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An AGV Parallel mechanism unloading device constructed by Position and Orientation Characteristics(POC) Theory

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Abstract: *A multi-functional, multi-purpose and efficient intelligent vehicle-moving AGV system is proposedfor aiming at the urban parking environment,. In order to study the wide adaptability of the attitude adjustment of the intelligent AGV system in the process of vehicle handling, the contact attitude and relative motion between the wheel and the end of the lifting mechanism are abstracted as the motion pair of the end of the branched chain, and the moving body, the operating mechanism of the lifting body and the whole of the transported vehicle are mapped to the dynamic and static platform of the parallel mechanism respectively. The vehicle attitude maintenance characteristics in the process of lifting mechanism, wheel clamping, length adaptation and vehicle width adjustment are regarded as the design requirements and task objectives of multi-task and multi-working state and abstracted as the structural synthesis problem of parallel mechanism. According to the task space and working state, the maximum azimuth feature set is realized and the mechanism is assembled. Based on mechanism synthesis, the basic structure of lifting device is deduced, and a 2T2R mechanism ensuring the attitude of unloaded vehicle is constructed, and its kinematics is analyzed. In this paper, the comprehensive concept of parallel mechanism is introduced into the design of lifting system, and the structure design which can adapt to the width and wheelbase of the transported vehicle is completed, which provides a new idea for the development of AGV transporting and unloading vehicle.*

Keywords: *AGV,parallel mechanism, characteristics,2T2R mechanism,lifting model abstraction,kinematics*

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I. INTRODUCTION

At present, there is a wave of wisdom city construction in the big cities of our country. Taking Hangzhou as the representative, with the help of Alibaba's mobile Internet and cloud computing, the real-time and reasonable urban traffic planning can be realized. Hangzhou has made some achievements in intelligent transportation, and the urban traffic efficiency has been greatly improved than before. This is to achieve the goal of intelligent city through intelligent transportation. Coincidentally, in addition to road traffic, the city also faces some problems of parking difficulty and low parking efficiency. The parking environment can be improved and the construction of a smart city can be effectively promoted by the automatic transformation of urban parking lots and the automatic handling of parking vehicles.

Current urban parking lots. Due to the limitations of manual parking, inexperienced parking skills of drivers may lead to long-term parking in designated parking spaces, and not necessarily complete parking. For this reason, the use of automatic parking robots (AGV) in the construction of parking lots is necessary to promote the realization of smart cities. In some big cities of our country, intelligent parking lots based on automatic parking robots (AGV) are being developed, which has triggered a wave of research on automatic parking robots.

Fig.1-1 Avert Handling Robot Fig.1-2 Serva Handling Robot


Fig.1-3 Yifeng Handling Robot

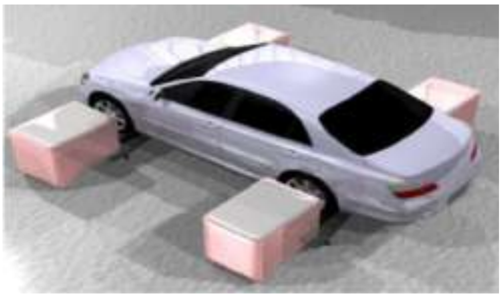
Fig.1-4Intelligent Cooperative Handling Robot

In order to meet the demand of automatic parking and handling, Avert, Serva robot and Yifeng comb-toothed lifting robot in Shenzhen have been formed, which include swarm robots, cantilever beams and other vehicle handling modes, all of which have their own characteristics. Avert swarm robots (shown in Figure1-1) work flexibly and can move in any direction. However, the power density of the driver is limited and its volume is large, which makes it difficult to be applied to vehicles with low chassis. In the process of working, it is difficult for multi-robots to locate and cooperate with each other. Because of the Mecanum wheel, the requirement of ground smoothness is relatively high. Serva arm-lifting robot (as shown in Figure 1-2) has a fast moving speed, but the lifting cantilever will bend when it is subjected to gravity, which will affect the vehicle's levelness when carrying heavy vehicles, and will cause the vehicle to slip in the extreme case. Yifeng Lifting Robot (as shown in Figure 1-3) has a fast moving speed, but it needs a special platform to use comb lifting device to place the vehicle on the handling robot, resulting in the change of the parking lot foundation. In addition, there is an intelligent cooperative handling swarm robot similar to Avert in Japan (as shown in Figure 1-4) which works flexibly, but has the disadvantage of occupying large space on both sides. The existing parking robots can not adjust adaptively for vehicles with different wheelbase. Some automobiles are expensive and require high stability of the platform. However, the existing AGV can not adjust the level and stability of the vehicle when the vehicle is lifted.

In this paper, the translational and rotational modes of the moving platform are obtained by analyzing the requirements of the vehicles being transported. When AGV transports vehicles, the relative motion between the lifting fork arm and the tire contact is abstracted as a pair of motion. Then the vehicle chassis is abstracted as a parallel mechanism moving platform, the AGV body is abstracted as a static platform, and each part of the transporting mechanism is abstracted as a branch chain of parallel mechanism. Through the above analysis, an AGV lifting mechanism based on the azimuth feature set of parallel mechanism and an AGV lifting device based on POC set are proposed.

II. Structural Design of AGV Lifting Mechanism

2.1 The Scheme Thought of AGV Lifting Mechanism

According to the actual demand and working condition investigation, the demand analysis of AGV lifting mechanism is given as follows:

Table 2-1 Demand analysis of AGV lifting mechanism

Specific needs	Solution
1.No damage to vehicles	Carry vehicles from tyres
2. Adjustable vehicle attitude	Parallel lifting of four groups of lifting arms
3.AGV Quick Vehicle Delivery	Drive the whole vehicle with the nose
4.Suitable for handling vehicles with different wheelbase	The lifting arm can move along the vehicle.
5.Vehicle Stability in the Process of Transport Vehicle	Four groups of lifting arm axisymmetric

2.2 Design of AGV lifting system

Based on the requirement analysis and solution of AGV in Table 2-1, the overall design scheme of AGV is proposed, which is shown in Figure 2-1. Four AGVs cooperate to realize the overall vehicle handling. Each AGV has a set of lifting fork arms, which can be adjusted by four AGV. Four AGVadopt four sets of lifting fork arms to lift tires.

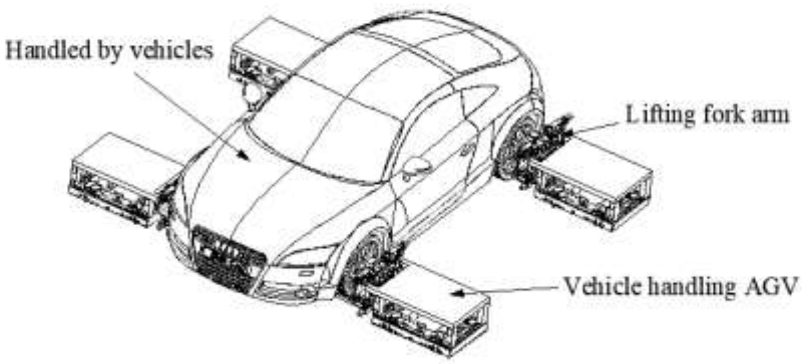

Fig.2-1 Overall design of the AGV handling vehicle

2.3 Rotation and translation analysis of AGV lifting device

2.3.1Rotation and translation analysis of AGV conveyor

In order to realize the stable and adjustable function of the attitude change of the transported vehicle, the overall scheme of the intelligent transporting AGV designed in this paper realizes the flexible contact of the tire with four sets of opposite lifting fork arms. Four groups of lifting fork arms on Intelligent AGV are used instead of Serva's two lifting arms. The expected function and operation mode of lifting mechanism are mapped to parallel mechanism. A new type of lifting mechanism for intelligent AGV is proposed based on azimuth feature set. After determining the basic structure of the intelligent AGV lifting mechanism, in order to meet the design requirements for the desired adjustment function of vehicle level, the movement trend of the vehicle under force is analyzed, and the number of translations and rotations required by the parallel mechanism is determined.

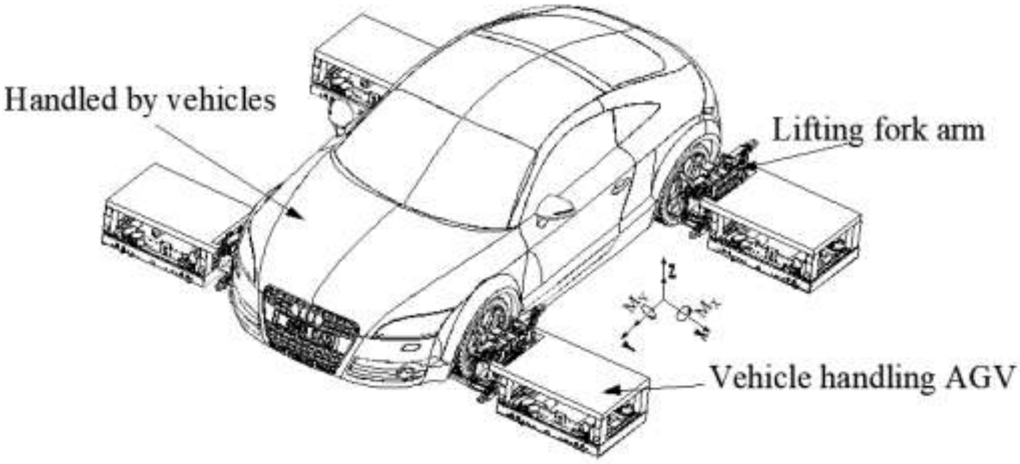

Fig.2-2 Analysis of the force and torque and translational rotation of the vehicle

In the process of vehicle handling with the cooperation of intelligent AGV and transport vehicle, when the intelligent AGV carries the vehicle on the carriage board, it has a movement in Z direction because of the need to lift the car on the carriage board. When the intelligent AGV system carries the vehicle off the carriage board, it will produce a movement in Y direction. Because of the different steps of AGV lifting, there is a rotation around the X and Y direction of the vehicle being moved at this time, as shown in Figure 2-2. The designed parallel mechanism of the whole vehicle lifting needs to have two rotations and two translations to realize the attitude adjustment of the vehicle being moved, that is, it needs to synthesize the topological structure and design a two translations and two rotations (2T2R) mechanism [1-2].

2.3.2 Equivalent kinematic pair at contact and parallel mechanism model of moving vehicle

The contact state and relative motion analysis of the lifting fork arm and the tire are the key to the design of parallel mechanism. According to the position and state of the contact between the fork arm and the tire, this paper proposes to abstract the contact point between the fork arm and the tire as a pair of motion. Through the analysis of the relative motion between the contact point and the lifting fork arm, it is determined what kind of pair it is abstracted into, and the pair of motion is abstracted as the end pair of the branch chain. Thus, the AGV body is abstracted as a static platform, the vehicle is abstracted as a moving platform, and the

whole structure of the lifting device is abstracted as a branching chain connecting the moving platform and the static platform.
(1) Analysis of relative motion at contact abstracted as motion pair
AGV lifts vehicle tyres in the order of front axle tyres and rear axle tyres.

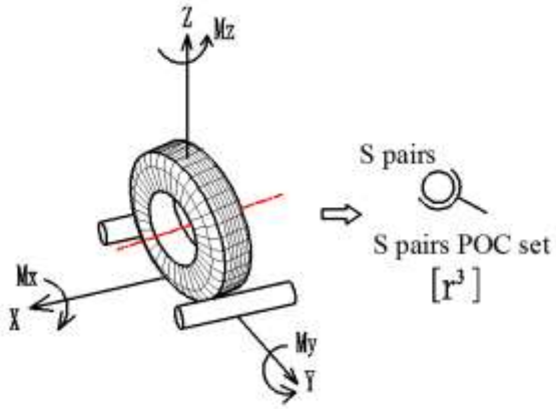

Fig.2-3 The front axle contact is abstracted as a ball pair

When the front axle tire is lifted, the vehicle is not fully fixed, the front wheel can turn with the axle, and there is a certain slope between the tire and the lifting fork arm. When lifting the two tires of the front axle, it can be seen from Fig. 2-3 that there is no restriction of freedom in other directions when lifting the front axle tire. There are three relative rotations of Mx, My and Mz at the contact between the drum tire and the roller fork arm, which are equivalent to the three degrees of freedom of the ball pair. That is to say, the contact between the lifting fork arm and the tire is abstracted as ball pair, as shown in Fig. 2-3, as the end motion pair of the branch of the front arm.

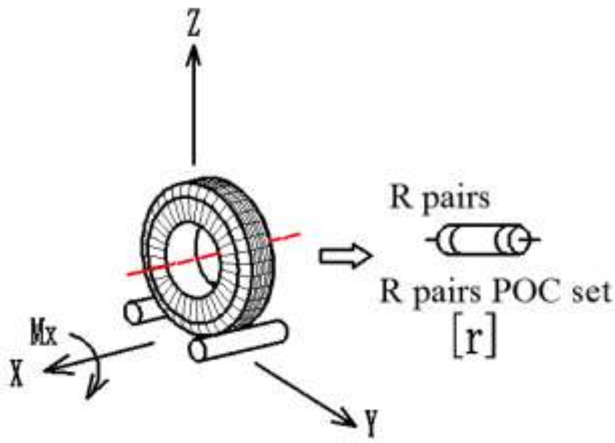

Fig.2-4 The intersection of the rear axle is abstracted as R

Since the rear wheel of a car can only rotate around its own axis, it cannot turn with the rear axle. Moreover, the rear wheel will be raised after the front wheel is raised. The degree of freedom of the vehicle has been limited by the intelligent AGV. The rear axle tire only has the relative rotation of Mx rotating around its own axle center. Because there is only one relative rotation, the contact point of the rear axle tire can be abstracted as R pair, as shown in Figure 2-4, as the end motion pair of the rear arm branch.

(2)The whole lifting model is abstracted into parallel mechanism

When carrying vehicles, the AGV body of intelligent moving vehicle is in a static state, and the ground can be abstracted as a static platform of parallel mechanism. The chassis of the lifted vehicle can be abstracted as a moving platform of parallel mechanism by adjusting its horizontal schedule by branches. Considering the easy realization of the structure design and the convenience of driving, the branch adopts the mobile sub-driver. The moving platform of parallel mechanism needs two rotations and two translations, and the mechanism has four branches.

Because the intelligent AGV device can be abstracted into parallel mechanisms of different modes in the process of handling, one of the parallel mechanisms of 2T2R mode is selected for type synthesis, kinematics and dynamics analysis.

2.4 Determine the type of mechanism topology

In the process of moving AGV system of intelligent mobile vehicle, the moving vehicle in y, z direction and the torque in M_x and M_y direction exist; the designed overall lifting parallel mechanism needs to have two rotations and two translations to realize the attitude adjustment of the moving vehicle, that is to say, it needs to synthesize the topological structure, and a parallel mechanism with two translations and two rotations (2T2R) is designed. The POC set of the moving platform of the parallel manipulator is:

$$M_p = \begin{bmatrix} t^2 \\ r^2 \end{bmatrix} \tag{2-1}$$

2.5 Determine the POC set of parallel mechanism

The intelligent AGV moving system is abstracted as a 2T2R parallel mechanism when adjusting forward and backward. As shown in Figure4-9, the desired output of the parallel mechanism is two translations and two rotations (2T2R).

The POC set of the parallel mechanism moving platform is:

$$M_p = \begin{bmatrix} t^2 \perp R \\ r^2 \parallel \Diamond(R, R^*) \end{bmatrix} \tag{2-2}$$

In formula $t^2(\perp R)$, there are two finite shifts

$r^2(\parallel \Diamond(\mathrm{R}, \mathrm{R}^*))$ denotes the existence of two finite rotations

The two translational and rotational directions are shown in Fig. 2-2.

(1) Determining the type of branch topology

$M_p, M_{bi} \supseteq M_{pa}$, the POC set of the branch end component is:

$$M_{bi} = \begin{bmatrix} t^2 \\ r^2 \end{bmatrix}, \begin{bmatrix} t^3 \\ r^2 \end{bmatrix}, \begin{bmatrix} t^2 \\ r^3 \end{bmatrix}, \begin{bmatrix} t^3 \\ r^3 \end{bmatrix} \tag{2-3}$$

（2）Determining the Branch Combination Scheme

The SOC branch in Table 2-2 can be used to synthesize the required combination scheme.

Table 2-2 Structure Types of SOC Branches

M_{b_i}	*SOC*	
$\begin{bmatrix} t^2(\perp R) \\ r^2(\mathrm{P}\Diamond(R, R^*)) \end{bmatrix}$	1	$SOC\{-P \perp R \mathrm{P} R \perp R-\}$
	2	$SOC\{-R \mathrm{P} R \mathrm{P} R \perp R-\}$
$\begin{bmatrix} t^3 \\ r^2(\mathrm{P}\Diamond(R, R^*)) \end{bmatrix}$	3	$SOC\{-P \perp RPR \perp R^* \mathrm{P} R^* -\}$
	4	$SOC\{-RPRPR \perp R^* \mathrm{P} R^* -\}$
$\begin{bmatrix} t^3 \\ r^3 \end{bmatrix}$	5	$SOC\{-P-S-S-\}$
	6	$SOC\{-R-S-S-\}$

In order to meet the contact requirement between tire and fork arm, branch types are selected as follows: Branch 1 and branch 2:

$$SOC\{-P_{i1} \perp R_{i2} \mathrm{P} R_{i3} \perp R_{i4} -\} i = 1,2 \tag{2-4}$$

Branch 3 and branch 4:

$$SOC\{-P_{i1}\text{-}S_{i2}\text{-}S_{i3}-\}\, i=3,4 \quad (2\text{-}5)$$

(3) Determining the geometric conditions for assembling branches on two platforms

The terminal component POC sets of branch 1 and 2 are:

$$M_{bi}=\begin{bmatrix} t^2(\perp R_{i2}) \\ r^2\left(\mathrm{P}\Diamond(R_{12},R_{14})\right)\end{bmatrix}(i=1,2) \quad (2\text{-}6)$$

The terminal component POC sets of branch 3 and 4 are:

$$M_{bi}=\begin{bmatrix} t^3 \\ r^3 \end{bmatrix}(\mathrm{i}=3,4) \quad (2\text{-}7)$$

(4) Establishing azimuth characteristic equation of parallel mechanism

The POC set of branch end components is substituted into the POC equation of parallel mechanism.

$$M_{bi}=\begin{bmatrix} t^2(\perp R) \\ r^2\left(\mathrm{P}\Diamond(R,R^*)\right)\end{bmatrix}=\begin{bmatrix} t^2(\perp R_{12}) \\ r^2\left(\mathrm{P}\Diamond(R_{12},R_{14})\right)\end{bmatrix}\mathrm{I}\begin{bmatrix} t^2(\perp R_{22}) \\ r^2\left(\mathrm{P}\Diamond(R_{22},R_{24})\right)\end{bmatrix}\mathrm{I}\begin{bmatrix} t^3 \\ r^3 \end{bmatrix}\mathrm{I}\begin{bmatrix} t^3 \\ r^3 \end{bmatrix} \quad (2\text{-}8)$$

According to the intersection operation of rotation elements of POC set, in order to realize the two-dimensional rotation of moving platform, and considering the principle of reducing passive motion pairs, the geometric conditions for assembling branches on two platforms should be as follows:

$\Diamond(R_{12},R_{14})\mathrm{P}\Diamond(R_{22},R_{24})$

And simplify it to $R_{12}\,\mathrm{P}R_{22}$ and $R_{14}\,\mathrm{P}R_{24}$

According to the intersection operation between the moving elements of POC set, the geometric conditions for assembling branches on the two platforms should be as follows: $R_{12}\,\mathrm{P}R_{22}$ 。

Therefore, the geometric conditions of assembling four branches on two platforms can be summarized as follows: $R_{12}\,\mathrm{P}R_{22}$ and $R_{14}\,\mathrm{P}R_{24}$, As shown in Figure 2-5. The POC set of the mobile platform meets the design requirements.

$$M_{bi}=\begin{bmatrix} t^2(\perp R_{12}) \\ r^2\left(\mathrm{P}\Diamond(R_{12},R_{14})\right)\end{bmatrix}=\begin{bmatrix} t^2(\perp R_{12}) \\ r^2\left(\mathrm{P}\Diamond(R_{12},R_{14})\right)\end{bmatrix}\mathrm{I}\begin{bmatrix} t^2(\perp R_{22}) \\ r^2\left(\mathrm{P}\Diamond(R_{22},R_{24})\right)\end{bmatrix}\mathrm{I}\begin{bmatrix} t^3 \\ r^3 \end{bmatrix}\mathrm{I}\begin{bmatrix} t^3 \\ r^3 \end{bmatrix} \quad (2\text{-}9)$$

However, the operation of POC set is also constrained by DOF of mechanism. It is necessary to check whether the degree of freedom of mechanism meets the design requirements (DOF=4) and whether there are negative motion pairs.

2.6 Inspection of degree of freedom of mechanism

Given the branch topology of parallel mechanism and the geometric conditions of its assembly on two platforms, the degree of freedom of parallel mechanism is checked.

(1) Determining the Independent Displacement Equation Number of the First Independent Circuit ξ_{L1} :

$$\xi_{L1}=\dim\{M_{b1}\,\mathrm{U}\,M_{b2}\}=\dim\left\{\begin{bmatrix} t^2(\perp R_{12}) \\ r^2(\mathrm{P}\Diamond(R_{12},R_{14}))\end{bmatrix}\mathrm{U}\begin{bmatrix} t^2(\perp R_{22}) \\ r^2(\mathrm{P}\Diamond(R_{22},R_{24}))\end{bmatrix}\right\}=4$$

Formula dim{} is a function of dimension. (2-10)

First, the DOF of the sub-parallel mechanism consisting of two branches:

$$F_{(1\text{-}2)}=\sum_{i=1}^{m} f_i-\sum_{j=1}^{v}\xi_{Lj}=8-4=4 \quad (2\text{-}11)$$

The POC set of the moving platform of the sub-parallel mechanism composed of $F_{(1-2)}=4,$ first and two branches is as follows:

$$M_{Pa(1-2)}=M_{b1}\,\mathrm{I}\,M_{b2}=\begin{bmatrix} t^2(\perp R_{12}) \\ r^2(\mathrm{P}\Diamond(R_{12},R_{14}))\end{bmatrix}\mathrm{I}\begin{bmatrix} t^2(\perp R_{22}) \\ r^2(\mathrm{P}\Diamond(R_{22},R_{24}))\end{bmatrix}=\begin{bmatrix} t^2(\perp R_{12}) \\ r^2(\mathrm{P}\Diamond(R_{12},R_{14}))\end{bmatrix} \quad (2\text{-}12)$$

（2）The independent displacement equation ξ_{L3} of the second independent circuit is determined as follows:

$$\xi_{L2} = \dim\left\{M_{Pa(1-2)} \cup M_{b3}\right\} = \dim\left\{\begin{bmatrix} t^3 \\ r^3 \end{bmatrix}\right\} = 6 \qquad (2\text{-}13)$$

The DOF of the sub-parallel mechanism consisting of the first, second and Third branches is as follows:

$$F_{(1-3)} = \sum_{i=1}^{m} f_i - \sum_{j=1}^{v} \xi_{Lj} = 16 - (4+6) = 6 \qquad (2\text{-}14)$$

The POC set of the moving platform of the sub-parallel mechanismconsisting of the first, second and Third branches is as follows:

$$M_{Pa(1-3)} = M_{Pa(1-2)} \cap M_{b3} = \begin{bmatrix} t^2\left(\perp R_{12}\right) \\ r^2\left(\parallel \Diamond\left(R_{12}, R_{14}\right)\right) \end{bmatrix} \qquad (2\text{-}15)$$

(3) Determine the number of independent displacement equations ξ_{L3} of the third independent circuit as follows:

$$\xi_{L3} = \left\{M_{Pa(1-3)} \cup M_{b4}\right\} = \dim\left\{\begin{bmatrix} t^3 \\ r^3 \end{bmatrix}\right\} = 6 \qquad (2\text{-}16)$$

The DOF of parallel mechanism is determined as:

$$F_{(1-2)} = \sum_{i=1}^{m} f_i - \sum_{j=1}^{v} \xi_{Lj} = 20 - (4+6+6) = 4 \qquad (2\text{-}17)$$

Therefore, DOF=4 meets the design requirements.

2.7 Negative motion pair judgment

First, the DOF of the sub-parallel mechanism consisting of two branches is as follows:

$$F_{(1-2)} = \sum_{i=1}^{m} f_i - \sum_{j=1}^{v} \xi_{Lj} = 7 - 4 = 3 \qquad (2\text{-}18)$$

The judgment criterion of passive pair is used to judge whether R_{24} is a passive pair.

（1）Rigidity R_{24}, branch $\{-P_{21} \perp R_{22} \parallel R_{23}\}$, The POC set at the end of the new mechanism is

$$\begin{bmatrix} t^2(\perp R_{22}) \\ r^2(\parallel R_{22}) \end{bmatrix}$$

(2) Determining the Independent Displacement Equation Number of the First Circuit ξ_{L1}

$$\xi_{L1} = \left\{M_{b1} \cup M_{b2}\right\} = \dim\left\{\begin{bmatrix} t^2(\perp R_{12}) \\ r^2(\parallel \Diamond(R_{12}, R_{14})) \end{bmatrix}\right\} = 4 \qquad (2\text{-}19)$$

By the same token:

$$\xi_{L2} = 6, \xi_{L3} = 6 \qquad (2\text{-}20)$$

Determine the new parallel mechanism DOF:

$$F_{(1-2)} = \sum_{i=1}^{m} f_i - \sum_{j=1}^{v} \xi_{Lj} = 19 - (4+6+6) = 3 \qquad (2\text{-}21)$$

$F \neq F^*$, R_{24} is not a negative pair. Similarly, it can be judged that there is no negative pair in the whole organization

2.8 Select the mechanism driving pair

In general, all driving pairs of parallel mechanism are located on the same platform. Now it is decided whether four P pairs of parallel mechanism can be driving pairs at the same time.

(1) Assuming that the moving pair $P_{11}, P_{21}, P_{31}, P_{41}$ is rigidized, a new mechanism is obtained, and the topological structure of other branches is changed as follows:

$SOC\{-R_{i2} \parallel R_{i3} - R_{i4}-\}, (i=1,2)$ and $SOC\{-S_{i2} - S_{i3}-\}, (i=3,4)$

(2) Determine the number of independent displacement equations for the first independent circuit:

The displacement equation number of the first independent circuit composed of two branches can be obtained from the POC equation formula.

$$\xi_{L1} = \dim\{M_{b1} \cup M_{b2}\}$$
$$= \dim\left\{\begin{bmatrix} t^2(\perp R_{12}) \\ r^2(\mathrm{P}\lozenge(R_{12}, R_{14})) \end{bmatrix} \cup \begin{bmatrix} t^2(\perp R_{22}) \\ r^2(\mathrm{P}\lozenge(R_{22}, R_{24})) \end{bmatrix}\right\} = \dim\left\{\begin{bmatrix} t^2(\perp R_{12}) \\ r^2(\mathrm{P}\lozenge(R_{12}, R_{14})) \end{bmatrix}\right\} = 4 \quad (2\text{-}22)$$

First, the DOF of the sub-parallel mechanism consisting of two branches is as follows:

$$F_{(1-2)} = \sum_{i=1}^{m} f_i - \sum_{j=1}^{v} \xi_{Lj} = 6 - 4 = 2 \quad (2\text{-}23)$$

First, the POC set of the sub-parallel online platform consisting of two branches is as follows:

$$M_{Pa(1-2)} = M_{b1} \cap M_{b2} = \begin{bmatrix} t^2(\perp R_{12}) \\ r^2(\mathrm{P}\lozenge(R_{12}, R_{14})) \end{bmatrix} \quad (2\text{-}24)$$

The same goes for:

$$\xi_{L2} = 6, \quad \xi_{L3} = 6 \quad (2\text{-}25)$$

(3) The DOF of the new mechanism is determined as:

$$F^* = \sum_{i=1}^{m} f_i - \sum_{j=1}^{v} \xi_{Lj} = 16 - (4 + 6 + 6) = 0 \quad (2\text{-}26)$$

The new mechanism DOF = 0, which is determined by the criterion of driving pair. The $P_{11}, P_{21}, P_{31}, P_{41}$ pair on the platform of parallel mechanism can be used as driving pair at the same time.

2.9 Determine the topological structure of parallel mechanism

In summary, the topological structure of the parallel mechanism shown in Fig. 2-5is as follows:

(1) The topological structures of the four branches of the parallel mechanism are 1 and 2:

$$SOC\{-P_{i1} \perp R_{i2} \mathrm{P} R_{i3} \perp R_{i4} -\}, i = 1, 2$$

Branch 3 and 4:

$$SOC\{-P_{i1} - S_{i2} - S_{i3} -\}, i = 3, 4$$

(2) The topological structure of the two platforms is as follows:

$$R_{12} \mathrm{P} R_{22}, R_{14} \mathrm{P} R_{24}$$

(3) set the sub $P_{11}, P_{21}, P_{31}, P_{41}$ on the platform as the driving sub

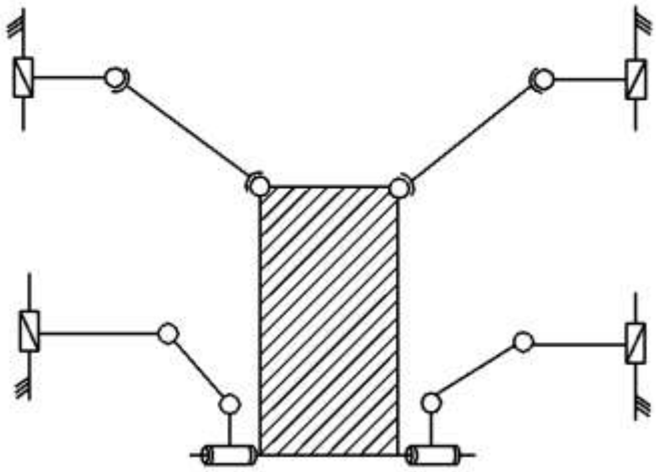

Fig.2-5 Topology of the 2T2R mechanism

The topological structure of the mechanism is used to adjust the attitude of the AGV in the process of intelligent vehicle moving. The configuration of the parallel mechanism in space is shown in Fig. 2-6. The moving platform is the chassis of the transported vehicle, the fixed platform is the ground, and the four moving pairs of the four intelligent AGV are the driving pairs, which can lift the vehicle.

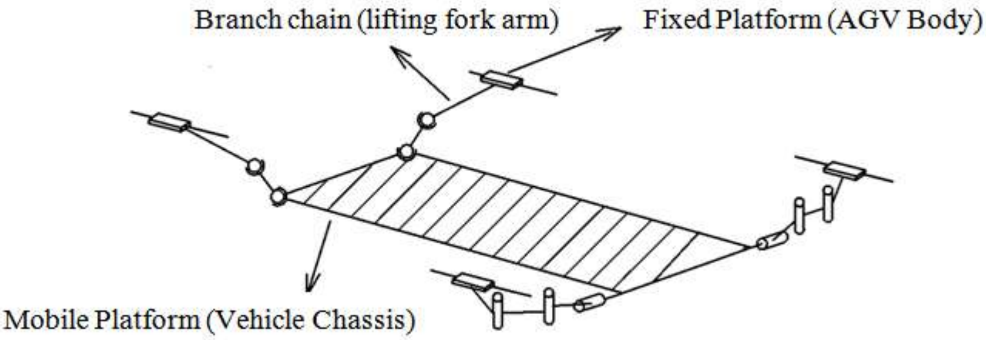

Fig.2-6 Configuration of AGV handling parallel mechanism configuration

III. Kinematics Analysis of Parallel Mechanism Based on AGV Device

3.1 Kinematics Analysis of the Handling Mechanism of AGV Device

The type synthesis of the parallel mechanism has been completed based on the azimuth feature set. The kinematics of the parallel mechanism is analyzed[3-4]. The designed 4-DOF of 2-translational 2-rotational parallel mechanism is shown in Fig. 3-1. It is composed of the ground (static platform), the dynamic platform and four branches. The driving pair of each branch is the mobile pair fixed on the static platform. The driving pair is the front and back movement of each intelligent AGV, and the four driving P axes are parallel to each other. There are two different branches in the four branches. These two branches are composed of $SOC\{-P_{i1} \perp R_{i2} \parallel R_{i3} \perp R_{i4} -\}, i=1,2$ and $SOC\{-P_{i1} - S_{i2} - S_{i3} -\}, i=3,4$.

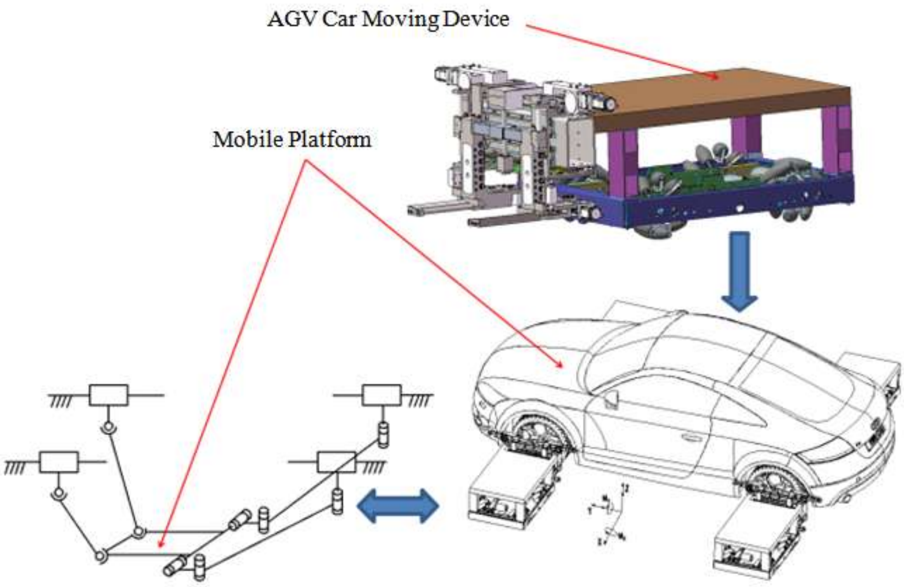

Fig. 3-1 Schematic diagram of the parallel mechanism of the AGV device

3.2 Kinematics Inverse Solution

Kinematics of 2T2R parallel mechanism is analyzed. In this 4-DOF parallel mechanism[5], when the pose (y, z, α, β) of output component of parallel mechanism is known, The process of solving the position (h_1, h_2, h_3, h_4) of input components of parallel mechanism is called the inverse solution of position [6-9].In order to analyze and solve the forward and inverse kinematics problems of parallel mechanisms, a kinematics model is established as shown in Fig. 3-2, in which the static platform coordinate system is $o-xyz$ and the moving platform coordinate system is $o'-x'y'z'$. The parallel mechanism has four degrees of freedom, i. e. the movement along the *y* and *z* coordinate axes and the rotation around the *x* and *y* coordinate axes.

The parameters are defined as follows：L_1、L_2、L_3、L_4 are rod length, T、Q、S、P are geometric dimensions of static and dynamic platforms respectively, and their values are fixed.

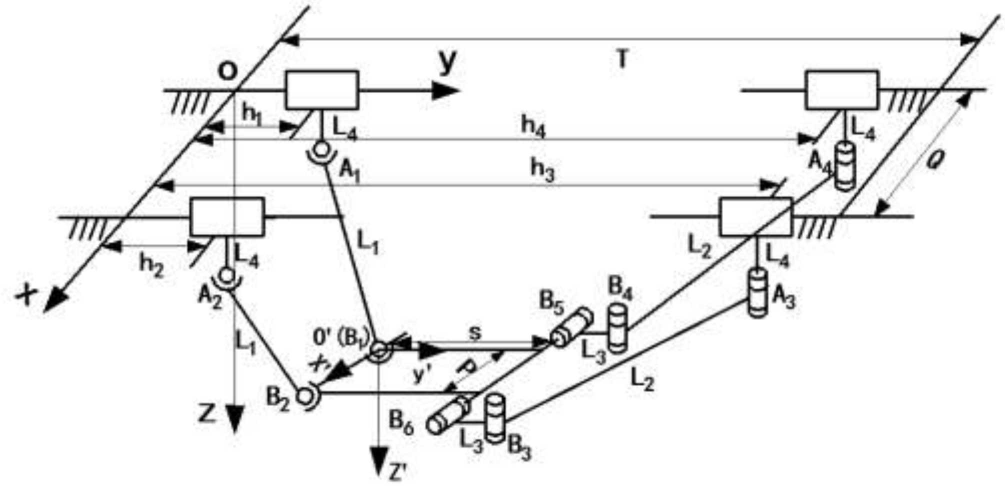

Fig.3-2 Kinematics model of the parallel mechanism of the AGV device

The analysis process is as follows:

1. In the moving coordinate system $o'-x'y'z'$, the vector coordinates of point $\boldsymbol{B_i}$ are:

$[\boldsymbol{B}_1]_{O'}=(0,0,0)^T$, $[\boldsymbol{B}_2]_{O'}=(P,0,0)^T$, $[\boldsymbol{B}_3]_{O'}=(P,S+L_3,0)^T$, $[\boldsymbol{B}_4]_{O'}=(0,S+L_3,0)^T$

2. In the static coordinate system $o-xyz$, the vector coordinates of point $\boldsymbol{A_i}$ are:

$[\boldsymbol{A}_1]_O=(0,h_1,L_4)^T$, $[\boldsymbol{A}_2]_O=(Q,h_2,L_4)^T$, $[\boldsymbol{A}_3]_O=(Q,h_3,L_4)^T$, $[\boldsymbol{A}_4]_O=(0,h_4,L_4)^T$

3. The coordinate transformation matrix $\mathbf{R}$ from the slave coordinate system o' to the static coordinate system o is:

$$\boldsymbol{R}=\begin{bmatrix}\cos\beta & 0 & \sin\beta & x_p\\ \sin\alpha\sin\beta & \cos\alpha & -\sin\alpha\cos\beta & y_p\\ -\cos\alpha\sin\beta & \sin\alpha & \cos\alpha\cos\beta & z_p\\ 0 & 0 & 0 & 1\end{bmatrix} \quad (3\text{-}1)$$

Where x_p, y_p, z_p are the coordinates of the origin of the moving platform coordinate system O' on the static platform coordinate system O. It can be seen from Fig. 3-2 that the parallel mechanism does not move in the x-axis direction, so x_p is a constant.

4. The coordinates of points $\boldsymbol{B_i}$ in moving platform coordinate system $o'-x'y'z'$ are expressed in static platform coordinate system $o-xyz$ as follows:

From the coordinate transformation formula:

$$[\boldsymbol{B}_i]_O=\boldsymbol{R}[\boldsymbol{B}_i]_{O'} \quad (3\text{-}2)$$

to

$$[\boldsymbol{B}_1]_O=(x_p,y_p,z_p)^T \quad (3\text{-}3)$$

$$[\boldsymbol{B}_2]_O=(P\cos\beta+x_p,P\sin\alpha\sin\beta+y_p,-P\cos\alpha\sin\beta+z_p)^T \quad (3\text{-}4)$$

$$[\boldsymbol{B}_3]_O=(P\cos\beta+x_p,P\sin\alpha\sin\beta+(S+L_3)\cos\alpha+y_p,\\ -P\cos\alpha\sin\beta+(S+L_3)\sin\alpha+z_p) \quad (3\text{-}5)$$

$$[\boldsymbol{B}_4]_O=(x_p,(S+L_3)\cos\alpha+y_p,(S+L_3)\sin\alpha+z_p) \quad (3\text{-}6)$$

The inverse solution of the parallel mechanism can be obtained by the following four constrained equations of fixed length connecting rods:

$$\|\boldsymbol{B_i}-\boldsymbol{A}_i\|=L_i \quad (3\text{-}7)$$

It can be obtained that:

$$x_p^2+(y_p-h_1)^2+(z_p-L_4)^2=L_1^2 \quad (3\text{-}8)$$

$$(P\cos\beta+x_p-Q)^2+(P\sin\alpha\sin\beta+y_p-h_2)^2+(-P\cos\alpha\sin\beta+z_p-L_4)^2=L_1^2 \quad (3\text{-}9)$$

$$\left(P\cos\beta + x_p - Q\right)^2 + \left(P\sin\alpha\sin\beta + \left(S + L_3\right)\cos\alpha + y_p - h_3\right)^2 + \left(-P\cos\alpha\sin\beta + \left(S + L_3\right)\sin\alpha + z_p - L_4\right)^2 = L_2^2 \quad (3\text{-}10)$$

$$x_p^2 + \left(\left(S + L_3\right)\cos\alpha + y_p - h_4\right)^2 + \left(\left(S + L_3\right)\sin\alpha + z_p - L_4\right)^2 = L_2^2 \quad (3\text{-}11)$$

From the above formula, we can see that:

$$h_1 = y_p \pm \sqrt{L_1^2 - \left(z_p - L_4\right)^2 - x_p^2} \quad (3\text{-}12)$$

$$h_2 = P\sin\alpha\sin\beta + y_p \pm \sqrt{L_1^2 - \left(-P\cos\alpha\sin\beta + z_p - L_4\right)^2 - \left(P\cos\beta + x_p - Q\right)^2} \quad (3\text{-}13)$$

$$h_3 = P\sin\alpha\sin\beta + \left(S + L_3\right)\cos\alpha + y_p \pm \sqrt{L_2^2 - \left(-P\cos\alpha\sin\beta + \left(S + L_3\right)\sin\alpha + z_p - L_4\right)^2 - \left(P\cos\beta + x_p - Q\right)^2} \quad (3\text{-}14)$$

$$h_4 = \left(S + L_3\right)\cos\alpha + y_p \pm \sqrt{L_2^2 - \left(\left(S + L_3\right)\sin\alpha + z_p - L_4\right)^2 - x_p^2} \quad (3\text{-}15)$$

3.2 Forward Kinematics Solution

For the 2-PSS&2-PRRR parallel mechanism shown in Fig. 3-2, the forward solution of its position [10-12]is as follows: Given the displacement $h_i(1,2,3,4)$ of the driving pair, the position (x_p, y_p, z_p) and attitude (α, β) of the moving platform are calculated.From the equations (3-8), (3-9), (3-10), (3-11), we can see that they are equations concerning the four unknowns of y_p, z_p, α, β:

$$x_p^2 + \left(y_p - h_1\right)^2 + \left(z_p - L_4\right)^2 - L_1^2 = 0 \quad (3\text{-}16)$$

$$\left(P\cos\beta + x_p - Q\right)^2 + \left(P\sin\alpha\sin\beta + y_p - h_2\right)^2 + \left(-P\cos\alpha\sin\beta + z_p - L_4\right)^2 - L_1^2 = 0 \quad (3\text{-}17)$$

$$\left(P\cos\beta + x_p - Q\right)^2 + \left(P\sin\alpha\sin\beta + \left(S + L_3\right)\cos\alpha + y_p - h_3\right)^2 + \left(-P\cos\alpha\sin\beta + \left(S + L_3\right)\sin\alpha + z_p - L_4\right)^2 - L_2^2 = 0 \quad (3\text{-}18)$$

$$x_p^2 + \left(\left(S + L_3\right)\cos\alpha + y_p - h_4\right)^2 + \left(\left(S + L_3\right)\sin\alpha + z_p - L_4\right)^2 - L_2^2 = 0 \quad (3\text{-}19)$$

The constrained equations of the forward kinematics solution of the 2-PSS-2-PRRR parallelmechanism.

IV. Conclusion

This paperstudies the organic combination of the position and attitude adjustment task of parallel mechanism moving platform and vehicle handling mechanism,it based on the azimuth feature set,and carries out kinematics analysis. The main research is as follows:

(1) According to the difference of front and rear axle tire structure, based on the different contact state and relative motion between tire and lifting fork arm, the contact points are abstracted into different motion pairs, and the types of motion pairs at the end of each branch chain are obtained.

(2) Based on the process of abstracting the whole AGV moving model into a dynamic and static platform of parallel mechanism, the degree of freedom of the moving vehicle is analyzed, and the number of translation and rotation of the moving platform needed to realize the adjustment of vehicle level is determined.

(3) Based on the theory of topological structure design of azimuth feature set and combined with the actual requirements of AGV transport vehicle, the types of end kinematic pairs of each branch chain are determined, which reduces the solution domain of mechanism synthesis.

(4) The kinematics of the abstract parallel mechanism is studied. By establishing the kinematics model of the parallel mechanism, the forward and inverse kinematics solutions of the parallel mechanism are solved.

(5) This study not only enriches the type of 2T2R mechanism, but also provides a new way to adjust the level of AGV vehicle during handling.

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