Sensing discomfort levels of standing passengers in a public rail transportation systems through a smart phone

Thommen Karimpanal George, Ruben S/O Sukumar, Harit Maganlal Gadhia
Department of Mechanical Engineering
John-John Cabibihan
Department of Electrical & Computer Engineering,
National University of Singapore

Abstract— This paper aims to investigate the effect of acceleration on the discomfort of standing passengers. The acceleration levels from different public rail transport lines such as the mass rapid transits (MRTs) and light rail transits (LRTs) of Singapore, as well as the associated qualitative data indicating the discomfort of standing passengers are collected and analyzed. Based on a logistic regression model to analyze the data, a discomfort index is introduced, which can be used to compare various rail lines based on ride comfort. Also, in any given rail line, a method for predicting the discomfort of passengers based on the acceleration values is proposed.

I. INTRODUCTION

It is a common sight to see crowded buses and trains in which several passengers remain standing during some part of their journey. The automatic transmission systems used in public transport vehicles produces sudden and high accelerations intermittently throughout the journey. As a result, standing passengers often struggle to maintain balance and experience a significant amount of discomfort at these instances of sudden accelerations and decelerations.

Several studies have been conducted over the years to quantify and relate the passenger comfort levels with the jerks and accelerations of the trains. Delton and Dale [1] presented the instrumentation system for the measurement of acceleration profiles associated with mass transit vehicles and maximum allowable jerk and acceleration values for passenger comfort were specified. Ramasamy et al [2] used measured vibrations and conducted questionnaire surveys simultaneously on few long distance trains in Sweden in order to understand the effect of vibration on performing sedentary activities. For this research, ISO-2631 and Sperling Ride Index [3] were used to evaluate the ride comfort. Graaf et al. [4] determined the limiting values for sudden accelerations that cause problems in maintaining postural balance. Omar Bagdadi and András Várhelyi [5] proposed a method for detecting jerks in safety critical events, based on the characteristics of the braking caused by the driver in time critical situations.

In this paper, the accelerations and decelerations in various public rail transportation systems in Singapore and its effects on the discomfort of standing passengers is studied. In order to achieve this objective, the accelerometer of a standard smart phone is tapped into and the acceleration data of various lines is recorded. Simultaneously, the discomfort levels of standing passengers are recorded while the vehicle is in motion. In this way, a qualitative description of the discomfort of standing passengers is obtained. Based on logistic regression analysis [6] of these data sets, a suitable discomfort index is introduced, and also, it is shown that the discomfort experienced during a journey can be quantified. Based on this index, a comparison between the various lines is also presented. Also, using logistic regression techniques, it is shown that for a particular rail line, passenger discomfort can be predicted with reasonable accuracy. Such an analysis can be helpful in the improvement of current forms of public transport as well as for the design and testing of new transportation systems.

II. METHODOLOGY

The methodology used to conduct this research experiment involves recording the acceleration data in different forms of public transportation such as MRTs and LRTs. Accelerometers are placed inside the vehicle at a fixed point such that there is no relative motion between the vehicle and the accelerometer. Owing to the convenience in portability and availability, as well as the ease of use, the accelerometer of a standard smartphone is used to carry out the data collection. In this experiment, an android based smartphone with a 3-axis accelerometer is used to measure
the acceleration. Of the 3-axes, the Y axis is aligned in direction of motion of the vehicle, the X axis is at 90° to the Y axis in the same horizontal plane and the Z axis is perpendicular to the plane made by X and Y. The figure below illustrates the directions of accelerations relative to the direction of motion of the train.

Figure 1. Figure showing the directions of accelerations according to the vehicle motion

Along with the acceleration data, simultaneously, another input, representative of the discomfort, is collected from standing passengers. In order to gather this data, a stopwatch is used so as to record the time instances of passenger discomfort. The standing passenger is instructed to press a stopwatch button which records the time instance corresponding to whenever he/she feels uncomfortable due to the acceleration levels experienced in the train. This set of readings, showing the record of time instances of discomfort was recorded for the entire period of the journey. A plot of the discomfort instances vs time can thus be obtained. Using the sampling rate for the collection of acceleration data, this information is later mapped to the acceleration levels of the train, which is simultaneously recorded using the accelerometer. By comparing these two data sets and plots, the variation in the discomfort of the passenger with the variation in the acceleration levels in the vehicle can be easily visualized and analyzed. Since different passengers have different discomfort tolerances to the same level of acceleration, the experiment is conducted with different standing passengers in order to obtain a data set which is applicable to any standing passenger, in general.

III. DATA ANALYSIS AND RESULTS

Data collected from the Circle, East-West, North-South and North-East lines of the MRTs as well as from the LRT trains are plotted below. The following plots show the acceleration values in the three orthogonal directions and the instances of discomfort of the standing passengers. The discomfort instances in these plots are represented with pulse inputs which have non-zero value during periods of discomfort and zero value during all other time instances.
A similar set of plots can be obtained using the jerk data. The jerk data can be generated by simply differentiating the acceleration data obtained with respect to time. The jerk profiles along with the discomfort instances are plotted for the different rail lines in figures 7-11.

It is clear from the graphs shown, that just by visual inspection, no relation can be deduced between the acceleration values and the instances of discomfort. Similarly, no clear relation can be deduced between the jerk values and the instances of discomfort. Thus, analysis of the data is done in order to establish some form of relationship between the two quantities. Those instances where the passengers recorded discomfort are labeled ‘1’ and all other instances are labeled ‘0’. As there are only two cases of output, that is, comfortable or uncomfortable, this is a problem of binary classification. Hence, the technique of
The above equation indicates that the task of classification into either cases is dependent on the parameter ‘z’. In terms of the three acceleration values, the value of ‘z’ is given as:

\[ z = a_x b_1 + a_y b_2 + a_z b_3 + b_4 \]  

(2)

Thus, the value of ‘P’ is ultimately decided by the constants \( b_1, b_2, b_3 \) and \( b_4 \) and the normalized values of the acceleration components along the three axes \( a_x, a_y \) and \( a_z \). Here, the coefficients are determined by using logistic regression analysis. In this research, the coefficients are solved for using MATLAB. The coefficients in ‘z’ are characteristic of a particular line. Hence, each line has a unique equation which can be used to predict the level of discomfort, given the values of acceleration. The equations for the lines investigated in this paper are shown below in the table:

<table>
<thead>
<tr>
<th>Line</th>
<th>Discomfort Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circle (yellow) Line</td>
<td>( z = a_x (0.1728) + a_y (1.2064) + a_z (-0.9458) + (-1.1528) )</td>
</tr>
<tr>
<td>North-South (red) line</td>
<td>( z = a_x (-1.1764) + a_y (-0.2396) + a_z (-1.0849) + (-3.283) )</td>
</tr>
<tr>
<td>North-East (purple) line</td>
<td>( z = a_x (0.8223) + a_y (0.2607) + a_z (-0.7349) + (-0.9995) )</td>
</tr>
<tr>
<td>East-West (green) line</td>
<td>( z = a_x (-0.2867) + a_y (3.3714) + a_z (0.4978) + (1.9170) )</td>
</tr>
<tr>
<td>LRT</td>
<td>( z = a_x (-0.7117) + a_y (0.4723) + a_z (-0.2185) + (-1.2651) )</td>
</tr>
</tbody>
</table>

Discomfort equations for each line (Table I)

Observing the values associated with each acceleration component reveals how much the discomfort experienced is dependent on that component of acceleration. For example, in the equation for the East-West (green) line, since the value associated with the y component of acceleration is significantly higher than those associated with the other two components, we can deduce that the discomfort experienced on the East-West line is mainly contributed by the acceleration values in the y direction. Similar analysis can be carried out for other lines. Such information could be useful to maintenance engineers who could take suitable action to improve the ride comfort. Equations (1) and (2) can also be used to predict whether a given set of acceleration data for a particular rail line is comfortable or uncomfortable. The prediction for a test data set of the East-West line is shown below:

The figure above shows the plot of predicted state of discomfort for a test data set of about 5000 samples for the East-West (green) line. The state of discomfort is predicted using the probability function in (1). In this figure, the probability is filtered and scaled for better viewing. The plots show that whenever the scaled probability curve rises above ‘0’, a state of discomfort is predicted. The prediction is validated by the actual discomfort pulse which was recorded for that particular journey, which is also shown in the plot. Such prediction can be useful to train manufacturers in the testing stage, in order to predict whether passengers will feel comfortable with the levels of acceleration generated by the trains.

As another outcome of the analysis, a discomfort index \( D \), based on equation (1) and a modified version of equation (2) is introduced. The discomfort index is given by:

\[ D = \frac{1}{1 + e^{-z}} \]  

(3)

Here, the value of \( Z \) is calculated as follows:

\[ Z = A_x b_1 + A_y b_2 + A_z b_3 + b_4 \]  

(4)

Where \( A_x, A_y \) and \( A_z \) are the mean values of the normalized acceleration components along the three axes in the training set of data.

Hence, \( D \) gives an overall discomfort value for a particular line. The higher the value of \( D \), the greater is the discomfort experienced. Based on this index, a comparison of the
different lines in terms of standing passenger comfort is depicted in the following figure:

![Discomfort Index](image)

Figure 13. Figure showing the discomfort indexes for different lines

This comparison can be extended to other forms of public transport as well, where passengers are often required to remain standing. Such an index may act as a guideline for design engineers while designing new public transport systems.

Alternatively, analysis may also be carried out using the jerk data. The jerk data can be obtained by simply differentiating the acceleration data obtained with respect to time. The remaining part of the analysis will remain the same.

IV. CONCLUSION

Accelerometer and discomfort data is collected and analyzed using the logistic regression technique. Discomfort equations are defined for each of the different rail lines. Using these equations, it is shown that for a particular line, the discomfort of standing passengers can be predicted, given the acceleration values. Further, a discomfort index is introduced, which can be used to compare different modes of transport on the basis of ride comfort for standing passengers.

REFERENCES


