REDUCTION OF TURNING RADIUS USING FOUR WHEEL STEERING SYSTEM

Sriram M[1], Manish Baddikuri[2], Manjunath M K[3], Manohar Reddy K[4]

[1-4]B.E Student, Dept. of Mechanical Engineering, Ramaiah Institute Of Technology, Bangalore, India

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Abstract -
In a conventional steering system, the front wheels turn whereas the rear wheels do not turn and thus reduce the efficiency of turning by demanding a larger radius of turning. In a four-wheel steering system, the rear wheels also turn giving various types of driving path based on direction of turning. It provides faster maneuverability, like changing lanes, parking in tight spaces etc. The basic principle of steering and steering conditions remain same as the system requires a few components to be replaced with different design and additional functions for facilitating all four wheels to turn and transmit motion simultaneously. In this steering mechanism the rear wheels are not just following the front wheels, but turn at a specific ratio. There are two modes of steering along with the traditional front wheel steering in our proposed system which enables the driver to switch between the systems at his will and also have a possibility to change the steering ratio as this is a completely electronic system. With advances in technology, four-wheel steering systems have high usability by adapting electronic steering systems, thereby pre-programmed steer angles for front and rear wheels, sensors to monitor the vehicle dynamics and adjust the steer angles in real time.

Key words: Four wheel steering system, Turning radius, Maneuverability, Electronic System.

1. INTRODUCTION

1.1 Front wheel steering system:

The traditional steering arrangement is to turn the front wheels using a hand operated steering wheel which is positioned in front of the driver, via the steering column to allow it to deviate somewhat from a straight line. The basic aim of steering is to ensure that the wheels are pointing in the desired directions. The front wheel steering system employs the well-known Ackermann steering mechanism which is a four-bar linkage mechanism providing stability of the vehicle and geometric equilibrium.

1.2 Ackerman Steering Mechanism:

It is a four-bar mechanism arranged such that the front wheels rotate at different angles such that all the four wheels turn about a common point providing the right amount of traction(grip). The intention is to avoid the need for tires to slip sideways when following the path around a curve. The geometrical solution to this is for all wheels to have their axles arranged as radii of circles with a common center point. The idea behind the Ackermann steering is that the inner wheel should steer for a bigger angle than the outer wheel in order to allow the vehicle to rotate around the middle point between the rear wheel axis. Consequently, the inner wheel travels at a slower speed than the outer wheel. The Ackermann driving mechanism allows for the rear wheels to have no slip angle, which requires that the turning center point lies on a straight line defined by the rear wheels' axis. This driving mechanism therefore minimizes tire wear and provides stability to the vehicle while turning. So, when a vehicle is turning, the inner wheel needs to turn at a different angle to the outer because they are turning on different radii.

The Ackermann steering mechanism is a geometric arrangement of linkages in the steering of a vehicle designed to turn the inner and outer wheels at the appropriate angles. This model is fully parameterized, allowing customization and component sizing. Using this model, the ideal Ackermann Angles can be identified, providing an effective starting point for further analysis.

Turning Radius: The turning radius or turning circle of a vehicle is the radius of the smallest circular turn (i.e., U-turn) that the vehicle is capable of making.
Steering Ratio: Steering ratio refers to the ratio between the turn of the steering wheel (in degrees) and the turn of the wheels (in degrees).

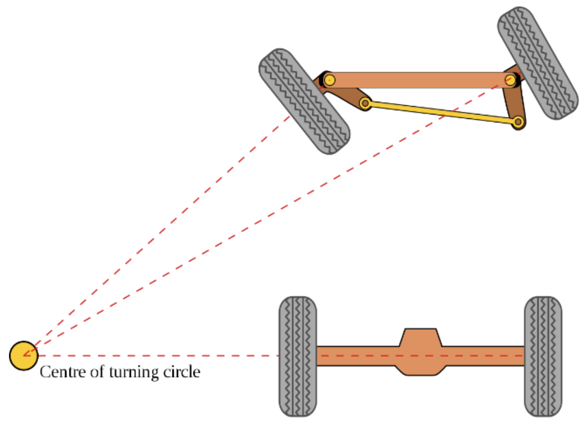

Figure 1: Ackermann Steering Mechanism

1.3 Steer-by-wire:

A steer-by-wire system aims to eliminate the physical connection between the steering wheel and the wheels of a car by using electrically controlled motors to change the direction of the wheels and to provide feedback to the driver. Since a steer-by-wire system is easily modifiable, different drivers will be able to adjust the system to accommodate their styles and this will enhance handling. Since there are virtually no physical connections between the steering wheel and the wheels, a steer-by-wire system can be implemented on different cars easily. The steering wheel could be placed on either side of a car (or anywhere else). Both of these improvements would reduce costs of production and allow a wider range of designs. Steer by wire concept is the future of steering due to its ability to be integrated with Auto-pilot or autonomous systems for the vehicles.

1.4 Four-wheel steering system:

Four-wheel steering, 4WS, also called all-wheel steering, provides a means to actively steer the rear wheels during turning maneuvers. It should not be confused with four-wheel drive in which all four wheels of a vehicle are powered. This improves handling and helps the vehicle make tighter turns. Four-wheel steering system is employed by vehicles to improve steering response, increase vehicle stability while maneuvering at high speed, or to decrease turning radius at low speed. In an active four-wheel steering system, all four wheels turn at the same time when the driver steers.

Primarily when the rear wheels turn in the direction opposite to the front wheels, it reduces the turning radius whereas when the rear and front wheels rotate in the same direction, provides a faster maneuverability like changing lanes in limited spaces which is necessary for parking or at driving at high speeds. When both the front and rear wheels steer toward the same direction, they are said to be in phase and this produces a kind of sideways movement of the car at low speeds. When the front and rear wheels are steered in opposite directions, this is called anti-phase, counter-phase or opposite-phase and it produces a sharper, tighter turn.

Production-built cars tend to understeer or, in a few instances, oversteer. If a car could automatically compensate for an under steer /over steer problem, the driver would enjoy nearly neutral steering under varying conditions. 4WS is a serious effort on the part of automotive design engineers to provide near-neutral steering.

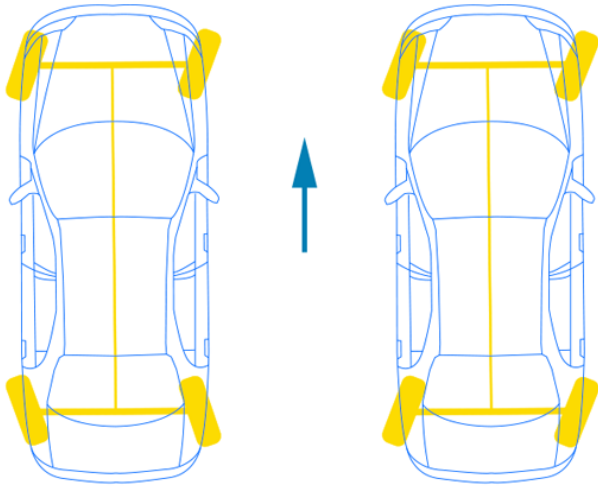

Figure 2: Two types of Four-wheel configurations, opposite directions (left) & same direction (right)

2. OBJECTIVES OF THE PROJECT:

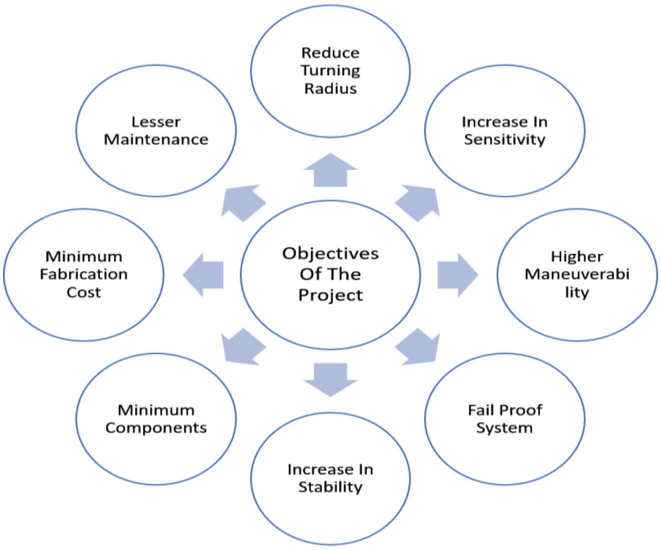

Figure 3: Objectives

3. Methodology:

The Four-Wheel Steering System can be categorized into four sub systems:

i. Signal inputs.

ii. Electronic Control Unit.

iii. Steering mechanism Actuator.

iv. Steering mechanism.

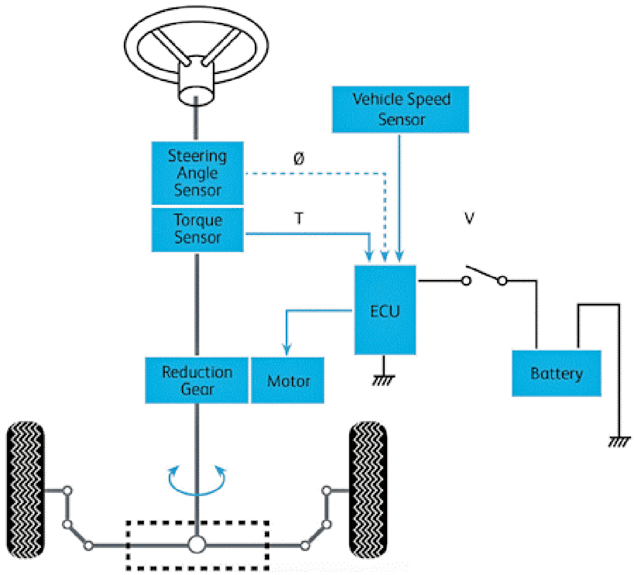

Figure 4 : Electric steering system block diagram

3.1 Signal inputs:

i) Steering angle Input: this part consists of a rotary encoder for steering angle input and this sensor will be directly meshed with the steering axle in a vehicle.

ii) Driving Mode input: this can be an interactive touch display which enables the driver to change or set the steering type based on his requirement like front wheel steering/all wheel's steering (opposite direction) /all wheel steering (same direction / Crab steer) as Mode 0, Mode 1, Mode 2 in our model. This can also be replaced or accompanied with a program to change modes automatically based on speed or other factors which again depends on the ECU.

iii) Other sensors for stability and enhancement: apart from the sensors mentioned above we can also add Torque sensor, speed sensor, yaw sensor which are crucial for features like stability control and drift control.

3.2 Electronic control unit for signal processing:

i) Signal processing can be achieved using a suitable microcontroller and a properly written algorithm to process and result in expected outputs without any scope of glitches.

ii) The microcontroller must be checked for sufficient memory to store the algorithm and also have a high processing speed to give fast outputs without any delay.

iii) The algorithm must be properly written without using excess variables and the least number of lines of code so that it has lower possibility of errors or glitches.

3.3 Steering mechanism actuator:

i) The Actuator plays a major part in giving the required output angle and the force required to move the wheels. Actuators add controlled energy to the steering mechanism, so the driver can provide less effort to turn the steered wheels when driving at typical speeds, and considerably reduce the physical effort necessary to turn the wheels when a vehicle is stopped or moving slowly.

ii) Generally, two types of actuators are used which are Electrical actuators and Hydraulic actuators. Hydraulic actuators consist of a pump and a piston arrangement whereas electric actuators can consist of either a servo motor or a stepper motor.

iii) Front and Rear Steering mechanisms each have an individual actuator which makes this a drive by wire method reducing the need of adding more axles to transmit the rotation.

3.4 Steering mechanism:

i) the steering mechanism is the same Ackermann steering mechanism but due to the requirement of turning both front and the rear wheels, two Ackermann systems are to be mounted (i.e., one for the front wheels which is already present and the second one for the rear wheels).

ii) When the torque is applied by the pinion over the rack, the rack moves which in turn steers the wheels (with the help of the tie rods).

4. Working Procedure:

4.1 Circuit diagram:

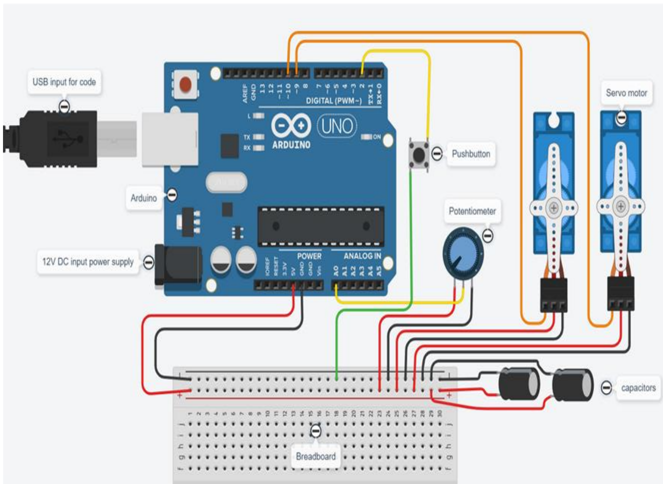

Figure 5: Circuit Diagram

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4.2 List of components:

i. Potentiometer
ii. Pushbutton
iii. Uno Arduino R3
iv. Micro servo motor
v. Polarized capacitor
vi. Breadboard
vii. Jumper wires

4.3 Demo Circuit:

The four-wheel steering (in opposite direction) is named mode 1 where the front and rear turn in opposite directions. It should also be noted that the rear actuator does not turn the same angle as the front in order to maintain vehicle stability and also follow the Ackermann geometry for perfect steering. So, both the servos turn based on the angular input from the potentiometer.

Mode 1 is the condition that facilitates us to reduce turning radius because the rear wheels turn in opposite direction to the front wheels.

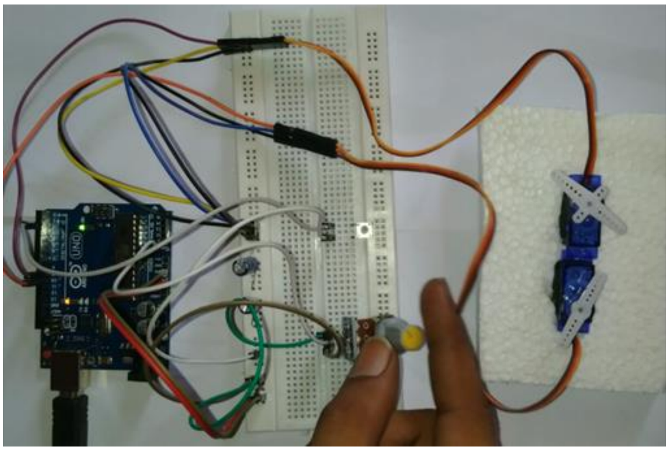

Figure 6: Mode 1

To switch to crab steering, the pushbutton is pressed once so that it switches from mode 1 to mode 2 which is four-wheel steering (in the same direction / crab steering).

The four-wheel steering (in the same direction / crab steering) is named mode 2 where the front and rear turn in the same direction. Again, the rear actuator does not turn the same angle as the front in order to maintain vehicle stability. So, both the servos turn based on the angular input from the potentiometer.

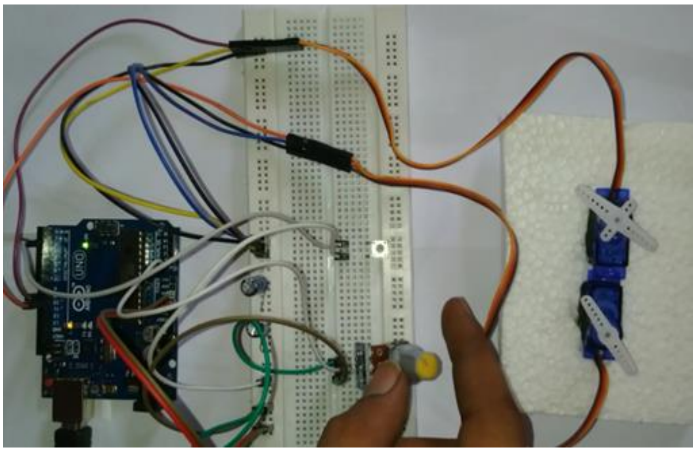

Figure 7: Mode 2

5. Calculations:

5.1 Front Wheel steering (FWS) using Ackermann steering mechanism:

In the below figure,

a = Length of front axle or distance

L = Distance b/w front and rear wheel or Wheelbase

a, L are fixed for a vehicle

R = Turning radius

O= instantaneous centre

ϴ = angle turned by inner wheels (the larger angle)

Φ = angle turned by outer wheels.

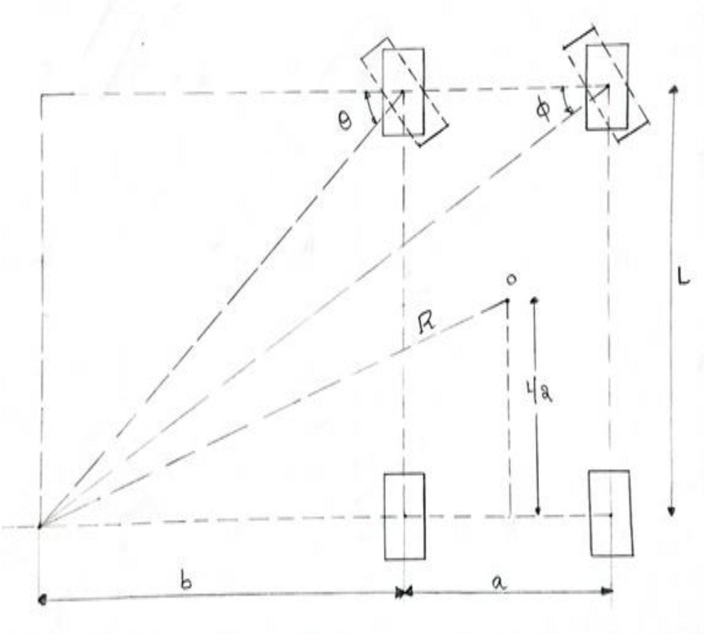

Figure 8: Front Wheel Steering System

From the figure, after performing calculations the following expressions are obtained,

- $b = L.\cot \Theta$
- $R^2 = (L/2)^2 + (b+a/2)^2$

By using the above expressions, we can calculate the turning radius of the vehicle whose wheelbase (L), axle length (a) and turning angle (ϴ) are known.

It is found that almost every vehicle's maximum turning angle lies between 25 to 28 , hence we are considering 25 as the maximum angle of turning the wheel.

5.2 Four-wheel steering (4WS type-1):

When the rear wheels turn along with the front wheels in the same angle as the corresponding front wheels (i.e., both the inner wheels turn the same angle and both the outer wheels turn the same angle) but in the opposite angle, the centre of turning and turning radius is along the line of instantaneous centre of the vehicle.

In the figure shown below,

a = Length of front axle or distance

L = Distance b/w front and rear wheel or Wheelbase

a, L are fixed for a vehicle

R = Turning radius

O= instantaneous centre

ϴ = angle turned by inner wheels (the larger angle)

Φ = angle turned by outer wheels

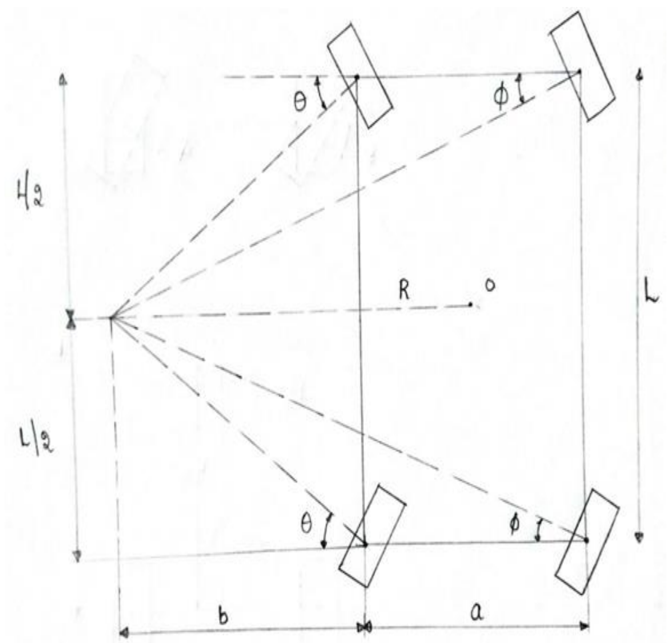

Figure 9: Four Wheel steering (type 1)

In this case the centre of turning and turning radius is along the line of instantaneous centre of the vehicle.

In other words, the wheelbase (L) is divided into two equal halves of (L/2)

From the figure, after performing calculations the following expressions are obtained,

- $b = (L/2). \cot \Theta$
- $R = b + a/2$

By using the above expressions, we can calculate the turning radius of the vehicle whose wheelbase (L), axle length (a) and turning angle (ϴ) are known.

For calculating the turning radius, the maximum angle of turning of the wheels for a vehicle is to be known. It is found that almost every vehicle's maximum turning angle lies between 25^0 to 28^0, hence we are considering 25^0 as the maximum angle of turning the wheel.

This type of system in which centre of turning and turning radius is along the line of instantaneous centre of the vehicle is found to be highly sensitive and gives drastic change in driving and stability of the vehicle.

In order to make this system relate to the driving conditions and also considering the stability and dynamics of vehicles, we came up with an idea of modifying the geometry like a passive rear wheel steering which will be explained next.

5.3 Four-wheel steering (4WS type-2):

In this system the centre of turning and turning radius is not along the line of instantaneous centre instead the centre of turning is offset such that the wheel base is divided in the ratio C_1:C_2 as shown in the figure above.

In the figure,

a = Length of front axle or distance

L = Distance b/w front and rear wheel or Wheelbase

a, L are fixed for a vehicle

R = Turning radius

O= instantaneous centre

θ_1 and θ_2 are the angle through which inner front and inner rear wheels rotate respectively

$\varnothing_1$ and $\varnothing_2$ are the angle through which outer front and outer rear wheels rotate respectively.

The centre of turning divides the wheelbase into a ratio C1:C2.

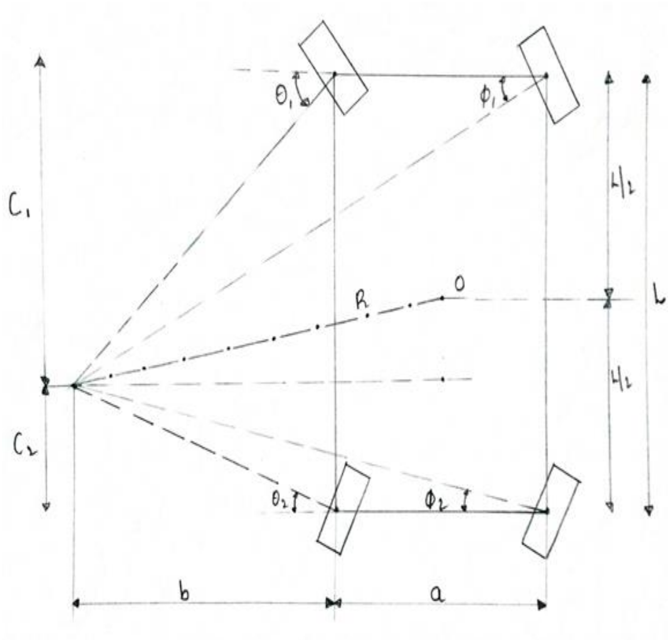

Figure 10: Four Wheel steering (type 2)

From the figure, after performing calculations the following expressions are obtained,

- $b = C_1 . \cot \Theta_1$
- $R^2 = (b+a/2)^2 + (L/2 - C_2)^2$

Taking $C_1 + C_2 = L$ and by knowing the ratio of $C_1{:}C_2$ the value of C_1 and C_2 can be obtained easily which can be used for further calculations.

Considering 25^0 as the maximum angle of turning the wheel and assuming the ratio of $C_1{:}C_2$ as 3:1 (this ratio can be assumed according to the sensitivity needed).

By using the above expressions, we can calculate the turning radius of the vehicle whose wheelbase (L), axle length (a) and turning angle (Θ_1) are known.

Also, the value of angles of turning of each wheel can be found by using the expressions obtained.

6. Results:

Based on the expressions obtained and dimensions of the benchmark vehicles considered the turning radii for the traditional system and our proposed solution has been tabulated for comparison:

Table-1: Results of calculated turning radii of different vehicles

Category	Sedan	SUV	Maxi Truck	Pickup Truck
Vehicle name	BMW G16 M8	Range Rover Lwb	Ford F550	Mahindra Bolero
Wheelbase	3.027 m	2.79 m	5.08 m	3.26 m
Axle length	1.627 m	1.585 m	1.89 m	1.46 m
Turning radius for front wheel steering	7.460 m	6.918 m	8.108 m	7.891 m
Turning radius for 4WS (type 1)	4.0592 m	3.784 m	5.392 m	4.225 m
Turning radius for 4WS (type 2)	5.735 m	5.325 m	6.403 m	6.026 m
% Reduction in turning radius in 4WS type2	23.12 %	23.02 %	21.02 %	23.63 %

It has been observed that when the C1:C2 ratio is considered as 3:1, the turning radius is reduced by 23% on an average by employing the 4WS type-2 when compared to the front wheel steering system.

This clearly shows a drastic change in turning radius of these well-known benchmark vehicles.

This data proves that the 4WS system will be highly effective in fulfilling the goal to reduce turning radius without compromising the stability of the vehicle.

Also, this system has a scope of changing the steering sensitivity and the C1:C2 ratio readily through its ECU without any mechanical changes or repairs.

7. CONCLUSIONS:

The ever-growing need of innovation of consumer-oriented products demands us to produce more safe and reliable products. The need of providing consumer a system that improves the driving experience and the luxury and not including irrelevant possibilities to make the system complex has brought us to this solution that is simple and feasible in every perspective along with high scope of improvement in the future.

The goals fulfilled by this project are as follows:

- By appropriate calculations we have found that this system surely succeeds in accomplishing the objective of reducing turning radius of the vehicle without compromising the safety and stability. There has been a drastic reduction in turning radius which makes this worth considering as a great replacement for the traditional steering systems.
- The system also allows easy customisation of the steering sensitivity without any mechanical replacements or adjustments of the components by merely changing the split ratio (wheelbase) in the program of ECU.
- The space requirement to employ this system is far lesser than the existing models and systems. Which makes it a go-to option for large vehicles which are in immediate need of such systems. The system assembly is easy to install and light in weight and can be implemented in all sections of cars efficiently.
- It can be easily incorporated in autonomous vehicles and electric vehicles with existing AI or other electronic systems.
- The effort made by the driver to steer the wheels would be reduced drastically.
- Due to smaller turning radius the parking of vehicle is easily performed. We can also crab steer, which is helpful both at parking and high-speed lane changing

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