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A Vibratory-based Method for Road Damage Classification

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Abstract—Automatic system to monitor the road condition is important to minimize losses due to traffic accidents. The system is required considering the size of the road network in many modern metropolitan cities. Various monitoring techniques have been proposed and in this work, we evaluate the use of vehicle acceleration data in the longitudinal and lateral directions to detect the road anomalies particularly pothole. This article reports the characteristics of the data obtained from various road anomalies and identifies the statistical variance of the data with regard to the road anomalies.

Keywords—Pothole; Smartphone; Road Surface Monitoring, Accelerometer, geo-location.

I. INTRODUCTION

Indonesia government has successfully established a law regarding the traffic safety and regulation in 2009. Particularly, Article 24, Item 1, of the law states that the road administrator must immediately improve the road condition that can cause traffic accidents. And followed by Item 2 that states: as for the damaged road that has not been repaired yet as mentioned by Item 1, the road administrator must place a sign on the road to prevent the occurrence of an accident [1].

In addition, Article 273, Item 1, of the law states that the road administrator who do not repair damaged roads accordingly and as quickly as possible and the damaged road leads to the occurrence of an accident and damaging the vehicle should be punished and imprisoned for a maximum of six months or paid a penalty for 12 million Rupiah at most [1]. Therefore, the road administrator must repair any damaged road as quickly as possible.

For the earlier reasons, the road administrator needs an information system that can provide the roads status across the entire road network in a timely manner. By considering the pervasiveness of the road network particularly in the metropolitan city such as Jakarta, it is extremely difficult and time consuming to monitor the road condition manually. The manual road monitoring is not only difficult but also very dangerous.

Various methodologies have been proposed for the automatic road monitoring system. References [2–4] utilized smartphones to provide accelerometer data of the vehicle vibration and analyze the data by a machine-learning approach. Balakuntala (2013) proposes a system consisting of a laser sensor and a pressure sensor. The pressure sensor is installed in a shock absorber and is used to detect and quantify the intensity of the vibration due to a pothole. In addition, a point-to-point communication device is also used to communicate other vehicles within a range of 20 m from the pothole location. References [5, 6] deployed computer vision techniques. Smartphone has also been used for assessing the driving safety [7].

In this research, we intend to establish a pothole monitoring system that provides the road status in real time. The system is a web-based system. The system will utilize a smartphone, which is enriched with a 3D accelerometer sensor and a geo-location sensor. The smartphone will be installed in a probe vehicle and the vehicle will be used to scan the road network. The accelerometer sensor will be used to record the vehicle vibration and some algorithms will be developed to differentiate the vibration due to a pothole and due to other factors such as a road bump. The associated location of the pothole will be detected by the geo-location sensor and the data will be transmitted to a designated web server for data aggregation and reporting.

II. RESEARCH METHOD

The detection method utilized in the current work was adopted from [2] with a few adjustments, which would be explained in Section III. The algorithm flowchart was reproduced in Fig. 1. The flowchart would be shortly discussed in this section for the self reliance of this document; however, the interested readers are recommended to consult [2] for more comprehensive description.

The main data for detection were the vehicle acceleration data in the vehicle latitude and longitude directions. The latitude direction is with respect to the vehicle-side direction, and the longitude direction is to the bottom of the vehicle. The first direction is defined as the z direction and the latter is the x direction.

The detection is performed in the following sequences. The detection begun with recording a stream of the 256 acceleration data. In the current work, the data were sampled at the interval of 10 ms. Firstly, the vehicle velocity was evaluated; if it was too low, the stream of the data would be ignored, and a new stream of the data would be taken. If the stream data passed the previous velocity checking, the data would be filtered with a high-pass filter. Subsequently, only the z direction acceleration data \( a_z \) were evaluated against a threshold, \( \epsilon_z \). The data stream would be further processed if the maximum of \( a_z \) (\( a_z^{\text{max}} \)
Fig. 1. The flowchart of the pothole detection procedure [2].

next, the \( \alpha_z \) direction acceleration data within the time interval centered at the time of \( \alpha_z^{\text{max}} \) was evaluated for its largest value \( \alpha_z^{\text{max}} \). The interval width was 32 data. Again, this extreme value would be checked against a threshold \( \epsilon_x \); and similar to the previous rule, if \( \alpha_z^{\text{max}} < \epsilon_x \), the data stream would be ignored and new one would be taken. As the last evaluation was thus to reject the data stream if \( \alpha_z^{\text{max}} < \epsilon_z \cdot \nu \), where \( \epsilon_z \) is the threshold and \( \nu \) is the vehicle traveling velocity.

III. RESULTS AND DISCUSSION

As described in Section II, the stream of data would be evaluated for a number of criteria and the most important are the \( \alpha_z \)-peak and \( \alpha_z \)-ratio evaluation. First, we discuss the typical acceleration data in \( \alpha_z \)-direction, which is the vehicle-side direction, and \( \alpha_x \)-direction, which the vertical direction. Figures 2–4 shows those data for the pothole, normal road, and bump road, respectively. The data were recorded with a constant sampling time of 10 ms.

The algorithm described in Fig. 1 assumes that when a vehicle crosses a pothole, the vehicle would vibrate significantly in the \( \alpha_z \) - and \( \alpha_x \)-direction. This can only occur if only one side of the vehicle tire passes through an obstacle such as a pothole. This phenomenon is hardly observable when the vibration is less significant.

In practice, the occurrence of the above phenomenon is sometimes difficult to be differentiated from the other cases. For example, when the vehicle cross two bumps, it produces the acceleration data such as those depicted in Fig. 3. Significant vehicle acceleration in \( \alpha_z \) is detected but it also follows with rather small vibration in \( \alpha_x \)-direction. If we compare these data to those obtained from the pothole case, see Fig. 2 and Fig. 5, the latter case only produces slightly higher maximum accelerations in the both directions. We should also note the normal road case may also produce a big acceleration but with less correlation between \( \alpha_x \) and \( \alpha_z \).

Figure 6 shows the aggregated data recorded in the experiments on the normal road, the road with a bump, and the road with a pothole.

Generally, the collected data, both \( \alpha_z^{\text{max}} \) and \( \alpha_x^{\text{max}} \), for the case of the normal road are smaller than the other cases. The largest acceleration data are obtained for the pothole case. The bump case data are in between the two cases. This is accordance with the design of Algorithm 1. The pothole is assumed to produce large vehicle acceleration in \( \alpha_z \) and \( \alpha_x \)-direction.

However, in the above data, we also observe that some data are overlap. The values of some collected data of the pothole case are rather small; thus, those data are difficult to be differentiated from the other cases. Despite of this, however, the assumption that when the vehicle runs over a pothole, it will produce large \( \alpha_z^{\text{max}} \) seems to be plausible.

Figure 7 provides a more clear description regarding this phenomena. The figure shows the distribution of the ratio data
that is computed by

\[ \text{Ratio} = \frac{a_{z,\text{max}}}{a_{z,\text{avg}}} . \]

In the numerical values, the descriptive statistics of the data are presented in Table I. Those evidents show that the data from the pothole case are significantly different in term of the sample mean and the sample variation; but, there are also a large portion of the data is overlap with the data from the rest of the cases.

The ANOVA results shown in Table II also supported this conclusion. We note that ANOVA test was performed with the assumption that

\[ H_0 : \mu_{\text{Normal}} = \mu_{\text{Bump}} = \mu_{\text{Pothole}}, \quad \text{and} \]

\[ H_a : \text{At least one of them is different from the others,} \]
and 5% significance level. With the $F$ statistic of 3.601 and
the critical $F$ of 3.226, it is statistically proven that at least of
the mean is different. By looking to the summary in Table I,
we can clearly see, without doing any paired t-test, that the
case of Pothole with the mean of 0.727 is the one that deviates
from the two-remain cases (the normal case with the mean of
0.409 and the bump road case with the mean of 0.495).

**TABLE II. ANOVA RESULTS FOR THE RATIO.**

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<th>Source of Var</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p-val</th>
<th>F crit</th>
</tr>
</thead>
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<tr>
<td>Between</td>
<td>0.780</td>
<td>2</td>
<td>0.390</td>
<td>3.601</td>
<td>0.036</td>
<td>3.226</td>
</tr>
<tr>
<td>Within</td>
<td>4.440</td>
<td>41</td>
<td>0.108</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**IV. CONCLUSIONS**

With the massive-size of the road network, an automatic
monitoring system for the road status is clearly of importance.
However, the development of such system faces the technical
difficulties particularly in detecting various types of road
anomalies. Various techniques have been proposed, from the
image-based technique to the vibration technique. In this work,
we have closely examined the vibration technique and the
acceleration data, which are used for the road classification,
showing potential application for the purpose. The study found
that the data collected from the pothole case statistically
deviated from the normal road and the bump road cases;
however, data overlaps existed, and it makes road anomaly
classification becoming a harder problem.

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