ADVANCED ALL-WHEEL STEERING FOR ALL TERRAIN VEHICLES

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Abstract: The vehicle steering system is an integral part of the vehicle dynamics of the automobile. While conventional steering system can perfectly perform the work of guiding the vehicle along straight line or curved paths, it is ridden with inherent drawbacks. These drawbacks include increased turning circle radius, reduction in high speed turning stability and the inability to perform a zero turn steer. Under steer and over steer characteristics have also not helped advocate conventional steering systems. The work proposed in this paper, deals with the inculcation of Crab Steer, Four-Wheel Steer and Zero turn steer into one comprehensive steering system package using electric motors. Crab steer helps with high speed turning ability. Four wheel steer turns the wheels in the opposite direction and aids with reduced low speed turning circles. Zero steer enables the vehicle to turn about its vertical axis so that, the vehicle can be maneuvered at dead-ends and tight spaces without much effort upon request. The proposed system is seen to greatly reduce the values of Turning Circle Radius. A reduction of 30 percent was observed during the simulation. The application of this work is endless. It can be of help to the agriculture and the commercial industry. Tractors, All terrain vehicles and off-roaders can now have a wider range of steering ability. Passenger cars can benefit with high stability lane change and easier navigation around parking lots.

I. INTRODUCTION

A. History of Four Wheel Steer

The steering system of a vehicle is an essential component to impart stability to the vehicle while travelling in a straight line and around corners, both during low speed and high speed maneuvers. While conventional steering system (2WS) can prove to be the most optimal solution, both from a complexity and an economical front, it puts forth a huge room for improvement in various other real world situations. These include:

- High Speed Turns and Lane Changing
- Low speed tight corners
- Navigating at dead end

These challenges have driven research to new directions and have given a plethora of innovative solutions, including the concept of Four Wheel steering (4WS). The first car to deploy this technology was the Nissan Skyline GT-R. The system was called the High Capacity Actively Controlled Steering (HICAS), was back in 1986. [1]. In this steering system the variation in turning direction of the rear wheels with respect to the front wheels will determine the change in vehicle dynamics. Two separate concepts of in-phase steering and counter-phase steering will are employed which are explained in detail in the subsequent chapters.

The 4WS upon varying the turning angles of the individual wheels effectively reduces the wheelbase of the vehicle. Hence, the driver will feel like he is driving a vehicle shorter in length than it actually is, which can enable him to drive out of parking spaces with minimal effort and relative ease.

All terrain vehicles such as tractors, dune buggies and other off road vehicles find themselves negotiating tight corners and high speed maneuvers all the time. This project aims to develop a steering system for just that, while inculcating an added mode of Zero Turn Steer.

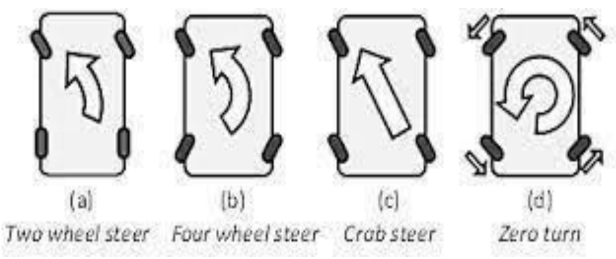


Fig 1.1 Example of Various Steering Mechanism [2]

B. Various Steering Wheel configurations

- Two Wheel Steer: In this mode only one axle is driven.
- Four wheel steer: In this case, both axle are driven but in direction opposite to each other.
- Crab steer: When all the wheels turn in same direction it is known as crab steer.
- Zero turn steer: In this mode vehicle follows the circular path.

C. Modern Steering Mechanism

Most modern vehicles are steered based on the Ackermann steering mechanism. A pinion is attached to the end of the steering wheel shaft, which meshes with a linear gear or rack. The rotational input of the driver is then fed to the wheels by converting it to translation motion by the rack and is fed to the wheels.

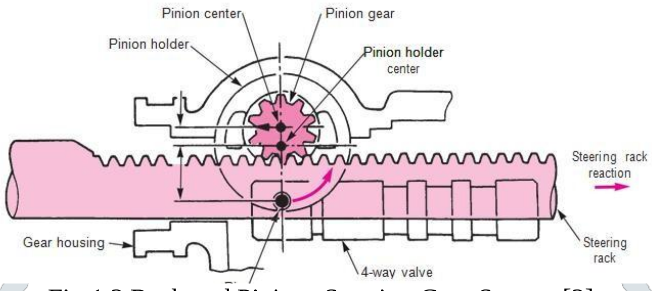


Fig 1.2 Rack and Pinions Steering Gear System [3]

The mechanism that actuates each wheel for the appropriate amount of toe in/out is known as the Ackermann mechanism.

D. Zero Turn Steer

Zero turn steering involves changing the wheel angles of the front and rear wheels such that the vehicle can turn about its geometric centre, making the theoretical turning radius zero. The immense number of advantages this system would potentially provide to the driver are only overshadowed by the impracticalities in its application in a real vehicle, ranging from the opposite-turning wheels on the same axle to changing the direction of rotation of half of the driven wheels [2], [4]. Still, some vehicles have demonstrated this concept like the Jeep Hurricane [5].

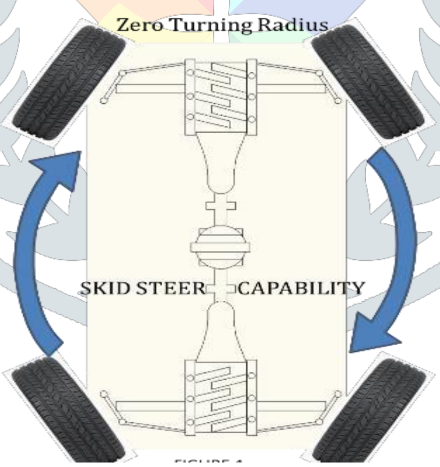


Fig 1.3 Zero-turn Steer

Advantages [6] [7]

- Superior cornering

The vehicle can take turns around smaller corners, in roads with lesser width. Or, it is better equipped to take turns of more than 90 degrees over a conventional vehicle.

- Improved steering response

Since the rear assist is electronically controlled, the overall steering response would be smoother at any vehicle speed.

- High speed stability and lane changing

As the crab steer kicks in at high speeds, the vehicle will feel more stable and in-control while changing lanes, can perform this maneuver faster.

- Smaller turning radius

The point about which the vehicle turns is closer to the geometric centre of the vehicle as the rear wheel toe increases out-of-phase, giving a smaller turning circle radius which is helpful in situations like turning, parking, and backing out of tight corners, maneuvering in tight spaces and taking U-turns.

Disadvantages

- Chance of electrical failure

This system depends so much on sensors, controllers ECU's and other electrical components, so the chance of any electrical component failing increases. This failure may lead to catastrophic accidents due to the steering system going haywire, and safety protocols in the case of electronic failures need to be set up before this system is implemented. [7]

- Space and complexity

Additional components require space, which need to be fitted near the wheel hub and suspension systems, an area which is already crowded. Apart from packaging problems, these components increase overall complexity of the system, potentially creating additional failure modes which need to be addressed.

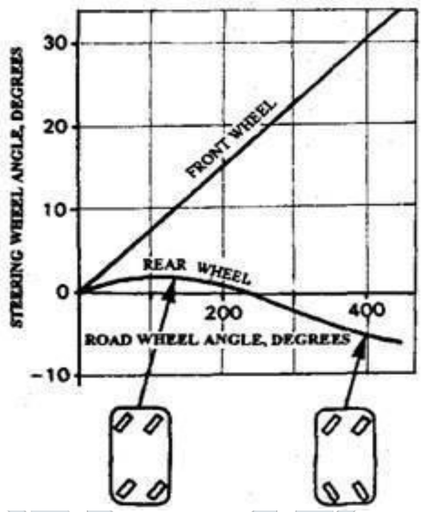


Fig 1.4 Relation between Steering Wheel angle and Road wheel turning angles (Front and Back) [8]

II. MATLAB MODEL SIMULATION

For simulating two wheel steering, standard Ackermann criteria is followed to calculate the outer wheel angle. This is done b y assuming the vehicle to be turning about a point lying on a line passing through the rear axle, and both the wheels should be perpendicular to the line joining this point and the pivot point at the axle, to draw geometrical constraints which were converted to equations. This allows us to calculate and plot the outer wheel angle, as well as the turning circle radius which can be taken as the distance between the outer front wheel and the point on the rear axle extension about which the vehicle is turning.

At low speeds, the 4-wheel turning allows for sharper turns, and at higher speed the crab steer makes the vehicle more stable while changing lanes. To decide if the turning should be in-phase steer or out-of-phase steer, we calculate the angle turned by the rear wheels as a function of vehicle speed and a function of front wheel turning angle. At low speeds, a typical driver requires minimum turning circle radius. Conversely, at high speeds the vehicle is steered subtly to shift lanes or follow the road bends. So it becomes convenient to use the front steering angle as a parameter in the function that controls the rear wheel toe angle.

To generate that function, we have the following constraints:

a) The rear wheels should turn with the front wheels to certain angle, then turn in the opposite side when the angle is increased above a certain value
b) The change in turn direction should not be too sudden
c) The rear wheels should never turn more than the front wheels in the same direction, as that would cause the car to turn in the opposite direction as intended.

Consulting existing literature, and using a curve-fitting tool in MATLAB, we generated a 4th degree polynomial from a set of points which the rear wheel angle should suffice when the front wheel angle is at a particular value. After getting the rear inner wheel angle for any value using this polynomial, we can apply a modified Ackermann criterion to calculate the outer wheel toe. To calculate them we assume the instantaneous point around which the vehicle is turning is a point formed by the intersection of perpendiculars drawn from the inner wheels, whose angles have already been decided. Then the outer wheels should turn such that they are perpendicular to the same point. Using this modified Ackermann criteria, we can calculate the outer wheel angles and plot them for a visualization of 4 wheel steering and obtain the turning radius, which is simplified as the distance between the outer front wheel centre and the instantaneous turning point.
The concept prototype can be understood by looking at the front and rear halves separately. The front is constructed based on traditional Ackermann geometry and the wheels are steered using a movable rack that is attached to the wheels using a tie rod. The geometry is designed so that at exactly 45 degrees of toe out for the inner wheel, the instantaneous centre of the mechanism occurs equidistant from the front and rear pivot points. This is done to enable 4WS about the centre line of the car which greatly reduces turning circle radius.

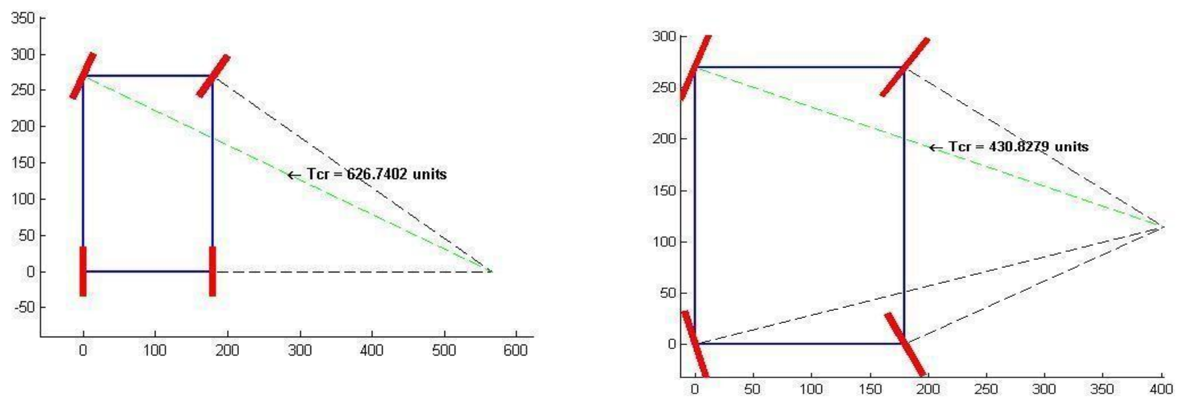


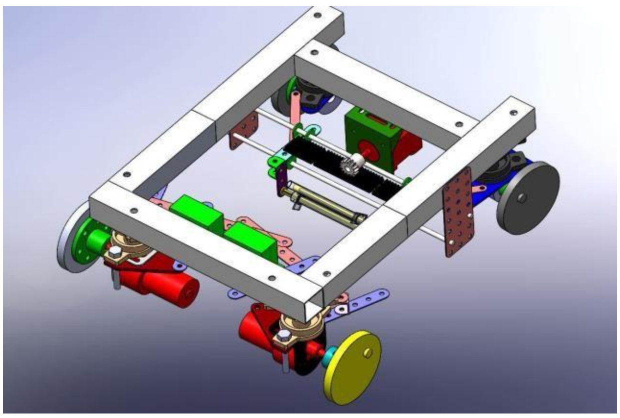
Fig 2.1 Simulation results for (a) 2WS and (b) 4WS
MATLAB Simulation

III. PHYSICAL MODEL

The rack length is also governed by a hydraulic system attached to a DC motor. Under zero steer condition, the hydraulic system enables the rack to be extended so that perpendiculars drawn from the centre of each wheel intersects at the geometric centre of the prototype to enable it to turn about its vertical axis.

The rear wheels are coupled with one DC motor each that powers the forward and reverse motion of the prototype. They are steered by a servomotor connected via a double crank mechanism. The toe of each of the rear wheels are thus governed by servomotors.

The stepper motor (employed to actuate the rack), DC motors and the servo motors are controlled by an Arduino MEGA controller board coupled with DC motor and stepper motor drivers. The code stored on the Arduino gives the instructions for each motor on the prototype regarding speed, angle and position of each motor allowing us to accurately control the vehicle. A 6V battery on board supplies the power for the motors, motor drivers and the Arduino. The prototype has three modes of operation: 4WS, Crab steer, and Zero turn steer.



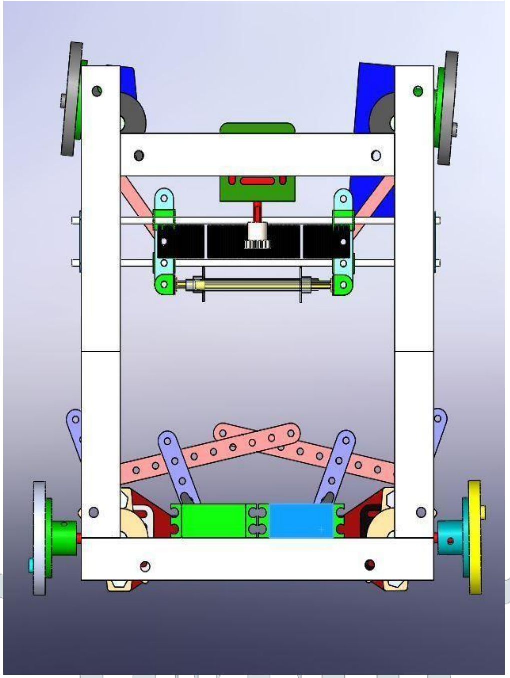


Fig 3.1(a) Top view of the CAD Model (b) Front three quarter view of the CAD Model

At low speeds, it employs counter phase steering i.e. the rear wheels are steered in a direction opposite to that of the front wheels. This greatly reduces the turning circle radius.

At high speeds, it employs in-phase steering enabling lane change with minimal load transfer and ensuring stability of the car. When the prototype is stationary, the hydraulics allows the rack length to be modified so that the car may turn about its vertical axis and achieve a zero turning circle radius.

IV. RESULTS

Turning Circle Radius of the vehicle was measured before and after implementing 4 wheel steering using IS12222 standard, and the data was correlated with theoretical values obtained via simulations.

As the data shows, experimental values correlate with theoretical values of Turning Circle Radius, and a marked decrease in Turning Radius is shown at high steering angles.

Table 4.1 Simulation results for (a) 2WS and (b) 4WS MATLAB Simulation

Front inner wheel turning angle (degrees)	Two wheel steering		Four wheel steering	
	Front outer wheel angle (degrees)	Turning Circle Radius (m)	Front outer wheel angle (degrees)	Turning Circle Radius (m)
0	0	infinity	0	infinity
5	4.73	3277.26	4.9	11002.35
10	8.97	1732.42	9.4	3082.02
15	12.81	1217.96	13.16	1465.81
20	16.33	960.55	16.08	904.29
25	19.58	805.61	18.26	649.56
30	22.63	701.68	19.88	512.98
35	25.52	626.74	21.12	430.82
40	28.28	569.80	22.16	377.85
45	30.96	524.79	23.26	343.92

V. FUTURE SCOPE

This technology can find its application in Forklifts, agriculture, construction as well as off-road vehicles. It may also be employed for domestic applications like wheelchairs in hospitals where they may have to navigate through narrow corridors. The purpose of building the front end hydraulic was to make sure it can be used in tandem with other systems who has hydraulics employed in their functioning. The front end was designed based on traditional steering systems used in vehicles that are mass manufactured to show compliance with current industry steering systems

VI. CONCLUSION

Using Four Wheel Turning mechanism, the vehicle is more maneuverable around turns and the Zero Turn allows it to turn on the spot making it ideal for parking and reversing. Four Wheel Steering at high angles reduce the turning radius by over 30%, making it an ideal system to implement in any vehicle for stability, convenience and flexibility if practical problems of packaging and suspension integration could be overcome.

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