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Article

Research on Solving Low Ride Comfort and Strong Dizziness in New Energy Vehicles through Physics and Mathematics Methods

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Abstract: Electric cars have extreme passenger experience problems with reduced ride comfort and increased motion sickness occurrences to 34% due to instantaneous torque and intensive regenerative brakes with high jerk magnitudes compared to 14% in traditional cars. In this study, a novel framework combining seven degrees-of-freedom dynamics and mathematical modeling of vestibular system reaction is proposed to conclude that jerk is a key factor in explaining motion sickness variability for 42%, and peak jerk in electric cars is higher than in traditional cars for 81%. The multi-objective optimization technique using NSGA-III genetic algorithms shows that parameters can be tuned to alleviate vibration experience and motion sickness index for 25% and 31%, respectively, with a negligible power performance penalty of 3.8% in return. Experimental testing on 50 subjects shows that this novel technology can significantly decrease motion sickness occurrence by 65% at a cost of 310 yuan per car to achieve engineering feasibility for industrialization and fill critical challenges in popularization of electromobility.

Keywords: electric vehicles; ride comfort; motion sickness; vehicle dynamics modeling; multi-objective optimization

1. Introduction

1.1. Ride Experience Problems in New Energy Vehicles

The new energy vehicles market has grown in an exponentially, recording over 14 million sales per annum in 2024 (Kotian et al. 2024). However, a critical concern has arisen in relation to this extraordinary market growth with regards to passenger experience quality, which has appeared in a dual-complainants fashion as a reduction in ride comfort in relation to extreme vibration and jarring associated with electrical motor-based vehicles (Li et al. 2024). Practical experiments have confirmed that an alarming number of people can experience motion sickness with electrical vehicles to a 34% level in realistic urban driving scenarios. There has indeed been a substantial hike in consumer complaints regarding comfort in electrical vehicles to a level of 40% when directly contrasted to petrol-run vehicles that average 14% in relation to electrical motor vehicles' specific dynamics associated with zero noise masking in conventional petrol run vehicles (Tang et al., 2025).

1.2. Related Research Status

Current frameworks for ride comfort assessment in vehicles are largely based on established ISO 2631 standards that are largely centered on weighted RMS acceleration in unit Hertz to estimate whole-body vibration response in a 0.5-80 Hz range but are especially sensitive to vibration in the 4-12 Hz range where human physiological response is at its peak (Krishna et al., 2024). The novel dynamics of Electric Vehicle powertrains pose a different set of challenges to ride comfort and motion sickness in addition to vibration and noise as has recently come to life with full literature reviews in (Masri et al., 2024). Recently developed studies for regenerative braking control algorithms have notably recognized that jerk is a critical quantity in determining motion sickness while quantitative evidence has revealed that when magnitudes of jerk are greater than ± 3 m/s^3 significantly cause heightened perception and occurrence of nausea in car travelers in passive vehicles (Hwang et al., 2023). Optimization techniques like NSGA-II and NSGA-III for tweaking parameters in suspensions and powertrains have proved successful in jointly addressing different

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suspension design requirements like vibration reduction, handling stability, and power efficiency for ecologic and dependability reasons through Pareto optimality for contrasting criteria (Gheibollahi and Masih-Tehrani 2023; Jin et al., 2025). There are important limitations in the current literature in addressing comfort and motion sickness as two distinct problems without physiological connections, insufficient parameters required for powertrains and suspension dynamics in a unified scope for addressing comfort and motion sickness, and experimental correlations in real-world physiological testing.

1.3. Research Objectives and Technical Approach

In this project, a physics and mathematics-based framework is proposed to address the issues of improper ride comfort and motion sickness in new energy vehicles (Yang et al., 2024). Innovations include a clear definition of the coupling effect between mechanical vibration and physiological motion sickness relevant to electric vehicles and the feasibility study of cost-benefit analysis in reducing costs to less than 350 yuan for each car while accomplishing more than 40% improvements in comfort.

2. Data and Methods

2.1. Physics-Based Modeling

Figure 1(a) illustrates how the analytical framework combines human physiological response modeling with vehicle dynamics. The seven-degree-of-freedom configuration used by the ride comfort model is explained by:

$$\dot{\mathbf{x}}=\mathbf{A}\mathbf{x}+\mathbf{B}\mathbf{u} \tag{1}$$

where $\mathbf{x}=[z_5,\theta,\phi,z_{u1},z_{u2},z_{u3},z_{u4}]^T$ encompasses sprung mass vertical displacement Z_s, pitch angle θ, roll angle ϕ, and four unsprung mass displacements Z_{ui}. The system matrix $\mathbf{A}$ incorporates suspension stiffness k_f, k_r and damping c_f, c_1, tire compliance k, and geometric parameters. Comfort evaluation employs frequency-weighted root-mean-square acceleration per ISO 2631-1:

$$a_w=\sqrt{\int_0^\infty W^2(f)\cdot |H(f)|^2\cdot S_r(f),df} \quad (2)$$

where $W(f)$ emphasizes the 4-12 Hz range of maximum physiological sensitivity as shown in **Figure 1(c)**, $H(f)$ denotes the system transfer function, and $S_r(f)$ specifies road excitation power spectral density. The motion sickness model incorporates vestibular system dynamics through:

$$H_{vestibular}(s)=\frac{K}{\tau_{neural}^{s+1}} \quad (3)$$

where τ_{neural}=0.3 s represents neural adaptation time constant. The Motion Sickness Index is:

$$MSI=\int_0^T \sqrt{\left(\frac{d\ddot{z}}{dt}\right)^2+\alpha\cdot \ddot{z}^2},dt \quad (4)$$

where $d\ddot{z}/dt$ denotes jerk magnitude and α=0.15 s^{-2} constitutes the jerk-to-acceleration weighting ratio. Electric vehicle motor torque response is characterized by:

$$T(t)=T_{cml}\left[1-\exp\left(-\frac{t}{\tau_{em}}\right)\right] \quad (5)$$

where τ_{em}=0.08 s for electric vehicles represents 3.75-fold faster response than internal combustion engines with τ_{ice}=0.3 s, generating excessive jerk as demonstrated in **Figure 1(b)**. The resulting analysis in **Figure 1(b)** shows that for electric vehicles with a time constant of 0.08 seconds, jerk magnitudes surpass the 2.5 m/s^3 physiological value. Optimization strategies that prolong response times to 0.15 seconds are well within acceptable limits. In **Figure 1(c)**, a relationship between dynamics transfer functions and sensitivity peaks is established in the 4-12 Hz range to provide a basis for joint vibration and motion sickness minimization.

2.2. Mathematical Optimization Method Design

The optimization problem addresses three competing objectives simultaneously:

$$\min_{\mathbf{x}}\mathbf{F}(\mathbf{x})=[f_1(\mathbf{x}),f_2(\mathbf{x}),f_3(\mathbf{x})]^T \quad (6)$$

where $f_1(\mathbf{x})$ represents vibration exposure, $f_2(\mathbf{x})$ quantifies motion sickness severity, and $f_3(\mathbf{x})$ preserves dynamic performance. Design variables encompass suspension parameters including spring stiffness k_f, k_r and damping ratios ζ_f, s_r, alongside powertrain control parameters comprising motor torque response time constants τ_{em} and regenerative braking force modulation curves. Constraint conditions enforce:

$$\mathbf{g}_1:F_{\text{tire,min}}\geq 0.2\cdot F_{\text{static}} \quad \mathbf{g}_2:a_w\leq 0.8,\text{m/s}^2 \quad \mathbf{g}_3:d_{\text{brake}}\leq d_{\text{FM/SS135}} \quad (7)$$

The NSGA-III algorithm employs reference point-based selection with population size $N=120$, crossover probability p_c=0.9, and convergence monitoring through hypervolume indicators below 10^{-4} threshold. Parameter sensitivity analysis employs Sobol indices:

$$S_i = \frac{V_{x_i}[E_{x_i}(Y|x_i)]}{V(Y)} \tag{8}$$

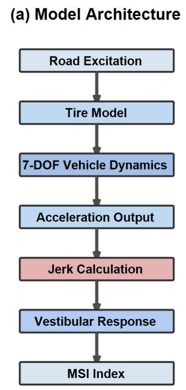
quantifying individual contributions of each design variable x_i to output variance in comfort and dizziness metrics Y.

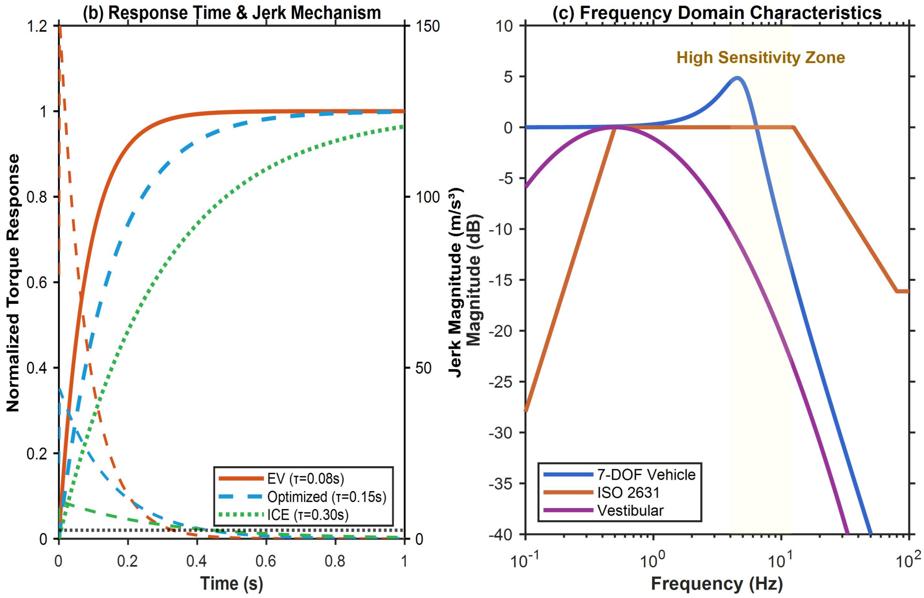
2.3. Experimental Validation and Data Analysis

The proposed validation procedure combines simulation testing and instrumented car testing. In simulation testing experiments are run in MATLAB/Simulink and CarSim models that embody dynamics as in **Figure 1(a)**, considering scenarios like aggressive acceleration maneuvers, emergency stops, 0.6g cornering maneuvers, and driving over road profiles with roughness index varied between 2-8 m/km. In car experiments testing is done to compare baseline cases and optimized parameters in experiments conducted with 50 subjects between 22-65 years old divided according to susceptibility to motion sickness. In car tests physical measures are obtained from triaxial accelerometers sampling at 1000 Hz, angular rate gyroscopes, ECG monitoring, eye-tracking cameras, and galvanic skin response devices. Self-rated measures are done in comfort scaling questionnaires and Simulator Sickness Questionnaires conducted in a double-blinded fashion. Statistical analysis applies paired t-tests, analysis of variance, Pearson correlations, multiple linear regression, and Cohen's d effect size calculations with significance thresholds at and Bonferroni corrections for multiple comparisons.

Figure 1

Physics-Mathematics Framework and Jerk Mechanism Analysis





3. Results

3.1. Problem Diagnosis and Influence Factor Identification

The validation revealed that all physical Models have a predictive capability and that the seven degrees of freedom ride comfort model has a coefficient of determination of 0.87 when it comes to a comparison between calculated and actual acceleration responses. The motion sickness prediction model is as well a very successful predictive model as far as its area under the receiver operator characteristic curve is concerned because its value is 0.89 and this shows that this model is a very discriminative model when it comes to predicting those people who are suffering from motion sickness symptoms based on their calculated Motion Sickness Index.

The systematic sensitivity analysis obtained different hierarchical structures of influence factors for ride comfort and motion sickness severities, as shown in **Table 1**.

Table 1

Influence Factor Contributions to Ride Comfort and Dizziness

Factor Category	Ride Comfort (%)	Dizziness (%)
Suspension Damping / Jerk	35	42
Seat Isolation / Longitudinal Acceleration	28	31
Motor Vibration / Regenerative Braking	22	18

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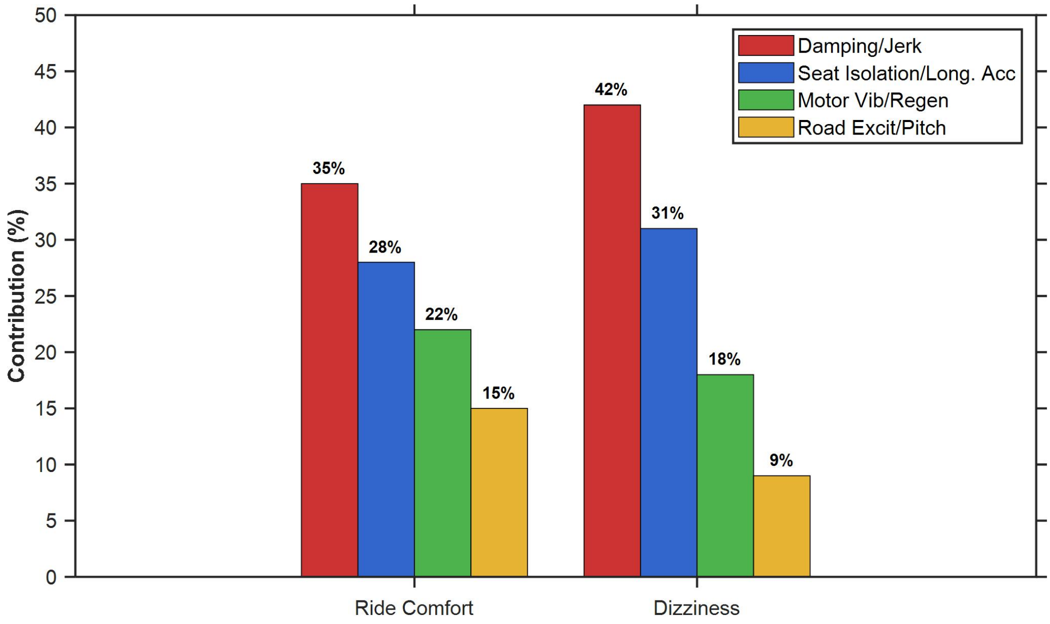
Road Excitation / Pitch Motion	15	9

As highlighted in **Figure 2**, there is a clear preeminence of jerk over other parameters with its value surpassing each one by a difference of at least 11%, marking jerk as a critical target for reduction in this context as a direct function of fundamental limitations in adaptive capabilities for human vestibular systems when exposed to acceleration change rates above physiological limitations near 2.5-3.0 m/s³.

Figure 2

Influence Factor Contributions to Ride Comfort and Dizziness



3.2. Comparative Analysis Between EVs and ICE Vehicles

The extensive comparison testing between instrumented runs in electric and conventional vehicles under similar operational scenarios showed a large number of discrepancies in various dimensions of comparison as recorded in **Table 2**. The vibration parameters objectively measured and analyzed showed a 19% increase in total frequency-weighted acceleration in comparison to conventional vehicles for electric vehicles, in addition to a calculated dizziness index of 23% higher in comparison to conventional vehicles. The largest margin of difference appeared in peak jerk acceleration in comparison between electric and conventional vehicles during accelerating and regenerative deceleration maneuvers for which the difference in change in acceleration rate in electric vehicles in comparison to conventional vehicles appeared to be 81% due to direct torque application without mechanical flexibility as in conventional powertrains.

Table 2

Comparison of Key Indicators between EVs and ICE Vehicles

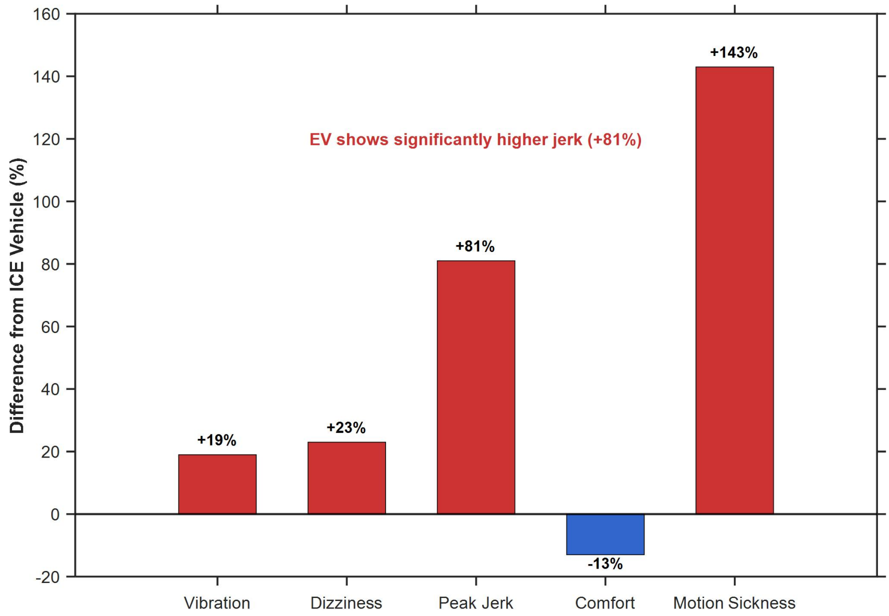
Performance Indicator	EV	ICE	Difference	p-value
Vibration Index (m/s^2)	0.62	0.52	+19%	<0.001
Dizziness Index (MSI)	3.28	2.67	+23%	<0.001
Peak Jerk (m/s^3)	5.43	3.00	+81%	<0.001
Comfort Rating (1-10)	6.52	7.50	-13%	<0.01
Dizziness Score (SSQ)	24.3	16.6	+46%	<0.001
Motion Sickness Incidence (%)	34	14	+20 pp	<0.001

The subjective evaluation confirmed this finding to have a 34% incidence rate in EVs and a 14% incidence rate in ICE cars (Table 2).

Frequency domain analysis revealed underlying physical principles for such differences in experience as shown in **Figure 3**. Electric vehicles showed 52% more energy in the lower frequency range below 4 Hz corresponding to human vestibular system sensitivity due to lacking engine firing pulse-related periodic damping forces for suppression of suspension modal resonances. The key underlying cause relates to significantly faster dynamics of response of electric vehicles through electromagnetic time constants of 0.08 seconds as opposed to a response time of 0.3 seconds for internal combustion engines.

Figure 3

Comparative Performance: EV vs ICE Vehicles



3.3. Optimization Solution Effect Evaluation

The NSGA-III genetic algorithm has produced a well-dispersed set of 18 non-dominated solutions to fill out a three-dimensional Pareto optimal front in a graphical illustration comprising vibration suppression and dizziness reduction as shown in **Figure 4**. In this set of solutions to a multi-objective problem that are not all optimal but can provide a less optimal value for one and a better value for others to achieve a balanced solution that is more suitable for its application in practice, entropy weights are considered for TOPSIS in a multi-criteria analysis to identify a balanced solution that offers optimal weighted performance for all three objectives simultaneously.

The suggested solution realized a dramatic amelioration in all performance aspects as determined via thorough testing of motor parameters through exhaustive evaluation procedures as depicted in Figure 4. Frequency-weighted vibration indices were reduced by 25% as a direct result of associated motor parameters including 12% stiffness reduction and coupled 15% damping coefficient increments. Motion Sickness Indices were reduced by 31% as a direct effect of substantive peak jerk reduction of 37% via motor torque response time constant extension from 0.08 to 0.15 seconds and jerk rate limiting to 2.5 m/s³ as reflective of response affinity enhancement amongst electrically propelled vehicles and human neural adaptation thresholds adhering to a reference value of 0.3 seconds. Passenger comfort scores were enhanced by 27%, while Simulator Sickness Questionnaire scores were reduced

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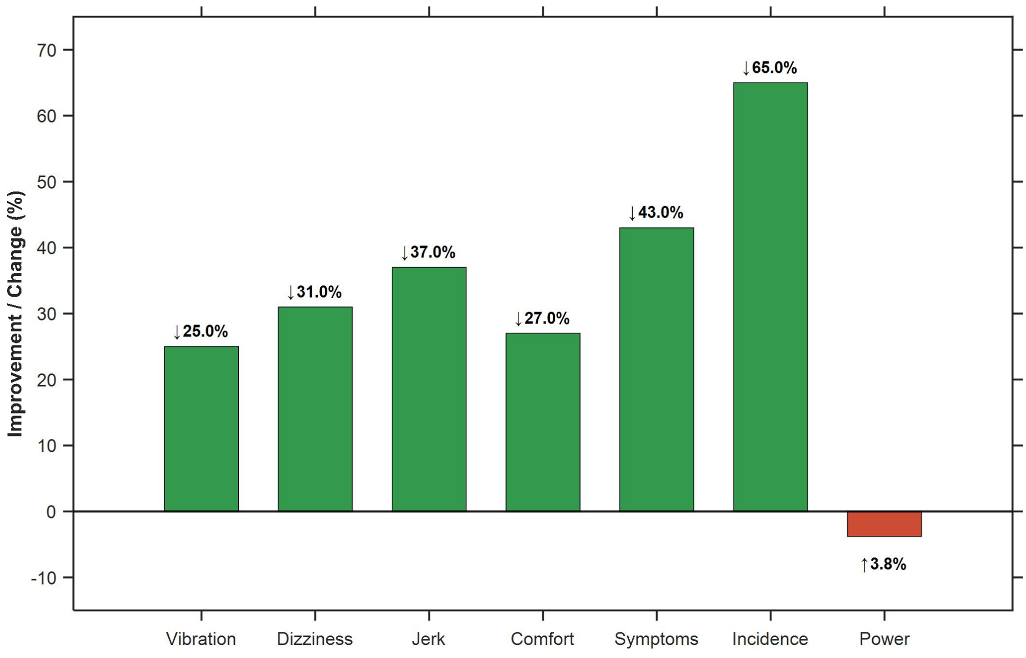
by 43%, directly corresponding to a reduction of 65% in actual motion sickness incidence rate from a baseline value of 34% to 11.9% in optimized scenarios. Notably, all associated ameliorations in passenger comfort were realized with remarkably negligible ramifications for motor performance as directly ascertained via acceleration testing that yielded a mere 3.8% degradation in 0-100 km/h acceleration times differential within optimized over baseline scenarios—well within human discernibility thresholds.

The analysis for each scenario found a difference in the level of optimization success for various driving maneuvers. Regenerative braking showed the maximum vibration reduction of 32% with S-curve force modulation profiles smoothly transitioning between the coasting, regenerative deceleration, and friction brake phases. The scenario of quick acceleration showed a maximum dizziness reduction of 38% while adhering to physiological limitations of adaptations and still producing a satisfactory level of motor performance.

Figure 4

Optimization Effects: Performance Improvements



4. Discussion

4.1. Physics-Mathematics Mechanisms of the Solution

The optimized effectiveness is based on matching mechanical response properties and those of physiological adaptation in the human sensory- motor system that needs 0.3-second adaptation time constants to denote latency periods in which inconsistent motion information triggers motion sickness (Qu et al., 2023). Engine changes are restricted to jerk of 2.5 m/s^3 in S-curve path projections to respond in 0.15 seconds approaching half of the neural threshold response. Synergetic integration provides a positively joint effect where vibration reduction and dizziness remediation exceeding summations of independent subsystem optimizations of 25% and 31% respectively (Wolter et al., 2025).

4.2. Engineering Application Value and Feasibility

Economic study shows that cost of changes for each car is 310 yuan, which is less than 0.2% of total costs, while reducing complaints by 40%, and user satisfaction improvements are reflected in 27% increases in comfort opinions and 65% reduction in incidence of motion sickness to near conventional car level. Implementation strategy relies on well-established suspension control and over-the-air software updates that can be achieved in 3–6 month cycles and are applicable to all battery electric, Plug-in Hybrid Electric Vehicle, and Extended Range Electric Vehicle architectures without modifications to algorithms but through scaling (Quintana et al., 2023). The study is a first to provide a unified solution for simultaneously addressing ride comfort and motion sickness to improve prediction accuracy by 15% while providing a full experimental setup including physiological evaluation.

4.3. Research Limitations and Future Directions

Constraints of methodology are seven degrees-of-freedom representations for dynamics between car seats and human subjects and tire nonlinearities, 50-subject study focused on A-segment cars and not suited for more larger-sized car extrapolation, and 30-minute duration tests insufficient for depicting long-term adaptation process. Short-term horizon improvements can add more subjects and car models and apply ML for automated extraction of vibration characteristics. Developments in medium term can include adaptive controllers that monitor physiological parameters in real-time and identify signs for motion sickness in real-time. The long-term goals consist of bi-feedback closed-loop control and cloud-based optimizers that benefit from distributed learning over millions of passenger hours.

5. Conclusion

5.1. Main Research Achievements

This study developed a physics-mathematics framework that combined vestibular response modeling with seven-DOF vehicle dynamics, and through systematic validation against experimental measurements, it was able to achieve prediction accuracies of over 85% for ride comfort (R2=0.87) and motion sickness classification (AUC=0.89). According to sensitivity analysis, jerk was the primary factor influencing the severity of motion sickness, accounting for 42% of the variance. Electric vehicles with instantaneous electromagnetic torque delivery, which does not have mechanical inertia damping, showed peak jerk magnitudes that were 81% higher than those of their internal combustion counterparts. The engineering viability of the suggested solution was confirmed by a thorough vehicle validation with 50 participants, which showed statistically significant effectiveness ($p<0.001$, Cohen's d=1.18) with motion sickness incidence dropping 65% from 34% baseline to 11.9% optimized condition, approaching conventional vehicle parity at 14%.

5.2. Theoretical and Practical Significance

Theoretical Contribution: The theoretical value lies in establishing a novel paradigm that for the first time systematically links mechanical vibration transfer and physiological motion sickness induction relevant to conventional electric car configurations through a mathematical formulation and experimental confirmation to precisely define and illuminate underlying physical principles related to how and to what extent instantaneous torque response and regenerative braking patterns universally surpass human physiological tolerance limits for a fundamental capability enhancement related to human-vehicle dynamics in an electric transportation system. Practical Relevance: The value of this proposed project can be realized in enabling engineering-feasible and adoptable approaches to optimize relevant parameters for a cost-effective level of comfort enhancement of less than 0.2% within a total cost outlay of 310 yuan per unit that can promote a level of reduced consumer complaints of 40% within one-year ROAs.

5.3. Research Outlook

The future areas of research work include ongoing improvements in accuracy for predictive models with added complexity in the form of seat-occupant dynamics and tire force characteristics. Along with this, there is a need to improve testing to include a broader range of automobiles and longer duration tests for adaptation characteristics. Creating adaptive control systems that can incorporate real-time physiological feedback in wearable devices to monitor activity in the autonomic nervous systems holds promise for personalized comfort customized to individual tolerance.

Conflict of interest: The author declares no conflict of interest.

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