Research Article

Leveling Control of Vehicle Load-Bearing Platform Based on Multisensor Fusion

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In the large-scale transportation, the leveling of the transport vehicle loading platform will determine the safety of the transportation. Therefore, the research on the leveling of the transport vehicle loading platform with hydraulic suspension is carried out. The hydraulic suspension systems are simplified as four-point support. Based on the multisensor data collected by the pressure sensors of the suspension hydraulic cylinders and the double axis inclination sensor of the load-bearing platform, the leveling control system of the four-point load-bearing platform is designed according to the principle of the highest point chasing. In order to verify the precision of the leveling method, the leveling of the control system is simulated by using the software AMESim and MATLAB, and the PID controller is added. The results show that the leveling precision and velocity of this method fully meet the leveling requirements of the transport vehicle. On the basis, the leveling control system for the 100 ton transport vehicle is designed. The double axis inclination sensor is used to monitor the tilt angle of the loading platform in real time. The controller can make the suspension hydraulic cylinders act accordingly according to the four height differences to keep the loading platform level. Finally, the leveling experiment of the transport vehicle is carried out, and the lifting experiment is carried out under the condition of no load to full load. It is concluded that the displacement of the four points of the load-bearing platform of the transport vehicle is basically the same. The leveling control system can control the inclination angle of the platform within 0.25 degrees, and the leveling time is less than 1 second. The leveling process has higher precision and shorter time than other methods, which can provide reference for the leveling design of similar platforms.

1. Introduction

With the development of science and technology, the leveling technology of the vehicle platform has been widely used. In the military, more and more military weapons, such as radar and rocket, need to change their working places at any time, so they need to be installed on the transport vehicles with the automatic leveling function [1]. In recent years, with the

improvement of leveling precision and velocity requirements, the automatic leveling control technology with short time, high precision, and strong antioverturning ability has emerged [2]. With the advantages of high efficiency and strong bearing capacity, the hydraulic suspension leveling system has obvious advantages in the field of the heavy-duty platform [3].

The suspension system composed of multiple hydraulic cylinders is widely used in heavy transport vehicles [4]. In

the process of transportation, the transport vehicle often encounters climbing, sudden braking, turning, wind load, and other conditions, which may lead to the change of load center position, so that the load-bearing platform of the transport vehicle will incline [5], in order to ensure the safety of the transportation and avoid the major engineering accidents caused by the tilting or sliding of the load in the transportation, which depends on the leveling of the load-bearing platform of the transport vehicle [6].

With the development of control technology and electronic technology, the leveling system has gradually developed from the original manual leveling system to the automatic leveling system. The support form of the platform has developed from the initial three-point support to the present four-point support and multipoint support [7]. The main leveling methods are pulse width modulation technology [8], computer and PLC technology, position error control leveling method [9], angle error control leveling method, and “cycle multiple” leveling method [10]. The purpose of leveling can be achieved by combining various control algorithms, such as PID control, fuzzy control, adaptive control, and neural network control [11].

Heng studied the motion synchronization control of the four multistage cylinder electrohydraulic elevating system [12]. Chunfang studied the synchronization control of an electrohydraulic leveling system based on adjacent cross coupling [13]. Yang studied on the hydraulic synchronization system used on the lift platform of the port embarkation bridge [14]. Zhao studied the electrohydraulic synchronization driving control for self-propelled transporter suspension lifting [15]. But they are limited to the platform on the horizontal plane, Li studied the autoadaptive multicylinder leveling system with electrohydraulic proportional control [16]. Yang designed the automatic leveling control system of the vehicle-mounted radar platform based on PLC. The position sensor was used to detect the position of leveling outrigger [17]. According to the application of the transport vehicle, the leveling control strategy based on four support points is proposed [18]. By using the double axis inclination sensor to monitor the levelness of the load-bearing platform, the four points of the load-bearing platform of the transport vehicle can be kept in a horizontal plane through the designed leveling control system [19]. In the process of leveling, each suspension hydraulic cylinder acts at the same time, which can improve the safety of leveling.

The leveling time of the researches cannot meet the requirements; in order to ensure the safety of transportation, the leveling process of transport vehicle needs fast response. In this paper, the leveling control of the vehicle load-bearing platform is studied. The leveling principle and leveling process are introduced, and the leveling control system based on multisensor fusion is designed in Section 2. In order to verify the leveling precision of the leveling control system, the simulation of the leveling process is carried out in Section 3. In Section 4, the leveling experiment of the vehicle load-bearing platform is carried out on the 100 ton transport vehicle, which further proved the practicability and reliability of the leveling control system. Finally, the design process and

the future research direction of leveling control are summarized in the Section 5.

2. Design of Leveling Process

The leveling system is a four-point support type, so there will be redundant constraints in the structure. One of the support points may not be stressed. This situation is not allowed in the platform support and leveling. The problem will cause the vehicle platform to tilt or even roll over, so the solution of this problem has become the key of leveling. For the hydraulic support system, there is a pressure sensor at the bottom of each hydraulic cylinder. By detecting the pressure feedback value of each support point after touching the ground and during the leveling process, the problem can be judged. According to the feedback signals transmitted by the double axis inclination sensor and pressure sensors, the four support points will be driven to extend or contract through the control until the four support points completely touch the ground, and the pressure is uniform.

The vehicle load-bearing platform can be simplified as a four-point support platform, and the coordinate system of the four-point support platform is established as shown in Figure 1.

The coordinate system $OXYZ$ of the horizontal plane is the reference coordinate system, and point O is the center of the four-point support platform, and the coordinate system $OX_1Y_1Z_1$ is the following coordinate system of the platform, which is fixed on the vehicle load-bearing platform. The rotation angles of the platform following coordinate system in two directions relative to the reference coordinate system are α and β , respectively. Therefore, when $\alpha > 0$ and $\beta > 0$, point 3 is the highest, and point 1 is the lowest; when $\alpha > 0$ and $\beta < 0$, point 2 is the highest, and point 4 is the lowest; when $\alpha < 0$ and $\beta > 0$, point 4 is the highest, and point 2 is the lowest; when $\alpha < 0$ and $\beta < 0$, point 1 is the highest, and point 3 is the lowest; when $\alpha = 0$ and $\beta = 0$, the load-bearing platform is in a horizontal state.

2.1. Levelness Measurement. In order to measure the levelness of the load-bearing platform of the transport vehicle, the double axis inclination sensor is installed on the center of the load-bearing platform, which can detect the inclination angles α and β of the load-bearing platform and transmit the inclination angles to the leveling controller. Taking the highest point as the reference point, The controller can calculate the height difference between the highest point and the other three points in the vertical direction [20]. If the platform coordinate system relative to the reference coordinate system first rotates β around the y -axis, and then rotates α around the x -axis, the coordinate transformation matrix T_1 can be obtained as follows.

$$T_1 = \text{Rot}(X, \alpha)\text{Rot}(Y, \beta) = \begin{bmatrix} \cos \beta & 0 & \sin \beta \\ \sin \alpha \sin \beta & \cos \alpha & -\sin \alpha \cos \beta \\ -\sin \beta & \sin \alpha & \cos \alpha \cos \beta \end{bmatrix}. \quad (1)$$

FIGURE 1: The coordinate system of the four-point support platform.

Similarly, if the platform coordinate system first rotates α around the x -axis, and then rotates β around the y -axis, the transformation matrix of the coordinate system is T_2 .

$$T_2 = \text{Rot}(Y, \beta)\text{Rot}(X, \alpha) = \begin{bmatrix} \cos \beta & \sin \alpha \sin \beta & \sin \beta \cos \alpha \\ 0 & \cos \alpha & -\sin \alpha \\ -\sin \beta & \sin \alpha \cos \beta & \cos \alpha \cos \beta \end{bmatrix}. \quad (2)$$

Since the angle of inclination is so small that it can be approximately regarded as $\sin \beta = \beta$, $\sin \alpha = \alpha$, $\sin \alpha \sin \beta = 0$, and $\cos \alpha = \cos \beta = 1$ [12], therefore, the transformation matrix can be seen as equal when the tilt angle is enough small, whether the platform rotates around the x -axis or the y -axis first. Equation (3) can be obtained as follows.

$$T_1 = T_2 = T \approx \begin{bmatrix} 1 & 0 & \beta \\ 0 & 1 & -\alpha \\ -\beta & \alpha & 1 \end{bmatrix}. \quad (3)$$

When the platform is horizontal, the platform coordinate system and the reference coordinate system are coincident. One of the four points in the platform coordinate system is P (P_{x1}, P_{y1}, P_{z1}). The point P is fixed to the platform coordinate system, and when the platform rotates α around the x -axis and rotates β around the y -axis, the coordinate of point P changes to P' (P_x, P_y, P_z) in the reference coordinate system, and Equation (4) can be obtained.

$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = T \cdot \begin{bmatrix} P_{x1} \\ P_{y1} \\ P_{z1} \end{bmatrix}, \quad (4)$$

so the P_z can be obtained as follows.

$$P_z = -\beta \cdot P_{x1} + \alpha \cdot P_{y1}. \quad (5)$$

The coordinate of a support point on the z -axis and the height difference of the other three points between

FIGURE 2: The leveling process principle.

the highest point can be obtained according to Equation (6).

$$\Delta z_i = z_1 - z_i = \beta(x_i - x_1) + \alpha(y_1 - y_i) \quad (i = 2, 3, 4). \quad (6)$$

2.2. Leveling Process Principle. The height difference between the four points can be calculated by the controller. According to the highest point, the controller will send out the corresponding control signals to adjust the opening of the proportional reversing valve, so the suspension hydraulic cylinders can make the load-bearing platform quickly approach the horizontal plane and achieve the purpose of leveling [21]. The control process principle of the automatic leveling system is shown in Figure 2.

During the leveling process, the double axis inclination sensor can detect the inclination angles α and β of the load-bearing platform, and the height difference between the reference point and other points can be obtained according to Equation (6). According to the transportation requirements,

FIGURE 3: The electrohydraulic leveling control system.

FIGURE 4: Simulation model of the control system.

the controller will judge whether the height difference between the highest point and other three points in the vertical direction is greater than H . If it is larger than H , the controller will control the hydraulic cylinders by adjusting the electrical signal of each reversing valve, and if it is smaller than H , the program will return to the first step. The hydraulic cylinders in the suspension system of the transport vehicle

are equipped with pressure sensors, which can monitor the pressure of each suspension hydraulic cylinder during the transportation, and the leveling can be achieved automatically according to the signals and the controller. If the pressure of the hydraulic cylinder is less than the limited pressure P' , the controller will adjust the pressure of the hydraulic cylinder and re level, and if it is not, the leveling

FIGURE 5: The simulation results.

process will go down until there is no height difference of the four points in the vertical direction, and the pressure of each hydraulic cylinder is basically the same.

2.3. Leveling Control System Design. The automatic leveling control system is an electrohydraulic control system based on multisensor fusion. The sensors are used to collect the tilt angle of the platform and pressure signals of the hydraulic cylinders and transmit them to the controller in real time. According to the leveling control principle, the electrohydraulic leveling control system is designed as shown in Figure 3.

The pressure sensors are installed in the hydraulic suspension system, which can monitor the pressures of the hydraulic cylinders and detect whether there is a nonstressed suspension hydraulic cylinder. The double axis inclination sensor is installed at the geometric center of the vehicle platform. The controller is responsible for receiving cab control commands, collecting and calculating sensor signals, and outputting the control signals.

3. Simulation of the Vehicle Leveling

3.1. Model Building. According to the suspension hydraulic system, the AMESim model is established, and the fuzzy PID control strategy is added into the leveling control system [22]. Finally, the MATLAB control system model is obtained as shown in Figure 4. In order to simplify the system model, the fuzzy PID control module is encapsulated into the model, and the control system in the model is the control program.

3.2. Simulation and Result Analysis. The situations that need to level the load-bearing platform of the transport vehicle mainly include the uneven road, sudden turning, and braking. In these situations, the center of gravity of the transport goods may shift, the suspension bearing force may be uneven, and the tilt of the load-bearing platform may cause the vehicle to overturn. Therefore, in the process of simula-

FIGURE 6: The experiment of leveling.

tion, the vehicle load-bearing platform levelness and pressure of each suspension cylinder are the key parameters [23]. In the simulation, the load of the supporting platform is set to 100 t, and the load is gradually loaded from 0 to 100 t, and then the load-bearing platform is lifted by 150 mm.

The simulation results are shown in Figure 5. In the process of load increasing, the heights of the four support points are basically the same, and the pressures of the four hydraulic cylinders are basically the same. It can be seen that the maximum inclination angle of the four-point support platform is about 0.15 degrees, and the leveling time is about 0.1 second.

4. Vehicle Leveling Experiment

In order to verify the correctness of the simulation and further prove the practicability and reliability of the leveling control strategy, the experiment was carried out on the 100 ton hydraulic transport vehicle. The prefabricated cement blocks are used as the load of the load-bearing platform, and the experiment of the scene is shown in Figure 6. In order to ensure the safety of transportation, the load-bearing platform of the vehicle must be in a horizontal plane during the transportation, and the pressure of each suspension hydraulic cylinder must be basically the same.

Because the transport vehicle is on the horizontal ground in the experiment, the leveling standard in the experiment is

FIGURE 7: The experiment results.

that the height and pressure of the suspension hydraulic cylinder are the same. In order to measure the tilt angle of the vehicle platform in the x -axis and y -axis directions in the horizontal plane, the double axis inclination sensor is installed in the center of the vehicle load-bearing platform. The pressures of the suspension hydraulic cylinders are collected by the pressure sensors. The controller can calculate the sensor values and control the suspension hydraulic cylinders of the transport vehicle to make the load-bearing platform in a horizontal state. The transport vehicle will be lifted from the no-load state. When the platform is risen to a certain height, it will be loaded. After the load gradually reached the full load, the transport vehicle load-bearing platform will lift to the highest. The height and pressure values of the four supporting points of the vehicle load-bearing platform during the lifting process are obtained as shown in Figure 7.

It can be seen from the experiment curves that the heights of the four points are basically the same and within the allowable range. The difference between the pressure values of the suspension hydraulic cylinders and the simulation curves is the fluctuation of pressure values. The main reason for this phenomenon is that the center of gravity of the load will slightly shift in the lifting process of the hydraulic suspension of the transport vehicle. The leveling control system can control the inclination angle of the platform within 0.25 degrees, and the leveling time is less than 1 second, which fully meets the engineering requirements.

5. Conclusion

According to the working condition of the transport vehicle, through the theoretical analysis of the four-point support leveling of the load-bearing platform, the multisensor fusion control strategy of the four-point support leveling of the vehicle platform is obtained. By analyzing the leveling control strategy and the requirements of the vehicle for the leveling control, the electrohydraulic leveling control system is designed. And the leveling precision is verified by simulation.

Finally, the leveling experiment is carried out, which shows that the leveling control system based on multisensor fusion is stable and easy to achieve. The leveling time is less than 1 second and the inclination angle of the platform can be controlled within 0.25 degrees, which show that the leveling control system can control the inclination angle of the load-bearing platform within the permitted range. The leveling control system can ensure the safety of transportation and provide reference for the design of similar systems.

6. Future Recommendations

The future research direction is to study the leveling of the load-bearing platform during the combined transportation of multiple vehicles. The multiple vehicles of combined transportation constitute complex electrohydraulic system groups. The coordinated control of the multiple suspension hydraulic cylinders can realize the leveling of the load-bearing platform, and it will realize the safety and stability of the multiple vehicles combined transportation.

Data Availability

The data used to support this study are available from the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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