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Vehicle Dynamic Analysis between Internal Combustion Engine Vehicles and Electric Vehicles using Experimental Method

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Abstract

Vehicle dynamic performance assessment is essential for evaluating ride comfort, stability and vibration behaviour as electric vehicle (EV) and internal combustion engine (ICE) architectures continue to develop. This study compares the dynamic response of a BYD Atto 3 EV and a Proton X50 ICE vehicle under real Malaysian highway and urban road conditions using an experimental Data Acquisition (DAQ) approach. A low-cost DAQ system was developed using an Arduino UNO, ADXL345 accelerometers, a DS3231 real-time clock, a TCA9548A I2C multiplexer and an SD card logger. Accelerometers were positioned at sprung and unsprung locations to obtain vertical acceleration responses for time-domain and frequency-domain analysis. Root Mean Square (RMS) acceleration was used to evaluate ride comfort based on ISO 2631-1 interpretation, while Power Spectral Density (PSD) was used to assess road-induced vibration response. The Proton X50 generally recorded lower sprung-mass RMS acceleration, particularly on urban routes where the average RMS was approximately 0.55-0.70 m/s2 compared with 2.0-2.3 m/s2 for the BYD Atto 3. However, the BYD Atto 3 showed lower and more consistent average PSD values, indicating reduced high-frequency vibration transmission. Overall, the Proton X50 demonstrated better ride comfort in most road conditions, while the BYD Atto 3 exhibited a more stable frequency response. The developed DAQ system was shown to be a practical and economical method for objective vehicle dynamics comparison.

1. Introduction

Vehicle dynamics describes the way a vehicle responds to road excitation, steering input, acceleration, braking and mass transfer. In ride-comfort studies, the vertical motion of the sprung mass is especially important because it represents the vibration transmitted to the occupant compartment. As EVs and ICE vehicles use different powertrain layouts, their mass distribution, centre-of-gravity location, engine or motor arrangement and suspension response can produce different ride and handling characteristics (Gillespie, 2021; Wu et al., 2018).

The transition from conventional ICE vehicles to EVs has introduced new dynamic behaviour that requires objective measurement. EVs commonly benefit from a low centre of gravity due to battery placement, but

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additional mass and motor placement may influence unsprung-mass response, damping demand and tire-road interaction. Suspension-related studies on EV configurations therefore remain important for understanding ride comfort, stability and road-induced vibration transmission (Kulkarni et al., 2018; Wang et al., 2024).

Traditional vehicle assessment may depend heavily on subjective driver impressions or isolated measurements. A DAQ-based experimental method enables real-time acquisition of acceleration and vibration signals, allowing a more quantitative comparison between vehicles. Low-cost DAQ systems have also been shown to be useful in automobile dynamics applications, particularly when MEMS accelerometers are integrated with microcontroller-based logging systems (Ahmed et al., 2023; González et al., 2018).

Accordingly, this paper presents a technical summary of an experimental comparison between a BYD Atto 3 EV and a Proton X50 ICE vehicle. The main objectives are to study quantitative vehicle dynamics parameters, to establish an experimental DAQ method for comparing the vehicle responses, and to analyse ride comfort and road profile characteristics through RMS acceleration, ISO 2631-1 comfort interpretation and PSD analysis.

Nomenclature

RMS	Root Mean Square acceleration
PSD	Power Spectral Density
DAQ	Data Acquisition System
EV	Electric Vehicle
ICE	Internal Combustion Engine vehicle
Z0	Sprung mass vertical acceleration signal
Z1	Unsprung mass vertical acceleration signal

2. Methodology

The study used an experimental road-test method to compare the dynamic response of two production vehicles. Both vehicles were tested on the same Malaysian routes so that the comparison focused on vehicle response to similar road excitation rather than different road surfaces. The testing covered highway and urban environments and included long-distance real-road operation to represent practical driving conditions.

Table 1 Test Vehicle Specification Used for Dynamic Comparison

Parameter	Proton X50	BYD Atto 3
Vehicle type	Petrol crossover SUV	Electric SUV
Powertrain	1.5 L turbocharged petrol, 3-cylinder, DOHC, direct injection	Electric motor, 150 kW peak power
Power output	175 HP (130 kW) @ 5500 rpm	150 kW (approx. 201 HP) peak power
Torque	255 Nm @ 1500-4000 rpm	310 Nm peak torque
Transmission	7-speed dual clutch transmission (DCT), automatic	Single-speed transmission
Energy source	Petrol, 45 L fuel tank	Electric battery, up to 420 km WLTP range

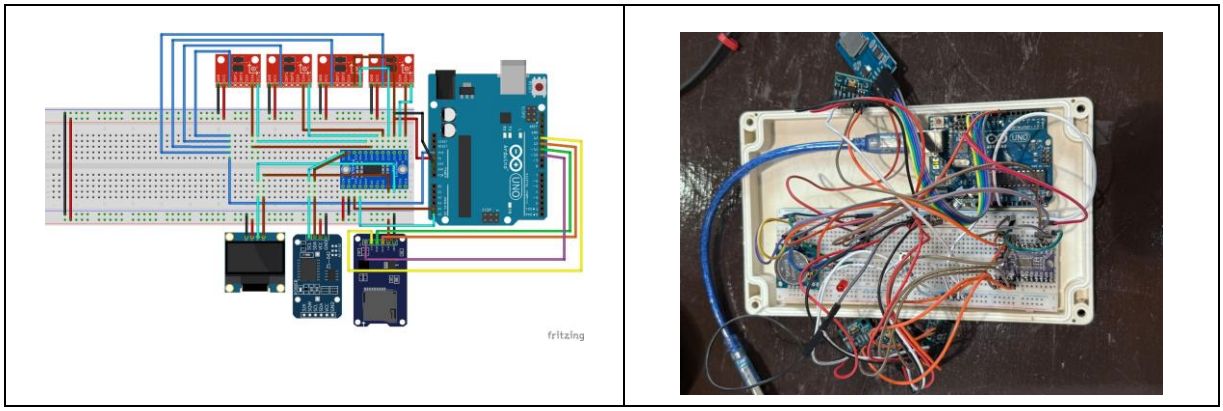
2.1 Data Acquisition System

The DAQ hardware consisted of an Arduino UNO microcontroller, four ADXL345 accelerometers, a DS3231 real-time clock module, a TCA9548A I2C multiplexer, an SD card logger, wiring and power supply. The Arduino operated as the main controller, the multiplexer enabled multiple accelerometers with similar I2C addresses to be read through different channels, the RTC provided time stamps and the SD card module stored the measured signals in CSV format for post-processing.

Table 2 DAQ Component and Experimental Function

Component	Function in experiment
Arduino UNO	Main controller for sensor acquisition and data logging
ADXL345 accelerometers	Measurement of acceleration and vibration along x, y and z axes
TCA9548A I2C multiplexer	Channel selection for multiple accelerometers with similar I2C addresses
DS3231 RTC module	Time-stamping of recorded data
SD card module	CSV storage of acceleration readings for later analysis

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(a) (b)

Figure 1 (a) DAQ Layout (b) Implemented DAQ

2.2 Sensor Placement and Road Testing

The accelerometers were fixed at locations representing different vibration paths in the vehicle. The main comparison used vertical acceleration from sprung-mass and unsprung-mass locations at the front and rear of each vehicle. This arrangement allowed the response of the vehicle body and wheel assembly to be compared under the same road excitation. Testing was conducted over highway and urban routes during a long-distance road campaign of approximately 2,000 km, covering routes such as Pagoh-Ipoh-Kuala Perlis, Kuala Perlis-Jeli-Kuala Terengganu, Kuala Terengganu-Kuantan-Johor Bahru and Johor Bahru-Pagoh.

3. Result and Discussion

First, the raw acceleration was inspected to observe the direct time-domain vibration response. Second, RMS acceleration was calculated to quantify vibration severity. Third, ISO 2631-1 comfort categories were used to interpret passenger comfort. Finally, PSD analysis was applied to identify dominant frequency components and road-induced vibration energy.

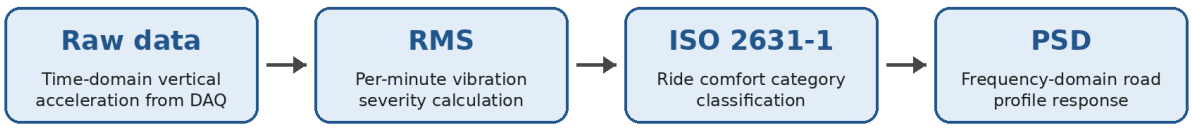


Figure 2 Placement of the Graph Workflow

Figure 3 shows the overall graphical analysis flow used for each highway and urban route in this study. The analysis consists of four main graphs: raw acceleration data, RMS acceleration, ISO 2631-1 ride comfort classification, and Power Spectral Density (PSD) analysis. The raw data graph presents the original vibration response recorded from the DAQ system, while the RMS graph quantifies the vibration magnitude over time. The ISO graph classifies the ride comfort level based on RMS acceleration, and the PSD graph identifies the dominant vibration frequency and road profile response. As a representative example, Figure 3 illustrates the complete analysis flow for Highway Route 1.

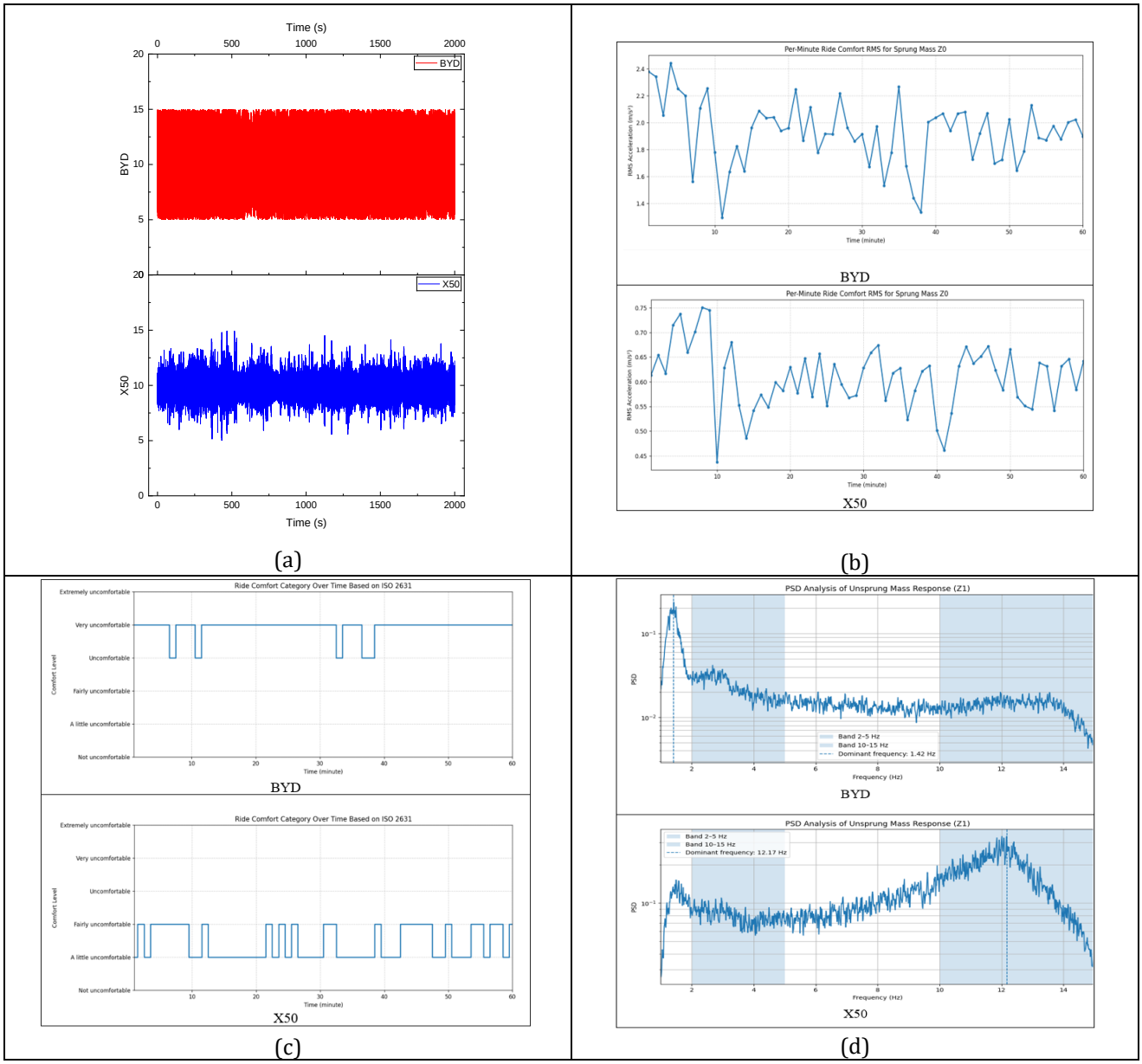


Figure 3 Representative graph flow for one route: (a) raw acceleration, (b) RMS, (c) ISO 2631-1 comfort classification and (d) PSD response

The RMS acceleration results show clear differences between the two vehicles. On highway routes, the Proton X50 recorded lower sprung-mass RMS values than the BYD Atto 3 on Routes 1 and 3. Route 2 was the main exception, where the Proton X50 showed higher RMS values, indicating that a specific highway road profile may have excited its suspension or unsprung-mass response more strongly.

Table 3 Overall RMS Comparison on Highway Routes

Route	Vehicle	RMS range (m/s2)	Approx. avg. (m/s2)	ISO Level
Route 1	BYD Atto 3	0.2-3.0	~1.8	Very uncomfortable
Route 1	Proton X50	0.2-1.0	~0.55	Fairly uncomfortable
Route 2	BYD Atto 3	0.5-3.0	~1.7	Very uncomfortable
Route 2	Proton X50	1.4-2.7	~2.0	Very uncomfortable
Route 3	BYD Atto 3	1.4-2.4	~1.9	Very uncomfortable
Route 3	Proton X50	0.45-0.75	~0.58	Fairly uncomfortable

For urban roads, the Proton X50 consistently showed lower RMS acceleration than the BYD Atto 3. The X50 average values remained approximately between 0.55 and 0.70 m/s2, while the BYD average values were

approximately between 2.0 and 2.3 m/s2. This indicates lower vibration transmission to the vehicle body for the Proton X50 under stop-and-go, uneven and low-speed urban conditions.

Table 4 Overall RMS Comparison on Urban Routes

Route	Vehicle	RMS range (m/s2)	Approx. avg. (m/s2)	ISO Level
Route 1	BYD Atto 3	0.0-5.0	~2.0	Extremely uncomfortable
Route 1	Proton X50	0.2-1.4	~0.70	uncomfortable
Route 2	BYD Atto 3	1.5-4.7	~2.3	Extremely uncomfortable
Route 2	Proton X50	0.1-1.2	~0.62	Fairly uncomfortable
Route 3	BYD Atto 3	0.0-5.0	~2.1	Extremely uncomfortable
Route 3	Proton X50	0.1-1.4	~0.55	Fairly uncomfortable

Based on ISO 2631-1 interpretation, lower RMS acceleration corresponds to lower vibration exposure and therefore better ride comfort. The Proton X50 was mainly within the fairly uncomfortable range during most tests, while the BYD Atto 3 frequently reached uncomfortable to very uncomfortable levels, particularly in urban routes. This suggests that the X50 suspension and body response were more effective at isolating vertical road inputs in most tested conditions.

Table 5 Average PSD Comparison

Road type	Route	X50 average PSD	BYD average PSD
Highway	1	0.11772	0.02129
Highway	2	0.02129	0.02036
Highway	3	0.10072	0.02312
Urban	1	0.10148	0.01840
Urban	2	0.12604	0.02754
Urban	3	0.13628	0.02459

The PSD results indicate that the Proton X50 produced higher average PSD values on most routes, especially on Highway Routes 1 and 3 and all urban routes. This suggests a stronger vibration energy response to the same road excitation. In contrast, the BYD Atto 3 showed lower and more consistent PSD values, indicating a more stable frequency-domain response and reduced high-frequency vibration transmission.

4. Conclusion

This technical paper compared the dynamic response of a BYD Atto 3 EV and a Proton X50 ICE vehicle using an experimental DAQ-based method. A low-cost DAQ system consisting of an Arduino UNO, four ADXL345 accelerometers, a TCA9548A multiplexer, DS3231 RTC and SD card logger was successfully applied to collect vehicle vibration data under real Malaysian highway and urban road conditions.

The RMS results indicate that the Proton X50 generally offers better ride comfort, particularly in urban driving, where its average RMS acceleration was approximately three to four times lower than the BYD Atto 3. Nevertheless, the PSD analysis shows that the BYD Atto 3 maintained lower and more consistent average PSD values, indicating lower high-frequency vibration transmission and a more stable frequency response. Therefore, the Proton X50 is more favourable in terms of ride comfort, while the BYD Atto 3 shows advantages in frequency-domain stability. The developed DAQ method is suitable as an economical platform for future EV and ICE vehicle dynamics studies, although further work should use more vehicle models, controlled road profiles and higher-resolution sensors for improved generalisation.

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