Optical Crack Detection of Refractory Bricks

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Abstract. In this work we show an approach to detect cracks in refractory bricks. The bricks have to be inspected while they are moving through the production line by chain conveyers. The cracks which have a width of down to 100 micrometer are very small compared to the dimension of the bricks. The surface of the bricks can vary in colour, lightness and roughness even if the bricks are part of the same batch. A non-contact optical measuring system is able to meet these requirements.

The approach we present in this paper works on images we receive from an industrial CCD-camera. One of the main difficulties in analysing these images is that we have to distinguish between real crack patterns and normal roughness of the brick-texture. The presented algorithm is split into four steps. The first includes image pre-processing to reduce resolution (for faster computation) without losing important information on the thin cracks, background subtraction and denoising. At the second step we use Gabor filter in different directions to enhance crack-like structures and get information about direction. Next a tracing-algorithm, which starts at thresholded seedpoints, let the cracks grow. At the final step, the possible cracks detected by the tracing algorithm, are checked for their length. If a crack obtains a certain length the brick needs to be rejected.

1. Introduction

Crack detection is a very important point in many fields of industrial production. One of these fields is production of refractory bricks. These bricks are used in high temperature applications, e.g. insulating a steel melt from the wall of a melting pot. Therefore cracks can cause capital damage if they lead to sudden breakup of the bricks.

At the moment the crack detection is done visually by humans but it should be automated. The bricks have to be inspected while they are moving through the production line by chain conveyers. The dimensions of the rectangular bricks can vary from 158,5mm to 251,5mm in length, while the width is fixed to 198mm. These dimensions define the necessary field of inspection. As the cracks have a width of down to 100 micrometer we have to work with high resolution cameras. To cover the whole width of the bricks a line scan camera needs at least 2000 pixels.

Due to the rough and nonmetallic surface common testing methods like dye penetrant inspection or magnetic particle inspection are not possible. Other testing methods like acoustical modal analysis or active thermography would be possible. On the one hand an advantage of these methods is that they can also detect cracks inside the bricks, on the other hand, the implementation of an optical inspection system is much easier. Therefore the algorithm should work on grey value images acquired by an industrial CCD camera.

2. Crack Detection

For our approach we have to process the images of the bricks in four main steps. Each of these steps leads to a new image or information that is used for the analysis of the following step.

2.1 Image Pre-processing

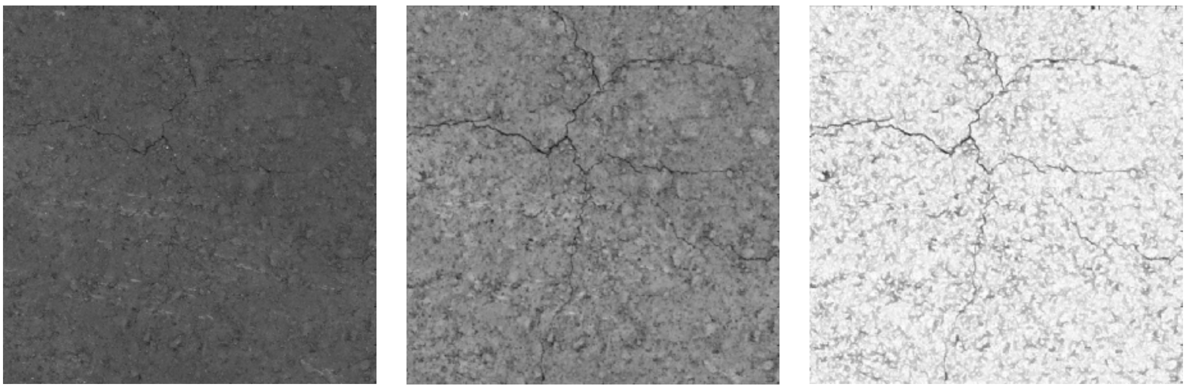
Image pre-processing has to meet some controversial requirements. On the one hand the features that should be detected (the cracks) are very tiny. So we need a high resolution image, otherwise they would disappear in the main surface texture of the bricks. On the other hand the picture should be smoothed to avoid invalid detection of cracks in one of the next steps of the algorithm. It is also necessary to reduce the image size to archive lower computing time at further processing steps. This is especially relevant for the tracing-algorithm.

In the original image (Fig. 1(a)) it can be seen that cracks always appear as dark areas on a brighter background. For better illustration just a section of the brick with some cracks is shown. It is possible to enlarge cracks by morphological erosion. For this operation a three by three square structuring element is used. The resulting image shows both, enlarged cracks as well as enlarged dark areas belonging to the background.

Due to the broadened cracks it is possible to reduce the size of the image. The new image (Fig. 1(b)) is derived by using a Gaussian smoothing kernel and reducing the resolution by one-half. This image is equal to the first layer of a Gaussian pyramid [1].

Short parts of the cracks can be considered as linear structures. Morphological opening using a set of linear structuring elements in different directions can identify such structures [2]. We use seven pixels long line-structuring elements in eight directions. The opening operation is applied to the inverted image and removes particles smaller than seven pixels.

The colour in different parts of the bricks and consequently the intensity in our grey value images can change. For the following algorithm it is necessary to compensate this intensity variations. Morphological top-hat operators can be used to compensate non-homogeneous illumination [3]. A morphological top-hat operator is applied to the image we got from the opening operation before in order to get a more homogenous background. This operator uses a structuring element with a diameter of five pixels. The result is represented in Fig. 1(c).



(a) **(b)** **(c)**

Fig. 1 Results of pre-processing: (a) Original image (b) Image after erosion and reduction of resolution (c) Image after background subtraction

2.2 Enhancing Crack-like Patterns

As above mentioned due to erosion all dark areas have increased. Even though huge dark areas can be compensated by subtracting the background crack patterns have to enhanced to be able to distinguish between real cracks and surface roughness of the bricks.

Typically cracks can be considered as areas with dark grey values (at least darker than the surrounding background) and which have an elongated structure [4]. They have a width of one to three pixels while their length can vary from a few pixels up to the whole width of the bricks. Generally cracks run perpendicular to the edges from one side of the brick to the other. Nevertheless the direction of a crack can change locally. Therefore we need information about local direction of the cracks.

Using a set of Gabor filters in different directions we get both: Enhancement of crack like patterns and information about their local direction. Gabor filters are often used to enhance elongated structures e.g. ridges in fingerprint images [5] or cracks in paintings [4].

Gabor filters are defined by a sinusoidal plane modulated by a Gaussian envelope. Formula (1) shows the even-symmetric real component of the original 2-D Gabor filter in spatial domain as a function of period and orientation [6, 5].

$$
\begin{aligned}
g(x, y; T, \theta) &= \exp\left[-\frac{1}{2}\left(\frac{x_\theta^2}{\delta_x^2} + \frac{y_\theta^2}{\delta_y^2}\right)\right]\cos\left(\frac{2\pi x_\theta}{T}\right) \\
x_\theta &= x\sin\theta + y\cos\theta \qquad (1) \\
y_\theta &= x\cos\theta - y\sin\theta
\end{aligned}
$$

In this equation T stands for the period of the sinusoidal plane while δ_x and δ_y represent the standard deviation of the Gaussian envelope respectively along x-axis and y-axis. For good results in the convolved image these parameters have to be selected properly. The used filters are computed according to formula (1) with four different orientations from 0° to 135°.

By convolution of the pre-processed image with the Gabor filters we get four images, one for each orientation. In each of them parts of the cracks with specific orientation are enhanced. For the following tracing-algorithm it is easier to handle one pixel wide cracks. Furthermore the crucial parameter of the cracks is their length and not their width and so we can reduce the width of the cracks by applying a non-maximum suppression algorithm. Next the maximum of the thinned images are combined into one resulting “maximum-image”, represented in Fig. 2. In addition a matrix the same size as the image is computed where the local orientation of each pixel is stored.

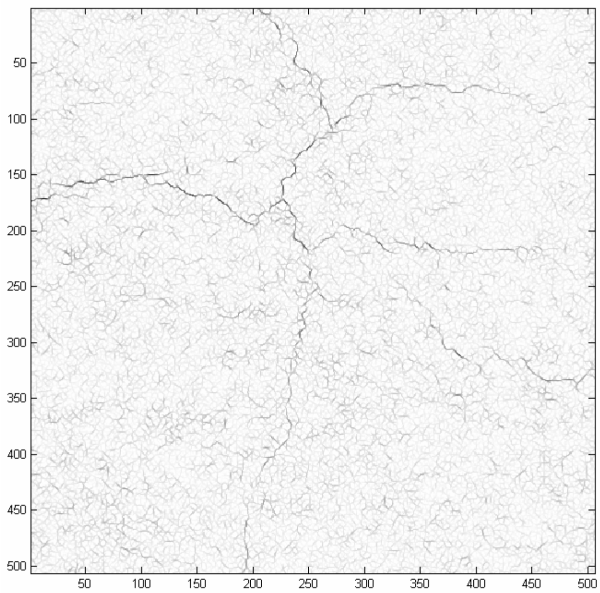


Fig. 2 Maximum of the four Gabor convolved images

2.3 Tracing-Algorithm

Although the mentioned steps result in significant enhanced images it is not possible to find an accurate threshold level to separate cracks from the background. If the threshold is set to such a high level that no background is segmented, cracks are interrupted and it is not possible to detect their length. Otherwise if the threshold is set to low, structures from background are detected while parts of real cracks remain invisible. We can partly eliminate this by thresholding with hysteresis. The resulting binary image called crack image is shown in Fig. 3. It is treated with morphological operators in order to get the endpoints of each detected particle. These points, called seedpoints, become origins for our tracing-algorithm.

This algorithm tries to elongate the crack particles and merge them wherever possible. Therefore the neighbourhood of each seedpoint is checked for the next most likely crack-pixel. The decision as to which pixels belong to the crack is made with respect to the grey value of the "maximum-image" and to the direction the crack runs. Depending on the determined direction, the neighbourhood of the seedpoint in the "maximum-image" is weighted differently. That pixel of the considered neighbourhood with the highest grey level is assumed to belong to the crack. The crack is grown, the detected pixel becomes the next starting point and the algorithm starts again. The algorithm is terminated if one of the following break conditions is fulfilled:

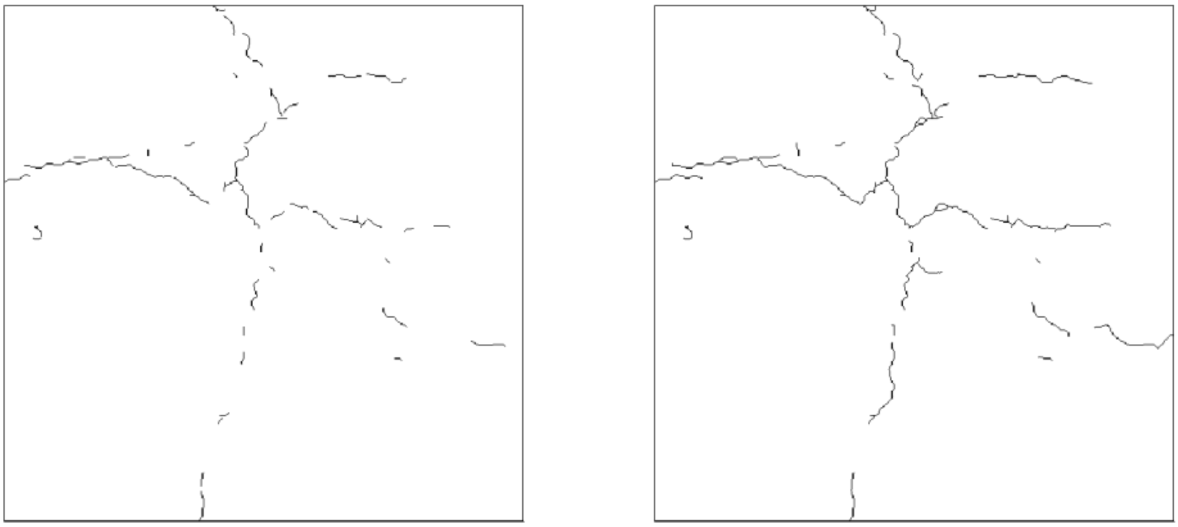
- The growing crack meets itself or another one
- A maximum number of pixels lower than a certain grey value are detected
- The direction has changed by 180°
- The crack reaches the image boundary
- A maximum number of iterations is reached

If the algorithm detects a pixel belonging to another crack particle these two parts are connected and the algorithm stops. If the growing crack meets itself, the algorithm also stops, but the crack is not enlarged in the crack image.

As the crack image was derived by thresholding the maximum-image, the crucial parameter to distinguish between cracks and background is the threshold level. The tracing-algorithm has to link several parts of the cracks over small breaks and therefore it is necessary that we find pixels with grey values lower than a certain grey value. If no pixel with a higher grey value is detected after a maximum number of iterations, the algorithm is terminated and the crack is shortened to the last pixel with a grey value higher than the threshold.

We assume that a crack that starts in a certain direction does not run in the opposite direction later. If the direction changes by 180° we rather trace parts of the background than a real crack. The algorithm stops and we do not overtake the changes to the crack image.

If none of the above mentioned break conditions is fulfilled within a maximum number of iterations the algorithm stops anyway.



(a) **(b)**

Fig. 3 Linking of crack parts during tracing-algorithm: (a) Initial binary image (b) Resulting crack image

2.4 Interpretation of binary crack image

In these images we see linked crack parts but also some structures of the background. We use two properties of the detected particles. First the area of the particles is considered. If the particles are too small they are assumed to be parts of the background or cracks of no importance. For larger particles their length is considered as well. Therefore we determine the Euclidian distance between the start and the endpoint of the particle. The ratio of the distance and the area is a criterion for the elongation of a particle. Large elongated particles are rather representing a crack than others. Fig. 4 shows the crack image after removing particles assumed not to be part of a crack. In comparison to Fig. 3(b) we see which particles have been removed.

Fig. 4 Crack image after removing background particles

If the sum of the particle-length is higher than a certain threshold the brick needs to be rejected.

3. Results

The algorithm has been tested on images of different stones, some of them with and others without cracks. For image acquisition, we used an array camera with a resolution of 1628 by 1236 pixels, so the field of view had to be reduced to approximately 220 by 160mm and did not cover the whole surface of the brick. The bricks did not move during image acquisition. The following figures show sections (1024 by 1024 pixels) of these images. As it can be seen in the original images (Fig. 5(a), 6(a) and 7(a)) the size of the cracks can vary as well as the roughness and colour of the bricks.

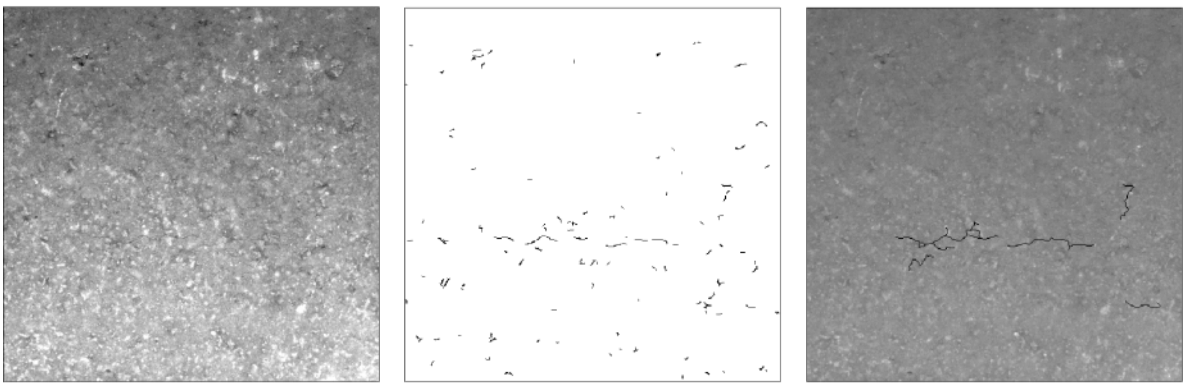
Fig. 5, 6 and 7 show the results of different bricks whereas (a) represents the original image acquired by the CCD-camera, (b) the binary image that is used to detect seedpoints for the tracing-algorithm and (c) the resultant detected cracks drawn in the (smoothed) original image.

In Fig. 5 a significant crack can be seen. Almost the whole crack is detected (Fig. 5(c)), only small parts of the crack were lost on the left side. Fig. 6 represents an image of a brick with a very weak crack that can hardly be seen in Fig 6(a). Nevertheless the main parts of the crack have been detected (Fig. 6(c)).

If there is no crack (Fig. 7(a)) the tracing-algorithm can not link the particles of the binary image (Fig. 7(b)) and therefore no cracks are detected.

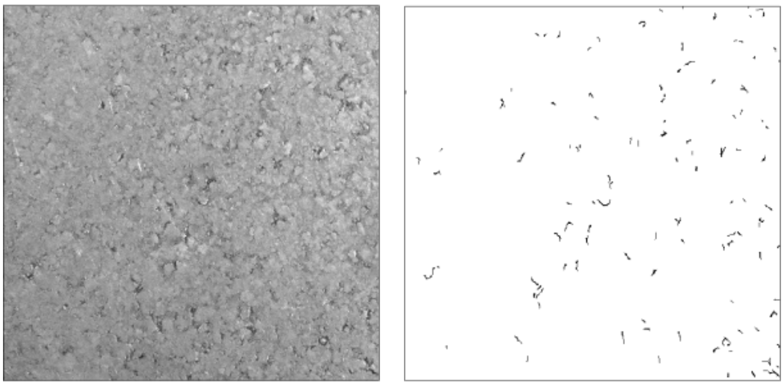
(a) (b) (c)

Fig. 5 Brick with significant cracks (a) Original image (b) Crack image before tracing-algorithm (c) Original image with detected cracks overlaid



(a) (b) (c)

Fig. 6 Brick with weak cracks (a) Original image (b) Crack image before tracing-algorithm (c) Original image with detected cracks overlaid



(a) (b)

Fig. 7 Brick without cracks (a) Original image (b) Crack image before tracing algorithm

4. Conclusion

In this paper we have presented an algorithm to detect cracks in refractory bricks. As it has been shown in several images the cracks are very small in proportion to the dimension of the bricks and their colour and surface structure can vary. The main difficulty is to distinguish between cracks and the normal roughness of the bricks. Therefore image enhancement has to be done before a tracing-algorithm can find seedpoints in the images and then let the cracks grow. A set of Gabor filters with different orientations are used to enhance the cracks, and to get information about their local direction. After the tracing-algorithm has linked parts of the cracks it is possible to separate bricks with cracks.

We have shown the original images of different bricks as well as the resulting images containing the detected cracks. Although we got considerably good results for many bricks, there are difficulties if the cracks are tiny. Sometimes either we can find just parts of the cracks or the crack remains undetected at all.

5. References

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