

Letter from the Guest Editors

Focus Issue on Active Wheel-Corner Technologies and In-Wheel Motors

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Electrification has reopened one of the oldest design spaces in automotive engineering: the wheel corner. For most of the last century, the corner was a largely passive assembly of hub, brake, spring, damper, and steering knuckle, and its behavior was fixed at the design stage. Removing the central powertrain and the mechanical driveline changes that. When traction, braking, steering, and suspension can each be actuated independently at the wheel end, the corner becomes an active and addressable subsystem, and the vehicle becomes an over-actuated plant with far more control authority than a conventional chassis can offer. In-wheel motors (IWMs) and integrated wheel-corner modules are the technologies that make this possible, and this focus issue of the *SAE International Journal of Vehicle Dynamics, Stability, and NVH* is devoted to recent advances in both.

The case for moving propulsion and chassis actuation into the corner rests on four broad arguments:

- **Packaging and architectural freedom.** Eliminating the central motor, gearbox, and driveshafts releases interior and crash-structure volume, and it allows a single modular corner to be reused across platforms and body styles.
- **Direct and independent wheel torque control.** Each wheel can be driven or braked on demand at a bandwidth that no differential-based driveline can match, which makes torque vectoring, slip control, and yaw stabilization continuously available rather than occasional interventions.
- **Cross-domain redundancy.** An over-actuated corner can compensate across functions, so that steering can substitute for a failed brake and drive torque can substitute for a failed steering actuator. Fault tolerance becomes a control allocation problem rather than a hardware duplication problem.
- **New degrees of freedom for ride and NVH.** Active and semi-active corner elements can be coordinated with drive torque to shape ride, pitch, and vibration rather than only to react to them.

History

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These benefits also come with several challenges. Unsprung mass rises, and with it the coupling among wheel-hop dynamics, dynamic tire load, and ride quality. Electromagnetic excitation introduces vibration and noise sources at the point in the structure least able to absorb them, and thermal management is constrained by the same limited volume that made the packaging attractive in the first place. Reliability requirements tighten once a mechanical fallback path no longer exists. The control problem also becomes harder, because subsystems that are each well designed in isolation can work against one another when several actuators serve overlapping objectives near the limit of adhesion.

Our call for papers therefore invited contributions across the full span of the topic: the design and control of in-wheel motors, wheel-corner module architectures, vehicle dynamics and stability, NVH performance, and system integration, reliability, and health management. The response was strong, and the 10 articles collected here address mechanism synthesis, state estimation and fault diagnosis, single-domain and cross-domain control allocation, energy-optimal torque distribution, and the state of the art itself. The breadth of validation is equally notable. Alongside offline simulation, readers will find multi-domain co-simulation, component testing, test bench experiments, hardware-in-the-loop studies, and full vehicle trials, which suggests that wheel-corner technology is moving out of the concept stage and into engineering practice.

Sonnino et al. opened the issue with a fault-tolerant control strategy for active wheel-corner systems that uses four-wheel independent steering (4WIS) to counteract the yaw disturbance produced by a brake failure at one corner. The distinguishing feature of the approach is that it does not depend on prior fault detection or fault quantification, which removes the delay and uncertainty associated with diagnosis. Corrective steering is generated against a reference model of yaw rate and sideslip angle that accounts for combined longitudinal and lateral dynamics, and a weighted pseudo-inverse control allocation distributes the correction across the four steering angles according to the capability of each tire. Simulated cornering maneuvers with a complete failure of the outer front brake show that steering redundancy alone recovers much of the intended vehicle response, which positions 4WIS as a complement to braking and torque vectoring in the fault-tolerance toolbox.

de Carvalho Pinheiro et al. addressed a gap that affects a large part of the torque vectoring literature: controllers are usually assessed on vehicle models that neglect the powertrain that has to deliver the commanded torques, so the trade-off between handling and energy consumption never appears. Six strategies, comprising PID, LQR, two first-order sliding mode controllers, and

two second-order sliding mode controllers, are benchmarked on a multi-domain platform that couples a 14-DOF vehicle model with electro-thermal models of the motors and the energy storage system. The comparison quantifies the trade-off. The LQR and suboptimal second-order sliding mode controllers achieve the best yaw rate tracking and stability but incur a measurable energy penalty, while the PID and continuous first-order sliding mode controllers offer a more balanced compromise between precision and efficiency.

Gad et al. turned to the ride penalty that in-wheel motors impose. Their contribution combines an optimal Kalman filter for a magnetorheological (MR) semi-active suspension, which correlates the road inputs at the front and rear wheels and so exploits wheelbase preview, with an experimental study of the spring element itself. Three coil spring types, of constant pitch, variable pitch, and conical geometry, were characterized on a computer-controlled universal testing machine and evaluated in combination with the MR damper. Comparing passive, uncorrelated, and correlated configurations, the authors identify motor vertical acceleration and dynamic tire load as the dominant contributors to degraded behavior and show that the correlated MR-controlled system with a conical spring recovers both ride comfort and dynamic stability.

Gao et al. took the corner module in an unusual direction, toward rough-terrain mobility, where high load-bearing capacity and long suspension travel have to coexist. Drawing on the skeletal-muscular system of the equine leg, they established a structure-function mapping between the biological and the mechanical system, then applied topology graph-based synthesis to generate and optimize a configuration atlas of multi-loop closed-chain wheel-legged mechanisms. The selected configuration is combined with a biomimetic vibration isolation system, steering, and a hub motor to form a reconfigurable corner module that can switch between wheeled locomotion and legged gait. The module is then realized as a modular transporter whose vibration reduction performance and locomotion modes are verified by multibody dynamic simulation.

Peng et al. confronted the actuator interaction problem directly. In corner module vehicles, the decoupling of driving, braking, steering, and suspension raises the handling ceiling, but near the limit the subsystems begin to work against one another. The proposed hierarchical hybrid game formulation treats direct yaw moment control (DYC) as the leader and active rear steering (ARS) as the follower in a Stackelberg game, then places the combined DYC–ARS system and the active suspension system in a non-cooperative game solved iteratively for the Nash equilibrium. The lower level allocates tire and suspension forces so as to minimize both the overall and

the maximum tire utilization rate, preserving adhesion margin. Test bench experiments under a low-adhesion double lane change and a medium-adhesion J-turn confirm improved path tracking accuracy and handling stability.

Meléndez-Useros et al. applied deep reinforcement learning to energy-optimal torque splitting in dual-motor electric vehicles. Two Deep Deterministic Policy Gradient agents are trained with different reward formulations, one power-based and one based on state of charge, under a deliberate constraint: the policies may use only standard CAN bus signals, the commanded longitudinal force, and the motor speeds, so that no specialized sensing or plant model is required. Validated in high-fidelity CarSim–Simulink co-simulation across soft, medium, and severe acceleration scenarios, the learned strategies come within a fraction of a percent of the theoretical optimum in consumption and recover a substantially higher share of braking energy than a conventional adaptive baseline, without imposing a heavy computational load on existing electronic control units.

He et al. proposed a coordinated strategy for distributed drive electric vehicles that reconciles two objectives, which typically compete under aggressive maneuvering, namely accurate path tracking and lateral stability. Model predictive control computes the front steering commands from the vehicle dynamics and the preview error, while dual feedback controllers generate an additional yaw moment for yaw rate and sideslip regulation. The balance between the two is adjusted adaptively through a phase-plane coordination mechanism, so that stability intervention grows as the vehicle state approaches the boundary of the stable region. The resulting yaw moment is distributed to the individual in-wheel motors by an optimization-based torque allocation that respects tire force limits. Hardware-in-the-loop double lane change experiments show better path following and yaw stability than conventional methods.

Fuse et al. examined an architecture that sits between a conventional driveline and full individual-wheel drive. A two-motor torque difference amplification mechanism (TDA-TVD) can generate a larger left-right torque difference than an individual-wheel-drive system, but its two resonance modes make it difficult to control. Building on earlier work that modeled the mechanism in the frequency domain and derived anti-vibration feedforward torque controllers based on average-differential coordinate transformation, the authors close the loop. The slip ratio control loop is modeled in the frequency domain, a parameter determination method is established, and several slip ratio control strategies are proposed according to the driver's request. Experiments on a real vehicle equipped with a TDA-TVD on slippery surfaces compare the

proposed controllers with conventional ones and analyze the effectiveness of each strategy.

Xiao et al. addressed the reliability question that a fully by-wire corner unavoidably raises. For an Active Wheel-Corner vehicle with four-wheel independent steering and four-wheel independent drive, they proposed a hierarchical active fault-tolerant control strategy based on fault information reconstruction. An adaptive observer combined with the Dugoff tire model estimates the nonlinear tire forces, and a fault effectiveness factor grades the severity of a steering fault quantitatively rather than treating it as a binary event. At the upper level, adaptive super-twisting sliding mode control determines the generalized forces required to hold the desired trajectory under the identified fault. At the lower level, a fault-aware model predictive controller adjusts its weighting matrices according to the effectiveness factor and the reconstructed tire stiffness, coordinating four-wheel drive allocation with the steering of the healthy wheels. Both hardware-in-the-loop simulation and real vehicle tests are reported.

Guo et al. closed the issue with a critical review of in-wheel motor systems, which places the preceding contributions in a wider setting. The article traced the development history of IWMs, classified current machines by air-gap flux direction and topological structure with a comparative analysis of their performance characteristics, and examined the coupled dynamic effects of IWMs on vehicle dynamics, separating internal from external excitation sources. Structural optimization approaches for vibration reduction and heat dissipation are then discussed, followed by a survey of control technologies organized along three axes of vehicle performance, namely NVH, stability, and economy, and a discussion of where the technology is likely to go next.

Read together, these articles suggested several things about where the field now stands. Fault tolerance has become a central rather than a peripheral concern, and the three contributions that treat it arrived at a common conclusion from different directions: the redundancy inherent in an over-actuated corner is best exploited through control allocation rather than through duplicated hardware. Energy is increasingly treated as a first-class objective alongside handling instead of something to be checked afterward. The methodological toolbox has broadened, with game theory, reinforcement learning, and biomimetic-type synthesis appearing alongside the established predictive and sliding mode formulations. And the level of validation has risen, with bench tests, hardware-in-the-loop platforms, and full vehicle experiments now the norm rather than the exception.

What remains open is equally clear. Thermal behavior and durability under realistic duty cycles, the NVH of the corner as an assembled system rather than of the motor

alone, calibration and diagnostic methods that scale to a fleet, and the cost and manufacturability questions that ultimately decide adoption all deserve more attention than they have received so far. We hope this issue sharpens those questions as much as it answers others.

We thank the authors for entrusting their work to this focus issue, the reviewers for their careful and timely assessments, and the Editor-in-Chief and the editorial staff of the *SAE International Journal of Vehicle Dynamics*,

Stability, and NVH for their support throughout. We hope that readers find the collection a useful account of a field that is changing quickly.

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