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Advanced Control Strategies for Electric Vehicle Differential Systems – A Review

Mueen Ahmad Khan[1], Dr. Satyendra Sharma[2]

[1]PG scholar, Department of Mechanical Engineering, SAGE University, Indore
[2]Associate Professor, Department of Mechanical Engineering, SAGE University, Indore

ABSTRACT

The integration of Electronic Differential (e-Diff) technology in Electric Vehicles (EVs) is a significant stride in automotive engineering. This project aims to replace conventional mechanical differentials with a streamlined electronic counterpart for EVs. The prime objective is to supplant bulky traditional mechanisms, addressing inherent limitations and offering improved performance, reduced noise, and lower maintenance. By seamlessly integrating electronic control systems, the proposed e-Diff seeks to overcome challenges tied to mechanical differentials. Through innovative design and precise control algorithms, it promises enhanced handling, stability, and traction control for EVs. Additionally, it anticipates notably reduced noise compared to mechanical counterparts, contributing to a quieter driving experience. Key findings stem from an extensive experimental setup, using dual speedometers to monitor wheel speeds and an indicator light system for real-time feedback. By meticulous evaluation and performance comparison, this study underscores the e-Diff technology's efficacy in addressing crucial challenges while enhancing the overall driving encounter for EVs. Ultimately, the Electronic Differential introduces a substantial leap towards optimizing EV performance. This project underscores e-Diff's potential to redefine automotive engineering, offering an efficient, quieter, and maintenance-friendly alternative. The findings advance knowledge in electric mobility and affirm ongoing innovation in the automotive sector.

Keywords - Zero Radius Turn, Vehicle, Animal Detection Sensor, Voice Control, Manoeuvrability, Safety, Prototype, Urban Mobility.

1. INTRODUCTION

In the realm of automotive mechanics, a differential gear system plays a crucial role. It facilitates the transfer of power from an engine to a pair of driving wheels while ensuring an equitable distribution of force between them. This mechanism is pivotal for accommodating varying path lengths, such as when navigating corners or uneven terrains. On straight roads, both wheels turn at the same rate, but during turns, the outer wheel covers a greater distance, causing it to rotate faster than the inner wheel. Differentials utilize gear ratios to achieve their function and are an integral part of many vehicles. They allow wheels to rotate at differing speeds, enhancing cornering capabilities. This contrasts with scenarios where wheels are fixed, as demonstrated by the analogy of a cardboard box car with straw axles and bottle cap wheels. When the wheels are unattached, turning is smooth; however, fixing the wheels complicates the process, a concept magnified in real vehicles. During high-speed turns, the stress exerted on the vehicle's structure due to locked wheels is substantial. Thus, the differential system stands as a pivotal element, balancing power transmission with the flexibility required for individual wheel rotation.

The invention of the differential gear has spurred numerous claims over time, although it might have been more recognized in certain regions historically. Several significant milestones in its evolution include:

- 100 BCE – 70 BCE: The Antikythera mechanism, discovered in 1902.
- 250 CE: Chinese engineer Ma Jun creates the south pointing chariot.
- 1720: Joseph Williamson employs the arrangement in a clock.
- 1810: Rudolph Ackermann, a German, invents a four-wheel steering system.
- 1827: Onesiphore Pecqueur secures the first patent for the modern automatic differential.
- 1832: Richard Robert of England patents the "gear of compensation" for road locomotives.
- 1874: Aveling and Porter of Rochester, Kent, feature a crane locomotive with their patent differential gear in their catalogue.
- 1876: James Starley of Coventry devises the chain-drive differential, initially for bicycles; later adopted for automobiles by Karl Benz.
- 1897: David Shearer incorporates the differential in an Australian steam car.

- 1958: Vernon Gleasman patents the Torsen dual-drive differential, an innovative limited-slip design relying solely on gearing.

These landmarks reflect the diverse contributions and advancements that have shaped the development of the differential gear across various periods and cultures.

2. PROBLEM STATEMENT

We're all familiar with the increasing challenges of traffic congestion nowadays, which complicates both parking and manoeuvring vehicles out of parking spaces. Thus, the concept of parallel parking emerges as a means to efficiently park or relocate a car with minimal space utilization. This approach eliminates the need for extra room to park or move the vehicle from its parking spot. Stray cats and dogs often seek refuge under parked cars and motorcycles due to the scarcity of trees offering sufficient shade. Consequently, if drivers were to suddenly start their vehicles, it could potentially cause severe harm or even fatality to these animals. To circumvent these substantial penalties and safeguard animal lives, we developed a prototype that not only facilitates parking and exiting through the zero radius turn mode but also incorporates an Advanced Driver Assistance System (ADAS) to avoid collisions with animals during parking. An auditory alert system has also been integrated.

3. LITERATURE REVIEW

A review and analysis of pertinent research, studies, and advancements related to efficient transportation methods for electronic differential system for EV would have the basis of a literature review on the subject. The following outline provides a general depiction of the potential content within such a literature review.

Victor Vidal et al In conclusion, the evolution of electric vehicles (EVs) has markedly transformed the automotive landscape, establishing them as a significant and growing presence in the market. The inherent advantages of electric powertrains, characterized by their precise wheel torque control and rapid motor dynamics, have positioned them favorably when compared to traditional internal combustion engines and friction brakes. This superiority is particularly pronounced in the context of in-wheel powertrain configurations, where the electric motor is seamlessly integrated into the unsprung mass, either directly as seen in direct drive in-wheel powertrains, or via compact in-wheel single-speed transmissions in near-thewheel configurations. The distinctive attributes of in-wheel powertrains, examined in this study, have unveiled numerous benefits. The absence of torsional dynamics in half-shafts has enabled enhanced wheel torque modulation, elevating the performance of wheel slip and direct yaw moment control systems. This has also rendered the conventional anti-jerk control function redundant, a marked divergence from on-board powertrains that necessitate this feature to counteract torsional half-shaft dynamics stemming from powertrain torque fluctuations. The pivotal contributor to torsional in-wheel drivetrain dynamics has been identified as the tire. While practical EV implementations have managed the associated vibrations without a dedicated controller, this study has introduced a specialized fuzzy logic algorithm for this purpose.

Jirachaya F Limprayoon et al Mobile robots were demonstrated to provide assistance in guiding users through intricate indoor spaces. While these robots could aid a wide range of users, the approaches taken in previous iterations typically necessitated users to visually locate and rendezvous with the robot. This requirement posed a potential challenge for individuals with visual impairments. The focus of this paper was to outline a proof of concept for a robotic system that tackled precisely this issue-enabling short-range rendezvous for users who had visual impairments. In summary, the deployment of mobile robots for aiding users in navigating intricate indoor environments has been a demonstrated success. This paper's contribution lay in its conceptualization of a robotic system tailored to facilitate short-range rendezvous for visually impaired users. Insights from an O&M Specialist affirmed the merits of our planner, while also suggesting enhancements for the robot's approach. As we looked ahead, real-world testing with users was poised to provide a wealth of insights for further system enhancement and validation.

Wenjun Zhang et al An adaptive differential control system was developed for 4-wheelindependent-drive (4WID) electric vehicles in the past. This innovative adaptive system was designed to manage the individual hub motors' operations without relying on conventional steering mechanisms. The control system had a hierarchical structure to address vehicle stability conditions. This structure encompassed a novel sliding mode control (SMC) augmented with fuzzy algorithm parameter adjustments at the higher level, aimed at achieving the necessary virtual control signal. At the lower level, a torque allocation algorithm based on quadratic programming was integrated into the controller. Vehicle stability was predominantly governed by lateral and yaw motions in electric vehicles (EVs). The vehicle model, depicted in Figure 1, encompassed longitudinal motion along the x-axis, lateral motion along the yaxis, and yaw motion around the z-axis. This model was characterized by three degrees of freedom. To streamline the analysis, external factors like wind resistance were disregarded, and the vehicle's pitch and roll angles were assumed negligible. The model further simplified assumptions that the wheel tracks were uniform and tire mechanical properties remained constant, and that the front wheel angles were identical.

Jun-Cheng Wang et al An in-wheel (IW) active vibration system was developed for an IW motor (IWM)-driven electric vehicle to mitigate the adverse effects of vertical vibrations arising from road roughness and the impact of rotary inertial forces generated by the IWM. Initially, a theoretical derivation was undertaken to elucidate the factors contributing to the suboptimal ride comfort observed in the General Electric wheel structure. Subsequently, a 6 degree-of-freedom (DOF) vehicle model was formulated, and a corresponding cost function predicated on 10 ride comfort indices was put forth. Employing the proposed control theory, a fuzzy optimal sliding mode (FOSM) control approach was introduced to design the IW active vibration system. To ensure a balanced evaluation, normalization and analytic hierarchy process (AHP) methodologies were implemented to determine appropriate weighted coefficients for the performance indices.

R. H. Palm et al Most fuzzy controllers (FCs) designed for nonlinear second-order systems were conceived with a two-dimensional phase plane in mind. It was demonstrated that the effectiveness and robustness of such FCs were derived from their capability to guide the system into a sliding mode (SM). This SM property rendered the controlled system impervious to variations in parameters and disturbances. Moreover, due to the continuous distribution of control values in the phase plane, these FCs exhibited behaviour akin to a sliding mode controller (SMC) accompanied by a boundary layer (BL) proximate to the switching line. This intrinsic trait ensured reliable tracking performance, even when confronted with substantial model uncertainties. By tracing the origins of the FC to the underlying principles of an SMC, a clear indication of the closed-loop system's stability was established. Calibration of the scaling factors for crisp inputs and outputs was facilitated by comparing the FC's performance against both the SMC and a modified version of the SMC. In the final section of the paper, an FC tailored for a higher-order system was introduced. Through simulation results, the feasibility and practicality of this approach were validated, underscoring its potential for realworld application.

Lucia Clavero-Ordóñez et al Light Electric Vehicles (LEVs) emerged as one of the most significant alternatives for achieving the goal of sustainable urban mobility. Although the precise definition of an LEV might not be perfectly delineated, it was generally applicable to vehicles with weight comparable to the combined weight of the passengers they were designed for. For instance, this concept encompassed approximately 75 kg for single-passenger vehicles and 150 kg for two-passenger vehicles. The central defining characteristic was their lightweight construction, leading to minimal energy consumption and consequently, greater mobility efficiency in contrast to traditional electric vehicles. Predominantly, two-wheeled models, such as electric bicycles, mopeds, and motorcycles, were the most commonly utilized LEVs. An interesting facet of this solution was that it didn't necessitate specialized sensors to measure steering angles and drive wheel speeds. Moreover, it was noteworthy that the implementation leveraged standard electric bicycle controllers and a versatile Arduino platform. These components were not only highly affordable but also widely accessible on a global scale.

Xuan Zhao et al Electric vehicles were categorized into those with a centralized single powersource drive and those with a distributed multi power-source drive. In the case of centralized drive electric vehicles, the transmission output shaft was linked to the drive axles through a mechanical differential. This component was essential within the drive train of centralized drive electric vehicles, as the left and right drive wheels exhibited differing speeds during cornering or navigating uneven road surfaces. The mechanical differential facilitated independent rotation of the left and right drive wheels on a single axle, accommodating varied speeds. This functionality proved vital for road-going vehicles, as during cornering or on uneven roads, the two wheels followed distinct paths, covering different distances. As a result, the inner wheel rotated at a slower pace than the outer wheel, a mechanism designed to mitigate tire wear on rigid axles. Simultaneously, the interior permanent magnet synchronous motor (IPMSM), featuring magnets embedded within the rotor core, offered an array of commendable traits. These included high efficiency, notable reluctance torque, a robust rotor design, and a compact effective air gap.

Abdelfatah Nasri et al Numerous efforts were undertaken in the past to diminish the body mass of Electric Vehicles (EVs), encompassing optimizations in structure, form, and the adoption of aluminium materials. Thanks to advancements in both motor design and control technology, contemporary configurations integrated motorized wheels, resulting in motors being incorporated within the EVs' wheels. EVs emerged as a prime solution to enhance air quality and mitigate dependence on fossil fuels for vehicular propulsion. The adoption of an ED yielded a dual advantage. Firstly, it led to an evident reduction in overall vehicle mass. Additionally, the EV's performance witnessed notable enhancements due to the swift response time inherent to electric motors. This electronic differential enabled precise control of individual wheel speeds, thereby accommodating various motion requirements during diverse scenarios like curvilinear trajectories or lane changes. The ED's capability to modulate wheel speeds played a pivotal role in ensuring the EV's optimal performance under varying conditions.

Merve Yıldırım et al The expansion of the transportation sector gave rise to certain issues, namely the escalation of environmental pollution and the depletion of fossil fuel reserves. Consequently, the adoption of electric vehicles (EVs) gained prominence as a means to curtail the emission of harmful gases, diminish reliance on imported oil, thereby conserving fuel, and combat air pollution. In recent years, the utilization of EVs has surged due to advancements in driver and battery technology, the incorporation of efficient electric motors, and the emphasis on safe driving practices. The weight of EVs featuring a single traction motor powering two wheels through a differential gear has undergone an increase due to the incorporation of batteries. To address the issue of weight and to optimize drive-trains for swift motor response while ensuring independent torque control for each wheel, a solution has been the integration of motors within the wheels themselves. In the context of vehicles, differential systems play a crucial role in distributing power and torque uniformly to traction wheels, especially on slippery or inclined roads. Traditional internal combustion engine vehicles have employed mechanical differentials through differential gears. In cases where differential gears are absent and a wheel accelerates, it results in wheel slip while the opposing wheel tends to decelerate. This leads to hazardous driving conditions, escalated fuel consumption, and accelerated tire wear.

4. CONCLUSION

In conclusion, our Electronic Differential System for Electric Vehicles stands as a testament to innovation, merging cutting-edge technology with practicality. This solution not only enhances EV performance but also aligns with energy efficiency and sustainability goals. We anticipate its transformative impact on driving experiences and the EV landscape, achieved through torque distribution, stability enhancement, and real-time wheel speed monitoring. The integration of dual speedometers further contributes to precision, safety, and streamlined maintenance. This project signifies a harmonious fusion of electronic and mechanical systems, paving the way for future advancements. Our gratitude extends to all contributors. This system seamlessly integrates into existing EV architectures, optimizing efficiency by managing power delivery and minimizing energy wastage, ultimately driving widespread adoption.

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