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Tire Contact Footprint Area Measurement Using an Alternative Bounding Box Method

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ABSTRACT
In this paper we represent an image processing technique for tire contact footprint area calculation. Two main stages are discussed – determining the actual contour of the footprint, and calculating the area of the enclosed image. For the first one task we propose an alternative method, allowing realization of an enclosing box for a point set in the two dimensional space.

Keywords - tire contact patch, bounding box, convex hull

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I. INTRODUCTION

The cause for this development is our colleagues' research in the field of breaks systems. A part of their work is estimation of the relationship between a tire contact footprint area [1], tire pressure, attached weight, break path, etc. The footprint is printed by applying a layer of ink to the test tire that is inflated with a certain pressure. Subsequent application of a certain pressure on the substrate results in a footprint on paper. There are two basic ways of contact footprint area determination: by using a planimeter [2] or by applying the contact spot on a graph paper [3, 4]. In our opinion both methods are subjective due to the manual determination of the footprint contour.

For calculating the area, we use the number of pixels that make up the contact footprint in the digitized image. The main problem, as well as with the traditional manual methods, is determining the actual contour of the image (contact footprint). After a thorough exploration of the existing image processing methods, we found out that the method most closely related to our needs is the so-called "convex hull" method [5]. When applying, according to our purposes, a set of points located in the 2D plane would be surrounded by a polygon whose vertices would be the outermost points. However, the area enclosed by the polygon includes points that are outside the area of the contact footprint.

The suggested method is based on crawling, in a selected direction (e.g., clockwise), at a set of points, from a circle of a certain radius. The movement of the circle is determined by the contact with the peripheral points of the given image. Further the method will be labeled as *rolling circle method*.

II. IMAGE PRE-PROCESSING

Initially, several steps of image pre-processing are performed. At first we compute a histogram of the original grayscale image (Fig. 1). It seen that the actual footprint pixel values are in the range around 80 and 130. The values over 210 are background noise, so we choose a threshold value between 130 and 210 – for example 140. Then, all pixels, which values are under the threshold value (140) are converted to 0 (“black”), and all that are over 149 are converted to 255 (“white”).

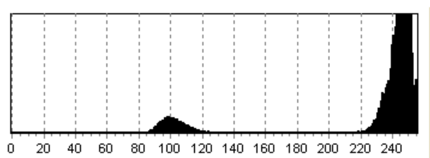


Fig. 1. histogram of the original image (see Fig. 5/a)

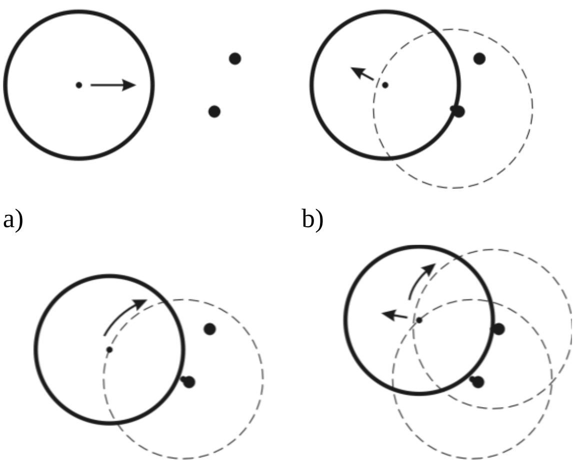
III. METHOD IMPLEMENTATION

In the next few paragraphs are described the main stages of the rolling circle method. There are some initial considerations that should be noted:

- The base used unit is a pixel, which is the smallest part of the digital image, and it has three parameters: *x* and *y* coordinates (also given in pixels) and *value* (representing the color);
- The processed image is binary – e.g. black objects on white background.

1. Using the Bresenham algorithm [6, 7, 8, 9], we calculate a set of circle points (coordinates of the points) with previously defined radius and center (user defined starting point). Further, we will label this circle as *checking circle*.
2. The values (colors) of this circle points are consequently checked. If there is a black pixel (considering that the processed image is black and white), the checking process stops; the coordinates of the found black pixel are stored, and the same pixel becomes a center of another circle, which we will label *trajectory circle*. It should be noted that it is advisable to set the radius of this circle at least one pixel larger than the radius of the checking circle.
3. The next center of the checking circle becomes the point of the trajectory circle, closest to the current center of the checking circle.
4. The points of the new checking circle are processed in the same way as in 2.
5. If there is no found black pixel, then the next center of the checking circle becomes the point of the trajectory circle, closest to the current center of the checking circle in the clockwise direction.
6. Repeat 5. until a new black pixel is found, or until the first found black pixel is found again.

In Fig. 2. is shown a simple representation of the method, considering that each of the two black points are composed of a single pixels. The process starts from a randomly selected point, somewhere to the left of the set of points (in this case there are just two points).



a) b)

c) d)

Fig. 2. a), **b)**, **c)** and **d)** simplified representation of the rolling circle method

In Fig. 3 is shown a snapshot of the real operation of the method with a sample set of objects (filled circles, in particular).

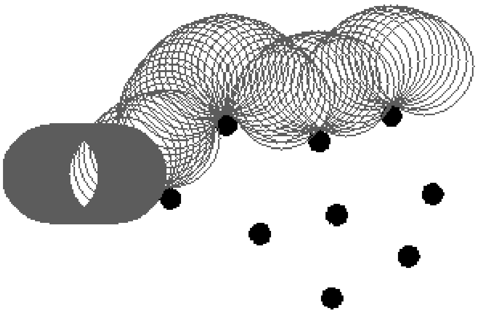


Fig. 3. a snapshot from the real performance of the rolling circle method

IV. FOOTPRINT AREA ESTIMATION

To determine the footprint area, we use three pixels values (colors). For the final result (footprint area), there is no matter what values (colors) are used, but for the clarity, and considering that the image is binary, black footprint on white background, for the third value we choose, for example, grey.

An image with a particular shape (Fig. 4) is used for better presentation of the performance of the method.

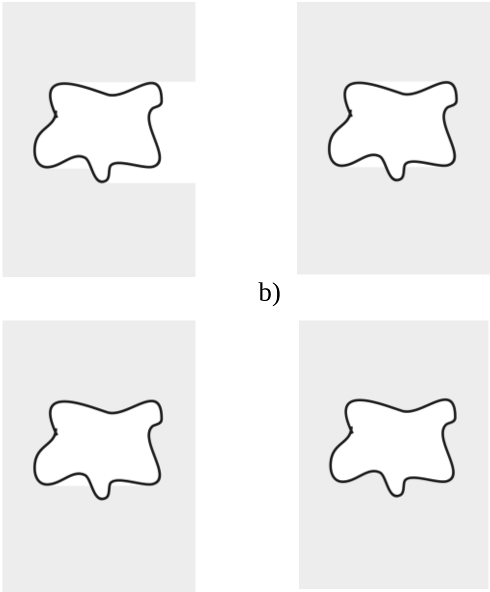
The area calculating method has the following sequence:

1. $A_1 = 0$, where A_1 is the number of the pixels, out of the footprint area;
2. Each pixel, from left to right (Fig. 4/a), row by row is checked – if the pixel value is not “black”, then the pixel acquires value “grey”, else – go to the next row;
3. Each pixel, from right to left (Fig. 4/b), is checked row by row – if the pixel value is not “black”, then the pixel acquires value “grey”, else – go to the next row;
4. Each pixel, from top to bottom (Fig. 4/c), is checked column by column – if the pixel value is not “black”, then the pixel acquires value “grey”, else – goes to the next column;
5. Each pixel, from bottom to top (Fig. 4/d), is checked column by column – if the pixel value is not “black”, then the pixel acquires value “grey”, else – go to the next column;
6. Finally, the bounded area is calculated using the following equation:

$$S_F = \frac{(A_0 - A_1) * S_{A4}}{A_0},$$

where

- S_F is the footprint array in dm^2;
- S_{A4} is the array of the format A4 in dm^2;
- A_0 is the array of the entire image in pixels.



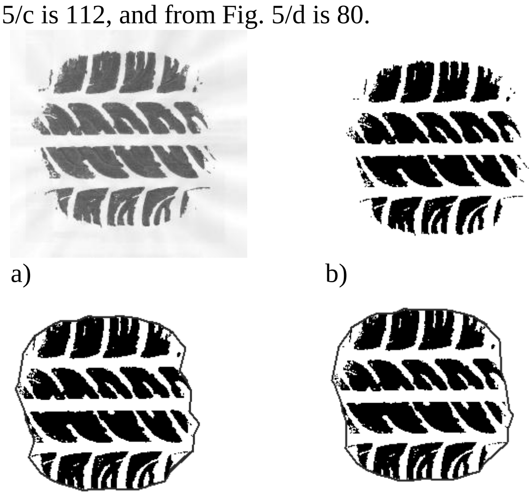
a) b)

c) d)

Fig. 4. a), **b)**, **c)** and **d)** stages of image area determination

V. EXPERIMENTAL RESULTS

In Fig. 5. are shown the processing stages of a real tire contact footprint image. In Fig. 5/a is shown the original grayscale image. There can be seen a shadows caused by the paper banding. In Fig. 5/b is shown the image, converted to black and white (binary) form, with the edge value of 140 (note that value of 0 means "black" and value of 255 means "white"). In Fig. 5/c is shown processed image, where the radius of the checking circle was 20 pixels, and in the Fig. 5/d is the image processed with the radius of the checking circle of 40 pixels. The number of contour points of the image from Fig. 5/c is 112, and from Fig. 5/d is 80.



a) b)

c) d)

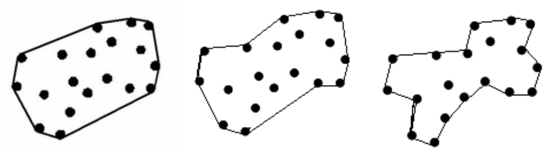
Fig 5. a), **b)**, **c)** and **d)** tire contact footprint image processing stages

In Fig. 6 is shown the tire contact footprint image, processed using "convex hull" method in Matlab (Fig. 6/a), and the same image, processed via rolling circle method, where the radius of the checking circle, used for the image in Fig. 6/b is 40 pixels, and the radius, used for the image in Fig. 6/c is 10 pixels.

a) b) c)

Fig. 7. a), **b)** and **c)** comparison of the results applying the "convex hull" method and the rolling circle method

In Fig. 7 is shown a better illustration of the result differences, using "convex hull" (Fig. 7/a) and rolling circle (Fig. 7/b, c) methods.



a) b) c)

Fig. 7. a) a sample image, processed applying "convex hull" method; **b), c)** the same image, processed applying rolling circle method with radius of the checking circle 20 and respectively 50 pixels

VI. CONCLUSION

A digital method for determining the tire contact footprint area was developed by using a new enclosing box technique. The method we propose allows the bounding contour to get closer to the shape of the footprint. The aim of our future work will be the estimation and optimization of the method performance.

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