*i*Journals: International Journal of Software & Hardware Research in Engineering (IJSHRE)
ISSN-2347-4890
Volume 10 Issue 10 October 2022

Testing Maneuverability of Electromechanical All Wheel Steering System

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Abstract:

Vehicles are traditionally designed with two-wheel steering systems. Two-wheel steering systems are used in all types of vehicles, be it front-wheel drive, rear-wheel drive or all-wheel drive. Since the evolution of Electric Vehicles stability of vehicles has become an important factor in the process of designing vehicles. Along with stability, it is always desirable to achieve better performance. In this project, a comparative analysis of two-wheel and four-wheel steering systems is performed for the radius of curvature of different steering angles for vehicles with varying base lengths. To demonstrate we have implemented a four-wheel steering system with the help of a Microcontroller, Servo Motors and PMDC Motors. Straight-line motions are controlled with PMDC Motors, whereas for turning servo motors will be used and for manual control Bluetooth communication is used.

1. Introduction:

Mechanical Steering mechanism:
Steering is an essential part of a vehicle that helps align it in the desired direction. Steering is achieved with the help of mechanical assembly which is made up of a series of linkages, rods, pivots, and gears. Furthermore, this steering can be for two wheels or four wheels. Traditionally vehicles are designed with a two-wheel steering system as shown in figure 1. A similar type of setting can be extended for four wheels with the help of a rod connection between two shafts which will move all the wheels together unidirectionally.

Differential steering:
In contrast to mechanical steering, the differential steering speed of the entire wheel assembly can be changed depending on the speed and direction of motion. This technique is more stable and accurate as compared to conventional mechanical steering. While turning, it is observed that the distance between the outer and internal wheel are not the same, so ideally, while taking turns, both wheels should have different speeds. It is impossible to achieve different speeds for different wheels using mechanical steering techniques. Still, with the invention of electric vehicles, it is possible to control the speed of each wheel individually. This leads to implementing differential steering for better performance and stability.

2. Literature Review:

Figure 1 shows the Ackerman steering model for two-wheel steered vehicles. Rudolf Ackerman founded this model in the 19th century. In this model front, wheels are steered with the help of the mechanical setup as shown in the figure and speed is controlled by powering the rear wheels [2]. When the vehicle moves in a straight direction, all the wheels move simultaneously. The Ackerman model, however, doesn't take into account real-life parameters of directional deviations due to tyre elasticity [3]

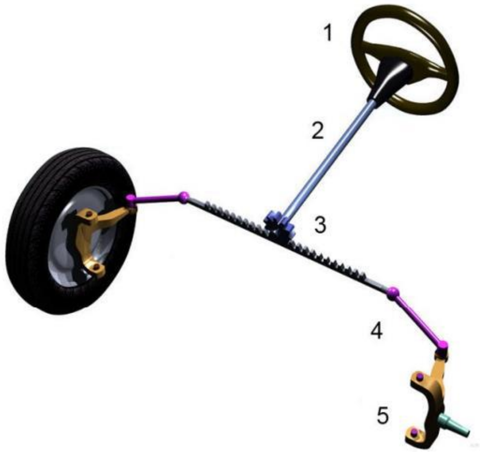

Figure 1. Rack and pinion steering mechanism 1 Steering wheel; 2 Steering columns; 3 Rack and pinion; 4 Tie rods; 5 Kingpins [1].

While turning on a curved path, the travelling distances for inner and outer wheels are different due to the different instantaneous steering centers. Figure 2 shows the top-view schematic of a steering vehicle. V_{ref} is the reference velocity of the center of gravity of the vehicle. For small values of steering angle δ, it is assumed that four wheels have an equal rotational angular velocity relative to the instantaneous steering center CG. In Figure 2, since $R_{RR} > R_{RL}$, the distance travelled by the outer wheel is more than that of the inner wheel. The same speed of the inner and outer wheels will lead to a serious slip between the ground and the wheel without a mechanical differential on an in-wheel motor-driving vehicle. It will also lead to an increase in tire wear. Tire slip also puts extra load on the driver shaft, reducing the driver's capacity to steer and control vehicles [4]. A proposed differential steering model that promises a zero turning radius but requires greater power and torque due to greater side slip. Also, wheel-ground interactions become increasingly difficult to study and account for in this model [5].

The arrival of Electric vehicles (EVs) on the market has invoked an interest in designing new techniques to control steering. Electric Vehicles Technology is developing at a rapid rate and at the same time, it is also helping in designing better control systems for steering mechanisms. Electric vehicles can have wheel motors for each tire and hence can give it a better facility for controlling motion and steering as it is possible to control torque for each wheel. In contrast to Internal Combustion Engine Vehicles, electric vehicles make it possible to use differential steering [6]. Since gearbox, retarder, transmission, and mechanical differentials are eliminated from electric vehicles, it has a flexible layout and a more efficient driving system [7]

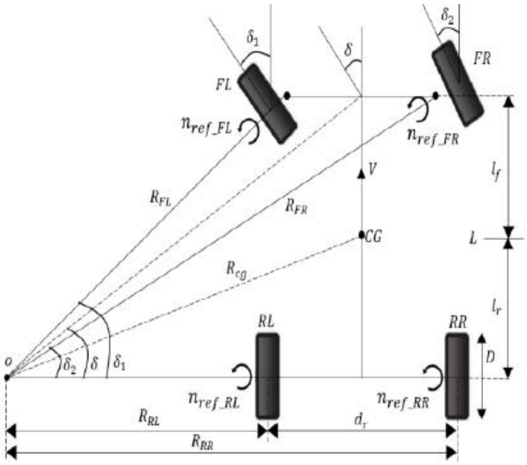

Figure 2. Ackermann Steering model of a vehicle [2]

In many automatic robots, differential speed steering is implemented, which employs a change of speed of the inner and outer wheels to achieve better stability [8]. Another approach talks about changing the steering angle of the rear wheel in proportion to the steering wheels in the same or opposite direction [9]. All the approaches we have discussed till now are somewhat targeted at reducing the radius of curvature while steering the vehicle. All-wheel steering systems can attain smaller radii hence better stability and performance. In this paper, we propose a system that will work with the help of Servo motors and PMDC Motors, which can overcome constraints on steering angle to achieve the radius of curvature calculated for various steering angles. The same data can also be analyzed and utilized in designing steering mechanisms.

3. Working:

In this project, we have implemented an all-wheel steering electro-mechanical system with the help of servo motors and PMDC motors. PMDC motors are used for normal movement in forward and reverse directions, whereas servo motors are used for turning in the desired direction. A microcontroller is also used for controlling direction and motion. For controlling the robot, a Bluetooth module is used to pass commands with the help of serial communication.

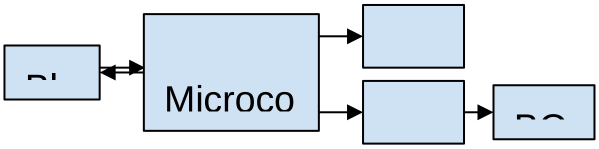

Figure 3. Block diagram of system

Figure 3 shows the block diagram of the project implemented in this paper. As shown in the figure, the microcontroller is the main controlling unit in the center which controls the motion of servo motors along with controlling PMDC Motors through a motor driver.

This type of system provides better control for straight motions and steering. In conventional two-wheel steering systems, only the front wheels are used for steering, leading to differences in the distance travelled by inner and outer wheels, eventually slipping. To reduce this, four-wheel steering can be used to control each wheel's steering angle with the help of a microprocessor unit. Since the servo motors can move the PMDC motor by an angle of 360°, it is possible to steer the vehicle in any direction without much effort. Since we can steer wheels in all directions, a comparison of the radius of curvature in different steering angles are done in this paper. For comparison, three different steering models are used as discussed.

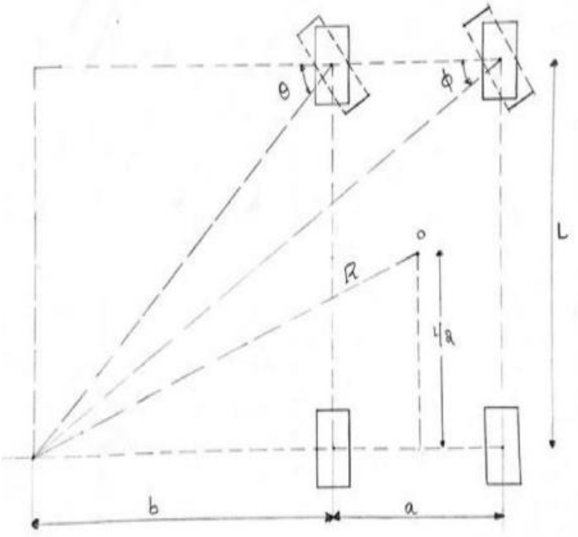

Figure 4: Geometrical representation of Front Wheel Steering System [10]

Front Wheel Steering (FWS) using Ackermann steering mechanism:

Figure 4 shows the top view of the Ackermann steering wheel mechanism with corresponding dimensions and steering angles

a = Length of the 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 center
ϴ = angle turned by inner wheels (the larger angle)
Φ = angle turned by outer wheels.

From Figure 4

$$b = L\cot\Theta$$

$$R^2 = (L/2)^2 + (b + a/2)^2$$

Four-wheel steering (type 1)

Figure 4 shows the top view of the 4-wheel steering wheel mechanism with corresponding dimensions and steering angles. In this type of steering, front and rear wheels move in opposite directions and the center of turning from point o and turning radius are along the line of the instantaneous center of the vehicle

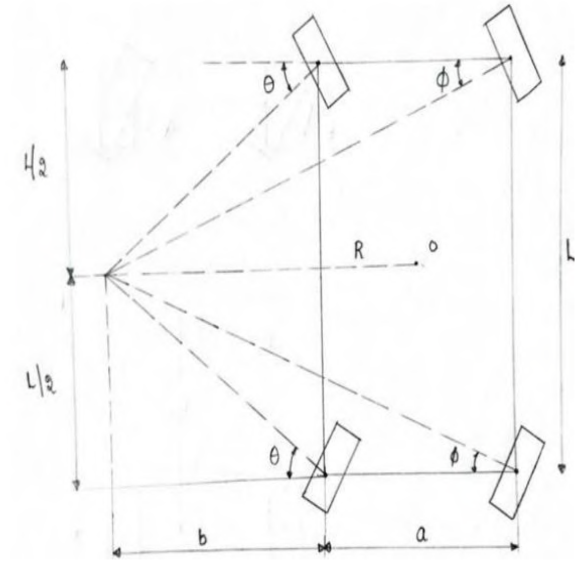

Figure 4: Geometrical representation of Four Wheel Steering System with counter phase steering [10]

In Figure 4,

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 center
Ɵ = angle turned by inner wheels (the larger angle)
Φ = angle turned by outer wheels

To calculate radius following equations can be used

$$b = L/2 \cot \Theta$$

$$R^2 = (b + a/2)$$

Four-wheel steering (type 2)

In this type of system it is assumed that the center of turning from point O and turning radius are not along the line of instantaneous center of the vehicle

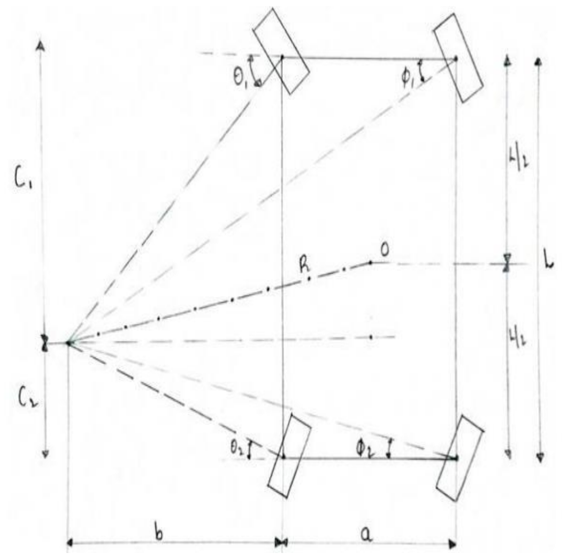

Figure 5: Geometrical representation of Four Wheel Steering System with counter phase steering [10]

In the figure 5,

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 center
θ1 and θ2 are the angle through which inner front and inner rear wheels rotate respectively
Ø1 and Ø2 are the angle through which outer front and outer rear wheels rotate respectively.
The center of turning divides the wheelbase into a ratio C1:C2

To calculate the radius following equations can be used

$$b = C_1 \cot \Theta$$

$$R^2 = (b + a/2)^2 + (L/2 - C_2)^2$$

Where $C_1+C_2=L$

4. Results and observations:

The table compares 2-wheel and 4-wheel steering systems for different vehicles and different steering angles. For analysis, we have considered four different vehicles as shown in the following tables:

Sedan car BMW G16 M8	Axle length a=1.627 m	Wheelbase L=3.027 m
Angle (in degrees)	Radius for two-wheel steering system (in m)	Radius for 4 wheel Steering System (in m)
5	35.44	18.12
10	18.05	9.4
15	12.21	6.46
20	9.25	4.97
25	7.46	4.06
30	6.24	3.43
35	5.35	2.97
40	4.67	2.61
45	4.13	2.32

Table 1. Comparison of two-wheel steering and four-wheel steering for Sedan car BMW G16 M8

SUV Range Rover Lwb	Axle length a=1.585 m	Wheelbase L=2.79 m
Angle	Radius for two-wheel steering system (in m)	Radius for 4 wheel Steering System (in m)
5	32.72	16.74
10	16.68	8.7
15	11.29	6
20	8.57	4.62
25	6.92	3.78
30	5.79	3.21
35	4.97	2.78
40	4.34	2.45
45	3.84	2.18

Table 2. Comparison of two-wheel steering and four-wheel steering for SUV Range Rover Lwb

Maxi Truck	Axle length a=1.89 m	Wheelbase L=5.08 m
Angle	Radius for two-wheel steering system (in m)	Radius for 4 wheel Steering System (in m)
5	59.09	29.99
10	29.87	15.36
15	20.07	10.43
20	15.12	7.93
25	12.11	6.40
30	10.07	5.35
35	8.58	4.57
40	7.44	3.97
45	6.54	3.49

Table 3. Comparison of the radius of curvature for two-wheel steering and four-wheel steering for Maxi Truck

pickup truck	Axle length a=1.46 m	Wheelbase L=3.26 m
Angle	Radius for two-wheel steering system (in m)	Radius for 4 wheel Steering System (in m)
5	38.04	19.37
10	19.29	9.98
15	13	6.82
20	9.82	5.21
25	7.89	4.23
30	6.58	3.55
35	5.62	3.06
40	4.89	2.67
45	4.31	2.36

Table 4. Comparison of radius two-wheel steering and four-wheel steering for pickup truck

Angle	Radius for two-wheel steering system (in m)	Radius for 4 wheel Steering System (in m)
5	59.09	15.52
10	29.87	8.25
15	20.07	5.83
20	15.12	4.61
25	12.11	3.88
30	10.07	3.39
35	8.58	3.04
40	7.44	2.77
45	6.54	2.55

Table 5. Comparison of radius two-wheel steering and four-wheel steering for a maxi truck for C1/C2=1/3

Angle	Radius for two-wheel steering system (in m)	Radius for 4 wheel Steering System (in m)

5	59.09	20.33
10	29.87	10.59
15	20.07	7.32
20	15.12	5.66
25	12.11	4.66
30	10.07	3.97
35	8.58	3.47
40	7.44	3.08
45	6.54	2.77

Table 6. Comparison of radius two-wheel steering and four-wheel steering for a maxi truck for C1/C2=½

Angle	Radius for two-wheel steering system (in m)	Radius for 4 wheel Steering System (in m)
5	59.09	39.68
10	29.87	20.18
15	20.07	13.62
20	15.12	10.29
25	12.11	8.26
30	10.07	6.87
35	8.58	5.85
40	7.44	5.06
45	6.54	4.42

Table 7. Comparison of radius two-wheel steering and four-wheel steering for a maxi truck for C1/C2=2

Angle	Radius for two-wheel steering system (in m)	Radius for 4 wheel Steering System (in m)
5	59.09	44.53
10	29.87	22.60
15	20.07	15.22
20	15.12	11.49
25	12.11	9.21
30	10.07	7.65
35	8.58	6.51
40	7.44	5.63
45	6.54	4.92

Table 8. Comparison of radius two-wheel steering and four-wheel steering for the maxi truck for C1/C2=3

It can be observed that the radius of curvature reduces significantly for four-wheel steering systems (for both type 1 and type 2) with an increase in steering angle for all types of vehicles.

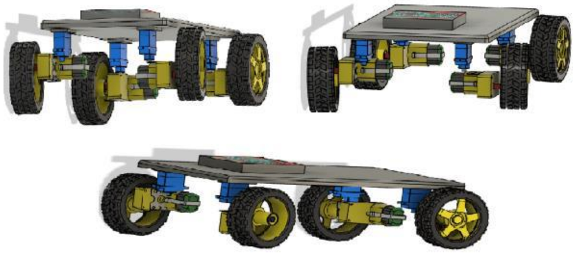

Figure 6. 3D Model of Implemented System

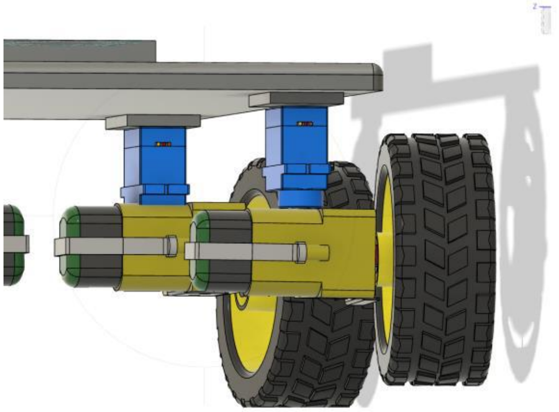

Figure 8. Servo Motor and PMDC motor assembly

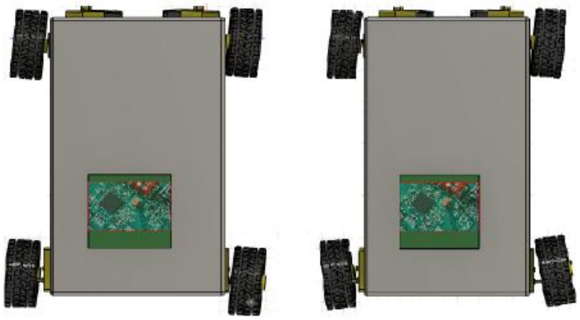

Figure 9. Top view of in-phase and counter-phase steering system

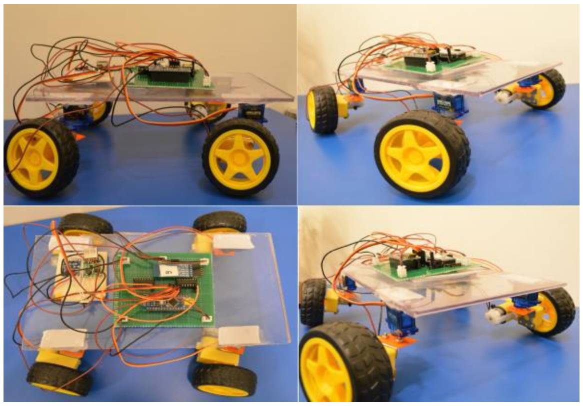

Figure 10. Implemented model

Implemented Model	Axle length a=14.5 cm	Wheelbase L=26.5
Angle	Radius for two-wheel steering system (in cm)	Radius for 4 wheel Steering System (in cm)
5	310.43	158.70
10	158.10	82.39
15	106.97	56.70
20	81.15	43.65
25	65.43	35.66
30	54.78	30.20
35	47.00	26.17
40	41.03	23.04
45	36.26	20.50
50	32.33	18.37
55	29.01	16.53
60	26.15	14.90
65	23.66	13.43
70	21.47	12.07
75	19.53	10.80
80	17.82	9.59
85	16.34	8.41
90	15.10	7.25

Table 9. Comparison of radius two-wheel steering and four-wheel steering for implemented system

Table 9 compares two-wheel steering and four-wheel steering mechanisms for the developed robot. As observed from the table, the radius of curvature reduces significantly for a four-wheel counter-phase steering system.

5. Conclusions:

Traditional mechanical steering constraints stability and accuracy as there is an upper limit on steering angle. The all-wheel steering system can be employed to overcome these constraints to achieve better stability and performance. Also, with the growth of EVs, it is possible to control the speed of individual wheels as per motion and steering angle. The implemented system in this project can steer vehicles in any direction with minimal effort, providing maneuverability. It can also be observed from the result that the radius of curvature- with the help of all-wheel steering- can be reduced to make a stable turning mechanism.

Furthermore, it is also possible to include differential speed steering to achieve better performance. In addition, the system can further be improved with the help of fuzzy logic and neural networks. The system can be steered 90 degrees, making the parallel parking task very simple. The performance of the system is also impeccable for lane-changing vehicular movements.

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