

The performance of independent wheels steering vehicle(4WS) applied Ackerman geometry.

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Abstract: Recently, The researches of vehicle's stability, controllability and comfortability are demanded because of increased usage of vehicle and mass transportation. The trend of vehicle is that the conventional vehicle accessories of mechanical link scheme are going to electronic module scheme connected by signal. The vehicle's heavy mechanical steering linkages will be replaced to servo motors and signal cables. For example, the four wheel steering(4WS) vehicle driven by electric power has made by WIA corporation. That 4WS type vehicle has various advantages of driving. The vehicle can go leftward or rightward without turning and can turn in standing state. But past researches were proceeded based on mechanical system. To convert heavy mechanical accessories to electronic modules, the proper modeled signals and research data based on electronic system are needed.

In this paper, the Ackerman geometry in mechanical system is applied to electronic independent four wheels steering system. And an analysis conducted about the real model 4WS vehicle was manufactured for using in factory to transport heavy loads by unmanned. Afterward, the effect of the converted presence of the Ackerman geometry in steering performance is simulated and examined.

Keywords: 4WS, FABOT, Ackerman geometry, Steering performance, Yaw rate, Electronic vehicle

1. INTRODUCTION

Recently, the development of auto-transfer-vehicle for transferring heavy load in factory is active. Those auto-transfer-vehicles have developed in many types of model. Most of the general type of model has four wheels like a car.

Past most of the researches of transfer-robots are focused on 2WD(two wheels drive)/2WS(two wheels steering). 2WD/2WS type robot has a weak point in performance of driving and rotating. In order to cope with weak points of 2WD/2WS, the method of 4WD/4WS which is reducing side-slip angle and increasing performance of driving was presented[1].

The method of 4WD(Four Wheel Drive) has a characteristic that the power is supplied to the front wheel and rear wheel. This method has more performance of driving, safety and the braking system especially harsh road than the method of 2WD[2].

And The method of 4WS can steer front wheel and rear wheel at once to least the side slip angle. So this method can increase the yaw response time of vehicle to the steering handle input and rotating performance by decreasing a radius of rotation.

Previous 4WS vehicles have researched and developed on mechanical system composed of machinery linkage. This Mechanic system uses fuel. There are many problems to use fuel like oil. The Oil makes a air pollution and is almost exhausted Therefore, electric vehicles using electric energy which do not produce air pollution are presented and developed.

The example of the current trend, factory robot(FABOT) was produced by WIA to transfer heavy load by unmanned in the factory using electric energy. The FABOT is a 4WD/4WS type installed independent wheel motor and steering motor.

It is needed that the research of mechanic linkage system is applied to the electronic signal system. To obtain characteristic data and to advance the performance of electric vehicle system, the research of modeling which replace mechanic linkage system by electronic signal system is active recently[3].

In this paper, the 4WS electric vehicle has a characteristic that four independent driving motors are installed directly to the each wheel and four independent steering motors to steer the each wheel independently. This type of vehicle has an advantage to minimize side slip angle and give an maximum controllability to drive unmanned.

The past most of researches are accomplished under the consideration the vehicle model is simplified to 2-DOF bicycle model which has the same steering angle of left-right wheel. But in this paper, Ackerman geometry dealt with mechanic linkage system is applied to real electric vehicle model connected each wheel by electronic signal. The Ackerman equation is presented for increasing a rotation performance. and finally the simulation and the experimental result are given.

2. ACKERMAN GEOMETRY

2.1 Ackerman geometry

Rudolf Ackerman discovered and defined this principle early in the 19th century. The principle of Ackerman Steering is the relationship between the front inside tire and front outside tire in a corner or curve. The Ackerman Steering Principle defines the geometry that is applied to all vehicles whatever they are 2WS or 4WS to enable the correct turning angle of the steering wheels to be generated when negotiating a corner or a curve.

The creation of toe-out when turning to minimize tire wear. To create the proper geometry, the steering arms are angled to turn the inside wheel at a sharper angle than the outside wheel. This allows the inside wheel to follow a smaller radius circle than the outside wheel and prevents scrubbing of the steer tires while turning.

The Ackerman concept is to have all four wheels rolling around a common point during a turn. This can greatly improve cornering ability and performance. The Fig. 1 and Fig. 2 are to explain the general principles of both parallel arm steering and Ackerman steering.

To understanding cornering is to analyze the low speed turning behavior of a motor vehicle. At low speed the tires need not develop lateral forces. Thus the roll with no slip angle, and the vehicle must negotiate a turn as illustrated in Fig. 2. If the rear wheels have no slip angle, the center of turn must lie on the projection of the rear axle. Likewise, the perpendicular from each of the front wheels should pass through the same point. If they do not pass through the same point, the front tires will 'fight' each other in the turn, with each experiencing some scrub(side slip) in the turn. The ideal turning angles on the front wheels are established by the geometry seen in the Fig. 2, and define the steering angles for the turn.

For proper geometry in the turn, the steer angles are given by blow equation (1).

$$\delta_o \cong \frac{L}{(R+t/2)}, \quad (1)$$

$$\delta_i \cong \frac{L}{(R-t/2)}.$$

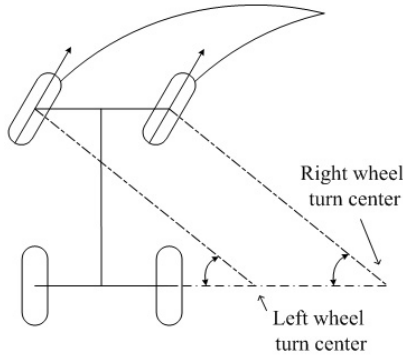


Fig. 1 Parallel arm.

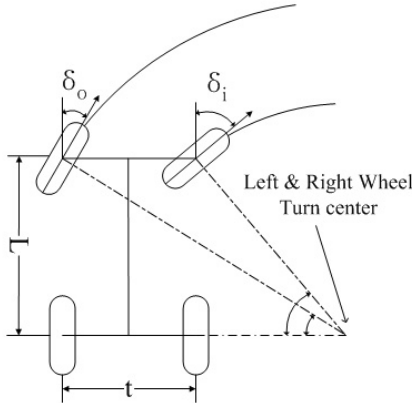


Fig. 2 Ackerman geometry.

The correct angles are dependent on the wheelbase of the vehicle and the angle of turn. Errors or deviations from the Ackerman in the left-right steer angles can have a significant influence on front tire wear.

The significant aspect of low speed turning is the off-tracking that occurs at the rear wheels. The off-track distance, Δ , may be calculated from simple geometry relationships as:

$$\Delta = R(1 - \cos(L/R)). \quad (2)$$

Using the expression for a series expansion of the cosine, namely:

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} \dots \quad (3)$$

Then

$$\Delta \cong \frac{L^2}{2R}. \quad (4)$$

For obvious reason, off-tracking is primarily of concern with long-wheelbase vehicle such as trucks and buses.

2.2 Four Wheel Steering applied Ackerman geometry.

Vehicle performance in turning can be enhanced by actively steering the rear wheels as well as the front wheels. Active steering is accomplished by steering action applied directly to the rear wheels, in contrast to passive steering in which the compliances are purposely designed into the suspension to provide incremental steer deviations that improve cornering[4]. Four wheel steering may be used to improve low speed maneuverability.

Low speed turning performance is improved by steering the rear wheels out of phase with the front wheels reduce the turn radius, thus improving maneuverability as shown in Fig. 3. Real wheel steer is accomplished by mechanical, hydraulic or electronic means.

Normally the rear wheel steer angle may only be applied at low speeds[5]. Analysis of the turning performance is simplified by assuming average angles for the front and rear wheels, analogous to the bicycle model approximation.

With the rear wheel steer angle proportional to the

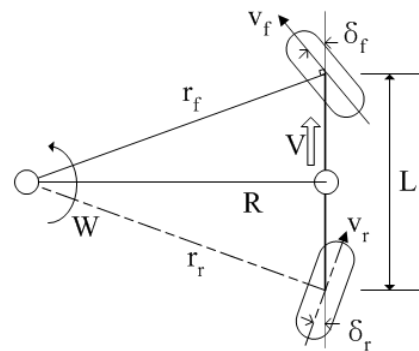


Fig. 3 Two bicycle model.

front wheel angle, the turning equations are as follows:

$$\delta_r = \xi \delta_f \quad (5)$$

$$\delta_f + \delta_r = \delta_f + \xi \delta_f = \delta_f (1 + \xi) = L / R$$

Then the turn radius is:

$$R = \frac{L}{\delta_f (1 + \xi)} \quad (6)$$

Equation (6) gives the explicit expression for the way in which the turn radius is reduced by use of rear steer.

The expression for off tracking with four wheel steer is somewhat more complicated than that for two wheel steer. Recognizing that the front and rear turn radius, R_f and R_r , respectively, are related by the expression.

$$R_f \cos \delta_f = R_r \cos \delta_r = R_r \cos \xi \delta_f \quad (7)$$

It is possible to obtain an equation in the following form as an approximation of the off tracking distance:

$$\Delta \cong \frac{L^2 (1 - \xi^2)}{2R (1 + \xi^2)} \quad (8)$$

With the rear wheels steered to the same angle as the front, the off tracking distance becomes zero.

Under those constraints, each wheels velocity and steer angle equations can be obtained using mechanical geometry approach on the Fig. 4.

$$\begin{aligned} R &= \frac{L}{\tan \delta}, \\ \omega &= \frac{V}{R}, \\ r_{fi} &= \sqrt{(R - D)^2 + L^2}, \\ r_{fo} &= \sqrt{(R + D)^2 + L^2}, \\ v_{fi} &= r_{fi} \times \omega, \quad v_{fo} = r_{fo} \times \omega, \\ \delta_{fi} &= \tan^{-1} \frac{L}{R - D}, \quad \delta_{fo} = \tan^{-1} \frac{L}{R + D}, \\ v_{fi} &= v_{ri}, \quad v_{fo} = v_{ro}, \\ \delta_{fi} &= \delta_{ri}, \quad \delta_{fo} = \delta_{ro}. \end{aligned} \quad (9)$$

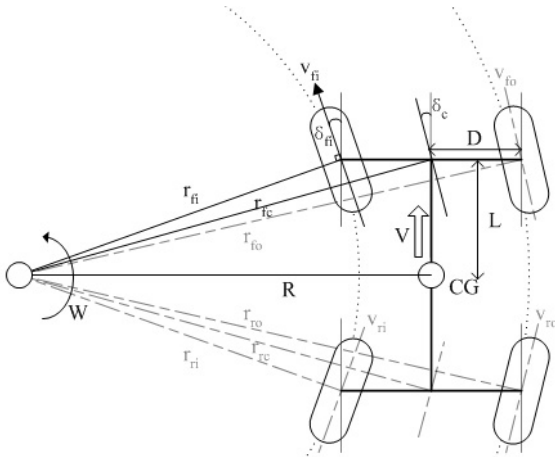


Fig. 4 4WS/4WD Ackerman geometry.

Some elaboration on notation and the various terms of equation (9) is in order:

R	: Turning radius of vehicle.
L	: 1/2 Wheel base of vehicle.
D	: 1/2 Tread of vehicle.
V	: Reference velocity of vehicle.
ω	: Angular velocity of vehicle.
r_{fi}	: Turning radius of front inner wheel.
r_{fo}	: Turning radius of front outer wheel.
v_{fi}	: Velocity of front inner wheel.
v_{fo}	: Velocity of front outer wheel.
δ_{fi}	: Steering angle of front inner wheel.
δ_{fo}	: Steering angle of front outer wheel.

3. SYSTEM CONFIGURATION

Previous mechanical vehicle is designed as parallelogram linkage framework to perform a Ackerman geometry. Mechanical linkage by parallelogram framework only generate a fixed steering angle to the handle input. Moreover heavy and complex mechanical devices have require a huge size space to be installed. But new concept vehicle linked electronic devices is needed simple connection each device and occupy a comparatively small size space. it can replace big and heavy gear accessories to simple wire

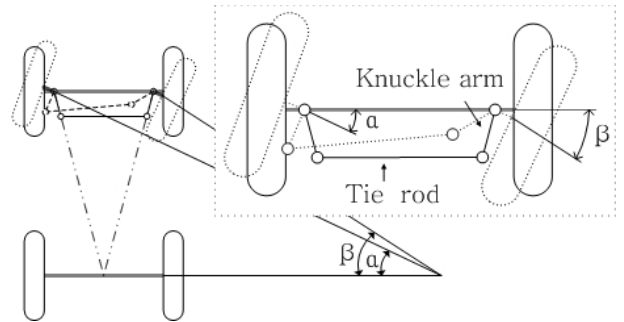


Fig. 5 Mechanical linkage system.

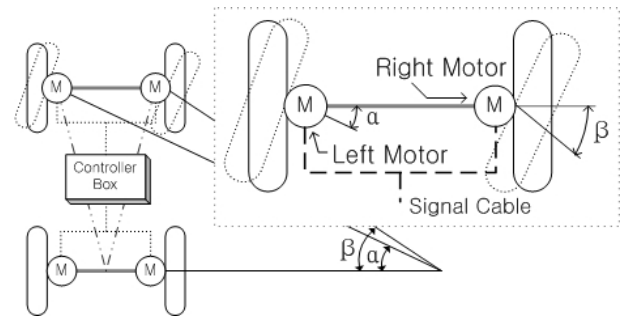


Fig. 6 Electronic signal link system.

connection and motor. it can save much space and reduce resources also power energy. And electronic devices are connected by signal so they can generate flexible steering angle to the specific condition.

But they have a weak coupling by signal. So it is needed to consider that response time, settling time, delay time, steady state error, and variety state performance.

If we can generate a proper control command using electrical flexibility feature, variety of steering mode can be applied. And electronic linkage vehicle can realize an outstanding performance rather than mechanical linkage vehicle.

In the Fig.5, mechanical linkage system consisted Parallelogram linkage framework by knuckle arm, tie rod and like those supporters. In those systems, Ackerman geometry can be generated by the law of parallelogram. When tie rod move left or right, both side of wheels are put on the Ackerman angle through mechanical link connection.

The FABOT(Factory Autonomous Robot) is made electronic linkage type like in the Fig. 6. It is replaced mechanical link connection to electronic signal link connection. Both side of front and rear wheels consisted steering and driving wheel module. It has two motors.

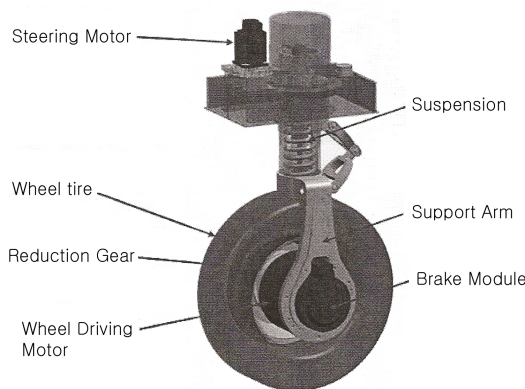


Fig. 7 Steering and driving wheel module.

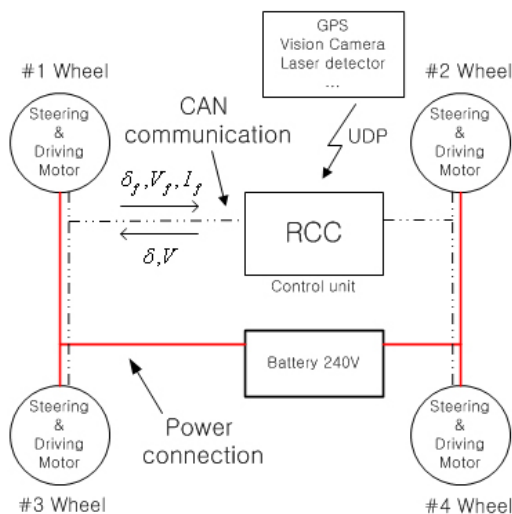


Fig. 8 Concept of FABOT configuration.



Fig. 9 4WS/4WD Electrical vehicle FABOT.

In the Fig. 7, the one is steering motor on upper side, and another is driving motor on left side of wheel. Suspension can reduce the shock from rough road. And all of electrical modules are connected by signal cable and power support cable. Communication protocol is the extended CAN 2.0B.

In the Fig. 8, RCC(Robot Control Computer) is a main controller of the system. Steering and driving modules receive operating commands generated in RCC. The command signals are generated belong Ackerman geometry and transferred to the each wheel modules.

The input command and feedback data are in order:

- δ : Steering angle command to #1,2,3,4 wheel ,
- V : Velocity command of #1,2,3,4 wheel ,
- δ_f : Steering angle feedback data of #1,2,3,4 wheel ,
- V_f : Velocity feedback data of #1,2,3,4 wheel ,
- I_f : Current feedback data of #1,2,3,4 wheel.

And Battery specification is that the capacity voltage is 240V and maximum current is 40A. GPS, vision camera, laser sensor and other sensors are attached to the Navigation Computer for unmanned navigation on the factory. RCC and Navigation Computer are connected by UDP protocol.

In the Fig. 9, The FABOT is manufactured to transfer heavy loads on the factory by unmanned.

4. SIMULATION AND EXPERIMENTS

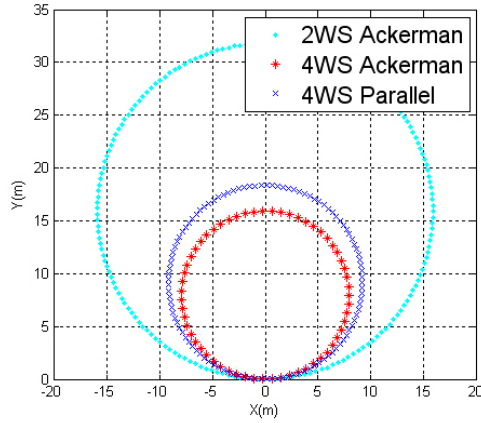
To verify the 4WS steering performance presented, experiments were carried out. The experimental vehicle was the FABOT made WIA performed four wheels steering and four independent electricity driving system in the Fig. 9. The all experiments are accomplished in the Gyeongnam Technopark Robot Center.

General steering angle 15° and 35° was chosen to verify the steering performance of 2WS front wheel steering, 4WS applied Ackerman geometry and 4WS of parallel arm.

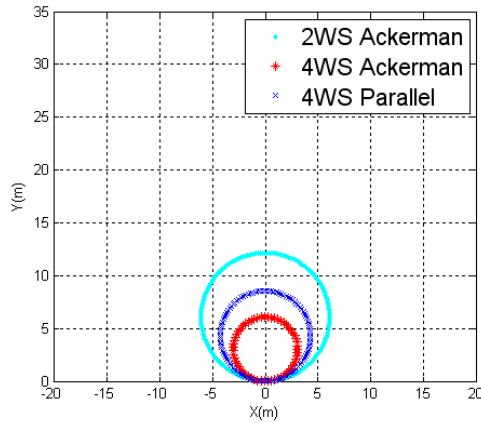
The vehicle's initial point and heading angle are almost same in those different steering experimental condition. And in the all of experiment, the reference velocity of vehicle is same as low speed 3Km/h. Exactly each wheel velocity isn't same. Because each wheel

velocity is calculated along the presented equations (9). The vehicle's speed is acceptable slow because the kinetics isn't considered to generate Ackerman geometry only kinematics is considered.

The experimental vehicle's specifications are that the wheel base length is a 4260mm and the wheel thread is a 1370 mm.



(a) Steering angle 15°



(b) Steering angle 35°

Fig. 10 Trajectory of FABOT to the different mode.

Fig. 10 represents FABOT trajectory to the steering angle 15° , 30° . In the Fig. 10(a) steering condition 15° , the 4WS applied Ackerman geometry mode has a least radius. The steering trajectory diameter is approximately 15.8m. Then the 4WS parallel steering mode needs the larger steering trajectory diameter approximately 18.4m. The 2WS applied Ackerman geometry mode needs the largest trajectory diameter approximately 31.8m.

In the steering angle 35° Fig. 10(b), the 4WS parallel steering performance is more worse approximately 8.6m compared with 4WS applied Ackerman geometry steering mode approximately 6m. If steering angle has more increased, we can see the 4WS applied Ackerman geometry mode has more outstanding effective. The 2WS applied Ackerman geometry mode needs the trajectory diameter approximately 12m.

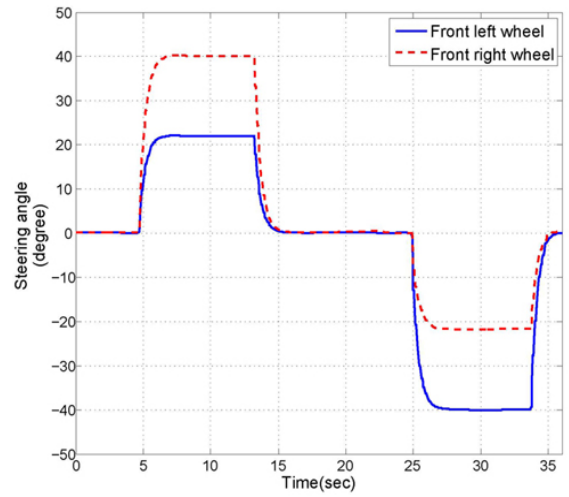
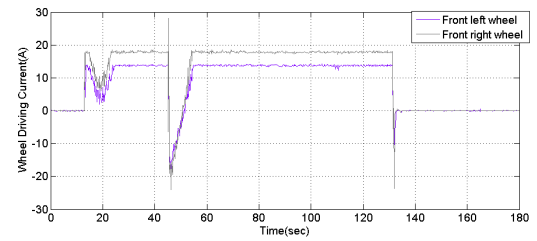
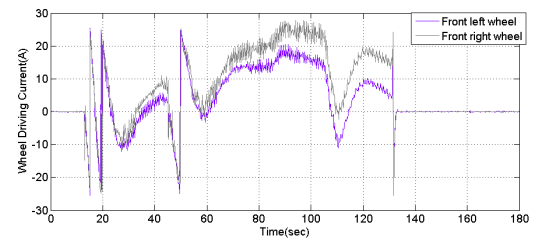


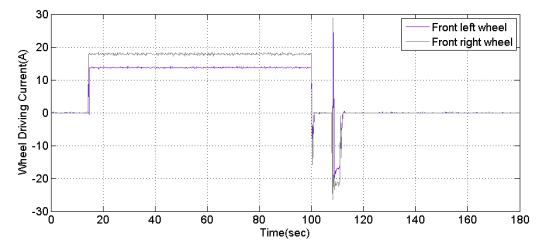
Fig. 11 Ackerman steering angle time response data



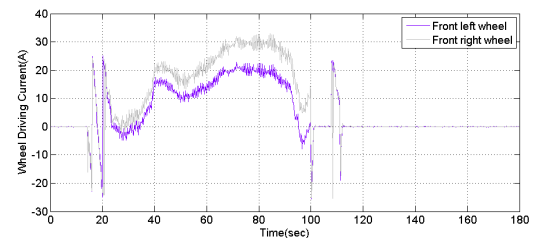
(a) Current for driving on Ackerman angle 20°



(b) Current for driving on parallel angle 20°



(c) Current for driving on Ackerman angle 30°



(d) Current for driving on parallel angle 30°

Fig. 12 Current usage of Ackerman and parallel mode

Fig. 11 shows the time response of front two steering wheel applied Ackerman geometry. Reference steering input is 30° . The rising time is nearly similar. PID control is used for steering input. In the Fig. 12, the current for driving motor is presented. PI control is used for velocity command input. From the current usage data, we can achieve the result that the mode applied Ackerman geometry is more stable and efficient than parallel steering mode.

5. CONCLUSION

In this paper, the performance of electricity 4WS applied Ackerman geometry has evaluated. The parallel steering mode has a geometry problem when the vehicle is turning. It may cause increasing the friction force of tire and decreasing the steering performance. To solve this problem, Ackerman geometry is used to electricity 4WS vehicle. Four independent steering and driving module is installed to the electricity 4WS vehicle. Because they are connected electronic signal, proper command and timing consideration are needed.

We derive the Ackerman angle and each wheel velocity equations, and design the RCC(Robot Control Computer) which generates Ackerman angle and suitable velocity. Also we have carried out a experiment to the real system FABOT.

As a result of experiment, we demonstrate the 4WS applied Ackerman geometry is the most perform to steering and driving.

In the future, it is needed the performance analysis of the dynamic approach and synthesis design. And also the study of independence passive control to the rear wheel is requested to raise the steering and driving performance.

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