Design and Development of a Steer-by Wire Control System for an All-Terrain Vehicle

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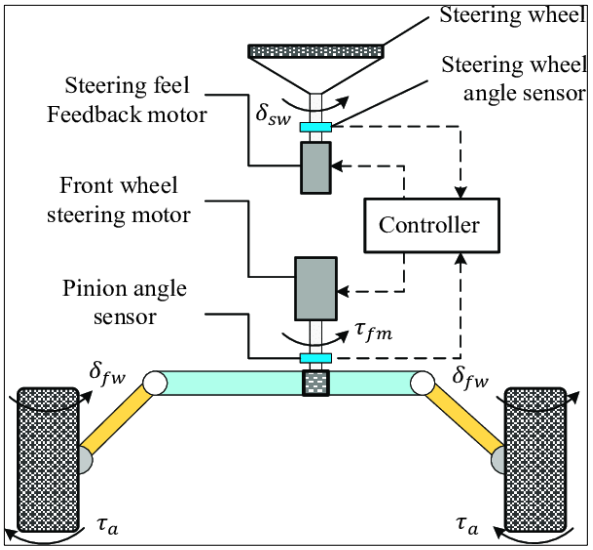
Abstract — The design and implementation of an all-terrain vehicle (ATV) Steer-by-Wire (SbW) control system are presented in this work. The suggested system uses a totally electronic architecture that interprets and carries out steering commands using sensors, actuators, and controllers in place of the conventional mechanical steering linkage. A thorough examination of the mechanical parts, force gearbox, and steering geometry was carried out. The system's operation was confirmed by simulation and actual testing, guaranteeing accurate steering reaction and improved vehicle handling. The study also uses ANSYS's static and dynamic analysis to assess the structural performance of important components. The outcomes show that SbW systems are feasible for off-road vehicles, and they also provide the advantages of lighter weight, better ergonomics, and flexibility for autonomous integration.

Keywords: Steer-by-Wire, All-Terrain Vehicle, Electronic Steering, Feedback Control, Vehicle Dynamics, Autonomous Systems

I. Introduction

The mechanical connection between the steering wheel and the front wheels of the car is removed by Steer-by-Wire (SbW) technology, which substitutes an electronic interface made up of sensors, actuators, and controllers. This development is important for the development of contemporary automobiles, especially those that are electric and self-driving. SbW systems offer better performance customisation, increased design flexibility, and possible weight savings in contrast to conventional electromechanical power steering systems.

The design and implementation of a steering-by-wire control system specifically for an all-terrain vehicle (ATV) are presented in this study. Improving handling accuracy, safety, and integration preparedness for upcoming autonomous features is the main driving force. A steering actuator, feedback motors for simulating steering feel, and control electronics to decipher user inputs and regulate wheel alignment are all part of the suggested SbW system. The system's functional feasibility in off-road circumstances is assessed using dynamic simulations, CAD design validation, and analytical calculations.

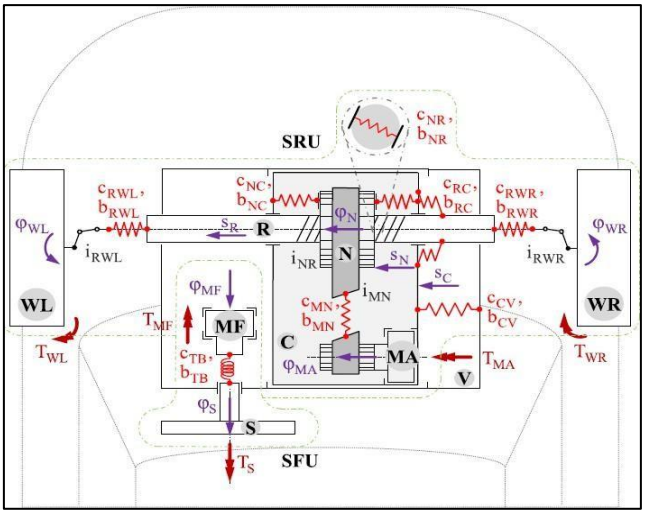


II. Literature Review

The difficulties and advancements in SbW systems have been the subject of numerous studies. In order to improve rack position monitoring and steering precision without relying on tire-road friction data, Kim et al. [1] presented an Adaptive Sliding Mode Control (ASMC). After examining the effects of CAN frame rate and sensor precision, Pietruch et al. [2] came to the conclusion that faster data transfer is more important than sensor resolution.

Nonlinear triple-step controllers were introduced by Li et al. [3] and Seiffer et al. [4] to improve handling stability by reducing external uncertainties and tyre saturation. In order to simulate genuine road feel, Mukundan et al. [5] investigated using electronic devices in place of the mechanical connection and suggested a feedforward approach. In order to maximise control strategies and reduce the requirement for physical prototypes, Irmer [6] placed a strong emphasis on model-based design and virtual testing. Using Hardware-in-the-Loop (HIL) configurations, Tavoosi et al. [7] verified the efficacy of a nonlinear 4-DOF vehicle model in crucial low-friction situations.

The development described in this study is guided by this research, which highlight the viability and advantages of SbW systems.



III. METHODOLOGY

The methodology followed includes system modeling, hardware selection, force and torque calculations, CAD modeling, and finite element analysis.

A. System Modeling:

In order to mimic the behaviour of SbW components such as the steering actuator, feedback motor, and sensors, a multibody model was created using Newton-Euler equations.

B. Hardware Selection:

The selection of motors, sensors, and controllers was based on the precision and torque requirements. For steering actuation, a 12V DC motor with 80 lb-in torque was employed.

C. Force Analysis:

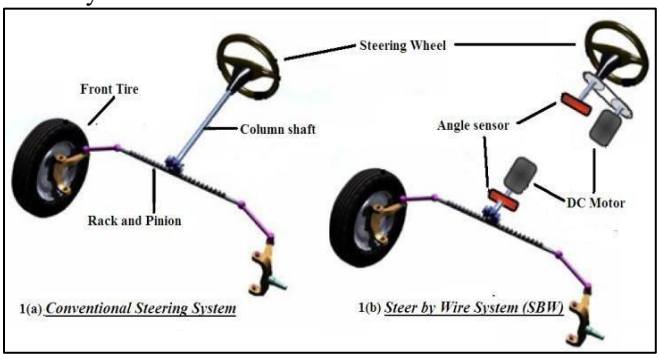
Both static and dynamic circumstances were calculated, including steering effort, rack force under load, and alignment torque.

D. CAD Modeling:

CATIA V5 was used to simulate components such the rack, pinion, tie-rod, clevise, and steering case.

E. Simulation & Analysis:

In order to verify design strength under load circumstances, finite element analysis (FEA) was carried out in ANSYS. Static stress on the pinion and clevise, tie-rod buckling, and total deformation under steering loads were all considered in the analysis.



IV. SYSTEM DESIGN AND ANALYSIS

With an emphasis on off-road performance, structural strength, and weight efficiency, the Steer-by-Wire system was created for an ATV platform.

A. Mechanical Design:

The steering wheel, angle sensors, feedback motor, and steering actuator are all part of the system. The steering actuator is attached to the wheels using a belt drive mechanism and ball screw. The steering gear assembly's rack travel is 40 mm, its turning radius is 1.8 m, and its computed steering ratio is 2.5:1.

B. Material Selection:

For steering components, aluminium 7075 T6 and 6063 were chosen because of their excellent strength-to-weight ratio and resistance to corrosion. To manage dynamic loads, metric grade 8.8 rod ends and fasteners were utilised.

C. Force and Torque Calculations:

Calculated maximum static steering effort: 257.68 N. 77.04 N is the dynamic steering effort. Pitch torque: 9.63 N-m (dynamic), 32.21 N-m (static). Rack force is 1137.9 N with a net aligning torque of 42.52 N-m.

D. Component Sizing:

Based on the highest torque demand, the steering actuator was chosen. Feedback motors are made to be highly responsive with little torque. For precise angle detection, angular sensors (optical encoders) have a resolution of 1024 pulses/rev.

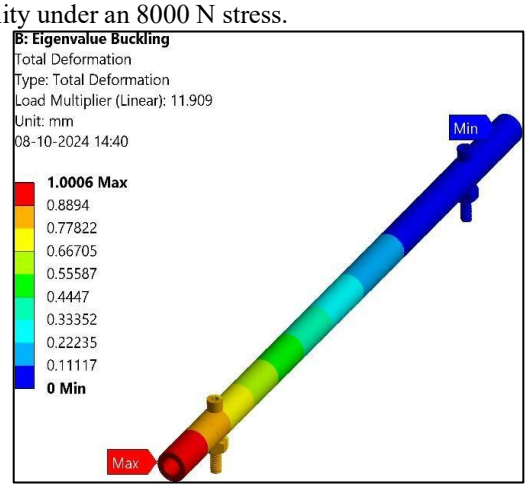
V. RESULTS AND DISCUSSION

Finite element analysis and static and dynamic simulations were used to validate the suggested system.

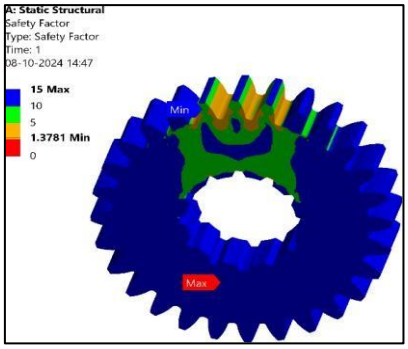
A. Finite Element Analysis:

1) Tie-Rod:

Using Al 6061 T6 material, buckling study verified structural stability under an 8000 N stress.

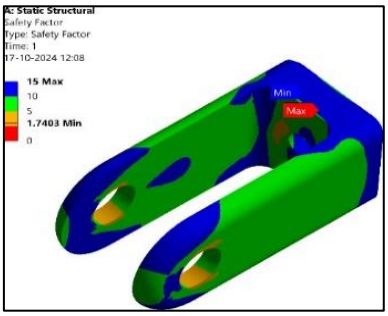


Static structural analysis demonstrated appropriate Factor of Safety (FOS) and safe stress levels under a 3000 N load.



2) Overall System:

No interference in dynamic motion was found by CAD assembly.



3) Performance Outcomes:

The system's design validity was confirmed when the simulated steering efforts under actual driving conditions matched expected values. Structural elements ensured durability for off-road situations by withstanding the hardest load conditions without failing.

4) Steering Feel and Feedback:

Despite being fake, the feedback motor improved the driving experience by accurately simulating real steering resistance.

5) Autonomy and Integration:

The system offers path tracking, obstacle avoidance, and terrain adaption features and is scalable for integration with autonomous vehicle platforms and ADAS (Advanced Driver Assistance Systems).

VI. Future Scope

1) Connectivity to Autonomous Driving Systems and ADAS:

Advanced Driver Assistance Systems (ADAS) like auto-parking, lane-keeping assistance, and eventually complete autonomy in off-road situations can be integrated into the current design.

2) Using HIL Simulation to Implement Real-Time ECU Control:

In order to verify closed-loop performance and dynamic reaction under a variety of terrain conditions, future work may entail creating and testing real-time control algorithms employing Hardware-in-the-Loop (HIL) systems.

3) Creation of AI-Based Adaptive Control Algorithms:

By learning from driving behaviours and sensor inputs, machine learning or adaptive algorithms can be used to enhance handling under unpredictable or changing road circumstances.

4) Customised steering feel and haptic feedback:

To enhance driver pleasure and safety, sophisticated haptic feedback systems can be made to provide adjustable road feel according to driving modes (sport, comfort, terrain, etc.).

5) Scalability through Modular System Design:

The architecture is adaptable for both defence and agricultural since it can be modularised to fit other vehicle types, such as quad bikes and UGVs (Unmanned Ground Vehicles).

6) Advanced Fusion of Sensors to Improve Decision Making:

In order to facilitate obstacle avoidance, terrain detection, and improved steering control in uncertain situations, integrate LIDAR, IMU, GPS, and vision sensors into the SbW system.

7) Sturdy Redundancy and Fault Detection Systems:

To improve dependability, future systems should have thorough diagnostic and fault-tolerant procedures with backup control routes and dual-sensor configurations.

8) Real Terrain Dynamic Testing:

Real-world field tests on various terrains (sand, rocks, slopes) are crucial to verifying the system's responsiveness and dependability following simulation and laboratory testing.

VII. Conclusion

The effective design and development of an all-terrain vehicle's Steer-by-Wire technology was illustrated in this study. The system achieved precise steering control, decreased mechanical complexity, and increased design flexibility through extensive modelling, simulation, and physical validation. The system's performance under dynamic, real-world situations was confirmed by the force and torque computations. The system's suitability for usage in electric and driverless vehicles is supported by the use of lightweight materials and fault-tolerant components. To further increase system autonomy and robustness, future research will concentrate on combining closed-loop control algorithms, sophisticated sensor fusion, and real-time fault detection.

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