Measurement of vehicle tire footprint pattern and pressure distribution using piezoresistive force sensor mat and image analysis

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Abstract

In this paper, a novel method to measure the footprint pattern of a vehicle tire and its pressure distribution will be put forward. The measurement principle will be presented. The automatic digital image processing methods of the footprint pattern and pressure distribution images, which are used to characterize the footprint pattern, are described. Especially, a novel envelope curve calculation algorithm for finding a pattern boundary is introduced. The experimental results have shown that the methods mentioned in the paper are of robustness and high accuracy.

Keywords: Tire footprint pattern, pressure-sensitive mat, image processing

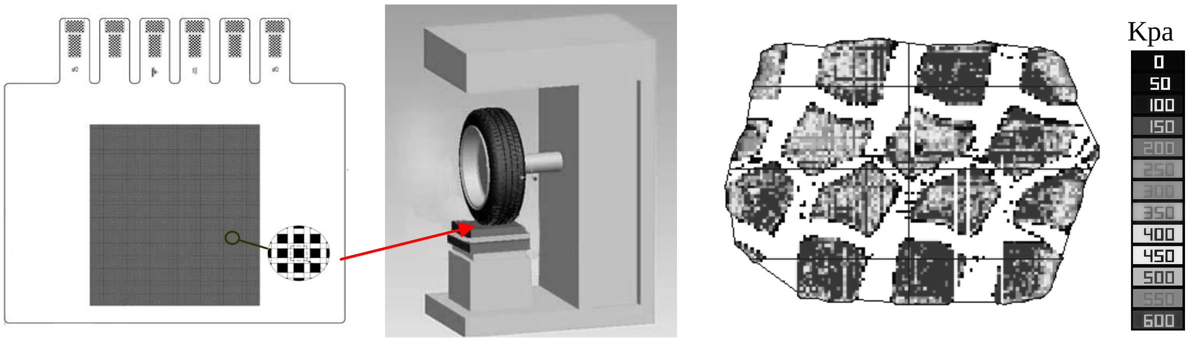
1. Introduction

The contact footprint patterns of a vehicle tire on the ground and its corresponding pressure distribution related to the vehicle load variation may indicate the tire quality and the state of the tire wear and tear. Accordingly, measurement of a tire's contact footprint pattern and pressure distribution is useful in inventing tread patterns and evaluating the tire design and assessing vehicle suspension, as well as many other factors associated with the tire quality, but a relatively unsophisticated affair. It is often implemented by archaic methods. One method is to paint the bottom part of a tire with ink and then press the tire against a sheet of paper mounted on a flat plate [1]. Another one is to employ multiple miniature pressure transducers, which are embedded into a flat plate and then played it under the tire to be inspected [2].

This paper will introduce a new method, which can more precisely complete tire footprint pattern and pressure distribution measurement. It is accomplished by a TireScan sensor, a thin and durable sheet of pressure-sensitive mat (sensor) consisting of piezoresistive force sensor matrix [3]. In this paper, the principle of the pressure-sensitive mats and measurement system will be presented. The digital image processing methods of the footprint pattern and pressure distribution images are concentrated on.

2. Measurement principle and requirements

The TireScan sensor mat is shown in Fig. 1 (a). The resistance of each sensing element or pixel that is located at a certain row and column in the thin and durable sheet of piezoresistive force sensor matrix is inversely proportional to the force applied to it. The raw and column spacing of sensing pixels is 1.524 mm. The sensing pixel's performance is very repeatable, and the response time of each element is very fast, (such as less than 18μs). The pressure-sensitive mat can be developed into a real-time measurement system for measuring vehicle tire footprint pattern and pressure distribution. The measurement setup is illustrated in Fig. 1 (b), where the pressure-sensitive mat is laid beneath the tire, which is fixed at the end of a cantilever. The tire pressure on the mat is caused by loading the tire through the cantilever. It is readily understood the measurement system can capture dynamic, high-resolution footprint pattern and pressure distribution images of a tire as it presses across the surface of the mat related to a certain load.



(a) (b) (c)

Fig. 1. Measurement setup and principle.

The color image of a tire footprint pattern and pressure distribution obtained from the measurement setup in Fig. 1 is shown in Fig. 1 (c). In accordance with the requirements of tire research and tire quality evaluation, the images are needed to characterize into the following items: the contact area of tire tread on the ground under a specific load, ratio of the contact area to the total area of the footprint pattern, ratio between the length and width of the footprint pattern, pressure center indicated by the tire footprint pattern, etc. The details of the image processing requirements are illustrated in Table 1. In the following section, the image processing method for characterizing the tires will be presented.

Table 1. Measurement requirements.

No.	Items
1	Load (kgf)
2	Drop down(mm)
3	Pressure(Kpa)
4	Long axis length (mm)
5	Short axis length(mm)
6	Contact tall area (cm2)
7	Effective contact area(cm2)
8	Ratio of effective area to total area

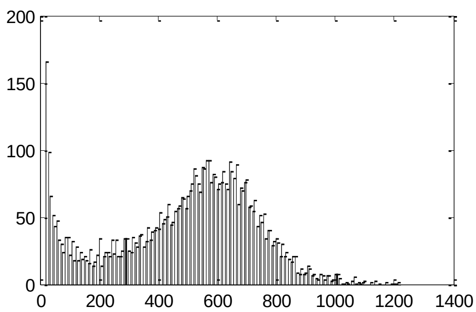


Fig. 2 Measurement requirements.

3. Data preprocessing

The force sensitive cells output of piezoresistive force sensor mat is a digital signal after processing by the TekScan data acquisition hardware. The digital signal may indicates the pressure rang of 0 to 2000 Kpa when dedicated calibration. In order to use image processing technique to characterize the data, the data transformation to image space is required. But the problem is that some cell outputs are further away from the sample mean what is deemed reasonable. These data can be regarded as noises or outliers in statistics, which are obliviously to see in the Fig. 1(c) and its histogram figure presented by Fig. 2. If these outliers are not removed before data transformation, the image obtained will be dark and its contrast will be very worse. Then the following image processing will become difficult. Though many algorithms in image processing can be used to remove the noise outliers, such as the median filter, most of them are not suitable to the precede data distribution because these methods also smooth the noise-free data. Here we use the 3σ criteria of normal distribution to determine which data are outliers and then evaluate their correct values by interpolation. About the details, readers are referred to the reference [4].

After removing the outliers and transforming the force sensitive cells output into image space, the following steps of image preprocessing are utilized:

(1) Image magnification.

The relevance of the first step to the image processing is that the resolution of the piezoresistive force mat is not enough to show the footprint pattern image clearly. To obtain a good image magnification, the spline interpolation is used.

(2) Salt and pepper noise filtering.

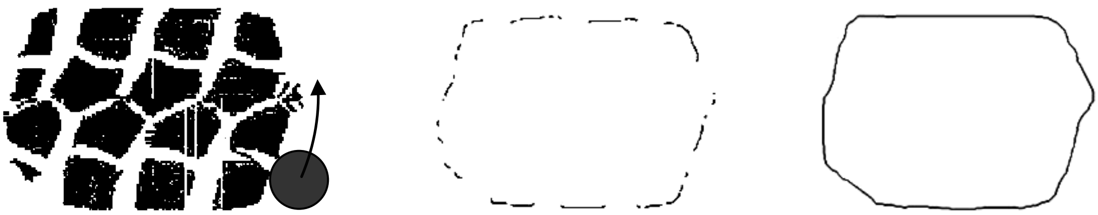
Considering Fig. 1(a), it is obvious that the footprint pattern image is contaminated by lot of salt and pepper noises. These noises will influence the following image processing and are needed to remove. Here the median filter is employed.

(3) Binary thresholding and connected component labeling.

This step is to extract each contact area in the footprint pattern. To do this, firstly image binary thresholding is implemented by automatic binary thresholding method, such as Otsu thresholding method. Then the contact area is yielded by two-pass labeling algorithm [5].

4. Boundary point extraction of the footprint pattern

This step is a challenging step. This is because most of tire footprint pattern surrounded by their boundary points are not convexes, which can be readily computed by the algorithms [6]. It is also inappropriately to regard them as concaves, which can be solved by the optimal convex decompositions [7]. The concave algorithm will cause lot of interior angles around the envolpe curves. In the following, a novel algorithm will be developed to tackle the problem.



(a) Circle template rolling method. (b) Contact points. (c) Envelope curve.

Fig. 3. Envelope extraction.

The algorithm is to use a circle template rolling around outside of the footprint pattern, as shown in Fig. 3(a), and then to pick up the discrete contact points. Finally, the envelope curve is yielded by connecting the discrete points together with short line segments.

In connecting the points, the following steps are applied:

(1) compute the centroid point of the footprint pattern;

(2) draw x, y axes at the centroid point and divide the boundary discrete points into to four quadrants;
(3) calculate the angles of the boundary points against x or y axis;
(4) based on the angle values, sort the boundary points, and then;
(5) connect the discrete points with short line segments and obtain the envelope curve.

5. Footprint characterization

In the preceding section, we mentioned that the task of footprint pattern measurement includes computing the long and short axis lengths, contact total area and effective contact area, etc. The long and short axes are defined as the corresponding axes of an ellipse, which is used to fit the envelope curve, as shown in Fig. 4. The long and short axis lengths are computed by the two axes intersecting with the envelope curve, respectively. The center point of the ellipse is then defined as the center point of the footprint pattern. For measurement report requirement, the footprint pattern often then is rotated an angle so that the long axis, such as x axis here, is in horizontal direction. The total area surrounded by the envelop curve and the effective contact area indicated by the connected component labeling method are readily worked out by numerical integration. As to other characteristics of the footprint pattern, it is not difficult to calculate.

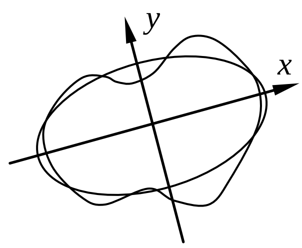


Fig. 4. Long and short axis.

6. Experimental illustration

In the following experiment illustration, TekScan Tire senor 8050Q is used, the resolution of which is 176 × 192 piezoresistive force sensors in row and column. Sensor spacing is 1.524 mm in each direction. Sensor saturation pressure is 2216.19 Kpa. A sensor area is 2.32258 mm^2. The load of the tire underwent from zero to 1000 kg. Sampling rate was 1.48687 second per frame. In the experiment, a series of 50 sampling frames were obtained, 6 footprint pattern images of which are listed in Fig. 5 at upper column. The lower column corresponding images show the image processing results, such as image noise removing, long and short axes, envelope boundary, etc.

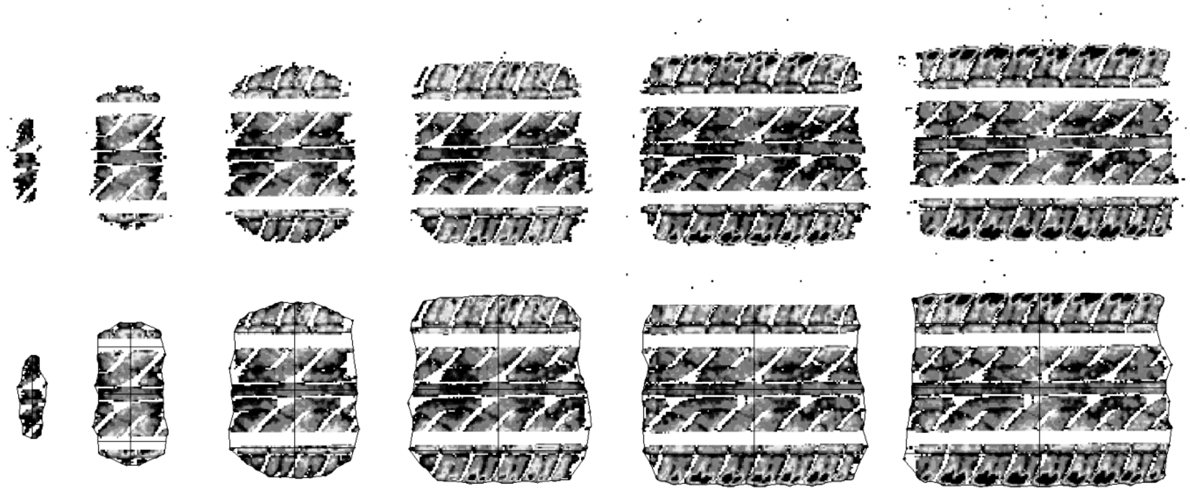


Fig. 5. 8 frames from 50 frames of footprint patterns and their image processing results.

7. Summary

The paper has put forward a novel method to measure the footprint pattern of a vehicle tire and its pressure distribution. The setup invented may be used to implement dynamic measurement. Especially, the envelope curve calculation algorithm is very useful find a pattern perimeter. Lots of experimental results show that the automatic image processing method is of robustness and high accuracy.

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