Measuring Bitumen Coverage of Stones using a Turntable and Specular Reflections

Hanna Källén[1], Anders Heyden[1] and Per Lindh[2]
[1]*Centre for Mathematical Sciences, Lund University, Lund, Sweden*
[2]*Peab, Peab Sverige, Helsingborg, Sweden*

Keywords: Segmentation, Classification.

Abstract: The durability of a road is among other factors dependent on the affinity between stones in the top layer and bitumen that holds the stones together. Poor adherence will cause stones to detach from the surface of the road more easily. The rolling bottle method is the standard way to determine the affinity between stones and bitumen. In this test a number of stones covered in bitumen are put in a rolling bottle filled with water. After rolling a number of hours the bitumen coverage are estimated by visually investigating the stones. This paper describes a method for automatic estimation of the degree of bitumen coverage using image analysis instead of manual inspection. The proposed method is based on the observation that bitumen reflects light much better than raw stones. In this paper we propose a method based on the reflections to estimate the degree of bitumen coverage. The stones are put on a turntable which is illuminated and a camera is placed straight above the stones. Turning the table will illuminate different sides of the stones and cause reflections on different part of the images. The results are compared to manual inspection and are well in agreement with these.

1 INTRODUCTION

When building roads one wants them to be as lasting as possible to avoid expensive repairs. Usually the surface of the road consists of a mixture of stones of different sizes and a petroleum-based material called bitumen. To avoid that stones get loose from the pavement the affinity between the stones and bitumen has to be as good as possible. The affinity is measured by the rolling bottle method. The goal with this paper is to improve the manual analysis in this method using digital image analysis techniques.

1.1 Rolling Bottle Method

The rolling bottle method is a method to investigate the affinity between stones and bitumen. The stones are first mixed with bitumen so that they are completely covered in bitumen. After they have been stored for a few days the stones covered in bitumen are put in a glass bottle filled with distilled water.

The glass bottles are then put on a bottle rolling machine, see Figure 1. On this machine the bottles are rolling for a couple of hours so that some of the bitumen gets teared off from the stones. After rolling a few hours the bottle is removed from the machine to estimate the degree of bitumen coverage. The stones are put on a piece of silicon coated paper and two experienced laboratory assistants are visually observing the stones in order to estimate the degree of bitumen coverage.

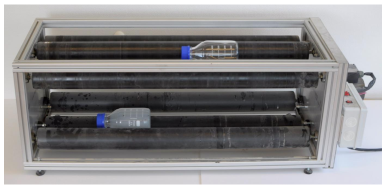

Figure 1: A bottle rolling machine.

A problem with current state of the art is that it is not objective, two different labs can get different result since the degree of bitumen coverage is estimated by different laboratory assistants in different labs. It is also very hard to make a correct estimation and the accuracy of the estimations are not sufficient. The purpose of this project is to improve the estimation by taking photographs of the rolled stones and then use digital image analysis techniques to analyze the stones. This would make the method more objective since the same computer program can be used in different labs.

Källén H., Heyden A. and Lindh P..
Measuring Bitumen Coverage of Stones using a Turntable and Specular Reflections.
DOI: 10.5220/0004291103330337
In *Proceedings of the International Conference on Computer Vision Theory and Applications* (VISAPP-2013), pages 333-337
ISBN: 978-989-8565-47-1

1.2 Previous Work

In (Merusi et al., 2010), an algorithm for trying to estimate the degree of bitumen coverage by using image analysis has been developed. In the proposed method, a cyan-colored background for easy segmentation of the background has been used. To avoid sparkles and reflections in the image a cyan-colored truncated cone, with the camera in one of the bases, is used. To classify pixels either as stones or bitumen, a principal component analysis was implemented. Using the first component the images were thresholded and pixels below the threshold were classified as bitumen.

A more advanced method for estimating the degree of bitumen coverage was suggested by (Wellner et al., 2011). To avoid reflections in the bitumen surface, the stones are put in a crystallization dish where they were covered with distilled water. A plastic cylinder were put around the aggregates and illuminated from outside to ensure diffuse lightening to prevent shadows to occur. A probability based segmentation method was used for segmenting the images. To train parameters in the classifier, reference images on the background, the raw aggregates and aggregates completely covered in bitumen were used.

Both these methods rely on a difference in appearance between the aggregates and bitumen. In this paper we focus on the more difficult problem when the color of the stones are very similar to the color of bitumen.

Concerning segmentation there is a vast literature describing several different segmentation methods. The first methods were based on thresholding and region growing techniques. Also methods from mathematical morphology were frequently used (opening, closing, etc.) in order to smoothen out the contours. The starting point of modern segmentation methods, based on variational formulations, was the introduction of active contours, so called snakes, see (Kass et al., 1987).

A development of active contours to more general level-sets was done by Osher and Sethian in (Osher and Sethian, 1988) and (Osher and Fedkiw, 2003). The main advantage of the level-set representation is the flexibility to change topology and improved numerical methods. A faster version of level-sets, so called fast marching, was presented in (Sethian, 1996).

Another approach to segmentation based on variational methods is the so called area based methods. The pioneering work, the Chan-Vese method, is based on the Mumford-Shah functional, see (Chan and Vese, 2001). Yet, the main drawback of those methods is the existence of local minima due to non-convexity of the energy functionals. Minimizing those functionals by gradient descent methods makes the initialization critical. A number of methods have been proposed to find global minima such as (Appleton and Talbot, 2006; Chan et al., 2006).

A new development into discrete methods, based on graph-theory, is the so called graph-cut methods, introduced by Boykov, Kolmogorov and others, (Boykov and Kolmogorov, 2001; Boykov and Kolmogorov, 2004; Kolmogorov and Zabih, 2004). The main advantage of these methods is that they can guarantee that the solution reaches the global minimum and they are usually very fast.

2 METHODS FOR ESTIMATING THE DEGREE OF BITUMEN COVERAGE

A problem when trying to take images of stones covered in bitumen is that we often get specular reflections in the bitumen. The idea in this paper is to instead of trying to avoid the specular reflections we try to use it for segmenting the images. For that reason we want to take several images, typically 20-30, with light from all possible directions. In practice it turns up to be more practical to place stones on a turntable which we turned a bit between images than to place a high number of light sources around the scene.

Our system for analyzing the images then consists of three parts. First we have to register the images to each other. After registration we segment the foreground, stones, from the background using all images. Last, for the pixels classified as foreground we estimate the degree of bitumen coverage by using a probability based classification method.

2.1 Experimental Setup

The setup used to take images can be seen in Figure 2. In the setup we have one camera, one light source and one turntable. The camera is placed straight above the turntable and facing downwards, looking at the stones from above. Beside the camera we have a light source that illuminates the stones from one direction. By turning the turntable we get light from many more directions. To easier segment the stones from the background we use a blue background on the turntable.

Figure 3 shows some examples of images that we get from our setup, these stones are completely covered in bitumen.

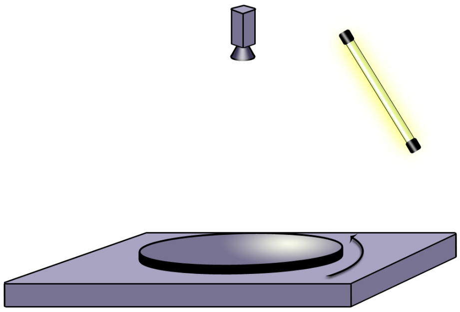

Figure 2: The experimental setup for taking the pictures. The camera is looking straight down to the turntable, the lamp gives light from one direction but turning the turntable different sides of the stones will be illuminated.

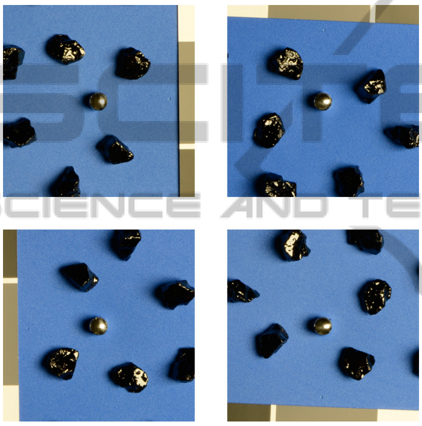

Figure 3: Example of images, the original images before transformation.

2.2 Registration and Segmentation of Stones from Background

To be able to use the images we have to register them to each other. This is done by extracting some corresponding key points in all images and compute a homography from all images to some reference image. The homography is a 3×3 matrix H so that

$$\lambda \mathbf{y} = H\mathbf{x}, \tag{1}$$

where H is the homography, λ a scaling factor, $\mathbf{x}$ is the point in the reference image and $\mathbf{y}$ is the corresponding point in the image that we want to transform, $\mathbf{x}$ and $\mathbf{y}$ are given in homogeneous coordinates.

Then the images are transformed according to the homography associated with the current image. Figure 4 shows the same images as Figure 3 after the transformations.

When the images are transformed we want to find out which part of the image that is stone and which part is background. Since the shadows are quite sharp in the images we take a mean image of all the images and use that for segmentation. The mean image can be seen in Figure 5, now the shadows are much smoother. The segmentation is done by thresholding in the blue channel of the image. The threshold is chosen manually, which is not crucial for the segmentation result.

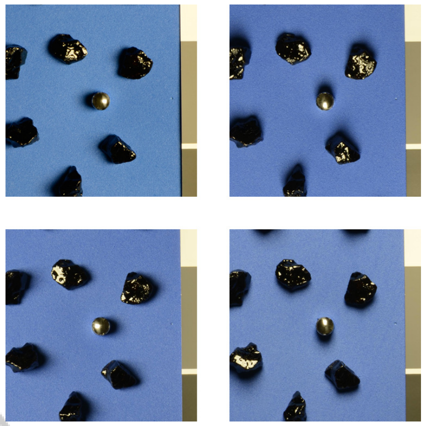

Figure 4: Example of images, the images after transformation.

Figure 5: The mean image used to segment foreground, stones, from background.

2.3 Estimation of the Degree of Bitumen Coverage

To estimate the degree of bitumen coverage we look at the difference between the highest value for a pixel through all images and the lowest value. If there are any specular reflections in any of the images this difference will be high. The difference image for stones completely covered in bitumen can be seen in Figure 6, as can be seen in the image we do not get reflections everywhere. We use some reference images with stones covered in bitumen and the raw stones to build histograms for the difference of the highest and the lowest value. These histograms are then used to find a probability function, that tells how likely a pixel with a certain difference is to be bitumen and stone respectively. The histograms are normalized so that they sum up to 1. The probability that a pixel with

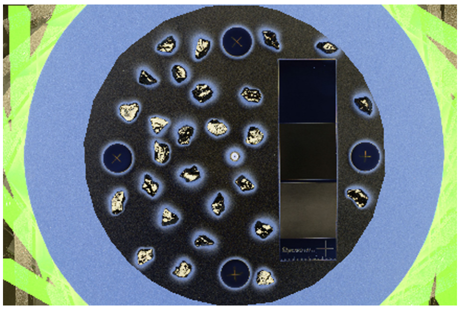

Figure 6: The difference image.

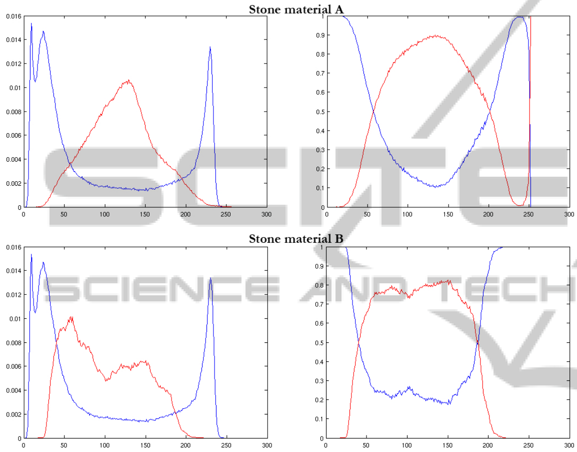

Figure 7: Histograms and probability functions for stone material A and B.

intensity i is bitumen can be calculated by

$$P_b(i) = \frac{h_b(i)}{h_b(i) + h_s(i)}, \tag{2}$$

where $P_b(i)$ is the probability that a pixel with intensity i is bitumen, $h_b(i)$ is the value of the histogram for bitumen pixels with intensity i and $h_s(i)$ is the is the value of the histogram for stone pixels with intensity i.

Figure 7 shows the histograms and the probability functions for two different stone materials. The blue curves show the curves for bitumen and the red curves show the curves for stone.

To estimate the degree of bitumen coverage for stones that are partly covered in bitumen the differences for all pixels are computed. The image is also segmented into foreground and background. For all the foreground pixels, the probability that a pixel is bitumen is calculated. Figure 8 shows an image of the probabilities that pixels is bitumen, white means that a pixels is very likely to be bitumen and black pixels are very unlikely to be bitumen. Then the degree of bitumen coverage is estimated by

$$dbc = \frac{\sum_i P(i \text{ is bitumen})}{N}, \tag{3}$$

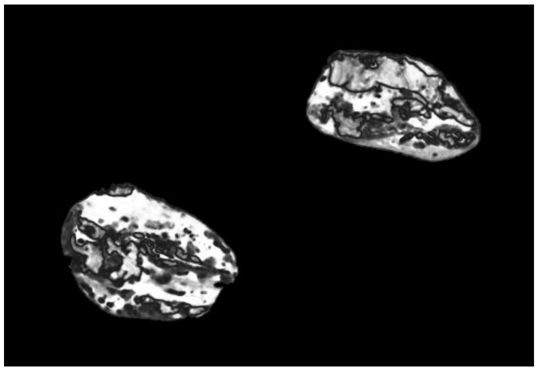

Figure 8: Probability image for being bitumen, white indicates high probability and black low.

where dbc is the degree of bitumen coverage, $P(i \text{ is bitumen})$ is the probability that pixel number i is bitumen and N is the total number of pixels. Only pixels that were classified as foreground are considered.

3 EXPERIMENTS AND RESULTS

The method has been tested for two different stone materials, one dark and one lighter. The results from the image analysis have been compared with the visual investigation by experienced laboratory personnel. Table 1 shows the result for the two materials. The results are close to the visual estimations by the laboratory assistant, but the visual estimation could also deviate from the true answer.

Table 1: The degree of bitumen coverage for the different stone materials estimated both by the image analysis system and by visual inspection.

	degree of bitumen coverage	
	image analysis	manual inspection
material A	46.8 %	50 %
material B	29.2 %	35 %

4 CONCLUSIONS AND FUTURE WORK

With this method we can automatically compute the degree of bitumen coverage even for stone materials with a darker color close to the color of bitumen. We still have to work a bit on the lightening arrangement to ensure to get more specular reflections in the images.

ACKNOWLEDGEMENTS

This work was founded by SBUF. We also want to thank PEAB for supplying images and stone material.

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