

Railway Dynamics Analysis Using Lego Mindstorms

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Abstract. In recent years, the high speed railway vehicle dynamics performances have been studied and investigated in order to determine the ride comfort of the passengers. Most of the time, these researches were involving expensive and high end technology of data logging system to record and analyze the data. In this research, a low cost data logging system (Lego Mindstorms) is used to gather the data from accelerometer and gyro during experimentation. The study about the behaviour of railway vehicle in term of roll and vibrations at three perpendicular axes during running at the curve track is performed. Actual field run of railway vehicle data collection is performed on the available high speed railway vehicle operating from Kuala Lumpur International Airport (KLIA) to the Kuala Lumpur (KL) Sentral. The route selected consists of several curves which are important to study the dynamics performance of the vehicle. The results from experiment establishes the dynamics performances of the railway vehicle in term of passengers' ride comfort. With the availability of the data logging system and sensors, the railway vehicle dynamics performance can be analyzed and monitored for future improvement of railway vehicle service and operation.

Introduction

In the previous researches, the performances of high speed railway vehicles were studied in terms of current collections [1-4]. The simulation results were never been validated with actual field performance. Some railway dynamics simulations were also studied [5-8]. The vibration is produced by virtual vertical high response actuator. Even though this method is highly favoured by researchers, the vibration is merely artificial, and the results do not reflect the actual dynamics performances of the railway vehicle. Several experiments were also performed during actual train operation [9]. However, generally, the train is designated for experiment and no passengers are allowed in the cabin. This empty train is good for experimental data gathering, nevertheless, without passengers, the results do not possess actual payload of the train during operational hours. Indeed, to do experiment during peak hour on actual train operation with passengers is costly and additionally affects the train schedule. In order to get actual experimental data on running train, the data logging system consists of several sensors such as gyros, 3 axes accelerometers, and data acquisition system [10]. These experimental setups are reliable and produce favourable railway vehicle dynamics performance data. On the other hand, due to high cost and time consumed, these setups are impractical for real-time data analysis experiment on peak hour full load (with passengers) operational train. Due to these constraints, a simple data logging system, Lego Mindstorms with gyro and accelerometer is used for the experiment to monitor the dynamics performance of the train. Previously, Lego Mindstorms is used for robotic and teaching purposes [11]. But, with the availability of data logging feature with MATLAB Simulink interface, the experimental setup for railway dynamics performance analysis is possible yet reliable.

Methodology

Lego Mindstorms™ with NXT brick is used as data acquisition system. NXT brick as shown in **Figure 1** featured 32 bit ARM7 microprocessor, 256 kilo bytes Flash, 4 input ports, 3 output ports, sound speaker, USB 2.0 and Bluetooth compatible. It came along with a rechargeable lithium battery system with an AC plug. Minimum operating system requirement include 512 MB RAM, 300 MB available hard disk space, XGA display with resolution of 1024× 768, 1 USB port, Bluetooth adapter, Window XP Professional or Home Edition with Service Pack 2 and Intel Pentium processor of 800 MHz [11]. HiTechnic gyro sensor (**Figure 1**) and accelerometer (**Figure 1**) are used to measure the roll and vibration of the railway vehicle. HiTechnic Gyro sensor has the capability of 300 Hz in reading, allowing minimum of 3×10^{-3} second of sampling time to be made literally. The orientation of gyro sensor is imperative as it involved only one single axis of measurement. The axis of measurement is in the vertical plane where black end cap of gyro sensor is directed upward [12]. Every gyro sensor has distinct offset value and may deviates when subjected to external factors such as temperature and voltage supply. This deviation phenomenon had been known as sensor drift. Temperature of sensor will rise and hotter than ambient temperature when in used. Sensor warm up is essential before determine the offset in order to obtain no bias reading. Previous observation has shown that drop of 1 volt will result drop of offset for 5° in linear relation but it varies with distinct gyro sensor. Thus, it is imperative to determine the offset of gyro sensor before it is applied in every single experiment. Moving average technique and low pass filtering technique can be used to minimize sensor drift to the minimum when the gyro sensor is stand still [12]. HiTechnic acceleration sensor has a measuring range of -2 g to $+2 \text{ g}$ where g is abbreviated from gravity acceleration constant of 9.81 m/s^2 with sensitivity up to 200 counts per g or 0.04905 m/s^2 . Standard NXT wire is connected to the brick's input port and uses the digital I2C communication protocol. Refreshment rate for each axis acceleration measurement is 100 Hz. The three axes of measurement are labelled x as longitudinally headed, y as laterally headed and z as vertically headed [12].

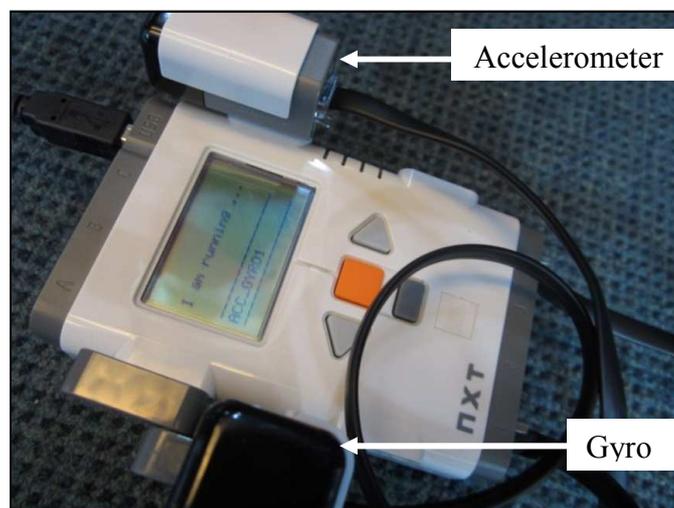


Figure 1: Lego Mindstorms NXT with accelerometer and gyro

Experiment

In the experiment, the railway selected is the KLIA Express. KLIA Express running track is approximated to 57 km, with maximum operating speed of 160 km/h that took 28 minutes for the journey. The train type is ET-425M from Siemens, a 4-cars train set as shown in **Figure 2** which made of two motor cars and two trailer cars. The total length of the train set is 68.7 m, width of 2.84 m and height of 4.16 m [13].



Figure 2: KLIA Express [13]

Results and Discussion

Figure 3(a)(b) and **(c)** show the results of filtered data from the experiment for the longitudinal, vertical and lateral vibration. The x-axis acceleration as shown in **Figure 3(a)** has periodically upshot graph trend behaviour, certain period with flatter graph climb and graph drop occurred twice within the 500 seconds. Upshot graph trend behaviour can be explained as acceleration of railway vehicle at straight rail track during 50 s, 125 s, 175 s, 280 s, 350 s, 400 s and 425 s. The maximum acceleration measured is 0.6 m/s^2 which imply that the railway vehicle did not come to full throttle acceleration as 1 m/s^2 . The y-axis acceleration as shown in **Figure 3(b)** had significant deviation at 50 s, 280 s, 400 s and 450 s. The contributing factors can be that railway vehicle is taking curve without significant reduced of velocity. The measured range was narrower than x-axis acceleration, between -0.5 until 0.4 m/s^2 . Time occurrence for significant deviation of y-axis acceleration at 50 s, 280 s and 400 s has been coincident with time occurrence for acceleration in longitudinal direction. Hunting occurred when railway vehicle approaches critical velocity and lateral motion started to be experienced. Parenthetically, the vibration trend is quite “noisy” rather than had significant differ between two adjacent vibration which can also explained for the hunting motion occurrence when the railway vehicle is moving forward. For z-axis acceleration case, the vibration is more likely crowded at the range of -0.2 to 0.2 m/s^2 as shown in **Figure 3(c)** with no significant deviation throughout the 500 seconds. Z-axis acceleration score the least vibration experienced compared to x-axis and y-axis acceleration. This happened as car body weight, the heaviest part in carriage is acting downward due to gravity attraction. Measured value of roll rate is negatively skewed instead of depicting both positive and negative value. Contributing factor might be the position of sensor placement during experiment. Gyro sensor is placed near to the right side from walkway for avoiding obstruction toward others passengers using the walkway. The roll data of the railway vehicle is shown in **Figure 3(d)**. Positive value depicted roll rate of clockwise while negative value is meant for roll rate of anti-clockwise. The ride indexes for all motions are tabulated in **Table 1**. **Table 1** depicted that greater value of standard deviation possessed greater range of comfort zone. Roll rate has the least standard deviation which is $0.754^\circ/\text{s}$, followed by 13.74 m/s^2 from y-axis acceleration, the third ranked is 15.97 m/s^2 from z-axis acceleration and the most standard deviation belonged to 17.14 m/s^2 from x-axis acceleration. Modulus is a compulsory for the ride index formulation as the operation within the modulus is meant to find the different between measured vibration responses (acceleration or roll rate) regardless of sign. Low standard deviation of roll rate is required as to keep passenger in comfort rather than dizziness. Conventional seat design that support passenger’s hip and back also explained why standard deviation for vertical and longitudinal acceleration is higher.

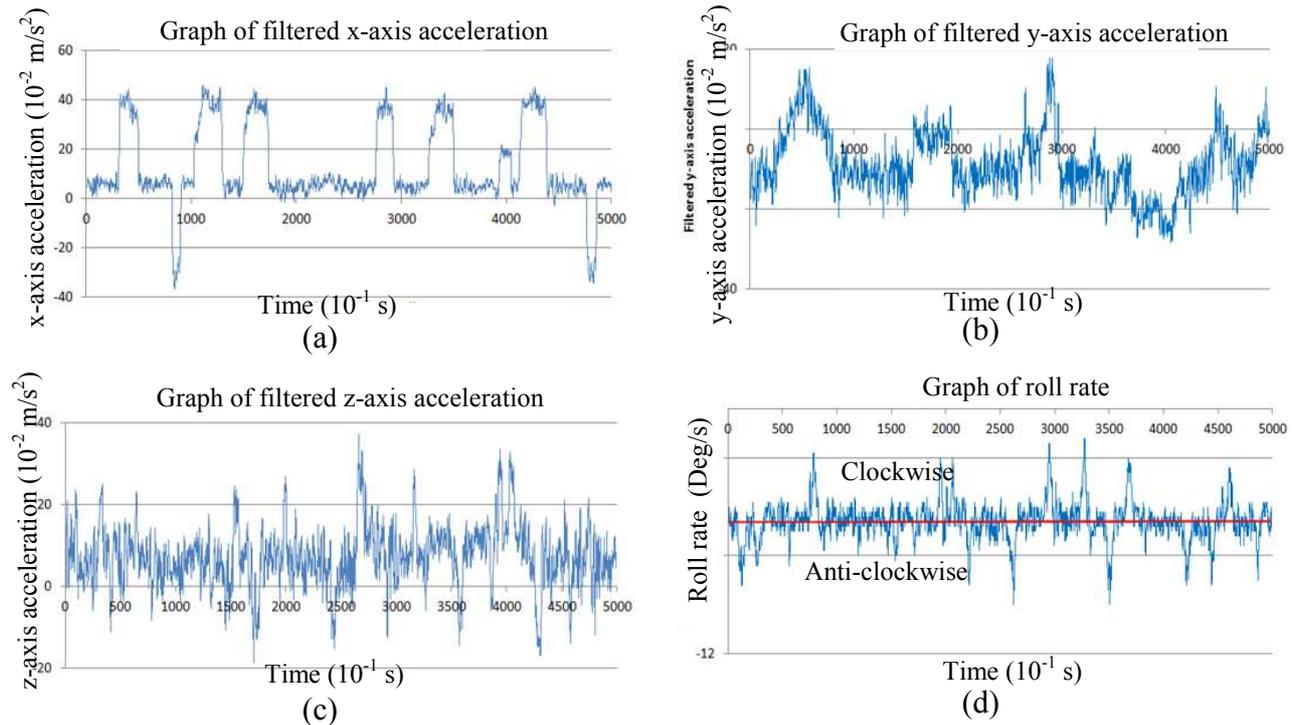


Figure 3: Filtered data (a) x-axis acceleration, (b) y-axis, (c) z-axis and (d) roll rate

Table 1: Statistical value of acceleration from each axis and roll rate

Mode of motion	Mean	Standard deviation	Range
X-axis acceleration	12.68 m/s^2	17.14 m/s^2	$-4.460 < a_x < 29.820$
Y-axis acceleration	$-8.756 m/s^2$	13.74 m/s^2	$-22.496 < a_y < 4.984$
Z-axis acceleration	7.322 m/s^2	15.97 m/s^2	$-8.648 < a_z < 23.292$
Roll rate	$-9.305 \text{ }^\circ/s$	0.754 $^\circ/s$	$-10.059 < \phi < -8.551$

Conclusion

The study of railway vehicle dynamics at a selected route has been performed on the KLIA Express train using Lego Mindstorms with gyro and accelerometer. The dynamics performances are possible to be monitored during data gathering. This advantage is applicable of low cost railway dynamics monitoring system. The results obeyed the ride index formulation depicts comfort level at that instant. The measured roll rate possessed with the least standard deviation indicated the more importance of the effect of that respective mode of motion especially on cornering. The railway vehicle dynamics performance can be analyzed and monitored for future improvement of railway vehicle service and operation with the availability of the data logging system and sensors.

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