Android and Cloud-Based Application Development to Predict Remaining Age of Four-Wheeled Vehicle Brake Pad with Varied Driving Behaviour

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Abstract. One important component in a vehicle is the braking system. The main function of the braking system is to provide deceleration to stop the vehicle speed. One important part of the braking component is the brake lining. But to know the physical condition of the brake lining, it is necessary to dismantle the wheel and brake components. So that one of the initial stages of development is to make an application that can predict the remaining life of the brake lining without having to do the demolition. Therefore, this study will design the calculation with the physical condition monitoring approach of the brake lining itself. In addition, in this study, the author will try to find a relationship between driving behaviour and its effect on the wear rate of the brake lining. After testing the road with 3 different driving behaviours, it was found that the driver with eco behaviour would consume 0.42\%, normal behaviour as much as 1.65\% and sport behaviour as much as 44.96\% of the thickness of the original brake lining. There was a significant result in sports driving behaviour because in this behaviour the braking pressure and temperature will be very high when compared to eco and normal. Furthermore, the application error which obtained from the application was higher than the other two behaviour.

1. Introduction
As the second largest four-wheeled automotive producer in Southeast Asia in 2014 – 2017 after Thailand, the automotive industry in Indonesia considered to become a priority [1]. The four-wheeled vehicle consumer market survey with the theme "Global Automotive Executive Survey" said that 58\% of four-wheeled vehicle consumers think that the digital platform is the desired buying attraction, where drivers can access their vehicle data from the platform [2] with three expected main functions namely accessing remote settings, checking for problems, and managing vehicle service schedule.

Four-wheeled vehicles have an incredibly complex system such as the braking system which has a crucial role because it functions to reduce or stop the speed. It could trigger collision accident due to the non-decreasing rate. Monitoring and maintenance of the braking system is important in a vehicle, thus from a physical point of view, the brake pads must be replaced when the thickness reaches 2mm [3]. The ideal age of a brake lining is around 30,000 to 40,000 kilometers [4], depending on the usage of the driver. The driving characteristic of each different driver was contributed to fluctuations in response data [5] that can determine the age of a vehicle component. However, the driving behaviour of the drivers often generalized, which affects the same service time for each driver. Therefore, three driving
behaviours had been established as test parameters to represent real driving conditions [5] and were designed using the Measurement System Analysis method to reduce errors that occurred due to measurement.

Internet of Things that supports the development of world technology provides opportunities for the automotive sector [6] which reducing road accidents due to the informative ability of four-wheeled vehicles [7]. The benefits provided by the implementation of IoT in the automotive sector had an impact on reducing maintenance costs by around 10% - 40% and increasing vehicle life cycles by around 3% - 5% [8]. Therefore, IoT application was designed with Raspberry Pi 3 and OBD II [9] as data collectors, cloud as backend, and Android as data visualization so that users could be access ubiquitous that had been trusted and tested in verification tests.

2. Methodology

2.1. Model Calculation Design
An application that had been developed was a program that runs in the Python base language. This calculation was a system for performing calculations based on data taken when the vehicle is running using a tool called On-Board Diagnostic (OBD). In a braking event, the brake system will convert the kinetic energy used by four-wheeled vehicles to move into heat energy which is discharged into the environment through the friction that occurs between the pads and the brake discs. During braking, a vehicle has two energies involved in it, which kinetic and rotation energy [10].

\[ E_k = \frac{1}{2} \times m \times ((v_1^2) - (v_2^2)) \]  

(1)

\[ E_r = \frac{1}{2} \times J \times ((\omega_1^2) - (\omega_2^2)) \]  

(2)

With \( v \) as velocity and \( m \) as mass, the joule (\( J \)) and rotational speed (\( \omega \)) could be obtain from:

\[ J = m \times R^2 \]  

(3)

\[ \omega = \frac{v}{R^2} \]  

(4)

From the braking energy, we can find the value of the braking power that occurs during the process, namely the amount of braking energy divided by the braking time.

\[ P = \frac{W}{t} \]  

(5)

This braking power was influenced by driving behaviour of the driver. Thus, after calculating the total braking power for each trip with varying driving behaviour. The next step is to link the reduction in thickness of the brake pads to the braking force used. So that the rate of wear per braking power or mm / Watt is obtained. Each driving behaviour will have varying wear rate values or constants. This constant will become the multiplier constant when predicting the remaining life of the brake lining is made. So, by knowing the multiplier constant for each driving behaviour (mm/Watt) and knowing the braking power for each brake curve (Watt), it can be calculated how much the thickness of the brake lining (mm) decreases every time the driver drives.

\[ \text{Brake Pad Spesific Wear Rate} = \frac{\text{Brake pad Thickness reduction}}{\text{Braking power}} \]  

(6)

2.2. System and Application Design
Vehicle monitoring applications was built with three main subsystems, the data collecting device, the data processing algorithm, and the data visualization user interface.
The first two subsystems were built using Python language and the data collecting device was designed using OBD II and Raspberry Pi 3 that connected directly from the vehicle with an embedded program to collect parameter values, empirically calculate the component condition and send it to the cloud [11]. The data processing algorithm was embedded in the cloud using the Django framework and PostgreSQL as the database storage. The data were being visualized using Android applications.

2.3. Experiment Design
In this subsection, the research experiment was described in two topics: driving behaviour and test drive distance. The driving behaviours were divided into three stage that determined by accelerator position and coasting time within 1 minute which obtained from MSA calculation. The results were 14.23% R&R percentage that indices representative driver could maintain the behaviour and 98.98% PV percentage that indices the driving behaviour can be differentiated into three, Eco, Normal, and Sport perfectly.

| Driving Behaviour | Accelerator Position (%) | Coasting Time (min/km) |
|-------------------|--------------------------|------------------------|
| Eco               | <12 (16)                 | >1.8                   |
| Normal            | 20 (16) – 25 (27)        | 1.3 (1) – 1.6 (1.8)    |
| Sport             | >30 (27)                 | <1                     |

From above parameters, the test was designed within 300 km distances for each behaviour with Nissan Juke 2015 as observed vehicle. After each behaviour, the components were replaced to keep the brake’s condition of every driving behaviour and being measured to verify the brake’s thickness.

2.4. Verification Test and Error Analysis
After testing the road and collecting the required data, the next step is to check the physical condition of the brake pads. Again, the wheel and brake components must be disassembled so that the brake pads can be reviewed. Like data collection before road testing, the data taken is thickness. Checking the physical condition of the brake pads is only carried out on the front wheels, but because each wheel has two brake pads, the number of brake pads reviewed is four. From the captured value, the error values from the application were calculated.

\[
\text{Error Value} = \frac{|\text{Actual Value} - \text{Application Value}|}{\text{Actual Value}} \times 100\% \tag{1}
\]
3. Result and Discussion

3.1. Brake Pad Thickness Reduction Results and Analysis

Three diving behaviours had its own braking power that being extracted from the experiment.

Table 2. Braking Power Total Each Behaviour

| Driving Behaviour | Braking Power (Watt) |
|-------------------|----------------------|
| Eco               | 8310308.8            |
| Normal            | 26870691.15          |
| Sport             | 60989601.39          |

These values became specific ware-rate constant.

Table 3. Specific Ware-rate Constant Each Behaviour

| Driving Behaviour | Specific Ware-rate Constant (mm/Watt) |
|-------------------|---------------------------------------|
| Eco               | 3.49E-09                              |
| Normal            | 4.32E-09                              |
| Sport             | 5.16E-08                              |

In the table above, it can be seen the value of the wear rate specific to the braking force that occurs. It can be interpreted that every driver brake in eco-behaviour conditions, then the brake lining will decrease in thickness by 3.49x10-9 mm in every 1 Watt of braking power. Likewise, with normal behaviour and sports conditions.

![Braking Power Amount (300KM)](image)

**Figure 1. Braking Power Amount for Each Behaviour**

The division of braking behaviour groups is done by sorting the braking power for each driving behaviour, after which the power is divided into four parts, namely 0-10000Watt, 10000-20000Watt, 20000-30000Watt and above 30000Watt. The results of the distribution of braking power for each driving behaviour can be seen in the graph. The table shows that eco braking behaviour occurs in the range 0 – 10000Watt, normal braking behavior is at 10000-30000Watt, and if it is greater than 30000Watt then braking behaviour falls into the sport category. This braking power range will act as a determinant of the specific wear rate which is a multiplier of the braking force.

Thus, from the test drive experiment, the brake pads reduction from the application was shown in table 4.
Table 4. Brake Pads Thickness Reduction Application

| Driving Behaviour | Thickness Reduction (mm) |
|-------------------|--------------------------|
| Eco               | 0.030                    |
| Normal            | 0.107                    |
| Sport             | 2.164                    |

3.2. Brake Pad Thickness Reduction Verification

Each brake pad on the front wheel (outside right, inside right, outside left, and inside left) will be counted as thick. The calculation of brake pads is carried out at 3 points of the pads which will eventually be calculated the average. This calculation is performed using a screw micrometer with an accuracy level of 0.01mm.

Table 5. Brake Pads Thickness Actual Reduction (mm)

| Driving Behaviour | Outer-Right | Inner-Right | Outer-Left | Inner-Left | Average |
|-------------------|-------------|-------------|------------|------------|---------|
| Eco               | 0.033       | 0.017       | 0.030      | 0.037      | 0.029   |
| Normal            | 0.097       | 0.113       | 0.123      | 0.130      | 0.116   |
| Sport             | 3.067       | 3.137       | 3.207      | 3.180      | 3.148   |

It can be observed that the depletion of brake linings in eco and normal behaviour is not very significant, when compared to sports behaviour which is very different in value. This happened because during sport driving behaviour it can be said that there is no condition where the vehicle is traveling at a constant speed (coasting). With very high acceleration and deceleration rates, the disc on the brake temperature increases significantly, and when the disc has not returned to its original temperature, the driver has returned to braking. Normally, the braking phenomenon occurs again when the temperature of the discs and pads return to normal, or what is commonly called the cooling phase, but in the case of driving with sports behaviour this does not happen.

![Figure 2. Physical Appearances, (a) Eco, (b) Normal, and (c) Sport](image)

Phenomenon such as sport driving behaviour will result in brake pads having a very high wear rate. Because the higher the braking temperature during the application process, the wear rate of the components will also be higher. In addition, the amount of braking pressure also affects the wear rate of a brake lining, where the higher the braking pressure, the greater the value of the wear rate [12]. It can be seen that in eco-driving behaviour, brake pads do not change drastically and tend to be similar to the initial conditions, in normal behaviour there are signs of friction with discs, and the most severe is in sports behaviour where there are so many friction marks that cause burn marks.

3.3. Brake Pad Thickness Reduction Results and Analysis
The results of the program are compared with the calculated data of the reduction in brake lining thickness that has been previously measured. It shown that the comparison of the results was for eco it has a deviation of 3%, normal is 8% and sport is 31%. There is a significant deviation in sports behaviour, this is again because of braking temperature when the lining rubs against the disc.

Table 6. Result Comparison

| Driving Behaviour | Actual Value (mm) | Application Value (mm) | Error Values (%) |
|-------------------|-------------------|------------------------|-----------------|
| Eco               | 0.029             | 0.030                  | 3.45            |
| Normal            | 0.116             | 0.107                  | 7.76            |
| Sport             | 3.148             | 2.164                  | 31.26           |

4. Conclusion

The conclusion of the study are as follows:

1. Variable driving behaviour variables have a considerable influence on the wear rate of reducing brake lining thickness. This is in accordance with the theory that the greater the initial temperature, pressure and braking speed, the greater the wear rate.
2. Brake pad thickness and its remaining age prediction can be done through the approach of experimental road test by the ratio from braking power (Watt) and its thickness reduction (mm) on each driving behaviour.
3. The brake pads monitoring application could predicted the thickness left with error value became higher as the more acceleration and deceleration happened.

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