introduce an error (up to 1.5%) in the expected location of side and end nail holes. The nail hole search area was increased so as ensure nail hole detection. Furthermore, the slate end position cannot be accurately estimated from knowledge of the slate front position and a software search for slate end position is necessary.

4 ROBUSTNESS TESTS USING THE FACTORY-TYPE TEST-BED

The inspection system was trained on several hundred slates to determine the threshold settings that gave the best trade-off between no false defects and correct defect identification. More than 300 fresh slates were received from the factory for use in the robustness tests. The success rate for correct identification of slates as acceptable quality or defective was 99.3% for reference slates based on 148 samples and was 97.5% for defective slates based on 159 samples. An analysis of results by defect type is given in table 1 (Carew, 2002). The results are very promising and encourage more complete robustness testing using several thousand samples.

Table 1: Summary of defect detection rates.

Type	Fail qty	Pass qty	Correct result
Missing paint	0	4	100%
Insufficient paint	0	9	100%
Efflorescence	0	15	100%
Shade variation	0	12	100%
Nozzle drip	0	14	100%
Droplets	0	8	100%
Dust	0	4	100%
Wax	1	7	87%
Template marks	2	33	94%
Template marks II	0	5	100%
Lumps	0	13	100%
Depressions	1	3	75%
Bad edge	0	18	100%
Misc. types	1	12	92%
TOTAL	**5**	**157**	**97%**

5 DISCUSSION

Testing the devised inspection solution in a factory-type environment was an important part of the development process. Several problems not apparent using the laboratory test bed were discovered and solutions were devised within the controlled environment of the laboratory. Testing on a factory-type test-bed enabled identification of problems that are linked to a factory environment. It is now known that one defect type cannot be detected using the four component algorithm and that three defect types are close to the detection capability limits of the devised system.

The development of solutions is more appropriate in the laboratory, where the developer has control of the environment, than in a real factory situation. It enabled us to verify that the devised mechanical system and the image-processing algorithm is feasible to be implemented in an industrial environment. The test results give a strong indication of the likely inspection results in a factory.

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