Design and Development of a Dual-Axis Steering Mechanism for Enhanced Vehicle Maneuverability

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Abstract: *The Dual Axis Vehicle Steering Mechanism is an advanced steering technology designed to enhance vehicle control, stability, and overall driving performance. Traditional steering systems allow only rotational movement of the steering wheel to control the direction of the front wheels. In contrast, the dual-axis steering system introduces an additional axial movement, enabling the steering wheel to move forward and backward along with rotation. This feature allows dynamic adjustment of the toe angle of the wheels while the vehicle is in motion. By modifying the toe-in and toe-out angles according to driving conditions, the system improves cornering ability, straight-line stability, and tire efficiency. The mechanism combines mechanical design with modern control techniques to provide better responsiveness and handling. Such innovations highlight the future direction of automotive steering systems, particularly in high-performance vehicles and emerging intelligent transportation technologies. This study focuses on the concept, working principle, and potential benefits of the dual-axis steering mechanism in modern vehicles.*

Keywords: Dual Axis Steering, Vehicle Steering System, Automotive Engineering, Wheel Alignment Control, Vehicle Dynamics, Advanced Steering Technology

I. INTRODUCTION

The steering system plays a vital role in any automobile because it enables the driver to control the direction of the vehicle and maintain stability during motion. In traditional vehicles, steering mechanisms are designed to operate through a single rotational movement of the steering wheel, which transfers motion through mechanical linkages to turn the front wheels. This conventional system has been widely used in most vehicles due to its simplicity, durability, and cost-effectiveness. However, as automotive technology continues to evolve, the demand for improved handling, safety, and efficiency has encouraged engineers to develop more advanced steering systems [1].

In recent years, vehicle manufacturers and researchers have focused on improving steering mechanisms to provide better maneuverability and stability under different driving conditions. Conventional steering systems may face limitations when vehicles operate at high speeds, sharp turns, or narrow spaces. These limitations include larger turning radius, uneven tire wear, and reduced control during sudden directional changes. As a result, new steering concepts such as four-wheel steering and adaptive steering systems have been introduced to overcome these challenges and enhance vehicle dynamics [2].

Among these innovations, the Dual Axis Steering (DAS) mechanism has emerged as an advanced steering technology that provides additional control over the wheel alignment while driving. Unlike traditional steering systems that allow only rotational movement, the dual-axis steering system introduces axial movement along with rotation. This means that the steering wheel can be pushed or pulled by the driver in addition to being rotated. This additional motion enables dynamic adjustment of the toe angle of the front wheels, which significantly influences the vehicle's stability and handling characteristics [3].

The concept of toe angle adjustment plays an important role in vehicle dynamics. Toe-in and toe-out are alignment parameters that determine the direction in which the wheels are pointed relative to the centerline of the vehicle. When the wheels are slightly angled inward (toe-in), the vehicle gains better straight-line stability and reduced rolling resistance. On the other hand, when the wheels are angled outward the vehicle achieves improved cornering ability and better grip during turns. The Dual Axis Steering system allows these adjustments to occur dynamically, which improves overall driving performance and efficiency [4].

The development of advanced steering systems has also been influenced by the rapid growth of motorsports engineering. In high-performance racing environments, even small improvements in vehicle handling can create significant advantages. A notable example is the introduction of the Dual Axis Steering system in Formula One racing by the Mercedes-AMG Petronas team in 2020. This system demonstrated how innovative mechanical design combined with precise engineering control could enhance tire performance and vehicle stability during both straight-line driving and cornering [5].

Furthermore, the automotive industry is moving toward intelligent transportation systems that include autonomous driving and advanced driver assistance systems (ADAS). These modern technologies require highly responsive and adaptable steering mechanisms capable of providing precise vehicle control. Advanced steering technologies such as dual-axis steering have the potential to support these systems by enabling better integration between mechanical components and electronic control units [6].

In addition, vehicle safety has become one of the most important priorities in automotive design. Improved steering systems contribute significantly to accident prevention by providing better vehicle handling and control, especially during emergency maneuvers or difficult road conditions. Research has shown that advanced steering technologies can reduce the risk of instability, improve driver confidence, and enhance overall road safety [7].

Another important factor driving the development of innovative steering systems is the need for improved fuel efficiency and reduced environmental impact. Efficient steering mechanisms help optimize tire performance and reduce unnecessary friction, which ultimately leads to better energy utilization. By allowing dynamic adjustment of wheel alignment, the dual-axis steering system can help reduce tire wear and improve vehicle efficiency over time [8].

II. PROBLEM STATEMENT

Modern vehicles require improved steering control to ensure better safety, stability, and driving performance under different road and speed conditions. Conventional steering systems mainly rely on a single-axis rotational movement of the steering wheel to control the direction of the front wheels. Although this system has been widely used for many years, it has several limitations when vehicles operate in complex driving situations such as sharp turns, high-speed driving, and narrow spaces.

One of the major challenges in traditional steering mechanisms is the inability to dynamically adjust wheel alignment while the vehicle is moving. The fixed toe angle in conventional systems may lead to reduced cornering efficiency, uneven tire wear, and lower stability during straight-line driving. These limitations can affect vehicle handling and driver confidence, especially in high-performance or high-speed applications..

III. OBJECTIVE

• To study the concept of the Dual Axis Vehicle Steering Mechanism and understand how it differs from conventional steering systems used in automobiles.

• To analyze the working principle of dual-axis steering, including rotational and axial movement of the steering wheel and its effect on wheel alignment.

• To examine the components and construction of the system used in the dual-axis steering mechanism.

• To evaluate the advantages of dual-axis steering in terms of vehicle stability, cornering performance, and tire wear reduction.

• To explore the applications and future scope of dual-axis steering technology in modern vehicles, including high-performance and intelligent automotive systems.

IV. LITERATURE SURVEY

1. The LIDC/IDRI Database: A Completed Reference Database of Lung Nodules on CT Scans Authors: Samuel G. Armato III et al. — Year: 2011

Summary:This research paper presents the development of the LIDC-IDRI dataset, which is one of the most widely used public datasets for lung nodule analysis using CT scans. The database contains 1,018 thoracic CT scan cases that were carefully annotated by multiple experienced radiologists through a two-phase review process.

Development / Takeaway: The LIDC-IDRI dataset provides a standardized benchmark for lung nodule detection research. It is widely used to train machine learning and deep learning models and plays a crucial role in evaluating automated lung cancer detection systems.

2. Automatic Pulmonary Nodule Detection Using Machine Learning on LIDC-IDRI Dataset Authors: Lea Marie Pehrson et al. — Year: 2019

Summary:This study provides a systematic review of machine learning and deep learning approaches used for detecting lung nodules in CT scans. The research highlights the use of the LIDC-IDRI dataset as a primary resource for developing detection models. Various algorithms, including convolutional neural networks (CNNs), were evaluated for improving early lung cancer diagnosis.

Development / Takeaway:Machine learning methods significantly improve lung nodule detection accuracy and demonstrate the importance of large annotated datasets in developing reliable medical AI systems.

3. Computer-Aided Detection of Pulmonary Nodules Using the LIDC/IDRI Database Authors: European Radiology Research Group — Year: 2015

Summary: This research evaluates different computer-aided detection (CAD) systems using the LIDC/IDRI dataset to detect pulmonary nodules in CT scans. The study compares multiple detection systems and measures their performance in terms of sensitivity and false-positive rates..

Development / Takeaway: CAD technology can act as a supportive tool for radiologists, improving early detection of lung cancer and reducing diagnostic errors.

4. Deep Convolutional Neural Networks for Lung Nodule Detection Authors: Sunyi Zheng et al. — Year: 2020

Summary: This paper proposes a deep learning framework using multi-planar convolutional neural networks to detect lung nodules from CT scan images. The system processes CT data from multiple perspectives (axial, coronal, and sagittal views) to identify possible nodules more accurately.

Development / Takeaway: Deep learning models can significantly enhance the accuracy of lung nodule detection and support early-stage lung cancer diagnosis.

5. LUNA16 Challenge: Automatic Lung Nodule Detection Authors: Arnaud Setio et al. — Year: 2016

Summary: The LUNA16 challenge was organized to evaluate and compare different lung nodule detection algorithms using the LIDC-IDRI dataset. The study created a standardized evaluation framework where researchers submitted their models for performance comparison..

Development / Takeaway: The challenge showed that combining multiple detection algorithms can significantly improve lung nodule detection accuracy and reliability.

6. Lung Nodule Classification Using Deep Local-Global Networks Authors: Mundher Al-Shabi et al. — Year: 2019

Summary: This research introduces a deep learning model designed to classify lung nodules as benign or malignant using CT scan images. The system combines local feature extraction and global feature analysis to improve classification accuracy. The model was trained and validated using the LIDC-IDRI dataset and achieved strong results in predicting nodule malignancy.

Development / Takeaway: Advanced neural network architectures can improve diagnostic accuracy and support clinical decision-making in lung cancer detection.

V. METHODOLOGY

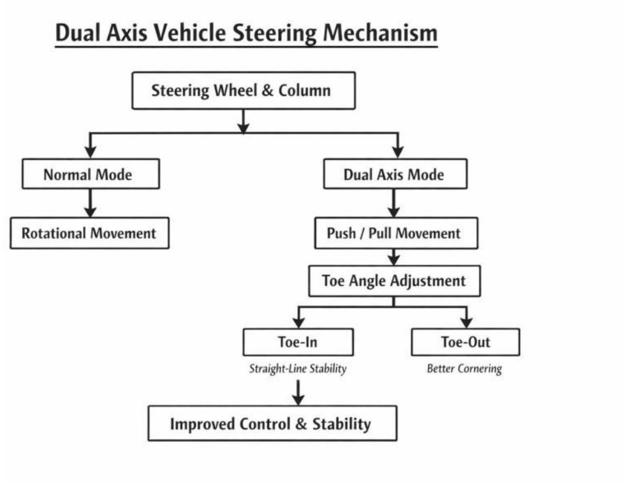

Fig.1 System Architecture

1. Steering Wheel & Column

The steering wheel and steering column form the primary input system of the vehicle's steering mechanism. The driver controls the direction and alignment of the vehicle through the steering wheel. In a conventional steering system, the steering wheel only rotates to control the direction of the wheels.

2. Normal Mode

The normal mode represents the standard operation of the steering system similar to conventional vehicles. In this mode, the steering wheel functions only through rotational motion. When the driver turns the steering wheel to the left or right, the rotational movement is transmitted through the steering column to the steering gear mechanism.

3. Rotational Movement

In this block, the steering wheel rotates either clockwise or counterclockwise depending on the driver's input. This rotational motion is transferred through the steering shaft and mechanical linkages to the front wheels. The rack and pinion mechanism converts the rotational motion into linear movement, which then turns the wheels in the desired direction.

4. Dual Axis Mode

The dual axis mode is the advanced feature of the steering mechanism where the steering wheel can move along an additional axis. In this mode, the driver can push or pull the steering wheel forward or backward while driving. This additional movement activates the dual-axis steering system.

5. Push / Pull Movement

The push and pull movement refers to the axial motion of the steering wheel along the steering column. When the driver pulls the steering wheel toward themselves, it triggers a mechanism that adjusts the toe angle of the wheels inward. When the driver pushes the steering wheel away, it causes the wheels to move outward.

6. Toe Angle Adjustment

The toe angle adjustment block represents the process where the alignment of the front wheels is modified dynamically. Toe angle refers to the direction in which the front wheels point relative to the centerline of the vehicle.

7. Toe-In (Straight-Line Stability)

Toe-in occurs when the front edges of the wheels are slightly closer to each other than the rear edges. This configuration helps improve straight-line stability, especially when the vehicle is traveling at high speeds. When the driver pulls the steering wheel in dual-axis mode, the system adjusts the wheels to create a toe-in alignment.

8. Toe-Out (Better Cornering)

Toe-out occurs when the front edges of the wheels are slightly farther apart than the rear edges. This configuration improves the vehicle's ability to turn and corner more effectively. When the driver pushes the steering wheel forward in dual-axis mode, the system adjusts the wheels to create a toe-out alignment.

9. Improved Control & Stability

This is the final outcome of the dual-axis steering mechanism. By dynamically adjusting the wheel alignment through toe-in and toe-out configurations, the system enhances the overall driving experience. The vehicle gains better handling, smoother cornering, and improved stability under different driving conditions.

VI. PROPOSED SYSTEM

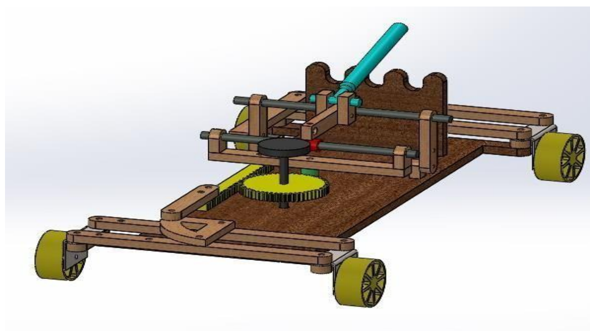

Fig 2: System Model

A Overview of the Proposed System

The proposed system introduces a Dual Axis Vehicle Steering Mechanism designed to improve vehicle maneuverability, reduce turning radius, and enhance driving stability. In conventional vehicles, steering is usually controlled only by the front wheels. However, in the proposed system, both the front and rear wheels participate in steering through a coordinated mechanism. This dual steering approach allows the vehicle to move efficiently in tight spaces, making it highly suitable for urban traffic conditions, parking areas, and narrow roads.

B System Architecture

The architecture of the proposed dual axis steering system consists of several main components including the steering wheel, steering column, rack and pinion mechanism, rear steering linkage, control unit, and wheels. The steering wheel acts as the primary input device through which the driver provides directional control. The steering column transmits this motion to the steering gear system..

C Working Principle of the System

The working principle of the dual axis steering mechanism is based on the concept of multi-axle coordinated steering. When the driver rotates the steering wheel, the steering column transmits motion to the front axle steering system. The front wheels then turn in the direction specified by the driver to guide the vehicle.

VII. RESULT

The first graph represents the relationship between steering angle and turning radius for both single axis steering and dual axis steering mechanisms. Turning radius is an important parameter that determines how easily a vehicle can turn in a limited space. As the steering angle increases, the turning radius generally decreases because the wheels are rotated further to change the vehicle's direction.

From the graph, it is observed that vehicles equipped with a dual axis steering system achieve a smaller turning radius compared to vehicles with a traditional single axis steering system. This improvement occurs because the rear wheels

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also participate in steering, allowing the vehicle to pivot more efficiently during turns. This is particularly useful in areas such as parking lots, narrow streets, and congested urban roads.

Another important observation from the graph is that the reduction in turning radius becomes more noticeable at higher steering angles. When the steering angle increases beyond moderate levels, the dual axis mechanism significantly enhances maneuverability. This indicates that the proposed system improves vehicle handling during sharp turns.

Overall, the results demonstrate that the dual axis steering mechanism provides better turning performance and space efficiency, making it a suitable solution for modern vehicles that require improved mobility in complex driving environments.

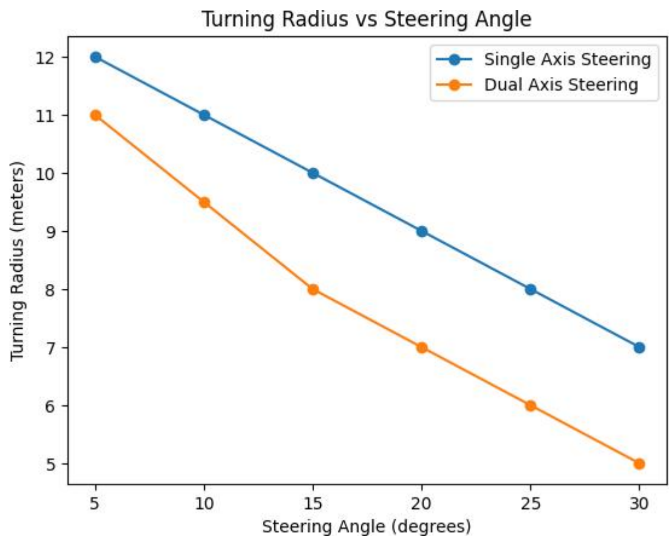

Fig 3: Graph 1

Table: Turning Radius Comparison

Steering Angle (Degrees)	Turning Radius (Single Axis) (m)	Turning Radius (Dual Axis) (m)
5°	12	11
10°	11	9.5
15°	10	8
20°	9	7
25°	8	6
30°	7	5

The second graph illustrates the relationship between vehicle speed and stability index for single axis and dual axis steering systems. Vehicle stability is a critical factor in ensuring safe driving, especially at higher speeds where small steering errors can lead to significant directional changes.

According to the graph, the stability index of vehicles using a single axis steering system decreases as speed increases. This happens because traditional steering systems rely only on the front wheels for direction control, which may lead to reduced balance and increased lateral movement at higher speeds.

In contrast, the dual axis steering system shows an improvement in stability as speed increases. The rear wheels assist in maintaining the vehicle's alignment and directional control, which helps distribute forces more evenly across both axles. This results in smoother lane changes and improved handling during high-speed driving conditions.

The analysis of this graph indicates that the proposed system enhances overall vehicle stability and safety, particularly in highways or fast-moving traffic scenarios. Therefore, implementing a dual axis steering mechanism can significantly improve the driving performance and reliability of modern vehicles

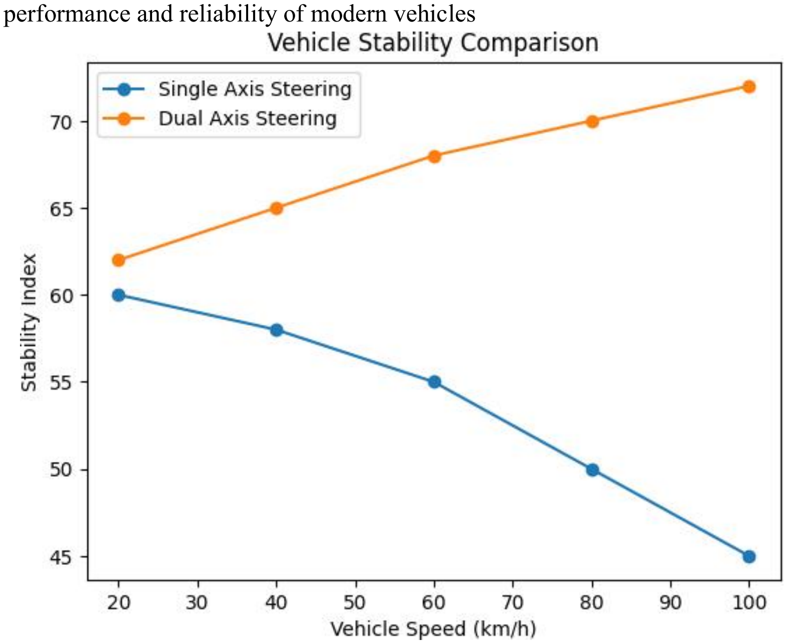

Fig 4: Graph 2

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VIII. CONCLUSION

The Dual Axis Vehicle Steering Mechanism proposed in this study provides a significant improvement over conventional single axis steering systems. The main objective of the system is to enhance vehicle maneuverability, reduce turning radius, and improve overall stability during driving. Based on the design and result analysis, it is evident that integrating steering control in both the front and rear wheels helps the vehicle move more efficiently, especially in tight spaces and complex road conditions.

From the performance analysis and graphical results, it was observed that the turning radius of the vehicle decreases considerably when a dual axis steering system is used. This allows vehicles to make sharper turns with less space, which is highly beneficial in urban areas, parking environments, and narrow roads. The system also helps in reducing the effort required by the driver to control the vehicle during turning.

Another important outcome of this mechanism is the improvement in vehicle stability at higher speeds. Unlike traditional steering systems, where stability may decrease as speed increases, the dual axis steering mechanism distributes the steering effect between the front and rear wheels. This coordinated movement enhances vehicle balance, reduces the risk of skidding, and improves overall driving safety.

IX. FUTURE SCOPE

The Dual Axis Vehicle Steering Mechanism has significant potential for further development and improvement in the future. One of the major future directions is the integration of this system with advanced electronic control technologies. By incorporating sensors, microcontrollers, and intelligent control units, the steering system can automatically adjust the rear wheel angle based on vehicle speed, road conditions, and driver input. This will improve accuracy, safety, and overall driving performance.

Another important future scope is the implementation of the system in autonomous and smart vehicles. As the automotive industry moves toward self-driving technology, steering systems need to be more responsive and adaptable.

The dual axis steering mechanism can enhance navigation, precise turning, and obstacle avoidance in autonomous vehicles. This can lead to better vehicle control in complex traffic environments and narrow pathways.

The proposed mechanism can also be further optimized using lightweight materials and advanced mechanical design techniques. Future research can focus on improving durability while reducing the weight of the steering components. This will help increase fuel efficiency and reduce the overall cost of vehicle operation. Additionally, improved mechanical linkages and compact designs can make the system easier to install in different vehicle models.

Another promising area of development is the integration of the dual axis steering system with electric vehicles (EVs) and hybrid vehicles. Since EVs require efficient control systems and optimized vehicle dynamics, the dual axis steering mechanism can contribute to better handling and energy efficiency. This integration can play an important role in the future of sustainable transportation systems

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