



(51) International Patent Classification:
G06F 19/00 (2011.01)

(21) International Application Number:
PCT/IN2012/000563

(22) International Filing Date:
23 August 2012 (23.08.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2383/MUM/2011 25 August 2011 (25.08.2011) IN

(71) Applicant (*for all designated States except US*): **INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY** [IN/IN]; Indian Institute of Technology Bombay, Powai, Mumbai 400 076, Maharashtra (IN).

(72) Inventor: **KULKARNI, Anish, Ajit**; Room 103 Hostel 4, Indian Institute of Technology, Bombay, Mumbai 400 076 (IN).

(74) Agent: **ROY CHOWDHURY, Mahua**; Intellectual Property Services, Calcot House, 3rd Floor, 8/10 M. P. Shetty Marg, Fort, Mumbai 400 023, Maharashtra (IN).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,

DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *of inventorship (Rule 4.17(iv))*

Published:

- *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) Title: MECHANISM FOR OMNI-DIRECTIONAL STEERING USING MECHANICAL LOGIC GATE SYNCHRONIZERS

(57) Abstract: This invention includes a steering Mechanism for a vehicle capable of exhibiting four modes of steering. These steering modes include a 4-wheel steering mode for tight situations (wherein the front wheels steer opposite to the rear wheels), a 2-wheel steering mode for road travel (wherein only the front wheels are steered), and a 4-wheel crab steer mode (wherein the front and rear wheels turn in the same direction) and Zero turn radius. The steering action may be achieved by either solely by manual steering signals or automated steering signals or a combination of both. An electronic circuit monitors the position of the wheels at any time and provides required steering signals to the corresponding wheels to make the wheels turn according to the driver's requirements. One or more motors with one or more gear boxes may be used to induce required automated steering in the wheels.



WO 2013/054357 A2

MECHANISM FOR OMNI-DIRECTIONAL STEERING USING MECHANICAL LOGIC GATE SYNCHRONIZERS

FIELD OF INVENTION

The present invention relates to a new steering mechanism based on a 7-bar 2-degree-of-freedom ("DOF") linkage that functions as a mechanical "OR" logic gate synchronizer. The mechanism makes a vehicle capable of exhibiting four interchangeable modes of steering (hereinafter also referred to as "the above-specified Four Modes of Steering") as follows:

"Mode 1": Two Wheel Steering (only front wheels steer);

"Mode 2": Four Wheel Steering (for reduced turning radius –both front as well as rear wheels steer; rear wheels steer opposite to front wheels);

"Mode 3": "Crab Steering": All four wheels steer in the same direction; and

"Mode 4": Zero Radius Turning: The vehicle rotates around itself: All four wheels steer; the front wheels toe in while rear wheels toe out.

Apart from the above Modes involving four-wheel-steering, the theme of the invention of steering system with mechanical logic gate synchronizers can also be applicable to the existing ordinary two-wheel front-steered vehicles as well, as elaborated below under the head "Summary of Invention". In such case only front wheels have mechanical logic gate synchronizers.

BACKGROUND AND LIMITATIONS OF PRIOR ART

Steering system is one of the most important sub systems of an automobile. Traditionally, almost all production vehicles have been front wheel steered whose steering systems are typically made up of the of the following interconnected components: steering wheel, which is connected to the steering module, which is connected to the track rod, which in turn is connected to the tie rods, which are connected to steering arms of wheels. Further, in order to ensure smooth turning any steering system must meet what is known as "Ackermann condition"(inner and outer wheels traversing circles of different radii but same virtual centre; further elaborated below under the head "Mathematical Modelling of the Mechanism").

Steering modules can have several designs (such as rack and pinion arrangement, re-circulating ball arrangement etc.), but all the designs essentially move the track rod left-to-right across the car. Thus, in effect, such steering systems can be modelled as 6-bar linkages (a track rod, two tie rods, two wheels and a fixed frame link) with input given to the track rod (horizontal displacement) and output seen in the wheel turn. Recent advances in steering systems include use of "power steering", "speed sensitive steering", "active/passive four wheel steering" etc. All such steering systems essentially use the basic 6 bar linkage or slight variations thereof.

Motorists today are experiencing that roads as well as parking places for vehicles are shrinking day by day, especially in super-crowded metro cities. In view of the same there is a necessity for vehicles with far smaller turning radii and far superior maneuverability and control so as to be able to be driven and parked in narrow spaces.

Presently, this need can be seen as being addressed, to a limited extent, though, by three-wheeler vehicles (popularly known in India as "auto rickshaw"), wherein one can easily experience and appreciate advantages of their smaller turning radii in tackling heavy traffic conditions as well as narrow parking places.

Therefore, it is desirable to equip ordinary four-wheel-vehicles also with smaller turning radii for better maneuverability. Going a step further, it is highly desirable to have a vehicle with zero turning radius (the vehicle being capable of turning about its vertical central axis). Further, it would be desirable to have a vehicle capable of being moved at an angle to its central horizontal axis, like a crab.

However, due to design limitations it is not possible with conventional steering mechanisms as existing presently (and typically involving mechanical links) to achieve these highly desired conditions, namely, shorter turning radii, zero turning radius, and "crab" steer.

Theoretically it may seem possible that mechanical links of the presently existing conventional steering mechanisms can be replaced with electronic means in order to accomplish the above-specified three Modes of steering along with the normal mode of steering. In such a design, input by driver (imparted by turning of steering wheel) can be received by an electronic control unit, which can process the same (so as to meet the basic

Ackermann condition) and send outputs to any and all of the four wheels. However, in practical scenario reliability is a very critical issue with such electronically controlled steering system, as probability of failure of electronic parts when exposed to vibrations, heat, dust etc. is much greater than probability of mechanical parts/components under similar conditions. Thus, electronically controlled steering systems are quite unsafe and unreliable.

OBJECTS OF INVENTION

The principal object of the present invention is to overcome the above-mentioned limitations and present a mechanism based on mechanical logic gate synchronizers, which is capable of achieving the above-specified Four Modes of Steering (hereinafter also referred to as "Mechanism for Omni-directional Steering"), thereby improving overall maneuverability of the vehicle.

Another object of this invention is to present "Mechanism for Omni-directional Steering" primarily comprising mechanical links.

A further object of this invention is to present "Mechanism for Omni-directional Steering" wherein the above-specified Four Modes of Steering can be interchanged as per needs and conditions.

SUMMARY OF INVENTION

At the core of the proposed Mechanism for Omni-directional Steering for achieving the above-specified Four Modes of Steering is a 7-bar 2-degree-of-freedom ("DOF") linkage that functions as a mechanical "OR" logic gate synchronizers.

The theme of the invention of steering system with mechanical logic gate synchronizers can also be applicable to the existing ordinary two-wheel front-steered vehicles as well. The steering systems of existing ordinary vehicles can be replaced by a mechanism employing mechanical logic gate synchronizers between two wheels (please refer figure 4) while the rear wheels remained unsteered. The steering characteristics of a vehicle equipped with such a mechanism will be more flexible than the vehicles with traditional one-degree of freedom, 6-

bar linkage steering mechanism. For instance, in a traditional steering system, once the mechanism is designed the steering performance is fixed and cannot be changed. However, if mechanical logic gate synchronizers are used instead, the steering performance can be continuously varied depending on various factors such as tire slip angle data, suspension dynamics, high speed cornering dynamics etc. Thus, steering systems equipped with mechanical logic gate synchronizers would be more flexible on account of having more degrees of freedom.

The desired conditions are achieved by providing two inputs to the said 7-bar 2-degree-of-freedom ("DOF") linkage and appropriately controlling one of them, namely "Correction Input"(elaborated below in the Detailed Description), wherein the combination of the two inputs result in one output.

In case of a four wheel steering system using the "Mechanism for omni directional steering", two pairs of the above mentioned mechanical logic gate synchronizers can be used. (please refer figure 5). A Forward-Neutral-Reverse (FNR) gear box can be installed in between the front pair and the rear pair of mechanical logic gate synchronizers, which may be electronically controlled to switch between above-specified Four Modes of Steering depending on the speed of the vehicle and as per the need. For example, the vehicle can be put in Mode 2 (rear wheels turning opposite of the front wheels) at slow speeds to reduce turning radius considerably (e.g. parking or maneuvering in the city). At higher speeds the FNR gear box may switch the mechanism to Mode 3 (both front and rear wheels turn alike), so that the vehicle may change position with less yaw, enhancing straight-line stability. Mode 4 (Mode 4 however requires change in the transmission system) enables a car to turn in its place (zero turn) thus enhancing its maneuverability significantly. This Mode of steering might be extremely useful for off road SUVs, military vehicles, monster trucks or other vehicles where maneuverability in small arenas is critical.

In addition to achieving the above-specified Four Modes of Steering, by controlling the correction input and the FNR gearbox, the mechanism can also be continually tweaked to include effects of tire slip angles or dynamic forces acting on the wheels during high speed cornering.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 represents the above-specified Four Modes of Steering.

Figure 1(a) shows "Mode 1": Two Wheel Steering (only front wheels steer);

Figure 1(b) shows "Mode 2": Four Wheel Steering (for reduced turning radius – both front as well as rear wheels steer; rear wheels steer opposite to front wheels);

Figure 1(c) shows "Mode 3": "Crab Steering": All four wheels steer in the same direction; and

Figure 1(d) shows "Mode 4": Zero Radius Turning: The vehicle rotates around itself: All four wheels steer; the front wheels toe in and the rear wheels toe out.

Figure 2 represents mechanical 'OR' gate synchronizers.

Figure 2(a) shows a 7-bar 2-degree-of-freedom ("DOF") linkage that functions as a mechanical "OR" logic gate synchronizers.

Figures 2(b) and 2(c) show the working of the mechanical OR gate synchronizers when the slider (105) is moved towards left and right respectively.

Figure 3 represents 'OR' gate synchronizers output C (106) linked to wheel (101) at steering arm (113) by tie rod (112).

Figure 4 represents relative positions of the two front wheels by application of proposed OR gate synchronizers, during the above-specified Four Modes of Steering.

Figure 4(a) shows relative directional positions of the two front wheels (101 and 102) when there is no input through steering wheel.

Figure 4(b) shows relative positions of the two front wheels when input is provided by steering wheel (through input pinion 124) and the Correction Input is provided by an electronically controlled motor (through pinion 126). Such relative directional positions of the two front wheels are found in Mode 1, Mode 2 and Mode 3.

Figure 4(c) shows relative positions of the two front wheels when there is no input through steering wheel and the Correction Input is provided. Such relative directional positions (toe-in) of the two front wheels are found in Mode 4.

Figure 4(d) shows the front wheels in toe-in mode. Here the wheels are tangential to the circle of rotation.

Figure 5 represents the above-specified Four Modes of Steering.

Figure 5(a) shows Mode 1;

Figure 5(b) shows Mode 2;

Figure 5(c) shows Mode 3; and

Figure 5(d) shows Mode 4.

Figures 5(e), 5(f), 5(g), and 5(h) represent another embodiment of the invention, viz. a slight variation of the Mechanism for Omni-directional Steering respectively in the above-specified Four Modes of Steering. Here, for providing Correction Input to left and right wheels two separate pinion and motor sets are used (unlike one, as shown in Figures 5(a), 5(b), 5(c), and 5(d)).

Figure 6 shows Ackermann geometry.

Figure 6(a): Two wheel steered car;

Figure 6(b): Four wheel steered car.

Figure 7 shows the geometry of the Mechanism for Omni-directional Steering.

Figure 7(a): Constant parameters;

Figure 7 (b): Inner wheel;

Figure 7 (c): Outer wheel.

Figure 8 shows comparison of Mode 1 with Ackermann geometry.

Figure 9 (a) shows comparison of Mode 2 with Ackermann geometry.

Figure 9(b): Mode 2: correction input x_3 plotted against driver input x_1 .

Figure 10(a) shows comparison of Mode 3 with Ackermann geometry: Mode 3: Outer wheel angle v/s inner wheel angle. In Mode 3 all wheel are steered by equal angles. $\phi_1 = \phi_2$.

Figure 10(b): Mode 3: correction input x_3 against driver input x_1 Negative correction input x_3 signifies input B (107, 117, 131 and 141 respectively) moving inwards in Mode 3.

[Note: The drawings are schematic and not to the scale. If there is any discrepancy between the drawings and the description the description is to be considered.]

LIST OF LABELS USED IN DIAGRAMS

- 101 Left front wheel
- 102 Right front wheel
- 103 left rear wheel
- 104 Right rear wheel
- 105 Left front input slider A
- 106 Left front output slider C
- 107 Left front input slider B (correction input)

- 108 Link
- 109 Link
- 110 Link
- 111 Front guide link (fixed)
- 112 Left front tie rod
- 113 Left front steering Arm
- 114 Left front upright (fixed pin joint)
- 115 Right front input slider A
- 116 Right front output slider C
- 117 Right front input slider B (correction input)
- 118 Link
- 119 Link
- 120 Link
- 121 Right front tie rod
- 122 Right front steering arm
- 123 Right front uptight
- 124 Front main pinion (steering wheel driven)
- 125 Front main rack
- 126 Front correction pinion (motor driven)
- 127 Front left correction rack
- 128 Front right correction rack
- 129 Left rear input slider A
- 130 Left rear output slider C
- 131 Left rear input slider B (correction input)
- 132 Link
- 133 Link
- 134 Link
- 135 Rear guide link (fixed)
- 136 Left rear tie rod
- 137 Left rear steering Arm
- 138 Left rear upright (fixed pin joint)
- 139 Right rear input slider A
- 140 Right rear output slider C

- 141 Right rear input slider B (correction input)
- 142 Link
- 143 Link
- 144 Link
- 145 Right rear tie rod
- 146 Right rear steering arm
- 147 Right rear uptight
- 148 Rear main pinion (steering wheel driven)
- 149 Rear main rack
- 150 Rear correction pinion (motor driven)
- 151 Rear left correction rack
- 152 Rear right correction rack
- 153 Input to gearbox
- 154 FNR gearbox
- 155 Output from gear box
- 156 Front left correction input pinion (two rack system)
- 157 Front left correction input rack (two rack system)
- 158 Front right correction input pinion (two rack system)
- 159 Front right correction input rack (two rack system)
- 160 Rear left correction input pinion (two rack system)
- 161 Rear left correction input rack (two rack system)
- 162 Rear right correction input pinion (two rack system)
- 163 Rear right correction input rack (two rack system)

DETAILED DESCRIPTION

As mentioned above, at the core of the proposed steering mechanism is a 7-bar 2 degree of freedom ("DOF") linkage that functions as a mechanical "OR" logic gate synchronizer. An "OR" gate synchronizer means that when at least one of the two input links is actuated, the output link gets actuated.

The mechanism involves two inputs: (i) A primary input actuated by rotation of steering wheel, which is in control of the driver of the vehicle; and (ii) A "Correction Input", also referred to as "Input B" and elaborated below. These two inputs combined together result in

one output. (This linkage is not an exact OR gate synchronizers in the sense that a certain amount of input displacement does not produce the same amount of output displacement. The relationship between the input and the output has been worked out herein below under the head "Mathematical Modelling of the Mechanism".)

In the proposed invention the desired conditions of steering (i.e. the above-specified Four Modes of Steering) are achieved by providing the two inputs to said 7-bar 2-degree-of-freedom ("DOF") linkage, so that their combination gives one desired output. As stated above, the 7 bar linkage acts like an OR gate synchronizers. One of the inputs (Input A) is assigned as primary input. The primary input is actuated by rotation of the steering wheel which is in control of the driver of the vehicle. Thus input A is manually controlled. The second input (Input B) is assigned as "Correction Input" since it corrects the manual input to produce the desired output. The correction input is actuated by an electronically controlled actuating mechanism (for eg. a servo motor). The manual input can be measured by a sensor (for eg. a potentiometer at steering wheel) and this data can be sent to an on-board computer chip. Depending on various parameters like the value of manual input, current mode setting and vehicle speed, the computer can calculate the "correction" required for the desired steering performance in the selected mode, and actuate the correction input (Input B) accordingly. Thus, the electronically actuated Input B adds on to the manual input A, or in other words, corrects Input A to produce the desired output.

Different Modes have different desired performance characteristics (hereinafter referred to as "the Respective Desired Condition"), and accordingly the mechanism can be operated in different modes, as discussed below:

Mode 1

In Mode 1, the Respective Desired Condition is that the wheels should ideally be steered such that the extended axes of the steered front wheels intersect at a point that lies on the axis of the non-steered rear wheels. This will ensure that the two front wheels turn in concentric circles.

When the vehicle is in Mode 1 the only input to the steering system is input A, (the manual input) and Input B (the "Correction Input") is locked. The design parameters of the mechanism are selected such that the performance of the steering system in this purely

mechanical mode (Mode 1) is very close to the ideal steering performance of a normal two wheel steered car (100% Ackermann for two wheel steer).

Mode 2

In Mode 2 all four wheels are steered (as opposed to only front wheels, as in Mode 1). For all 4 wheels to move in concentric circles, the Respective Desired Condition is that the extended normals of all the wheels must intersect at a common point that lies on the line passing through the centre of the vehicle and perpendicular to its length.

Mode 3

In Mode 3 the Respective Desired Condition is that all four wheels are steered by equal angles.

Mode 4

In Mode 4, in order to undertake a "zero turn" the front wheels toe-in and the rear wheels toe-out. The Respective Desired Condition for Mode 4 is that all the four wheels should be steered such that they are tangential to the circle of rotation of the vehicle. (The centre of the circle of rotation should coincide with the centre of the vehicle.)

Thus, it can be seen that we need to change the performance of the mechanism in different Modes to match the ideal performance in each of them. This can be achieved by actuating input B along with manual input A where input B is controlled electronically.

The exact amount of displacement to be given by input B is calculated based on what Mode the vehicle is currently in. The combined result of actuation of both inputs A and B should result in the desired wheel steer output. Thus, as specified earlier, Input B can be seen as a "correction input" which "corrects" the manual input (input A) to get the required output. Again, in Mode 1 there is no correction input. Manual input alone will give the desired steering performance as the mechanism design parameters are tuned for this Mode. However in Modes 2 and 3 manual input alone is insufficient to achieve desired wheel steer angles. Here we need input B to add to the manually driven input A (OR gate synchronizers: $A + B \Rightarrow C$) so that the correct output is obtained.

In Mode 4 (zero turn), manual input A is locked and only input B is actuated. In this Mode input B is the primary input. In Mode 4 the electronically driven input B is displaced until the wheels are tangential to the circle of rotation.

EVOLUTION OF THE INVENTION

The functional requirements of the new steering mechanism are:

1. The steering mechanism should enable a vehicle to turn around an axis that passes through the centre of the vehicle. A vehicle possessing such functionality would seem to rotate in its place and change direction without having to translate on the ground. This is called as "Zero Radius Turn" (Figure 1(d)).
2. The mechanism should enable a vehicle to "Crab steer" or move sideways without turning the nose of the vehicle, which can be achieved if all the four wheels turn in the same direction (Figure 1(c)).
3. The mechanism should enable the vehicle to steer with all four wheels, where direction of turn of rear wheels is opposite to that of the front wheels. With all four wheels steered thus, the vehicle has a smaller turning radius than normal front steering vehicles (Figure 1(b)).
4. The driver should have an option to switch between the regular two wheel steering mode (Figure 1(a)) and the above 3 Modes of steering.

Considering the above mentioned requirements, a mechanism is developed to steer only a set of two wheels (say front wheels). The same mechanism can then be used for the other set of wheels (back wheels). From the kinematic scheme of the system it is seen that there are two different operational modes. The first operational mode is where two wheels turn opposite sides; the second mode is where two wheels turn same side. The first one is essential for a "zero turn" (in fig.1 (d) front wheels turn opposite sides). The second one is essential for the rest (in fig.1 (a), 1(b) and 1(c) front wheels turn same side).

Now, for this required mechanism, the inputs should have two states depending on whether input is given or not. Also the output should have two states corresponding to whether the wheel has turned or not. By treating the finitely separated positions of these elements as Boolean variables the positions of interest of each element could be assigned a value "0" or "1" in accordance with a predefined convention. It is to be emphasized that the interest is only in the two finitely separated end positions of the output link as well as the two input links, even if the links actually go through all positions in between the extremes (0 and 1). As there

are two binary inputs and a single binary output a 2 DOF mechanical system should be installed to obtain the requisite operational features. Then the structure of the mechanism can be determined by a mechanical logic gate synchronizers. More specifically, the desired thing is an output actuation (wheel turn) when at least one of the two inputs is initiated. So, the structure of the mechanism can be determined by a mechanical OR gate synchronizers. Figure 2(a) shows a 2 DOF seven-bar linkage that is at the core of the proposed steering mechanism. For simplicity consider the system to be binary with the sliders A(105) and B (107) as inputs and slider C (107) as the output. The sliders occupy 2 positions of interest during operation: original un-displaced position (state "0") and a horizontally displaced position (state "1"). The linkage in this way constructed represents a mechanical OR gate synchronizer as shown in figure 2(b). It is to be noted that the mechanism works similarly if the other input is given. Another important point to consider here is that this mechanism is not an exact OR gate synchronizer in the sense that an input displacement of x does not ensure an output displacement of x . It only ensures that there will be an output displacement when at least one of the two input displacements is given. The relationship between the output and input displacements is discussed further. Figure 3 shows the linkage between the proposed mechanical OR gate synchronizers and the wheel. The output element C (106) is connected to the wheel (101) at the steering arm (113) by a tie rod (112). The wheel rotates about a pivot (114) (king pin or suspension upright) when the output link moves. Thus the horizontal displacement of output C is converted to a wheel turn by this linkage.

STEERING MODES

Figures 4 and 5 show the application of the proposed OR gate synchronizers in a steering mechanism. To actuate slider inputs A (105 and 115) and B (107 and 117) rack and pinion gear sets are used. Figure 4(a) shows the Mechanical linkages between front wheels, where 125 and 124 represents a rack and pinion gear set for inputs A (105 and 115). 127, 128 and 126 represents a 2- rack 1 pinion gear set for inputs B (107 and 117). Pinion 124 is steering wheel driven (driver); Pinion 126 is motor driven.

For Steering Actuation in modes 1, 2 and 3, as shown in Figure 4b, the Inputs A (105 and 115) on both right and left wheels are connected by a single rack link such that the two wheels always have opposite inputs ($\{1, -1\}$ or $\{-1, 1\}$). This ensures that both the wheels turn in the same direction when in the normal steering mode. The pinion 124 is driven by the steering wheel which is controlled by the driver. Driver turns steering wheel left causing

wheels to turn left. The amount by which the steering wheel is rotated can be measured by a sensor. This information is passed on to the Electronic Control Unit (ECU), which computes the required correction in the manual input based on the current mode of steering (mode 1, 2, or 3). The ECU then drives pinion 126 to actuate inputs B (107 and 117) to get the desired steering performance in each of the modes. This is discussed further in "Mathematical modeling" section.

For Toe-In Actuation, the inputs B (107 and 117) of both the wheels are fixed on two different racks 127 and 128 with one pinion 126 in between them such that they always have the same input ($\{-1,-1\}$ or $\{1,1\}$ and never $\{1,-1\}$ etc.). This ensures both wheels turn opposite to each other, which is necessary for toe in/out. Also, in the Toe-In mode, the wheels need to be tangential to the circle of rotation as the angle of wheel turn is always fixed. Hence the pinion 126 of the two racks 127 and 128 is driven by a motor which always turns the wheels to the required angle when switched on. Figure 4(c) shows the front wheels in toe-in mode. Here the wheels are tangential to the circle of rotation.

So far only the two front wheels are considered. A similar mechanism can be constructed for the rear wheels. Now to have a four wheel steering system there is a need to couple rear wheel steering linkage to front wheel linkage by means of a shaft or a belt-pulley mechanism that runs down the length of the vehicle. The proposed four wheel system is shown in figure 5(a). Here only inputs A of the front (105 and 115) and rear (129 and 139) mechanisms are connected. The inputs B (107, 117, 131 and 141) are driven independently by motors. To fulfill the requirement of switching between different Modes, a 1:1 Forward-Neutral- Reverse (FNR) gear box (154) between the front and rear steering linkages is needed.

Mode 1: When the gear box (154) connecting the front and the rear steering linkages is in neutral, the rear wheel mechanism is cut off from the front wheel mechanism as a result the vehicle has only two wheel steering. (Figure 1(a)). This is the primary mode of steering and is purely mechanical in the sense that the steering input is given by the driver using the steering wheel through inputs A (105 and 115) while input B (107 and 117) is locked (figure 5(a)) shows the mechanism of Mode 1 where Pinions 124 and 148 are connected by a shaft/belt pulley mechanism with a 1:1 FNR gearbox (GB) (154) between them. When GB switched to "Neutral"; rear wheel steering is disconnected from front wheel steering mechanism.

Mode 2: When the FNR gearbox (154) is shifted to 'reverse', the Inputs A of the rear wheels (129 and 139) move in the same direction as that of the front wheels which causes the rear wheels to turn in the opposite direction of front wheels. This results in the normal four wheel steer mode with a smaller radius of turn than that of Mode 1 "two wheel steer" turn. (Figure 1b). Here the desired steering performance for four wheel steering differs from that of two wheel steering. Hence inputs B (107, 117, 131 and 141) are also actuated as correction inputs in this Mode to attain the required performance. Figure 5(b) shows the mechanism in Mode 2 when GB shifted to reverse gear. Pinion 124 is driven by steering wheel. Pinion 148 rotates opposite to pinion 124. Rear wheels (103 and 104) turn opposite to front wheels (101 and 102). Motorized pinions 126 and 150 also driven as "correction inputs".

Mode 3: When the FNR gearbox (154) is shifted to 'forward', the inputs A of the rear wheels (129 and 139) move opposite to that of front wheels which causes the rear wheels to turn in the same direction of the front wheels. This results in the "Crab-Steer" Mode where a vehicle can move parallel sideways without changing its direction. (Figure 1(c)). Again, in this Mode, Inputs B (107, 117, 131 and 141) are actuated as a correction inputs along with inputs A (105, 115, 129 and 139) to get the desired parallel steering. Figure 5(c) shows the mechanism in Mode 3 when GB shifted to forward gear. Pinion 124 is driven by steering wheel. Pinion 126 rotates in the same direction as pinion 124. Rear wheels (103 and 104) turn in the same direction as front wheels (101 and 102). Motor driven pinions 126 and 150 also driven as "correction inputs".

Mode 4: Finally, to put the vehicle in "zero-radius turn" Mode (figure 1(d)), the driver should turn on motors that drive those pinions (126 and 150), whose racks are connected to inputs B (107, 117, 131 and 141) of the wheels. (Figure 5(d)) which shows MODE 4 - Motors drive pinions 126 and 150. This causes the front wheels to toe-in and the rear wheels to toe out such that they are exactly tangential to the circle of rotation. In this Mode Inputs A (105, 115, 129 and 139) are locked and only inputs B (107, 117, 131 and 141) are actuated.

As stated above, Figures 5(e), 5(f), 5(g), and 5(h) represent another embodiment of the invention, viz. a slight variation of the Mechanism for Omni-directional Steering respectively in the above-specified Four Modes of Steering. Here, for providing Correction Input to left and right wheels two separate pinions sets (156, 158 and 160, 162) and motor sets are used

(unlike one, as shown in Figures 5(a), 5(b), 5(c), and 5(d)). The advantage of using separate pinion-motor sets is that separate Correction Inputs can be given to left and right side wheels, whereby the steering geometry is made more close to the perfect Ackermann condition.

It should be noted that the selection of gears of the FNR gearbox is based on the current design of the mechanism as shown in figure 5 and not inherent to the mechanism. If the orientation of primary inputs and secondary inputs is reversed in the rear wheel steering mechanism, the same modes can still be achieved albeit with an opposite gear selection as mentioned above. In such a case for instance, mode 2 would be actuated in forward gear and mode 3 in reverse gear.

As stated above, apart from the above-specified Four Modes of Steering, the theme of the invention of steering system with mechanical logic gate synchronizers can also be applicable to the existing ordinary two-wheel front-steer steering mechanism as well. The steering characteristics of a vehicle equipped with mechanical logic gate synchronizers will be more flexible than the vehicles with traditional one-degree of freedom, 6-bar linkage steering mechanism. For instance, in a traditional steering system, once the mechanism is designed the steering performance is fixed and cannot be changed. However, if mechanical logic gate synchronizers are used instead, the steering performance can be continuously varied depending on various factors such as tire slip angle data, suspension dynamics, high speed cornering dynamics etc. Thus, steering systems equipped with mechanical logic gate synchronizers would be more flexible on account of having more degrees of freedom.

TRANSMISSION

The transmission system of the proposed vehicle capable of undertaking a "zero-turn" (Mode 4) must allow the right side wheels to rotate opposite to that of left side wheels. For instance, to make a "zero-turn" to the right, first the front wheels should toe in and the back wheels should toe out at the exact predetermined angle such that they are tangential to the circle of turn. Then the right side wheels must rotate backwards and the left side wheels must rotate forward so that the vehicle rotates in its place to the right. For this purpose, the current transmission systems can be replaced by some alternative transmission system like the "Triple differential" transmission system, that is used in tanks or other tracked vehicles to allow the two sets of track wheels (right and left) to rotate in opposite directions.

Alternatively, a modified four wheel drive with the right wheels powered by one shaft and the left side wheels powered by another shaft can also be used in place of the regular four wheel drive where the front wheels are driven by one shaft and the rear wheels driven by another shaft.

MATHEMATICAL MODELLING OF THE MECHANISM

Whenever a vehicle negotiates a turn, ideally, the outer wheel and the inner wheel should follow two concentric circles of different radii. Since the inside wheel is taking a tighter turn, it has to turn a larger angle than the outer wheel (Figure 6). Hence, for a car to turn smoothly the wheels should always be tangential to their circles of turn. And because the two circles (inner and outer) are concentric, the extended axes of all the wheels should always intersect at the centre. This geometry is known as "Ackermann steering geometry" and it must be followed by any steering mechanism for it to prevent slipping and undue stress to the wheels and tires.

Figures 6(a) and 6(b) show the ideal Ackermann geometric conditions for two wheel and four wheel steered vehicles respectively.

Figures 7(a) shows the design parameters of the system. Figures 7(b) and 7(c) show the variables involved in the mathematical modelling of the system.

For the purpose of simplicity in illustration the mechanism has been assumed to be symmetric, and the various design parameters have been set accordingly. For instance in figure 7(a) the lengths of the links 108 and 110 are taken equal (l_1). Similarly, angles between link 108 and link 109, and link 109 and link 110 are taken equal (θ_0). It should be noted, however, that this is not a limitation of the mechanism, and the mechanism would function even when the above-mentioned lengths and angles are unequal. Figures 8, 9(a), 9(b) and 10(a), 10(b) relate to graphical representations of results of comparison of the performance of the mechanism of the invention to the desired "ideal" steering performances. For this purpose a common passenger-car geometry has been chosen (Wheelbase=1.3 meters, Track = 2.6 meters).

The design parameters are then chosen in such a way that the steering performance of the mechanism in Mode 1 (purely manual input, no correction input) is close to the two wheel Ackermann condition for a vehicle with these dimensions.

Table 1 below shows a set of the chosen values of the design parameters for the purpose of illustration through mathematical modelling:

Table 1: Set of Chosen Values of Design Parameters for a Particular Vehicle
(Wheelbase $L = 2.6$ m , Track $B = 1.3$ m)

Table 1

DESIGN PARAMETER	CHOSEN VALUE WITH UNIT
l_1	0.19 (m)
l_2	0.2(m)
θ_0	30 deg
α_0	8 deg
P	3.3 inch
Q	11 inch
α_s	13 deg

(These values need not necessarily give the best performance results; an algorithm can be derived for obtaining a set of optimum design parameters.)

Once the set of values is chosen, then correction inputs for Mode 2 and Mode 3 can be calculated (details have been discussed below) so as to get a performance close to the ideally desired one.

Figures 9(b) and 10(b) plot the correction input (x_3) values against the primary input (x_1) for Modes 2 and 3 respectively. These values have been calculated for the set of design parameters chosen in Table 1 above.

MODE1

This section describes the performance of the proposed steering mechanism in Mode 1 vis-à-vis the Ackermann condition.

For two wheel Ackermann geometry as shown in Figure 6(a) the relation between the two wheel turn angles (ϕ_1 and ϕ_2) is:

$$\cot(\phi_2) = \cot(\phi_1) + b/l$$

Where ϕ_1 and ϕ_2 are the inner and outer wheel angles respectively;

'l' and 'b' are the wheelbase and the track respectively.

To correlate the relation between outer angle and inner angle of the mechanism, the geometry is studied.

Figure 7 shows the geometry of the mechanism on a straight road and on a left turn. From the figure 7 the equations are stated that give a relation between ϕ_1 and ϕ_2 . For a certain left wheel angle ϕ_1 , we get $x \frac{1}{2}$

$$X_2 = p \cos(\alpha_0) + q \sin(\alpha_s) + q \sin(\phi_1 - \alpha_s) - p \cos(\alpha)$$

Where,

$$\sin(\alpha) = \sin(\alpha_0) + (q/p) \cos(\alpha_s) - (q/p) \cos(\phi_1 - \alpha_s)$$

From x_2, θ for the left wheel mechanism can be obtained.

$$X_2 = l_1 [\cos(\theta_0) - \cos(\theta)] + l_2 \left(\sqrt{1 - \left[\frac{l_1}{l_2} (\sin \theta) - (\sin \theta_0) \right]^2} - l_2 \right) + x_3$$

Now for Mode 1, $x_3 = 0$ as input B is locked and input is given only through input A(X_1)

From θ , the rack travel x_1 is:

$$x_1 = l_1 \left[\left(\sqrt{1 - (\sin \theta)^2} - 2 \sin(\theta_0) \right)^2 - \cos(\theta) \right] + x_3$$

Where $x_3 = 0$ for Mode 1

For the right wheel mechanism, input x_1 will be negative of that of left wheel mechanism. (rack travel; figure 7(c))

$$\text{Right wheel } x_1 = - \text{left wheel } x_1$$

Now using the above equations in the reverse order for the right wheel,

From x_1 , θ is:

$$x_1 = l_1 \left[\left(\sqrt{1 - (\sin \theta)^2} - 2 \sin(\theta_0) \right)^2 - \cos(\theta) \right] + x_3$$

Again for Mode 1, $x_3 = 0$

From θ , x_2 for the right wheel mechanism can be obtained as:

$$x_2 = l_1 [\cos(\theta_0) - \cos(\theta)] + l_2 \left(\sqrt{1 - \left[\frac{l_1}{l_2} (\sin \theta) - (\sin \theta_0) \right]^2} - l_2 \right) + x_3$$

And finally from x_2 , right wheel angle ϕ_2 is:

$$x_2 = p \cos(\alpha_0) + q \sin(\alpha_s) + q \sin(\phi_2 - \alpha_s) - p \cos(\alpha)$$

Where,

$$\sin(\alpha) = \sin(\alpha_0) + (q/p) \cdot \cos(\alpha_s) - (q/p) \cdot \cos(\phi_2 - \alpha_s)$$

When appropriate values of constants ($l_1, l_2, p, q, r, \theta_0, \alpha_s$ and α_0) are chosen, the outer wheel angle ϕ_2 is plotted for a range of values of inner wheel angle ϕ_1 for the proposed mechanism as compared to the required Ackermann condition (please refer to Figure 8). Here the values of the aforementioned constants are chosen considering the design parameters of the wheel, the suspension system etc. From figure 8, it can be concluded that the geometrical performance of the proposed mechanism is very close to 100% Ackermann geometry and lies in between 80% and 120% Ackermann systems.

MODE 2

In Mode 2 all four wheels are steered with the rear wheels turning opposite to the front wheels. For such a four wheel steering the Ackermann condition differs from that of two wheel steering (Mode 1). So for four wheel Ackermann geometry as shown in figure 6(b), the relation between the two wheel turn angles (ϕ_1 and ϕ_2) is:

$$\cot(\phi_2) = \cot(\phi_1) + 2b/l$$

Where ϕ_1 and ϕ_2 are the inner and outer wheel angles respectively;

'l' and 'b' are the wheelbase and the track respectively.

As described earlier, the mechanism parameters ($l_1, l_2, p, q, \theta_0, \alpha_s$ and α_0) are optimized for Mode 1. Hence the mechanism performs approximately like two wheel Ackermann when input is given only through input link A (105 and 115) (x_1) and input link B (107 and 117) is locked ($x_3=0$).

For Mode 2 input should be given thorough input link A as well as link B ($x_3 \neq 0$) for achieving a four wheel Ackermann performance. The same equations were used to solve for a range of values of x_1 and to obtain corresponding values of x_3 .

Figure 9(b) shows the plot of x_3 v/s x_1 . As the motor that drives input B is electronically controlled, by feeding the values of x_3 calculated above into the controller such that it senses the input x_1 given manually from the steering wheel and accordingly gives an input x_3 such that the resulting output is close to a four wheel Ackermann condition. The motorized input link B thus acts as a "correction input" that changes the left and right wheel angle relation to achieve the desired relation. Figure 9(a) compares the performance of the mechanism in

Mode 2 with the four wheel Ackermann condition. It can be seen from Figure 9(a) that the performance of the mechanism in Mode 2 is very close to the Ackermann condition for four wheel steering.

MODE 3

Mode 3 requires all the wheels to turn by equal angles. However as described earlier, the parameters are set in such a way that when input B (107 for front left wheel and 117 for front right wheel) is locked the mechanism performs like a two wheel Ackermann. Hence in Mode 3 inputs from both links A and B should be given at the same time. So solving the equations for a range of values of x_1 , corresponding values of x_3 can be computed and because of this, left and the right wheels turn by equal angles. Thus in Mode 3 as well, link B acts as a "correction input" to get the desired relation (equal turn angles).

Figure 10 (b) shows the computed x_3 for a range of values of x_1 and figure 10(a) shows the resulting performance. It can be seen from Figure 10(a) that in Mode 3 the inner and outer wheels are steered by equal angles.

MODE 4

In Mode 4 only inputs B (107, 117, 131 and 141) are driven by motors and inputs A (105, 115, 129 and 139) are locked. The only geometric condition is that the wheels should be tangential to the circle of turn with the diameter of turn being the diagonal of the vehicle ($\sqrt{l^2 + b^2}$) and the centre of turn coinciding with centre of the vehicle. The toe angle ϕ for all wheels can be calculated by simple trigonometry:

$$\tan \phi = \frac{1}{2b}$$

Apart from the above specified structural design of the Omni-directional steering mechanism, a few auxiliary mechanisms are also required for the proper functioning of the steering system. For instance the mechanism can be switched into Mode 4 only when the car is not moving. And if the wheels are already turned first, the driver should either be indicated to bring back the wheels to zero before inputs B are actuated or an automated drive-back mechanism should automatically bring back the wheels to the unsteered (straight) position. Also, after a zero turn is completed the wheels should be brought back to zero position by driving the pinion in the opposite direction. All these requirements can be realized by appropriately programming an Electronic Control Unit (ECU) or an on-board computer.

Another example of a supplementary mechanism that needs to be used along with the Omni-directional steering linkage is a slide-brake mechanism for locking sliders in their positions. When the steering system is put in mode 1, the secondary correction inputs (Inputs B) need to be locked in their undisplaced positions. Also, when in mode 4, manual primary inputs (Inputs A) need to be locked in their undisplaced position. For this purpose a slide-brake braking mechanism can be used.

CLAIMS

1.) A steering method comprising:

- a. providing one or more primary input signals to at least one of two pairs of wheels of a vehicle through at least one of two link members associated with each wheels;
- b. providing one or more secondary input signals through at least one other of said link members associated with said wheels; and
- c. obtaining wheels turning outputs when at least one another link member associated with each wheel gets at least one of said primary input signals or at least one of said secondary input signals.

2.) The steering method as claimed in claim 1, wherein, only two wheels make an unidirectional turn when such said two wheels get one primary input signal and no secondary input signals.

3.) The steering method as claimed in claim 1, wherein, primary input signals preferably add with secondary input signals.

4.) The steering method as claimed in claim 3, wherein, one pair of wheels turn in one direction and another pair of wheels move in a direction opposite to said one direction when two of said primary input signals are different and two or more of said secondary input signals are different.

5.) The steering method as claimed in claim 3, wherein, all wheels of said vehicle make a unidirectional turn when two of said primary input signals are similar and two or more of said secondary input signals are similar.

6.) The steering method as claimed in claim 1, wherein, said primary input signals are null when said vehicle has at least one pair of wheels in toe-in and at least another pair of wheels

in toe-out and said secondary input signals are fixed based on vehicle dimensions.

7.) The steering method as claimed in claims 1 to 3, wherein, said one or more primary input signals are given by manual steering.

8.) The steering method as claimed in claim 1 and claim 3, wherein, said primary input signals are given to at least an electronic circuit which forms an interface between said primary input signals and said secondary input signals, wherein said electronic circuits calculate said secondary input signals.

9.) The steering method as claimed in claims 1, 3 and 6, wherein, said secondary input signals are given to at least an automatic device which is preferably a motor.

10.) The steering method as claimed in claim 9, wherein, said motors add with said primary input signals by actuating said at least one other link member with said secondary input signals.

11.) A steering system comprising:

- a. four groups of three link members connected with four wheels of an automobile;
- b. one of said three link members being preferably a sliding member is an output connected with one wheel individually with a sliding contact;
- c. two of said link members are inputs being preferably sliding members being connected said wheels;
- d. said link members connected with actuating members; and
- e. said actuating members connected with motion transmitting members.

12.) The steering system as claimed in claim 11, wherein, said actuating members include and not limited to rack and pinion, recirculating ball and piston and cylinder arrangement and

recirculating ball mechanism.

13.)The steering system as claimed in claim 11, wherein, said motion transmitting members include but are not limited to one or more of gear boxes, belt pulley mechanism, and shaft mechanism.

14.)The steering system as claimed in claim 11, wherein, an electronic circuit forms an interface between said primary input signals and said secondary input signals.

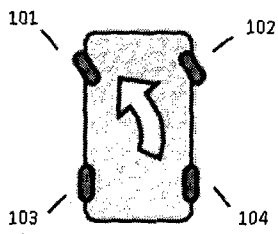


Fig 1a

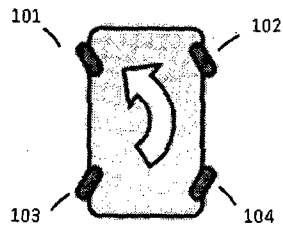


Fig 1b

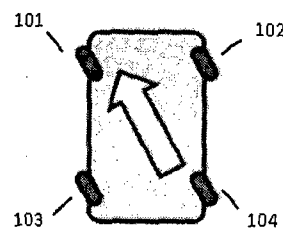


Fig 1c

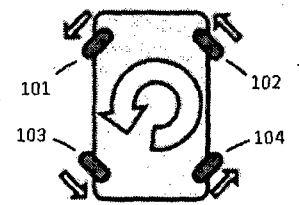


Fig 1d

Fig. 1

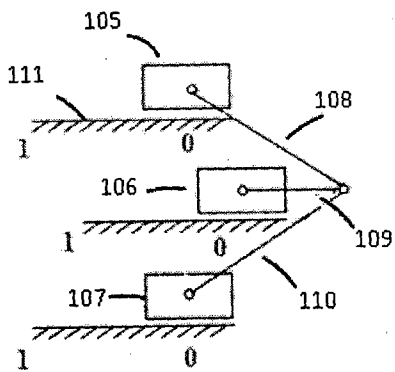


Fig 2a

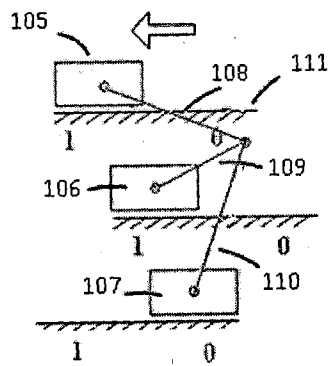


Fig 2b

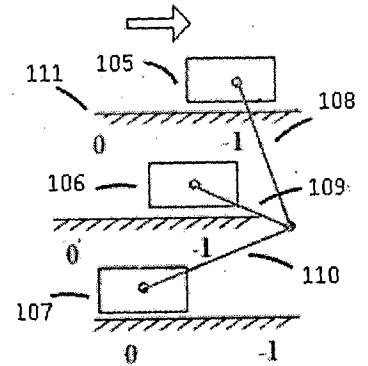


Fig 2c

Fig. 2

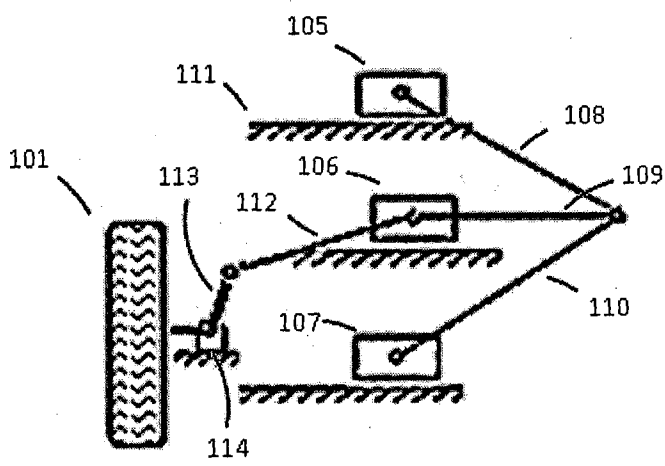


Fig 3a

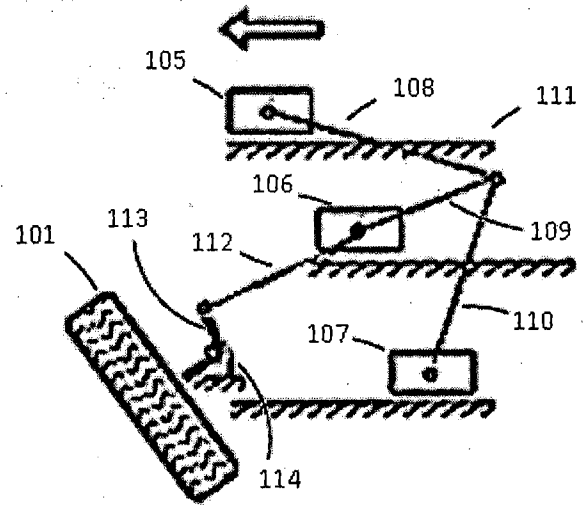


Fig 3b

Fig. 3

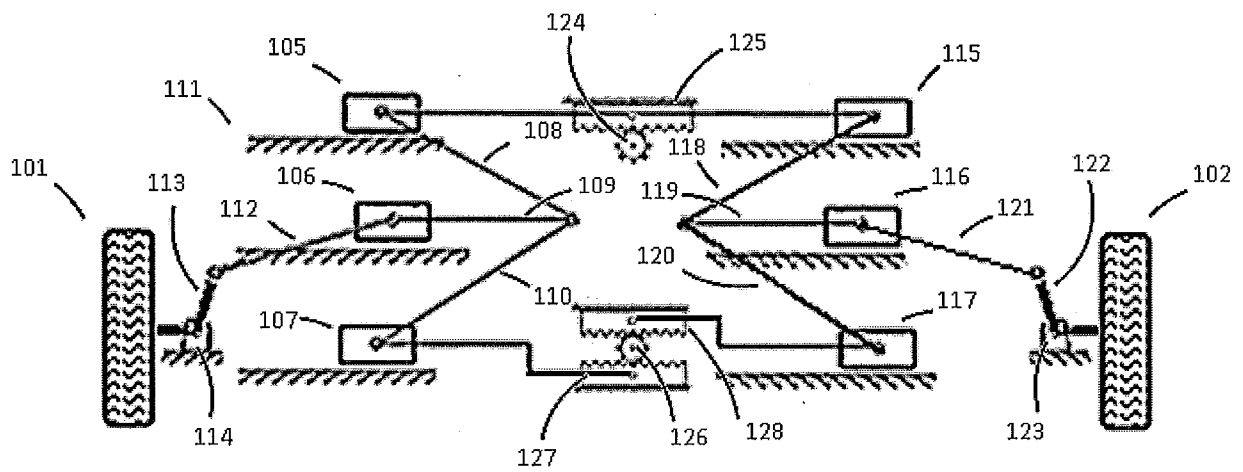


Fig. 4(a)

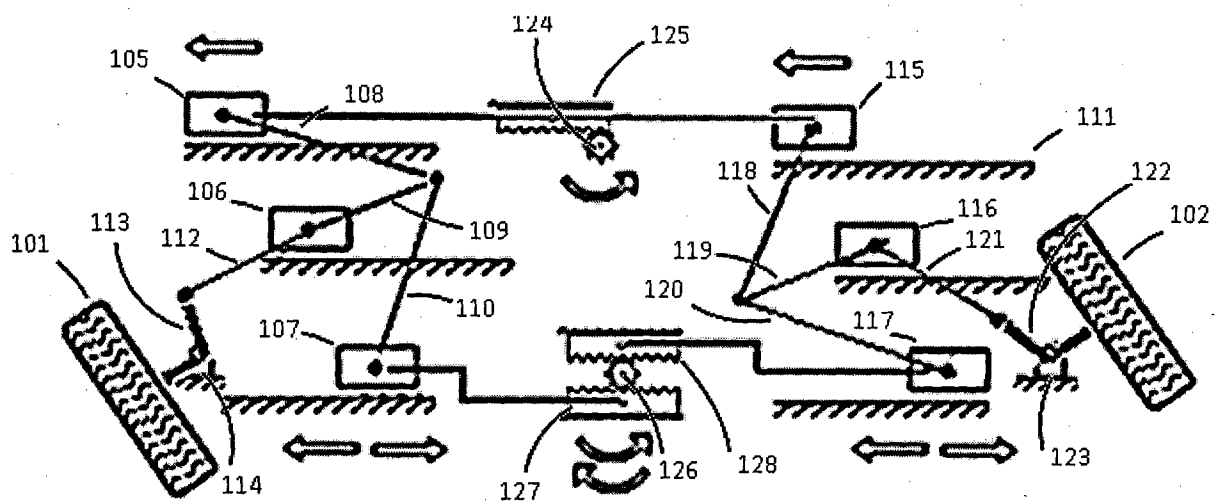


Fig. 4(b)

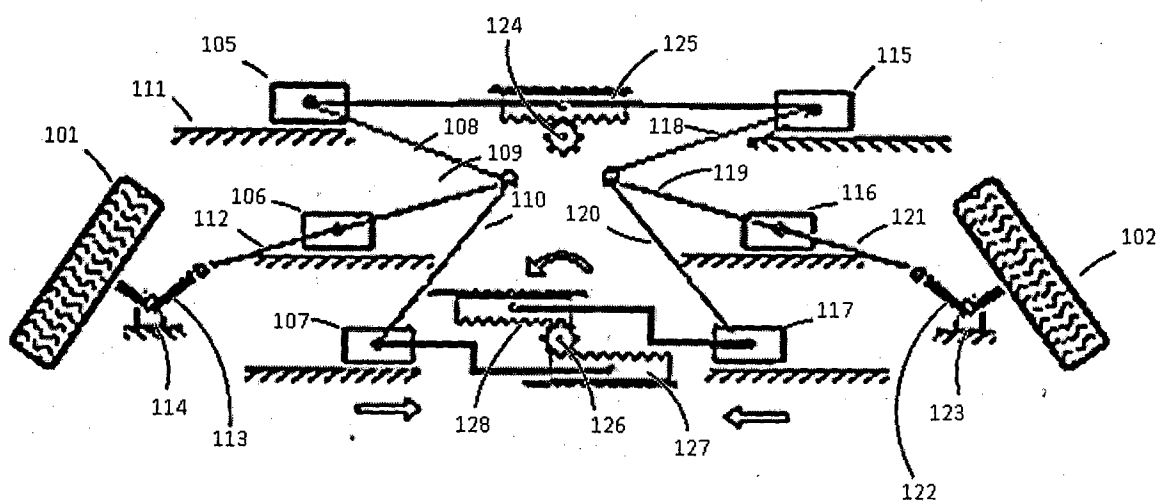


Fig. 4(c)

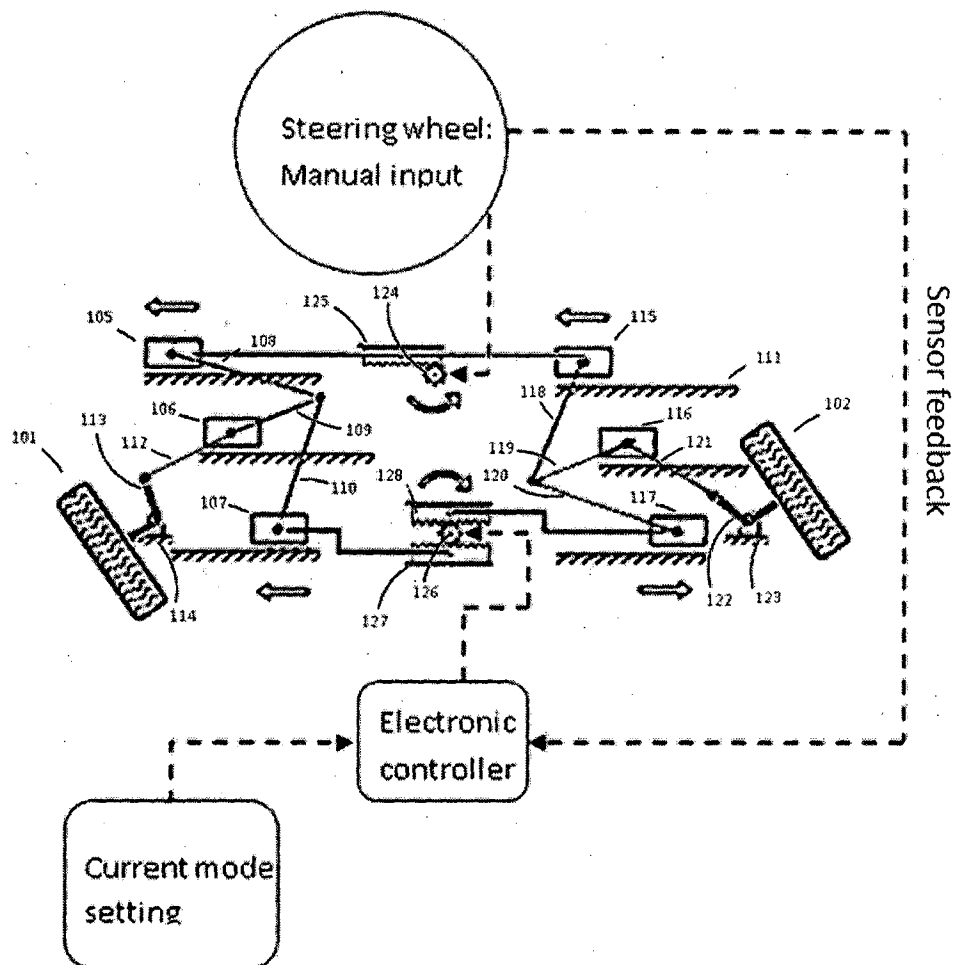


Fig. 4(d)

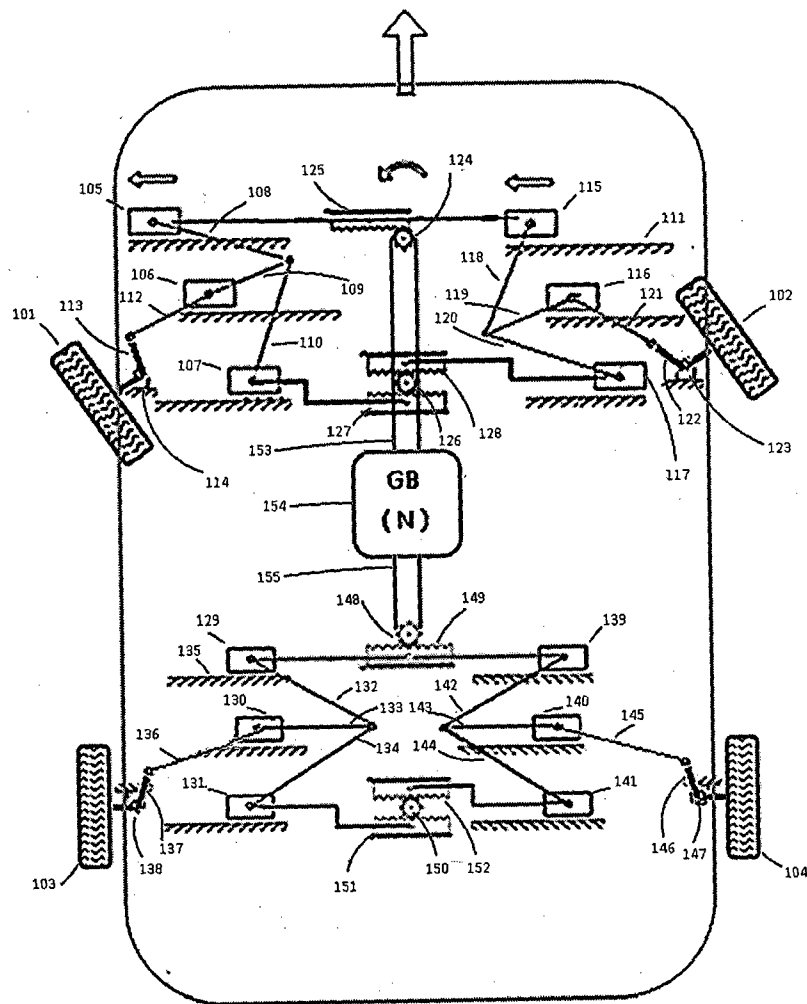


Fig. 5 (a)

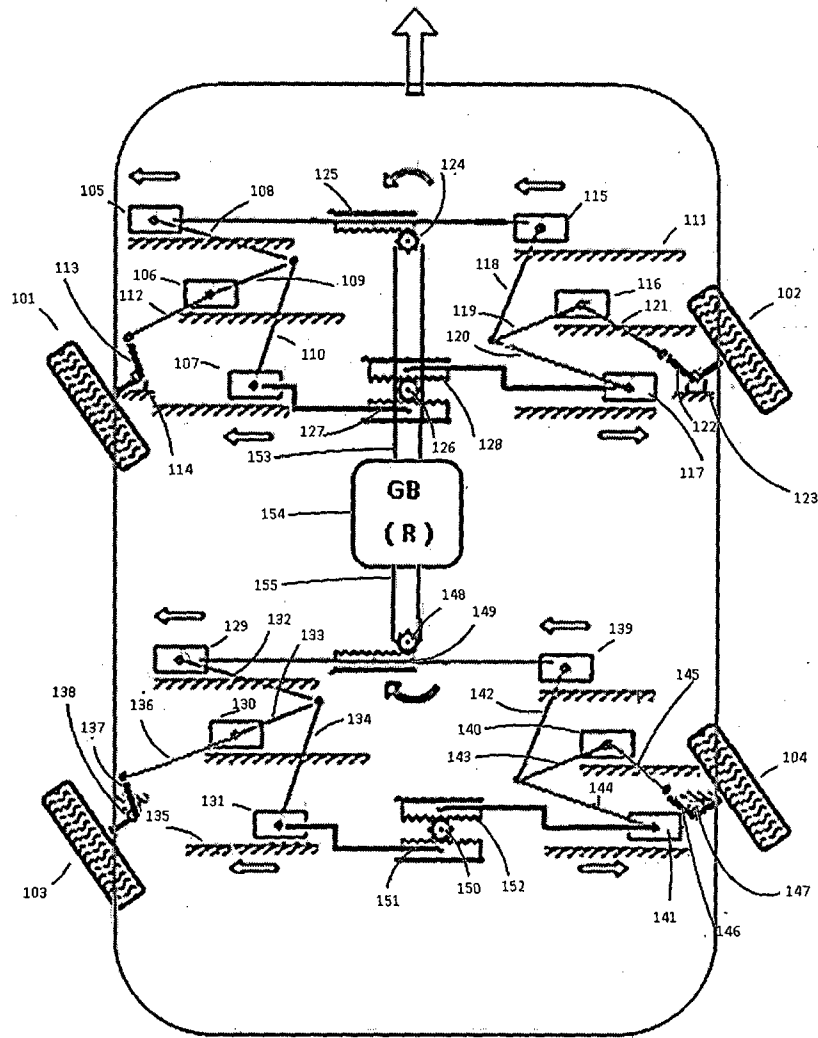


Fig. 5 (b)

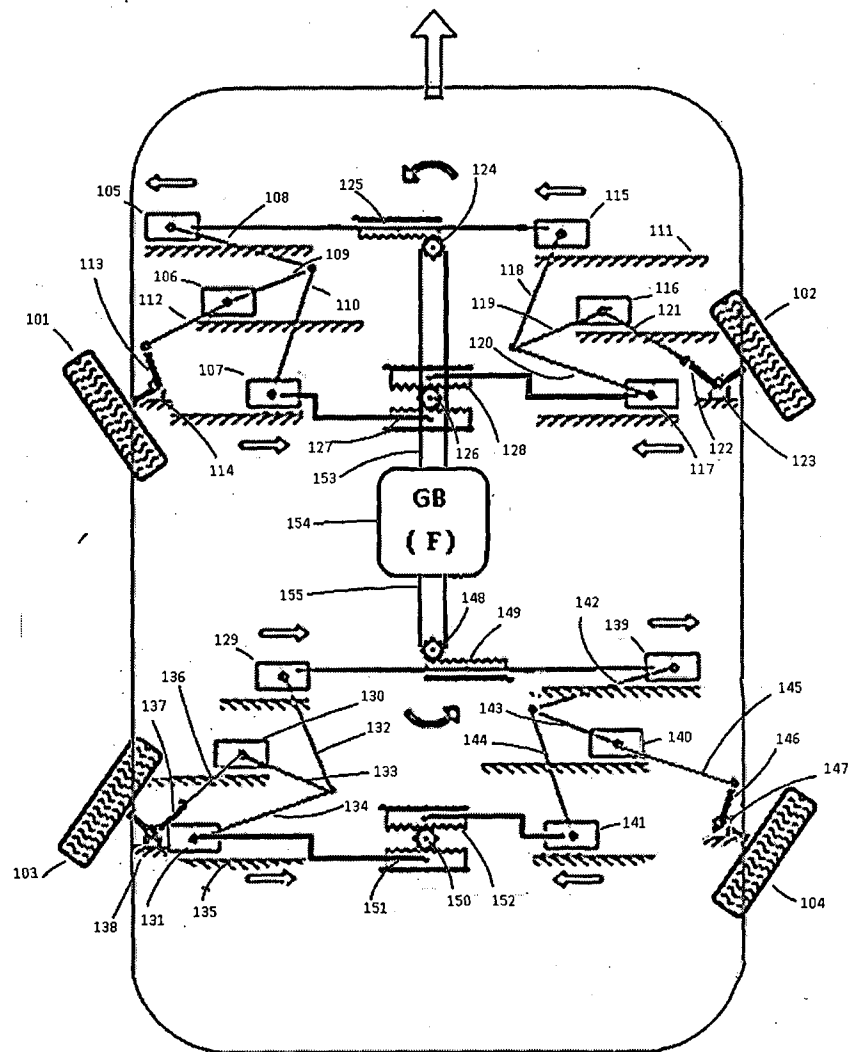


Fig. 5 (c)

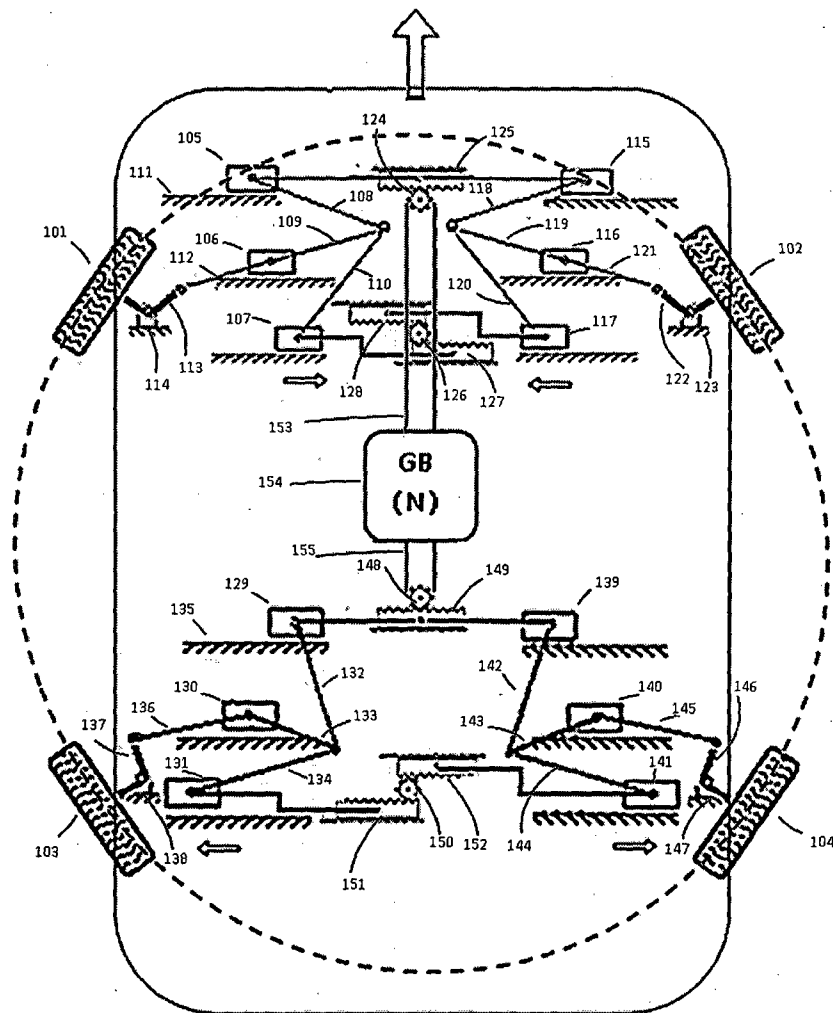


Fig. 5 (d)

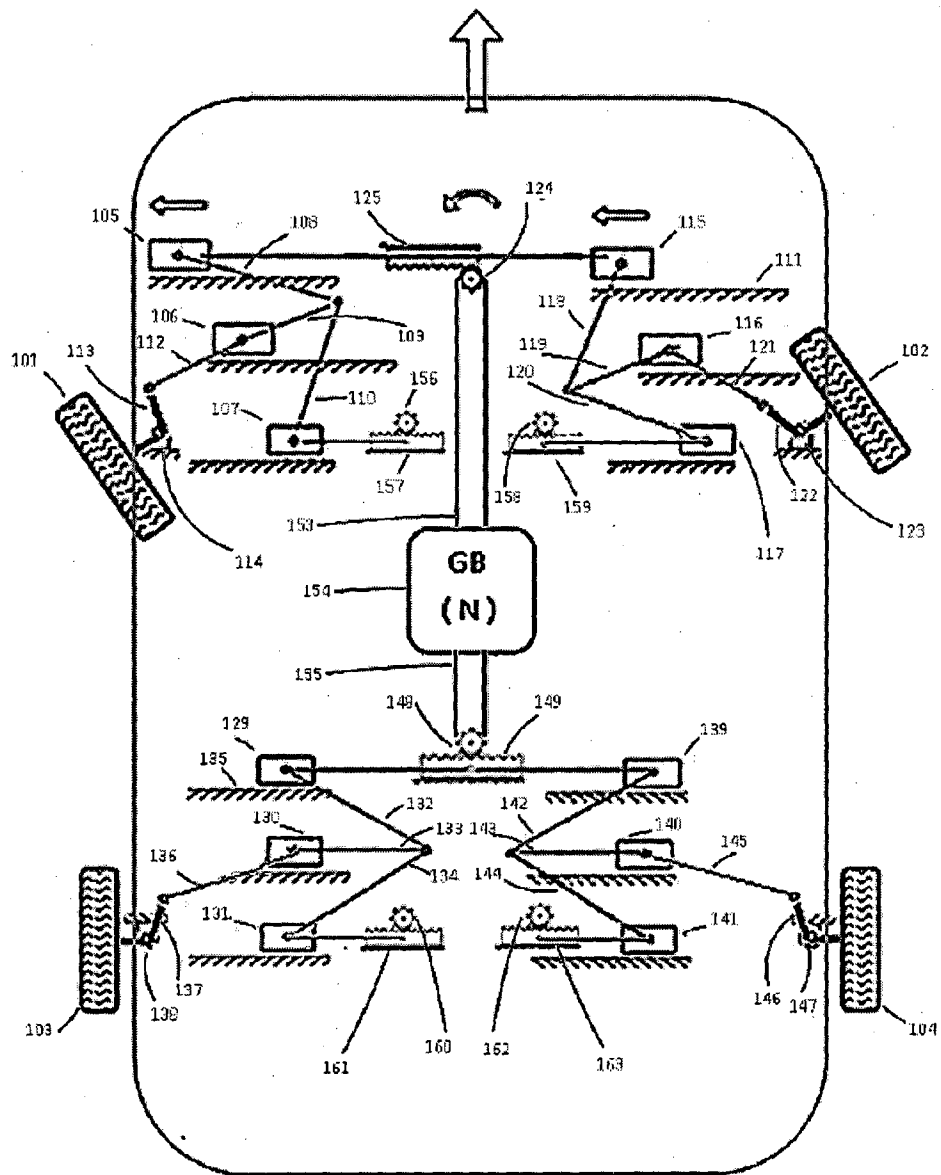


Fig. 5 (e)

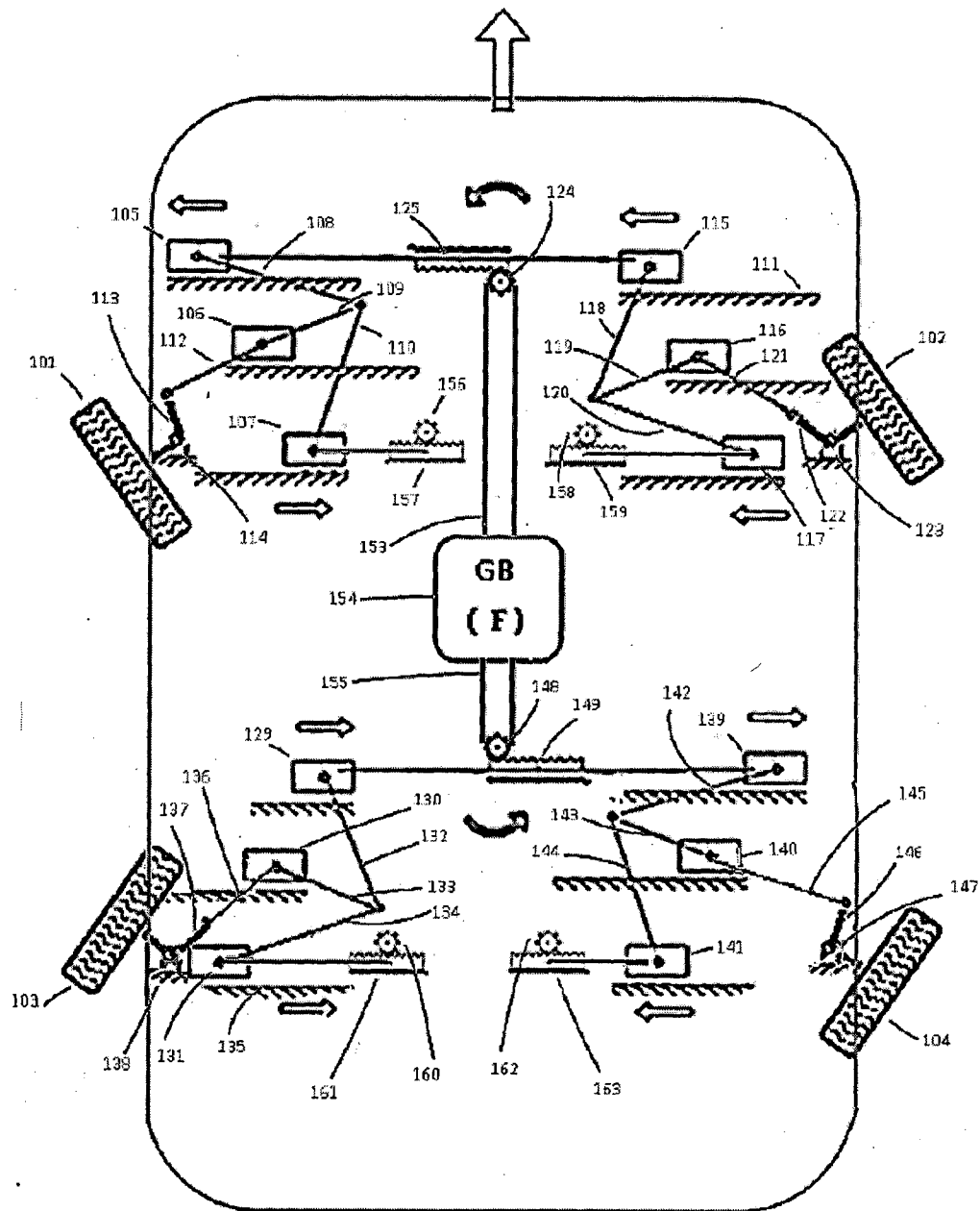


Fig. 5 (f)

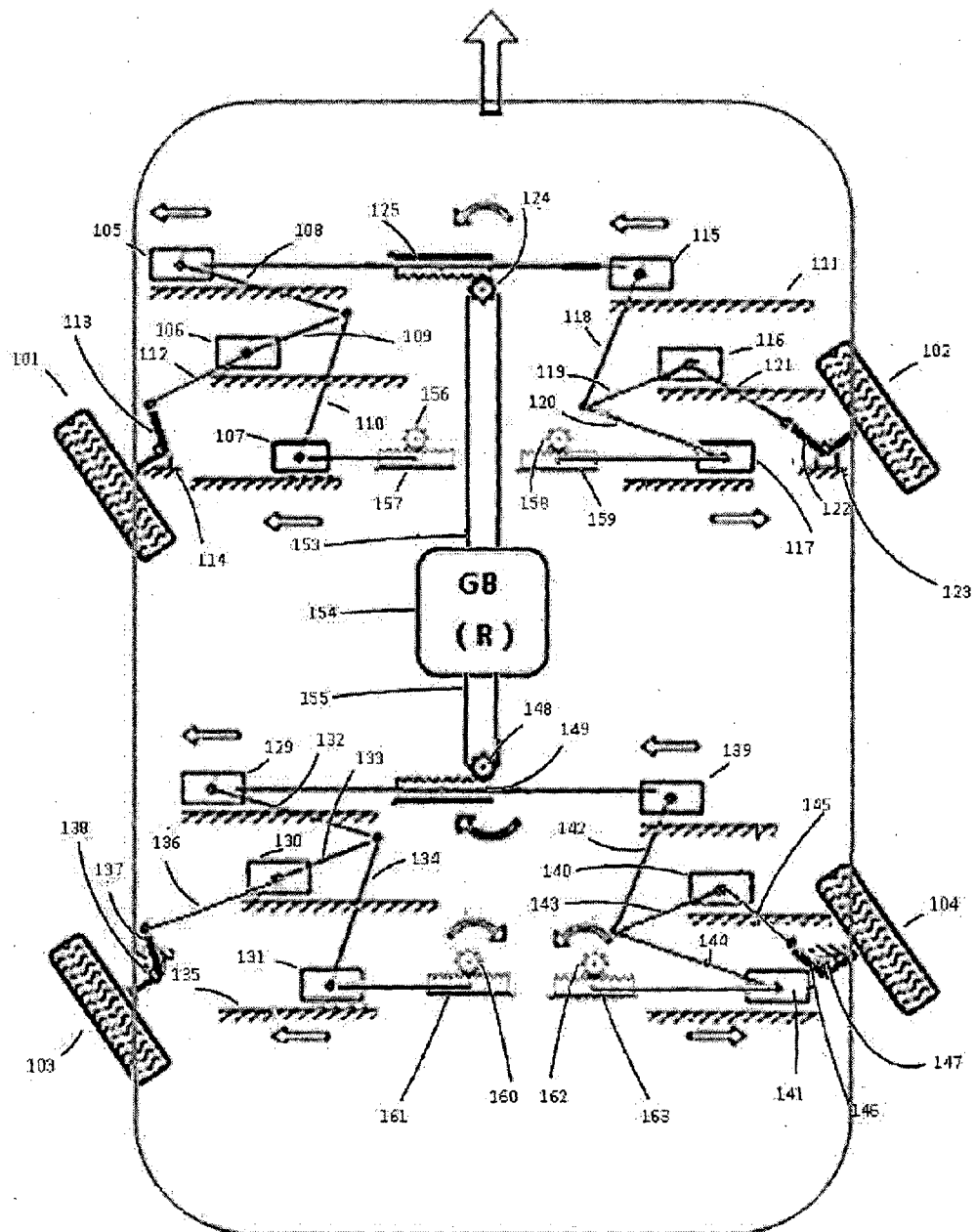


Fig. 5 (g)

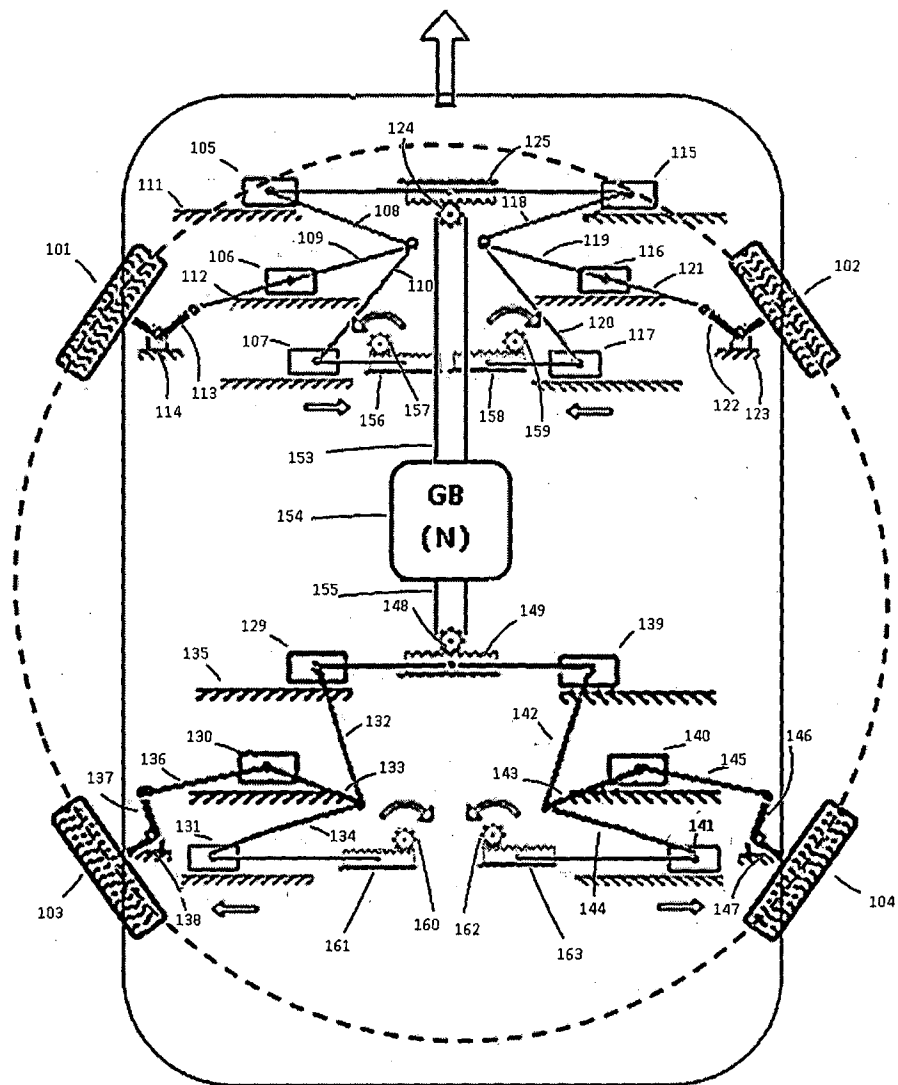


Fig. 5 (h)

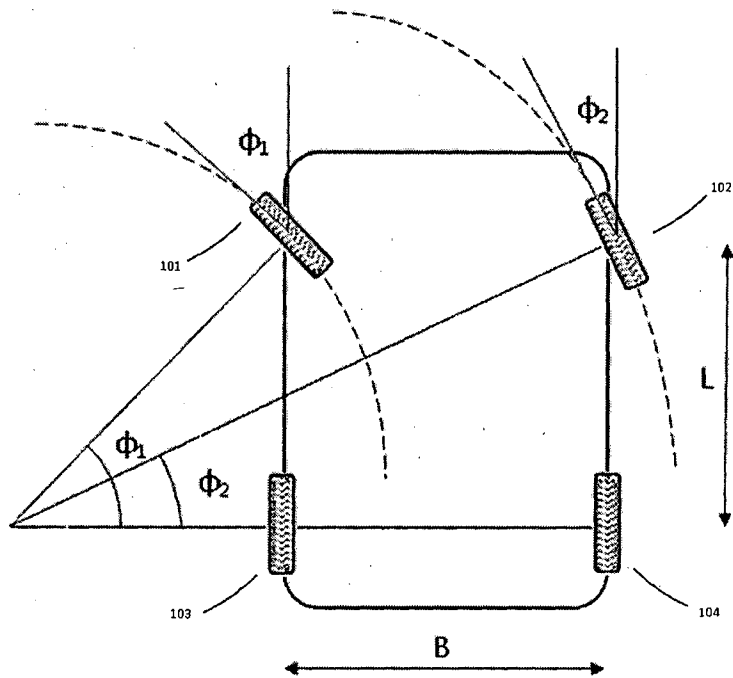


Fig. 6(a)

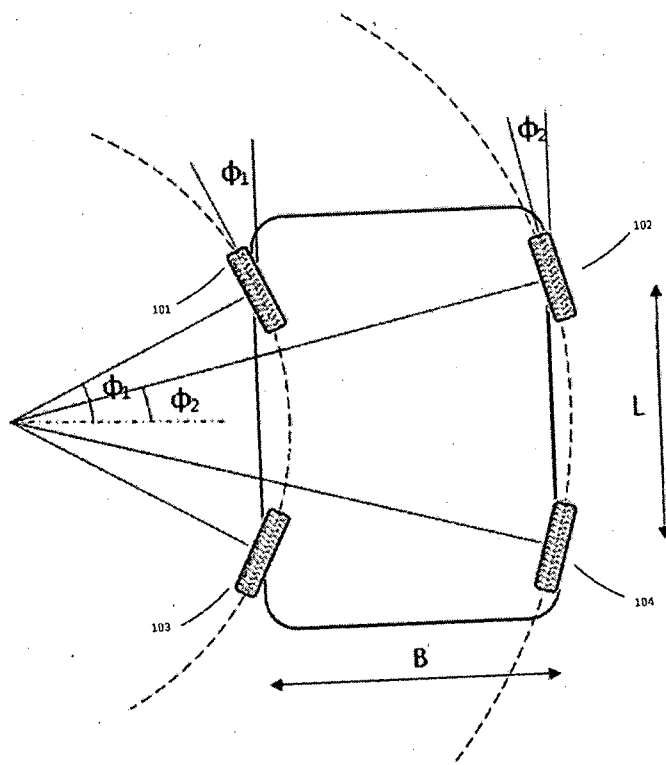


Fig. 6(b)

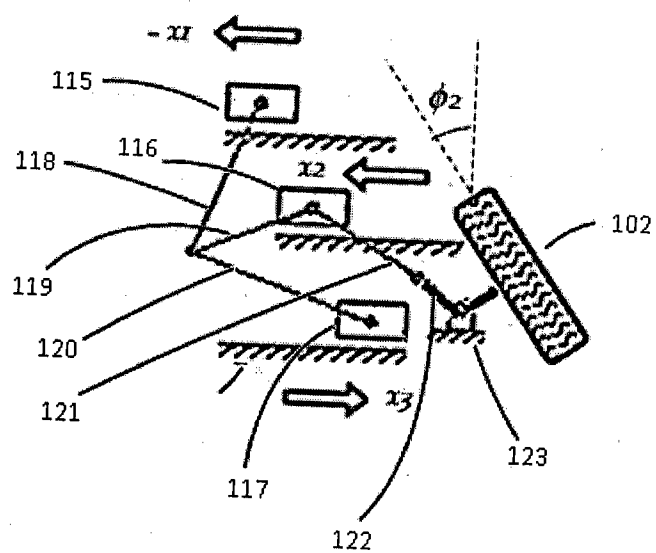


Fig. 7 (c)

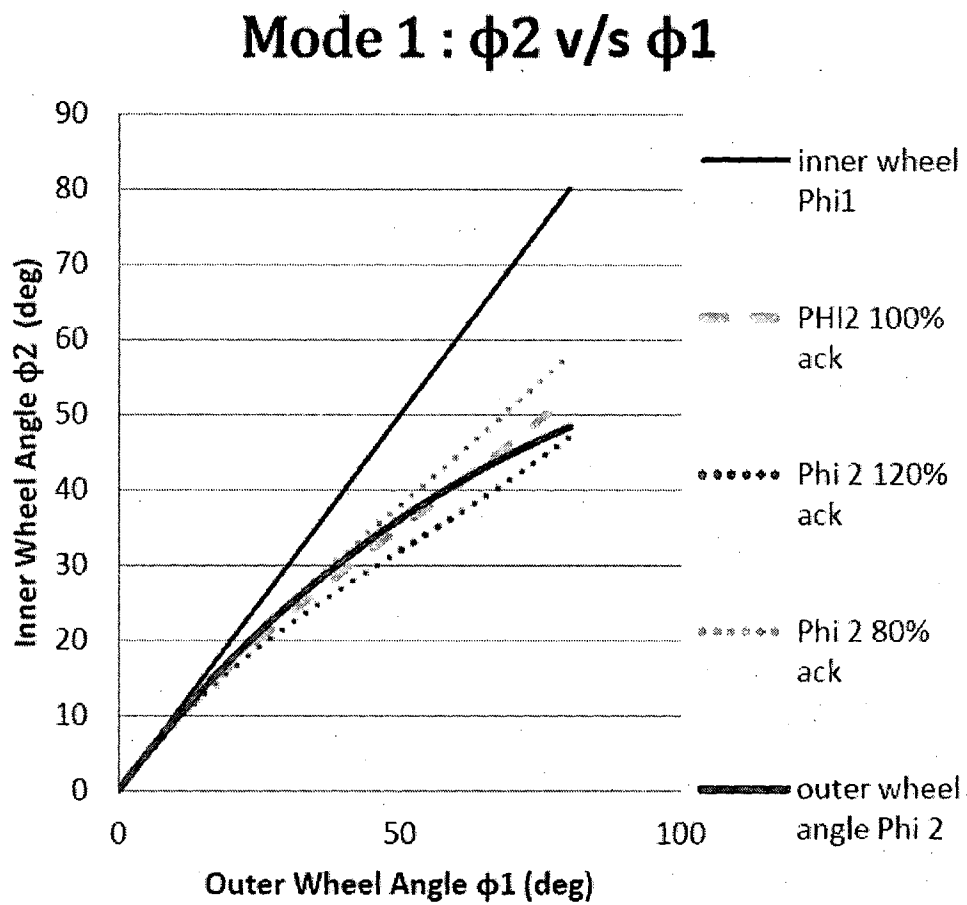


Fig. 8

Mode 2: ϕ_2 v/s ϕ_1

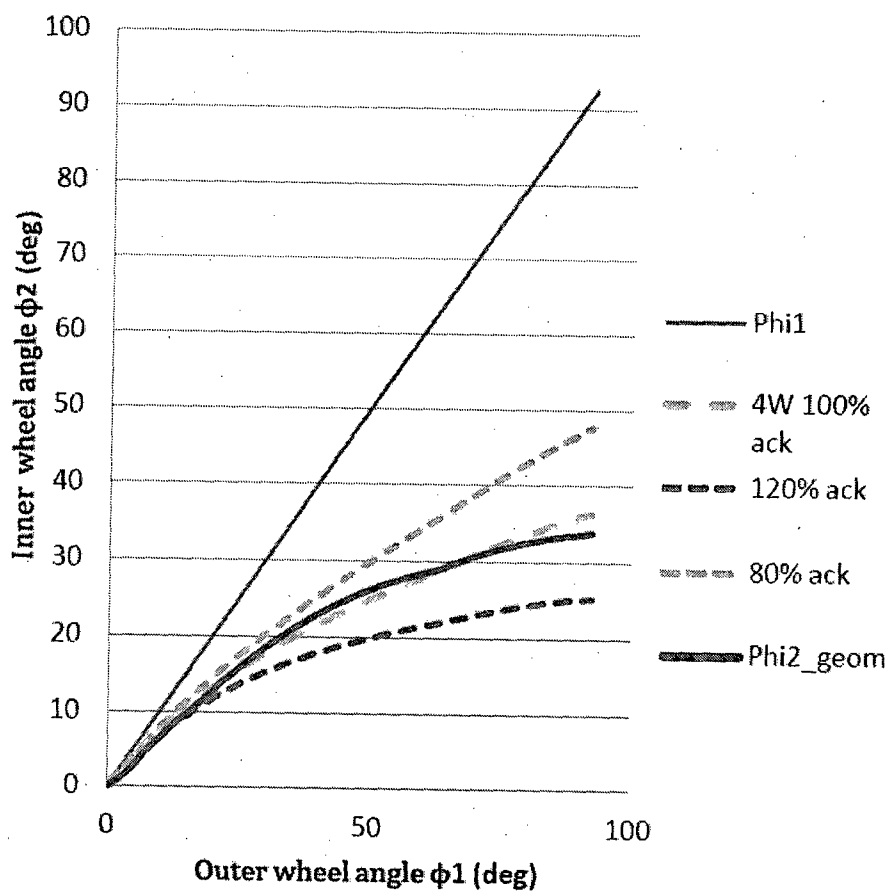


Fig. 9(a)

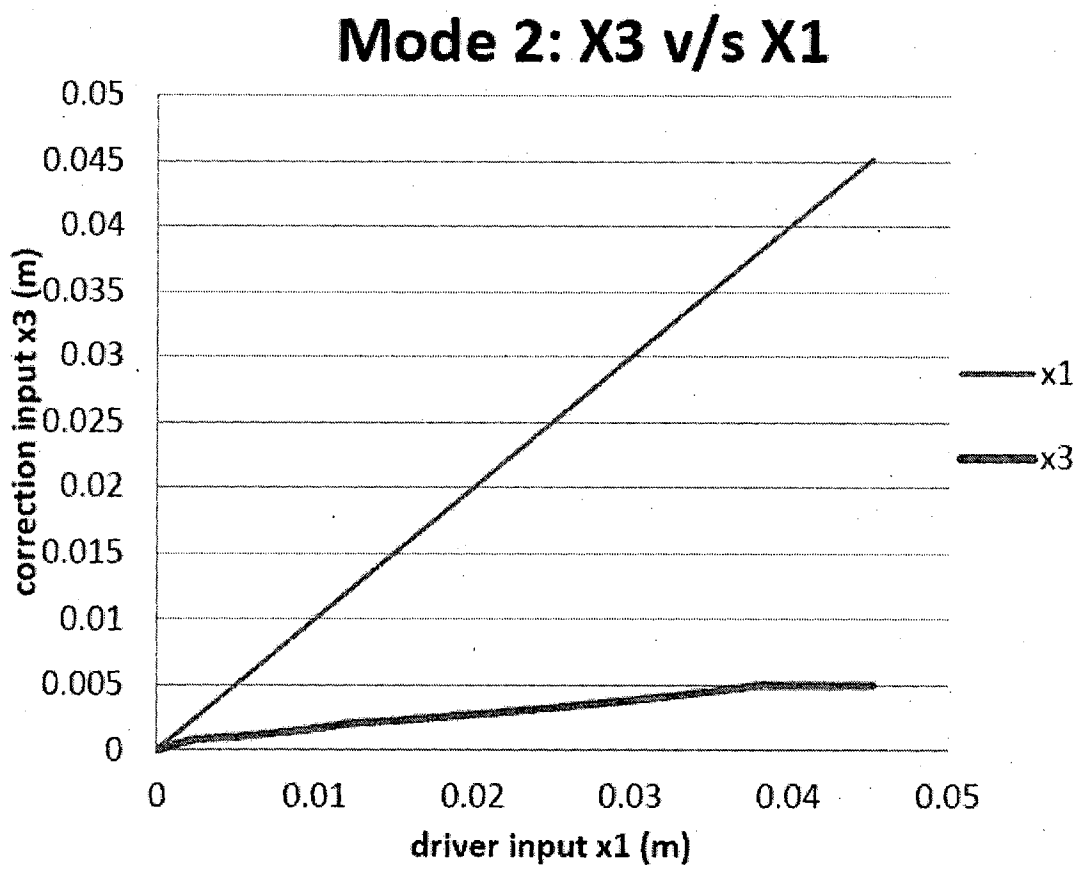


Fig. 9(b)

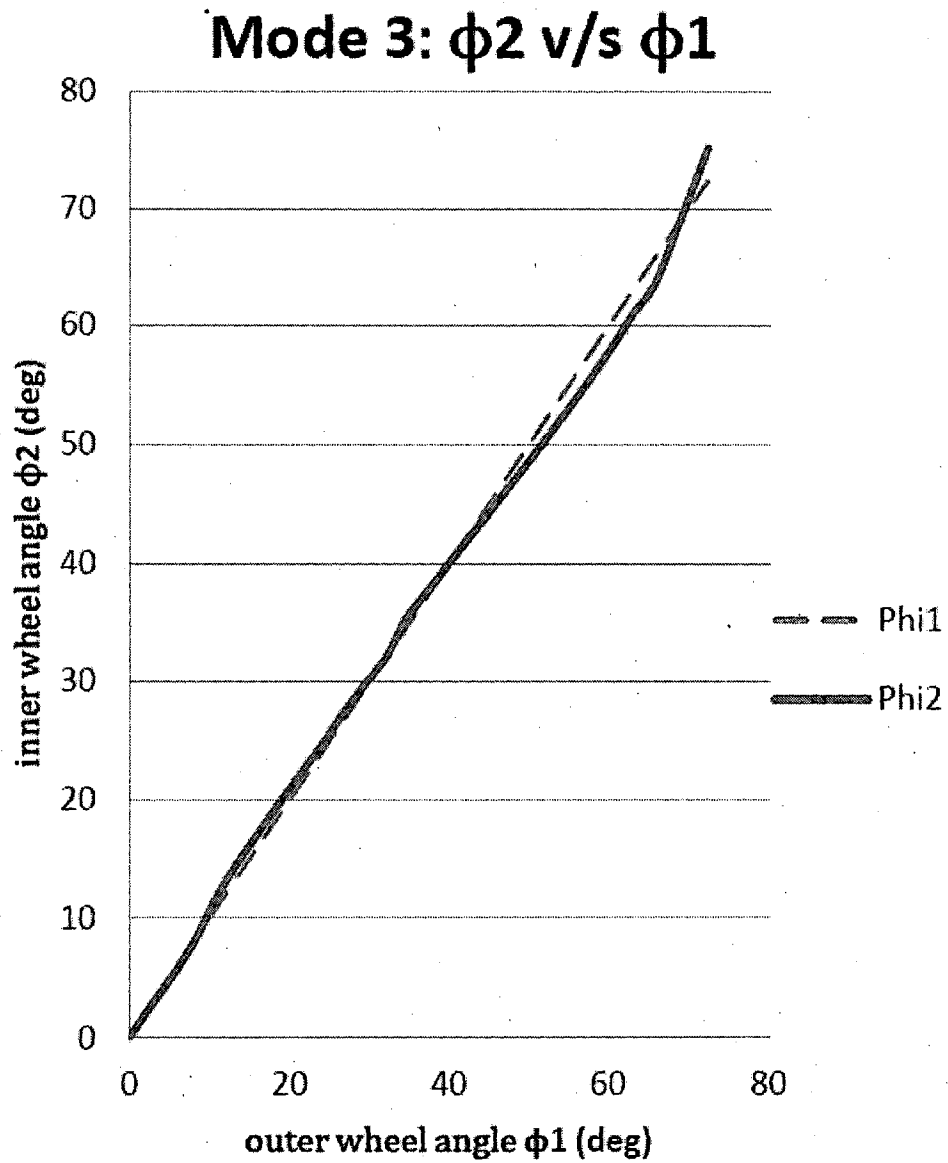


Fig. 10(a)

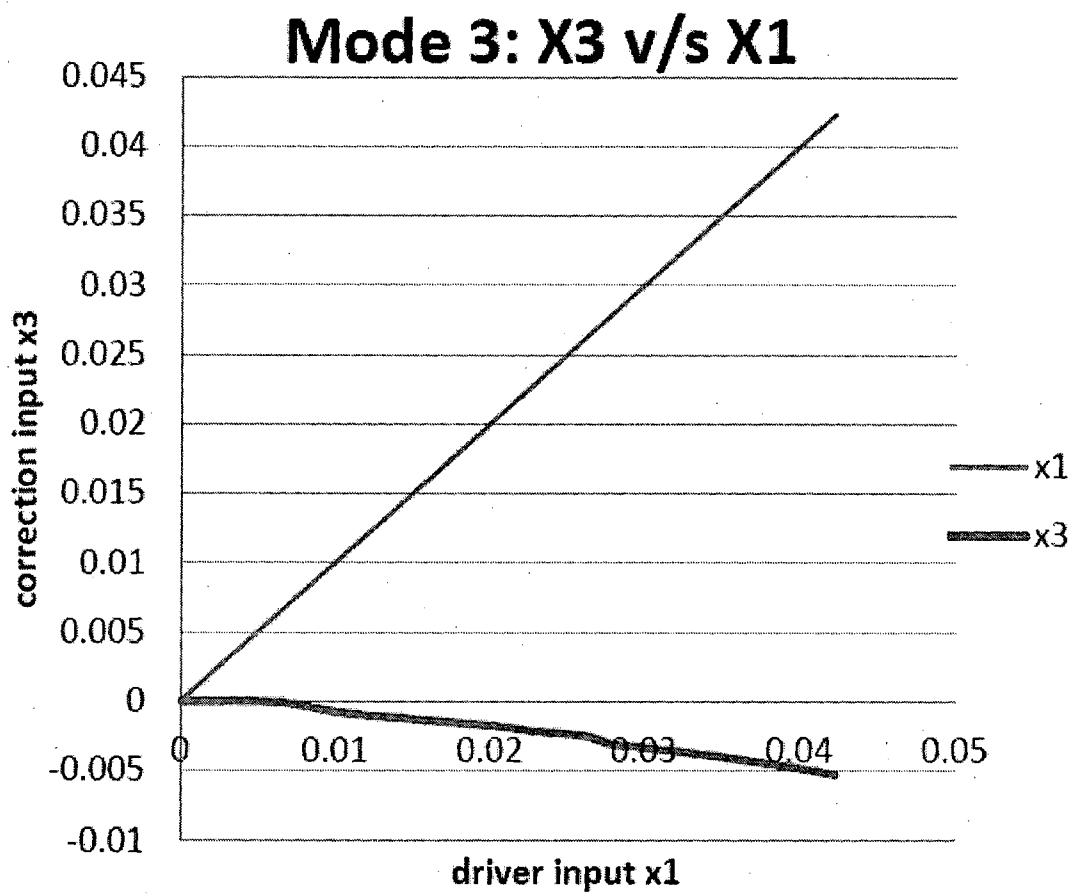


Fig. 10(b)