INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 5, Issue 2)
Available online at: www.ijariit.com

Brake pad wear detection using machine learning

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ABSTRACT

Most of the vehicles use a brake disk and brake pad system to stop the vehicle. Brake pad wear is a very important parameter in this system it has a direct effect on the braking performance of the vehicle. A machine learning approach, without using any intrinsic properties like the coefficient of friction of the brake pad material or the area of the brake pads or the composition of the brake pad material, has been proposed. The braking performance of the vehicle is reflected in its stopping distance and hence it is essential to relate the stopping distance and the brake pad wear. The same has been proposed in this document.

Keywords— *Brake pad thickness, Stopping distance, Multivariate linear regression, Second order curve*

1. INTRODUCTION

The braking system on a vehicle defines the safety of the vehicle. Most of the vehicles use brake pads and brake disk setup as the braking system where the brake pads are the safety critical components. In this setup, when the driver steps on the brake pedal the brake fluid is pushed inside the brake lines which in turn pushes the brake pads against the rotating brake disk, the frictional force between the pads and the disk will oppose the motion of the vehicle and brings it to a stop. Therefore, the surface of the brake pad wears off due to the frictional force and the thickness of the brake pads reduces gradually. With regular usage, the thickness of the brake pads reduces to an extent beyond which it is dangerous to use it on the vehicle. Figure 1. Shows the visual representation of the new and worn brake pad.

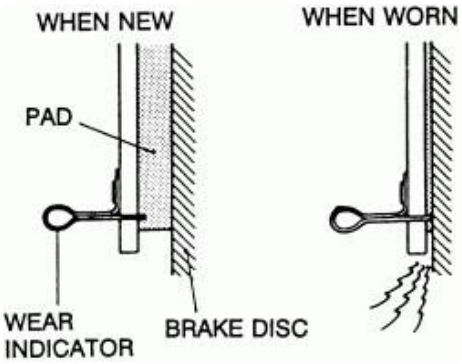

Fig. 1: New brake pad (left) and worn brake pad (right)

These brake pads have to be changed on regular intervals of vehicle mileage specified by the vehicle manufacturer and they also have certain indicators to indicate the driver that it is time to change the brake pads. Few brake pads have a metal piece on them when enough brake pad material is worn, the metal piece comes in contact with the disk first and then the brake pad pushes against the disk. When the metal piece comes in contact with the disk it makes a squealing sound indicating that it's time for new brake pads [1]. Figure 2 shows the brake pad with a metal piece that makes a squealing sound.

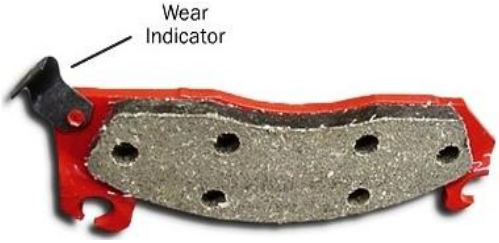

Fig. 2: Metal indicator that makes squealing

Also, in some of the brake pads, these metal pieces are replaced with electronic sensors similar to the previous method in this method also when enough brake pad material is worn, the sensor material comes in contact with the disk and indicates on the vehicle's instrumentation cluster [2]. Figure 3 shows a warning light on the vehicle dashboard.

Fig. 3: Warning light to indicate the driver

There are few attempts that have been made to predict the brake pad wear using different methods, parameters and analogies. In one of the documents, an artificial neural network based approach [3] has been made to predict the wear debris and friction temperature of the brake pads using a 2 layered neural network having 8 nodes in the first, 7 nodes in the second layer and using the conjugate gradient as the training function. This has been successfully implemented and the model has a reasonable agreement with the experimental results. In another model, a single variable linear regression model has been implemented taking the mileage of the vehicle as the only parameter [4]. But the wear rate depends on the road conditions, driving style and technical condition of the automobile. Wear of the brake pad set may become unbalanced depending on the local conditions of use. The observed variance of the data does not allow acceptable prediction of brake pad wear, using modelling based on linear regression. In the paper, Wear Analysis on contact pressure of disk brake/squeal generation [5]. This paper focuses on the meshing and analyzing the brake disk model for finding out contact pressure distribution is the major steps of the overall project. The paper edge concludes that leading-edge of the brake pad experiences more wear than the trailing edge.

2. PROPOSED METHOD

The vehicle's braking system performance can be evaluated based on the stopping distance of the vehicle i.e. the distance travelled by the vehicle from the point where the driver applies the brakes and till the vehicle is brought to a complete stop. Any malfunction in the braking system or wear and tear of components of the braking system will be reflected in the stopping distance of the vehicle. In this approach, without making use of any external sensors and parameters, making use of the onboard sensors and data like the vehicle's speed, an attempt has been made to relate the stopping distance and the brake pad thickness. In this approach for simplification, the braking force is assumed to be constant for all the attempts; the load on the vehicle is the same for all the attempts, and also during all the attempts data is collected when the vehicle is retarding from 100kmph to 0kmph. And the stopping distance is noted down for the same.

First, the variation vehicle's stopping distances for various thickness of the brake pad is recorded and then a suitable machine learning algorithm is fit to this data. This algorithm outputs a mathematical relation between the stopping distances and the brake pad thickness. Now, this mathematical model can be used on the vehicle to calculate the brake pad thickness by monitoring the stopping distance of the vehicle. And whenever the stopping distance crosses a point where the thickness calculated will be less than or equal to one-fourth of the actual thickness of the brake pad, it can be considered that the brake pads are not safe for further usage and it's time to get to change the brake pads.

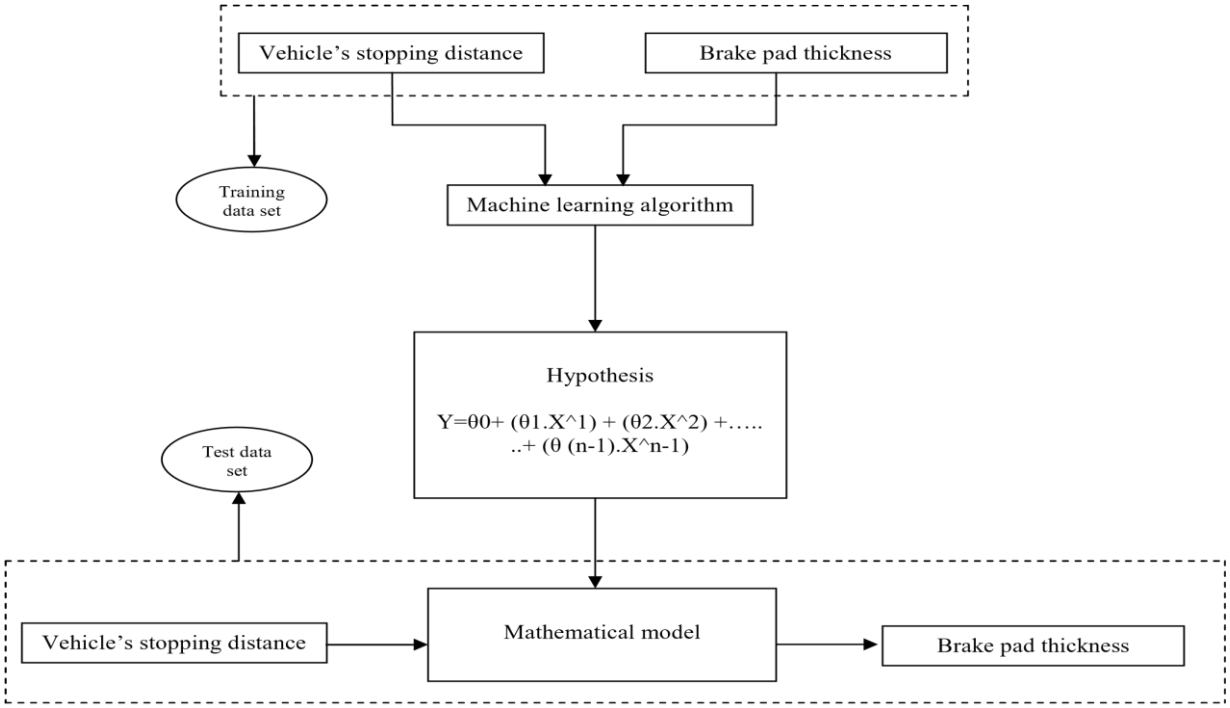

Fig. 4: Flow diagram of the proposed method

3. EXPERIMENT AND RESULT

The test set for this evaluation experiment has been taken from a test conducted by the BMW Group Brand Protection team in May 2017 [6]. A BMW 5 series is set up with a robotic braking arm which performs the same braking action for all the attempts during the test and also the BMW 5 series vehicle is brought to a complete stop from 100kmph for all the attempts. The brake thickness of each brake pad of the BMW 5 series is 18mm. This test was conducted in order to investigate and reveal high safety risks of the counterfeit brake pads. The BMW Group Brand Protection Team provides the measurement results [7] in order to verify the correct documentation. Figure 5. Show the plot between the stopping distance and the brake pad thickness.

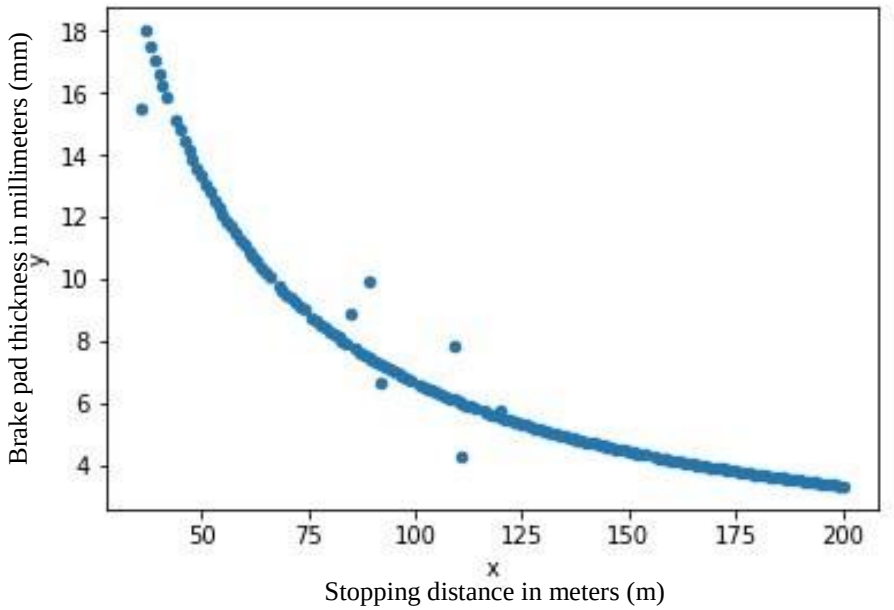

Fig. 5: Plot between stopping distance (x-axis) and brake pad thickness (y-axis)

By observing the plot of the data set, multivariate linear regression is used to fit a curve over the data. As the plot is parabolic a second order curve is to be fit on the data and the below hypothesis (Equation 1) is considered. With 'Y' as the brake pad thickness in millimetres and 'X' as the stopping distances in meters. The hypothesis constants *'θ_0',' θ_1'* and *'θ_2'* are to the outputs of the Multivariate linear regression over the data set.

$$Y = \theta 0 + (\theta 1.X^1) + (\theta 2.X^2) \qquad \text{Equation (1)}$$

Figure 6 shows the values of 'θ0', 'θ1' and 'θ2' for the hypothesis after implementing the multivariate linear regression algorithm on the data set. Figure 7 shows the second order curve obtained by the same algorithm and has been it has been fit efficiently on the data set. Now using these values of 'θ0', 'θ1' and 'θ2 a final mathematical model can be obtained for this particular vehicle and can be used to determine the brake pad wear by providing the value of stopping distance.

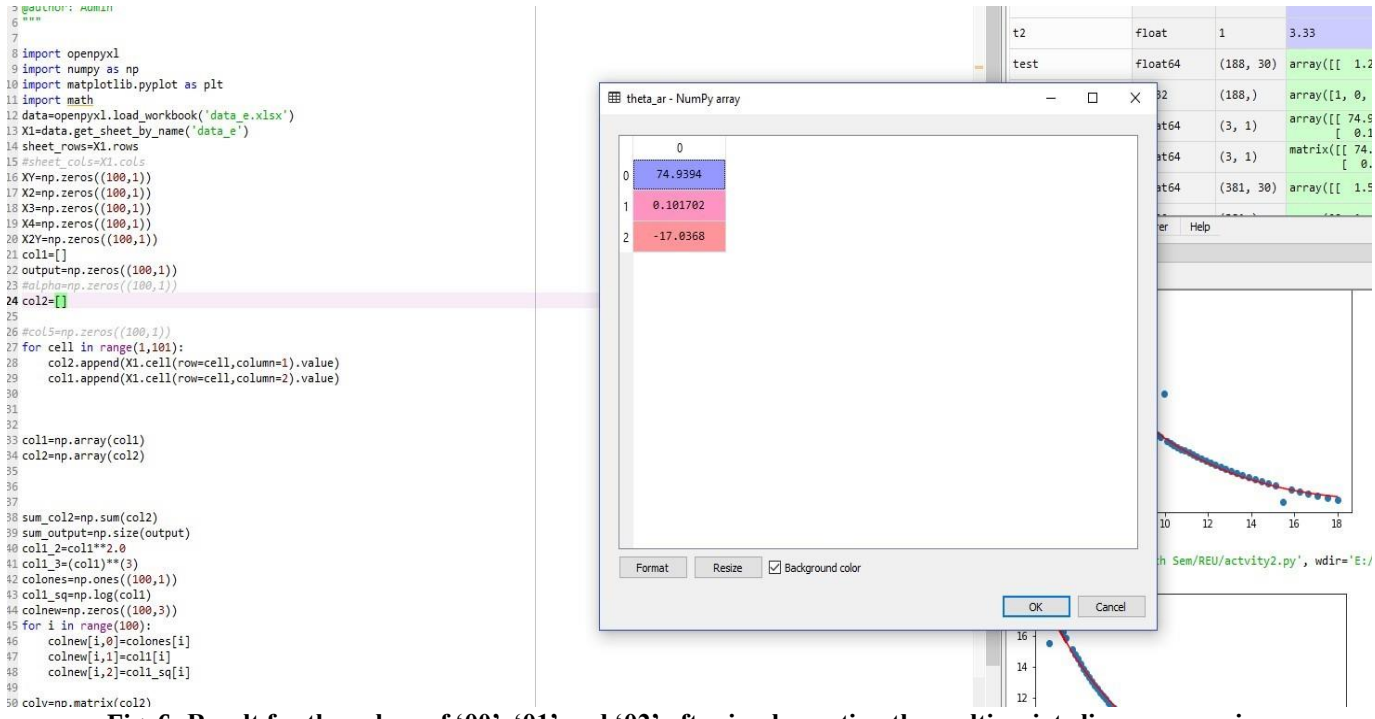

Fig. 6: Result for the values of 'θ0', 'θ1' and 'θ2' after implementing the multivariate linear regression

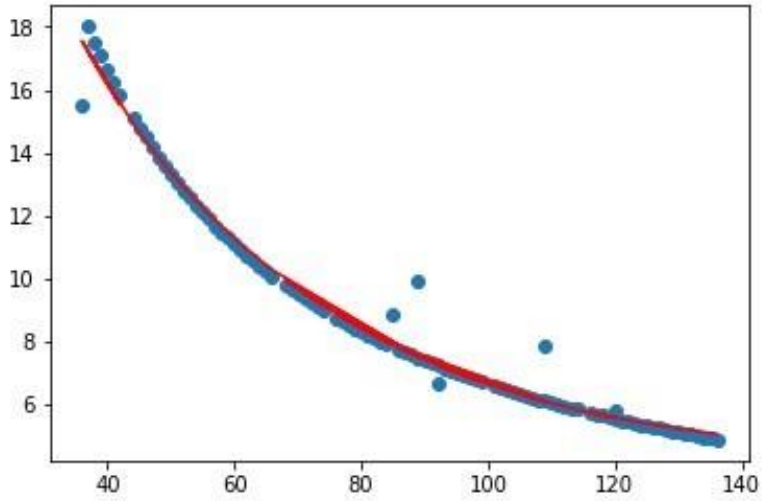

Fig. 7: Second order curve (red line) over the data set plot

3.1 Result

From this experiment a mathematical relation has been obtained between the stopping distance and brake pad thickness, it is being done by using the values for 'θ0', 'θ1' and 'θ2 obtained from the multivariate linear regression algorithm on the test set and applying them as follows:

$$\theta 0 = 74.93$$
$$\theta 1 = 0.10$$
$$\theta 2 = -17.03$$

Now substituting these in Equation (1). We get the mathematical model (Equation 2) relating the stopping distance and brake pad thickness for the test conducted with the BMW 5 series vehicle.

$$Y = 74.93 + (0.10.X) + (17.03X^2) \qquad \text{Equation (2)}$$

4. CONCLUSION

A relationship between stopping distance of a vehicle with its brake pad thickness can be obtained by simple machine learning algorithms. In this approach, many parameters have been assumed to be constant. But in real life implementation, these parameters will not be constant and a higher lever machine learning algorithms like deep learning using artificial neural networks can be applied to relate the two parameters. Hence the stopping distance value can be used to determine the brake pad wear.

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