DETEKTION UND KLASSIFIZIERUNG VON OBERFLÄCHENRISSEN WÄHREND DES AUSROLLPROZESSES VISKOELASTISCHER WEIZENTEIGE DURCH ONLINE-FÄHIGE BILDVERARBEITUNG

DETECTION AND CLASSIFICATION OF SURFACE CRACKS FORMED DURING THE ROLLING PROCESS OF THE DOUGH VIA DIGITAL IMAGE PROCESSING

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Abstract
Bread can be considered a basic food for mankind throughout recorded history, and probably for a much longer period. Bread with smooth surface and without large cracks or tears is usually obtained from high quality dough. The present study deals with extracting crack information from images of wheat dough surfaces during the rolling process. This approach intends to demonstrate that without any knowledge about the composition of the dough or its rheological properties, it becomes possible to detect the crack's outline by the use of digital image processing techniques. Detection, analysis and classification of the cracks formed on the surface of the dough during the rolling process can lead to predicting effective crack formation patterns. Moreover, using an automated system to achieve this aim by processing all the images at the same time could resemble great improvements towards industrial use. The automatic detection and analysis system for surface cracks on laminated wheat dough was developed in Matlab 2008a software. By using a high-resolution digital camera, the cracks are automatically extracted using an integrated image processing technique involving mean and median filtering, adaptive local thresholding and edge detection together with the suitable morphological operations. By running the developed algorithm the area of the crack can be measured using pixel order accuracy. Moreover, a qualitative and quantitative analysis system is implemented, apart from the image processing methodology, in order to convert the system in a more efficient tool for assisting engineering specialists in possible future or resembling procedures.

Introduction
Bread manufacturing profession is as old as the beginning of human civilization when every house had its own bakery. Now, with automation and with the emergence of new technology bread is manufactured in a large scale. Bread supplies a significant portion of the nutrients required for growth, maintenance of health and well-being. Therefore its industrialization is an issue of essential importance to improve the quality and distribution of wheat products as bread has always been and remains the principal food product made from wheat.Also, the largest country bakery market, Germany, makes up 25% of the total 2008 West European bakery products market, worth 98.4 billion euro (for 20% of the total population).

The presented project focuses on the main processes encountered during bread making and more specifically on the sheeting process, also called laminating or rolling process of the wheat dough. The investigation being reported is aimed at the conception and implementation of a novel image processing algorithm in order to study the formation of the surface cracks during the rolling process of wheat dough. Moreover, a great range of quality information is obtained during the rolling process of the dough via image processing. In bakery industry this information can be used to decide which batch should be considered for further processing and which one has to be rejected.

Materials and methods

The wheat dough is prepared using a spiral kneader and the dough is rolled using a dough rolling machine similar to the one used in the Bakery Industry. Then photos were taken during the rolling process with a digital camera. The brightness of the pictures obtained from the CCD camera (pco pixelfly vga) is maintained constant using 2 LED lights to make it as independent as possible of the availability of surrounding natural light (Fig.1).

Fig. 1: Experiments being developed using the RONDOSTAR 4000 dough rolling machine

CCD Camera measurement is an optical method used for the determination of position and indication of crack formation along with the deformation of the laminated dough. Therefore the methodology to describe the crack formation is based on a CCD camera with related image analysis method. From this system it is also possible to obtain the width changes of the pastry after the rolling process.

The software chosen to develop the image processing algorithm for crack detection on the dough surface is MATLAB R2008a (release). The preprocessing stage for this algorithm consists in the extraction of the region of interest (ROI) of the digital image. Image preprocessing methods can be classified into categories according to the size of the pixel neighborhood that is used for the calculation of new pixel brightness [1]. In this case, the ROI involves the existence of cracks on the surface of the wheat dough. The main objective then is to try to separate or segment them from the rest of the photo.

Digital image processing with MATLAB

The use of digital image processing allows a much wider range of algorithms to be applied to the input data and can avoid problems such as the build-up of noise and signal distortion during processing [2]. The basic MATLAB distribution can be expanded by adding a range of toolboxes but the one relevant to the presented project is the image-processing toolbox (IPT) which provides a large selection of functions to process the input images. MATLAB supports reading all of the common image formats, but the developed algorithm focuses on the TIFF (Tagged Image File Format) format [3]. The main objective for the first block of the developed algorithm was to correct the different illumination problems (caused by the position of the artificial light source) and to eliminate the presence of possible shadows.

A. Boundary tracing and segmentation of the ROI

This section will actually include the segmentation of the dough surface using masking and boundary tracing. Once the real boundaries are established, using **bwtraceboundaries** and the coordinates of the polygon, two masks are generated. Finally, the image is cropped using the non interactive **imcrop** function and the maximal and minimal values of the (x, y) boundary coordinates to create horizontal bottom and top lines as well vertical left and right lines establishing the cropping limits.

B. Thresholding and cracks segmentation

Binarization is needed to segment the cracks. In the present algorithm a 19x19 squared kernel neighborhood will be used as a result of "trial and error". For a smoother and better result in the output binary image some morphological operations, like cleaning and deleting small areas, are performed using the **bwmorph** and **bwareaopen** functions respectively.

C. Edge detection using sobel operator

After proper preprocessing and converting the images from gray scale to black and white, the next phase is the identification of the cracks. In order to detect the cracks in the wheat dough surface the Sobel mask, provided by Matlab **edge** function, was used.

D. Cracks segmentation and representation

This is the last part of the algorithm involving image processing. Once the image processing algorithm reaches its end, two feature vectors are obtained. These vectors contain the relative pixel area and the percentage of the cracked dough surface are used to decide whether dough is in very good, acceptable or non acceptable condition for undergoing the rolling stages or further processing.

Results and discussion

a. Results of the preprocessing stage

The major aim of preprocessing, apart from solving high illumination gradient problems, was to separate the dough surface from the surrounding background by tracing the boundaries. In the following images, the accuracy of the developed algorithm in performing the given task is demonstrated. Regarding the image series (Fig.1, Fig.2, Fig.3, Fig.4), the first left images represent the original image. The second image represents the result of applying filtering and correcting strong illumination gradients. The third picture shows the traced boundary burned into the original adjusted image. The fourth and fifth images in the series are the inside and outside masked regions of the wheat dough, respectively. The study was performed on four different images to later discuss the possible results.

Case1: Very cracked dough surface with strong illumination gradient

This case is a good example of fairly damaged dough with a great amount of cracks on its surface that would not be suitable for further industrial processing.

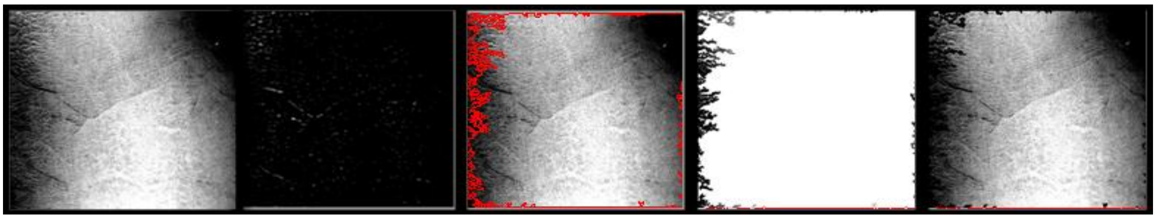

Fig. 2: Preprocessing result for Case 1. From left to right: 1. Original image; 2.the result of correcting illumination gradient; 3. the boundaries of the surface of the dough; 4. the inside masked region; 5. the masked background

As it can be seen in Fig. 2, the algorithm really traces the boundary accurately and the most important thing is that the masked areas really represent the real surface of the dough.

Case 2: Very cracked dough surface with disturbing background
In the Fig. 3, another case of very cracked dough surface is presented but this time the original image also has background parts that disturbs and causes inconsistent results in image processing algorithms. It can be seen that the algorithm accurately manages to separate the background by the masking process and solve the issue to allow better results in the following parts of the algorithm

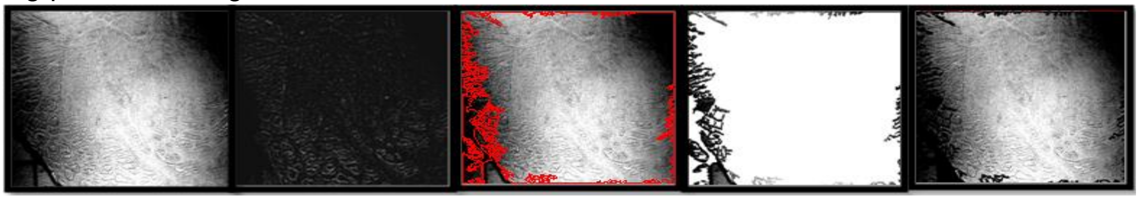

Fig. 3: Preprocessing result for Case 2 From left to right: 1. Original image; 2. the result of correcting illumination gradient; 3. the boundaries of the surface of the dough; 4. the inside masked region; 5. the masked background

Case 3: Fairly cracked dough surface with disturbing background and strong illumination gradients and shadows
In the Fig. 4, dough surface is not so damaged anymore, although it still has cracks. However, the main issue in the present figure is the fact that the dough surface has a high illumination gradient that causes also shadows and an added unwanted background problem. In the third picture, starting from the left it can be seen how effective the algorithm is in this case in tracing the exact boundaries and separating the dough surface from the background and obtain the result shown in the fifth image.

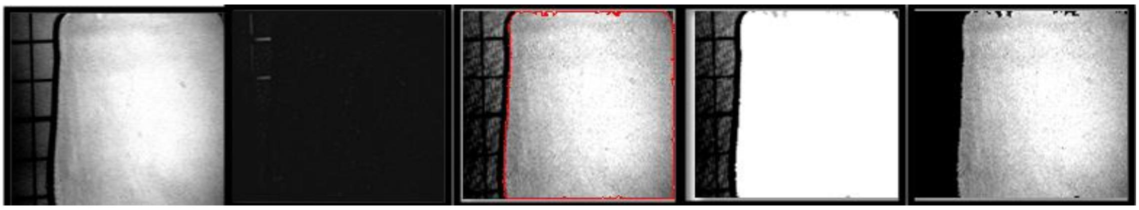

Fig. 4: Preprocessing result for Case 3 From left to right: 1. Original image; 2.the result of correcting illumination gradient; 3. the boundaries of the surface of the dough; 4. the inside masked region; 5. the masked background

Case 4: Smooth dough surface with illumination gradient and shadows
Fig. 5 represents exactly how the ideal dough surface should look like. It is fairly smooth, it has non important background issues and the illumination gradient is fairly acceptable and the algorithm manages to correct it. The performance and result of the developed system it is shown in the fifth figure (from left to right) and a good and accurate result can be seen.

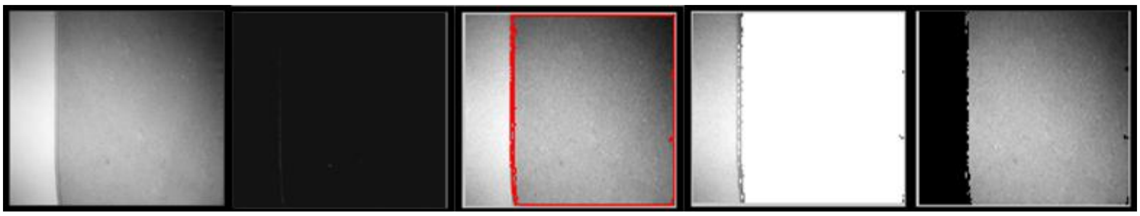

Fig. 5: Preprocessing result for Case 4 From left to right: 1. Original image; 2.the result of correcting illumination gradient; 3. the boundaries of the surface of the dough; 4. the inside masked region; 5. the masked background

b. Results of applying median adaptive thresholding to binarize the surface of the dough

The second part of the developed algorithm was designed to deal with the binarization of the previous segmented dough surface. Very similar to the previous section, the same four cases are used to show the performance of the algorithm regarding binarization.

Case 1: Very cracked dough surface with strong illumination gradient

The result of applying local adaptive thresholding on the picture of a much damaged dough surface is shown in Fig. 6. If a comparison is made between the original image (left) and the binarized resultant picture (right) a fairly good similarity can be seen regarding the localization of the cracks. While global thresholding causes inconsistent and noisy results, dynamical thresholding shows up to be a quite good approach.

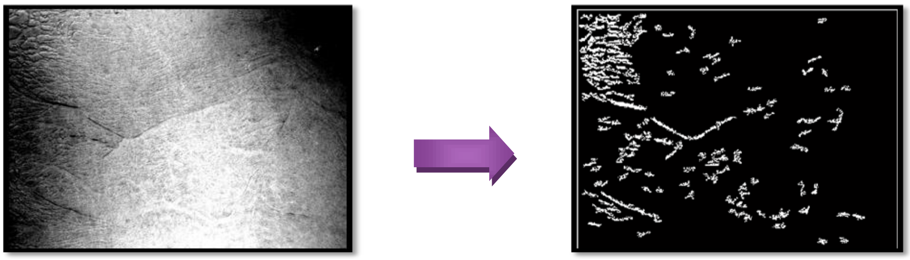

Fig. 6: Adaptive thresholding and binarization using median filter for Case 1

Case 2: Very cracked dough surface with disturbing background

Fig. 7 is fairy similar to figure 30 analyzed before as cracked dough surface is being processed. The main difference with the previous photo is that, in this one, the unwanted background is present and might disturb the final result. However, the algorithm has a quite accurate result and, as it can be seen in the result of the binarization (right) no background appears, only the damaged areas represented as cracks.

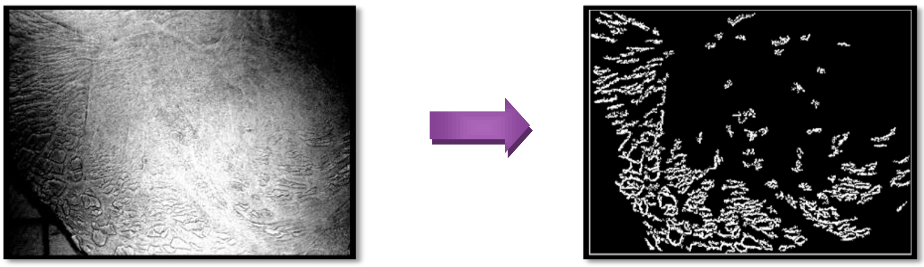

Fig. 7: Adaptive thresholding and binarization using median filter for Case 2

Case 3: Fairly cracked dough surface with disturbing background and strong illumination gradients and shadows

In this example it can be seen how well adaptive thresholding can deal with shadows and great illumination gradients. Although in Fig. 8 the original image has a great variety of pixel intensities the result of the binarization shows up to be quite accurate. This fact makes the algorithm to be able to deal with almost any kind of photos with a great range of unwanted details (background, rotation, illumination, reflexion, darkness) and , as a result, very suitable for industrial implementation.

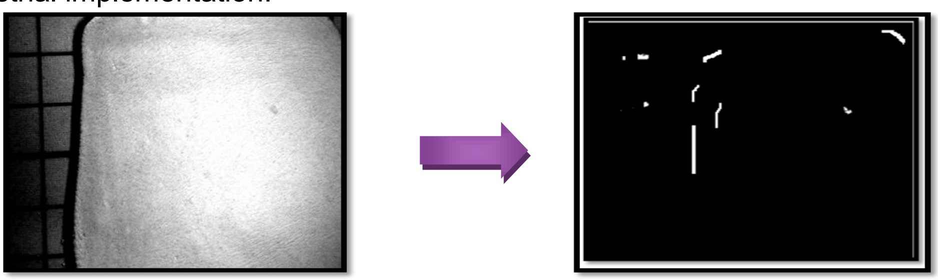

Fig. 8: Adaptive thresholding and binarization using median filter for Case 3

Case 4: Smooth dough surface with illumination gradient and shadows
As for the last case, consisting of the processing of the ideal smooth and clear dough surface with only unwanted reflexion, the result is as good as expected. The vertical line shown in the result of the binarization (see Fig. 9 right), is obviously part of the boundary, so in the following pages of the present work it will be explained how to eliminate these boundaries to avoid unwanted results.

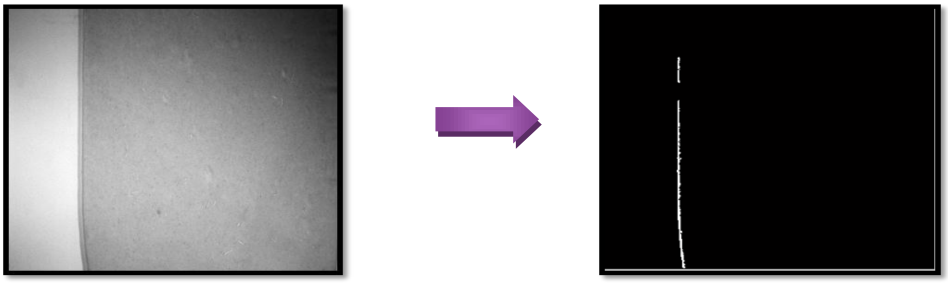

Fig. 9: Adaptive thresholding and binarization using median filter for Case 4

c. Results of edge detection operator and cracks segmentation
The final part of the image processing algorithm was the actual crack determination using the Sobel operator for edge detection. The results shown below are divided in two images corresponding to the four previous cases: one representing the raw output using only the Sobel edge detector and the other one representing the final cracks segmentation after the discussed morphological operation performed in the last part of the developed algorithm.

Case 1: Very cracked dough surface with strong illumination gradient
This last part of the image processing algorithm shows the final result of the cracks segmentation. This is achieved applying the Sobel edge detector on the preprocessed original image after eliminating the background, correcting the illumination gradient and removing noise by filtering. After applying the Sobel edge detector on the image of a much damaged dough surface a noisy and unwanted result is obtained concerning the edges (see figure 13 left). By removing small areas and thinning the lines cracks are finally segmented as shown in the right picture in Fig. 10. Thinning is normally only applied to binary images, and produces another binary image as an output [4]. The great amount of segmented cracks is a clear evidence of the damage level on the surface of the dough and this result is of great importance for decisions regarding industrial further processing of the dough batch.

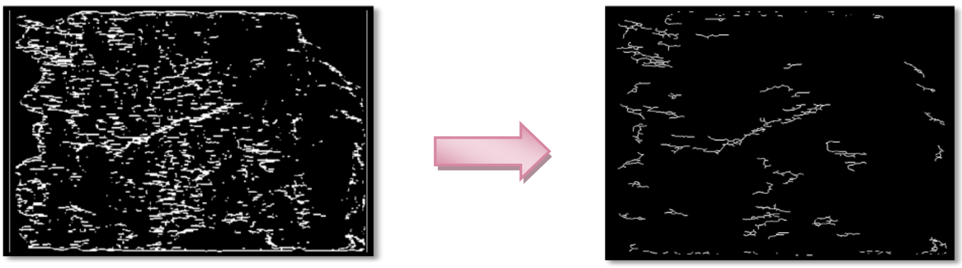

Fig.10: Result of applying the Sobel edge detector before and after the morphological operation for Case 1

Case 2: Very cracked dough surface with disturbing background
Fig. 11 is another clear example of how accurate the developed algorithm really is. This is, again, the case of a very cracked dough surface, and after eliminating the background with the procedures presented before the cracks are well segmented (see chapter 4). As it can be seen (figure14 right) the dough surface is fairly cracked and there is not much noise present or any unwanted background that could cause a false positive result.

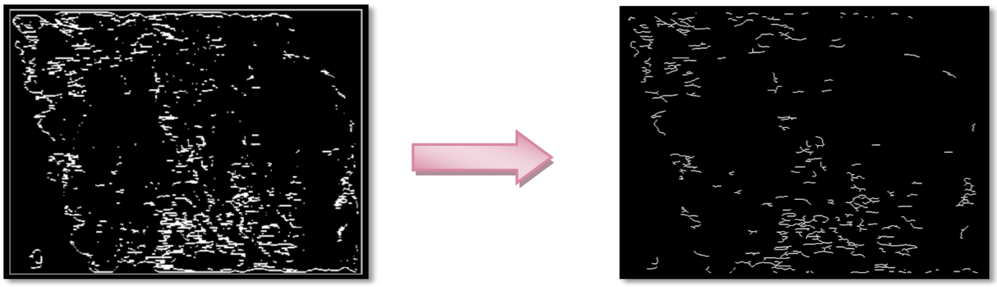

Fig. 11: Result of applying the Sobel edge detector before and after the morphological operations for Case 2

Case 3: Fairly cracked dough surface with disturbing background and strong illumination gradients and shadows
Fig.12 shows a relatively cracked dough surface but the important fact in this image is the fact that the background is separated and only real cracks and edges are segmented.

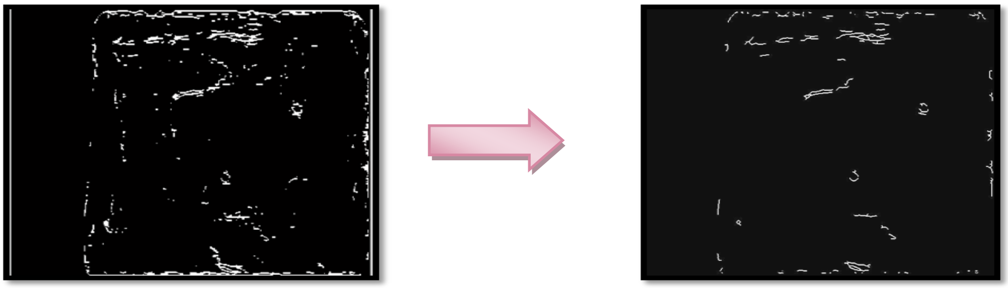

Fig.12: Result of applying the Sobel edge detector before and after the morphological operations for Case 3

Case 4: Smooth dough surface with illumination gradient and shadows
The last analyzed image of the dough surface, Fig. 13, represents, as stated before, the ideal non cracked dough surface, and as it is expected, the edge detection part followed by the morphological operations give a widely good result.

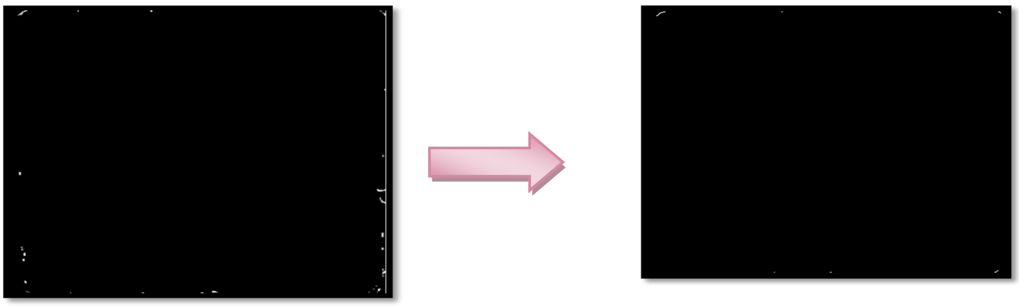

Fig.13: Result of applying the Sobel edge detector before and after the morphological operation for Case 4

d. Numerical results describing the cracks
Apart from the resulting images, the developed algorithm also gives as a final result two arrays, one containing the relative pixel area of the cracks and the other one representing the percentage of the cracked surfaces related to the total surface of the dough. The elements of the first array are simply calculated by summing up all the white intensity pixels, with value 1. The ratio, is obtained by dividing this area by the total area of the dough surface calculated from the inside mask (all the pixels are white and accurately mask the dough surface). The

final decision related to the quality of the dough surface is made using these values. For a batch of arbitrary images from the given data set the following results were obtained

Outlook

The proposed software architecture provides a quantitative and qualitative analysis with satisfactory outcomes to engineering specialists in inspecting cracks and offers a new and improved method to study possible mechanical defects found in surfaces without any knowledge about its composition or rheological behavior. The final results given by the digital image processing algorithm will be used to build up an artificial neural network with back propagation learning algorithm. In the past few years, neural networks have shown increased power over many other statistical methods when solving nonlinear prediction problems [5].
The proposed neural network uses as an input the information stored in the array containing the areas of the segmented cracks together with other possible data provided by real time experiments or simulation software. This neural network is designed in order to obtain as an output wider and more precise description of the status of the dough in a particular stage of the lamination process.

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