OPTIMIZATION DESIGN AND EXPERIMENT OF AUTOMATIC LEVELING SYSTEM FOR ORCHARD OPERATING PLATFORM IN HILLY AND MOUNTAINOUS AREAS
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丘陵山区果园作业平台自动调平系统的优化设计与试验

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ABSTRACT
A multifunctional leveling platform for orchard in hilly and mountainous areas is developed. The platform design optimizes the double circuit hydraulic system and the horizontal and vertical bidirectional leveling structure to realize synchronous adjustment. Based on the attitude sensor, an intelligent detection and control system is developed to realize the automatic leveling and platform stabilization. The test results show that the platform can reach the maximum climbing capacity of 30° and the limit leveling angle of 15°, which can meet the requirements of orchard operation in large slope and complex terrain, and provide theoretical basis for the future design of orchard operation platform in hilly and mountainous areas.

摘要
本文研发一种适用于丘陵山区果园的多功能调平作业平台。该平台设计优化了双回路液压系统及横、纵双向调平结构可实现同步调节，并基于姿态传感器，开发了智能检测控制系统实现作业平台自动调平与机身稳定。试验结果表明，该平台最大爬坡能力达到 30°、极限调平角度达到 15°，能满足大坡度复杂地形果园作业的要求，可为今后丘陵山区果园作业平台的设计提供理论依据。

INTRODUCTION
With the continuous expansion of orchard planting area, fruit tree planting has become an important branch of agriculture *(China Smart Agriculture Development Research Report, 2021)*. China's orchards are mainly distributed in hilly and mountainous areas, the terrain in these areas is undulating, not suitable for large-scale mechanical operations, and traditional operation methods such as manual ladder climbing, tree climbing, etc. have great potential safety hazards, and the operation efficiency is low *(Li et al., 2021)*.

The research of foreign orchard machinery started earlier, and the Windegger Picking Platform series produced by N.P. Seymour company in Italy can be turned on all wheels, and the workbench can be lifted in two stages, and the angle can be adjusted, which has a wide range of applicability. The Piattaforma orchard platform produced by Macfrut in Italy has a two-stage scissor lifting mechanism, which can realize cross-slope leveling and longitudinal slope leveling at the same time, with a lifting height of 3.85 m, and has the functions of multiple people working at the same time to complete picking and transportation *(Lu et al., 2023)*. The Bielevatore picking platform jointly designed and produced by D'Amico and the Faculty of Engineering of the University of Bari in Italy is connected to the tractor through a three-point suspension mechanism, and has two telescopic booms, the working platform on each telescopic arm can be controlled independently, and the operating platform is equipped with an air source to complete the pruning operation with pruning tools such as saws and scissors *(Meng et al., 2012)*. However, the environmental and topographic characteristics of foreign countries are not fully applicable to the mechanical operation of orchards in China, and the structural function needs to be further optimized *(Ding et al., 2022)*.

Liu Dawei developed a small orchard lifting platform for citrus orchards in the hilly and mountainous areas of southern China, and leveled by the telescopic hydraulic cylinder through the "secondary leveling" method, but the leveling method was manual leveling, which had low leveling accuracy and low operation efficiency *(Liu et al., 2022).*

Qiu Wei developed a folding arm lifting leveling platform based on the characteristics of hilly and mountainous areas of orchards and orchard operations in southern China, and verified the tipping stability in hilly and mountainous areas through theoretical calculation, simulation analysis, and prototype test analysis, which has certain reference significance in the operation and the design of related machinery *(Qiu et al., 2018)*.

In recent years, domestic research on orchard platforms has made rapid progress, but most of them are still in the stage of theoretical design or prototype trial production, and most of them are miniaturized machinery with small load, which has certain limitations in the scope of application *(Fan et al., 2017)*. The stability of existing products of agricultural machinery manufacturers is not good enough when operating on slopes, and it is not suitable for use in hilly and mountainous orchards *(Duan et al., 2018*; *Chaoran et al., 2019*).

MATERIALS AND METHODS

Overall platform structure and parameters

The overall structure of the operating platform is shown in Figure 1.

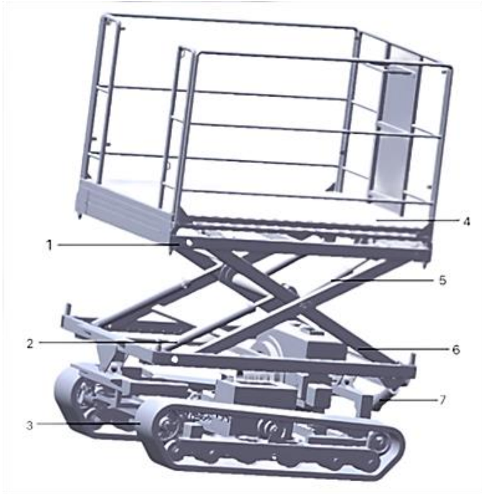


Fig. 1 - 3D model of the overall structure of the operation platform

a) Upper frame; 2 - Lifting mechanism; 3 - Track; 4 - Bearing platform; 5 - Longitudinal adjustment mechanism; 6 - Fork cutting mechanism; 7 - Transverse levelling mechanism

The leveling structure of orchard platform includes longitudinal leveling structure and transverse leveling structure. The platform has four degrees of freedom: lift, pitch, roll and expansion. The leveling structure of the orchard platform is a key component designed to ensure stable operation of the platform on uneven terrain *(Fan et al., 2017)*.

Table 1

Main parameters of operation platform

Item	Technical parameter
Overall dimensions (length × width × height) (cm)	185×130×198
Maximum size of table (length × width) (cm)	175×210
Load rating (kg)	300
Lifting height range (cm)	0-100
Maximum horizontal leveling angle (°)	±15
Maximum longitudinal leveling angle (°)	±15
Maximum gradeability (°)	30
Track grounding length (cm)	130

Longitudinal leveling structure design

Considering the topography characteristics of gentle hilly orchards and combined with Chinese Adult Body Size Standards, it can be seen that the lifting height of the workbench up to 2.2 m can fully meet the requirements of orchard operations *(Fan et al., 2019)*. Therefore, a single-stage scissor-fork lifting mechanism was selected and improved into a folding arm scissor-fork lifting mechanism with more independent and flexible movement on this basis.

The designed structural schematic diagram is shown in Figure 2, where: O is the origin of the lifting structure coordinate system, O_1 is the origin of the longitudinal leveling structure coordinate system, DE is the workbench, PQ is the lifting hydraulic cylinder, MN is the longitudinal leveling hydraulic cylinder; OD and EH are the cutting fork arms, OB, BD, EB and BH is the same length, two points A and C are the connection points between the upper and lower ends of the lifting hydraulic cylinder and the shear fork arm, and AP is perpendicular to EH. CQ is perpendicular to OB; O is the articulation point between the shear fork arm and the frame, E is the articulation point between the shear fork arm and the table, B is the articulation point between the two shear fork arms; h is the lifting height of the table, G is the total weight of the table and the loaded object; α is the Angle between the shear fork arm and the horizontal plane, β is the Angle between MO_1 and O_1B, φ is the Angle of rotation of the pitching arm O_1D around O_1 point, θ is the Angle between the workbench and the horizontal plane, that is, the pitch angle of the platform, F_1 is the thrust of the lifting hydraulic cylinder, F_2 is the thrust of the longitudinal leveling hydraulic cylinder.

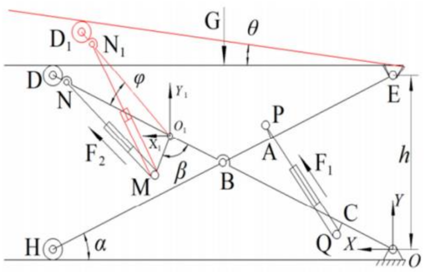


Fig. 2 - Schematic diagram of lifting and longitudinal leveling structure

According to Figure 2, the relationship between hydraulic cylinder thrust, pitch hydraulic cylinder displacement and platform angle is established to determine the thrust required for optimizing hydraulic cylinder and platform size.

In Figure 2, $X_1O_1Y_1$ is used as the coordinate system, and the following relationship is obtained:

$$X_{MN} = L_{Q_1N}\cos(\alpha+\varphi) - L_{Q_1M}\cos(\pi-(\alpha+\beta))$$
$$X_{MN} = L_{Q_1N}\cos(\alpha+\varphi) + L_{Q_1M}\cos(\pi-(\alpha+\beta))$$
$$L_{MN} = \sqrt{X_{MN}{}^2 + Y_{MN}{}^2} \tag{1}$$
$$Y_G = \frac{L_{Q_1D}\sin\alpha + L_{Q,D}\sin(\alpha+\varphi)}{2}$$

X_{MN} and Y_{MN} are the projected lengths of the longitudinally levelled hydraulic cylinder MN on the O_1X, O_1Y axis, and L_{O1D}, L_{O1M} and L_{O1N} are the lengths of the longitudinally levelled structural parts O_1D, O_1M and O_1N respectively.

The virtual displacement of the longitudinal levelling hydraulic cylinder under the action of thrust F_2 is d_{MN}, and the virtual displacement under the action of total load G is d_{YG}, and the derivative of phi is obtained respectively.

$$F_2\frac{dL_{PQ}}{d\alpha} = G\frac{dh}{d\alpha} \tag{2}$$

Bringing the formula into the above equation gets:

$$F_2 = G\frac{L_{O_1D}cos(\alpha+\varphi)\sqrt{L_{O_1M}{}^2+L_{O_1N}{}^2+2L_{Q_1M}\cdot L_{O_1N}cos(\varphi-\beta)}}{2L_{O_1M}\cdot L_{O_1N}sin(\beta-\varphi)} \tag{3}$$

From the equation (3), it can be inferred that the magnitude of the vertical leveling hydraulic cylinder thrust force F_2 is related to the pitch angle and lifting height of the worktable. Due to the limitation of the leveling structure, when the worktable is lowered to the lowest position, it cannot be tilted backward for leveling, otherwise the worktable will collide with the upper frame. Therefore, the hydraulic cylinder thrust required at the lowest workbench position is maximum and can be optimized under this condition.

L_{O1M} and β should be increased, L_{O1D} and L_{O1N} reduced as much as possible, but too much L_{O1M} will cause the mechanism O_1M to interfere with the frame when the workbench is in the lowest position, and too much β will cause the problem of insufficient installation position and small stroke of the longitudinal leveling hydraulic cylinder, which will affect the longitudinal leveling angle of the workbench.

Considering the rationality of structure, installation position of hydraulic cylinder and leveling angle, the structural parameters determined are shown in Table 2.

Table 2

Basic parameters of longitudinal leveling structure

Parameter	Unit	Numeric value
L_{O1N}	mm	410
L_{O1M}	mm	160
L_{O1D}	mm	560
β	°	88

The thrust F_2 of the horizontal hydraulic cylinder is related to the pitch Angle and lifting height of the workbench. In the design process, the values of L_{01M} and β should be increased and the values of L_{o1D} and L_{o1N} should be reduced as far as possible.

In Figure 2, obtaining equilibrium equation in the XOY coordinates:

$$\begin{cases} x_{OD_1} = L_{OQ_1} cos\ \alpha + L_{O_1D_1} cos\,(\alpha+\varphi) \\ y_{OD_1} = L_{OQ_1} sin\ \alpha + L_{O_1D_1} sin\,(\alpha+\varphi) \end{cases} \tag{4}$$

Since $tan\ \theta = \frac{y_{OD_1}-h}{x_{OD_1}}$, we get:

$$\begin{aligned} \theta &= \arctan \frac{(L_{OO_1}-L_{EH})\sin\ \alpha + L_{OD_1}\sin\,(\alpha+\varphi)}{L_{OO_1}\cos\ \alpha + L_{O_1D_1}\cos\,(\alpha+\varphi)} \\ \varphi &= \arccos \frac{{L_{QM}}^2 + {L_{ON}}^2 - (L_{MN}-y)^2}{2L_{O_1M}\cdot L_{O_1N}} \end{aligned} \tag{5}$$

where: y is the displacement of the piston rod of the longitudinally leveled hydraulic cylinder, and L_{MN} is the length of the pitching hydraulic cylinder MN.

It can be seen from the formula that the leveling angle of the knuckle arm scissor longitudinal leveling structure is related to the displacement of the piston rod and the installation position of the hydraulic cylinders for lifting and longitudinal leveling (*Li et al., 2022*). According to the determined dimension parameters of the longitudinal leveling structure, the longitudinal leveling hydraulic cylinder stroke of 1500 mm can meet the requirements of the installation position and the leveling Angle, and the longitudinal leveling Angle of the workbench is increased to 15°. The specific dimensions are shown in Table 2.

Horizontal leveling structure design

The horizontal leveling structure is responsible for adjusting the left and right tilt Angle of the orchard platform. The schematic diagram of the designed structure is shown in Figure 3.

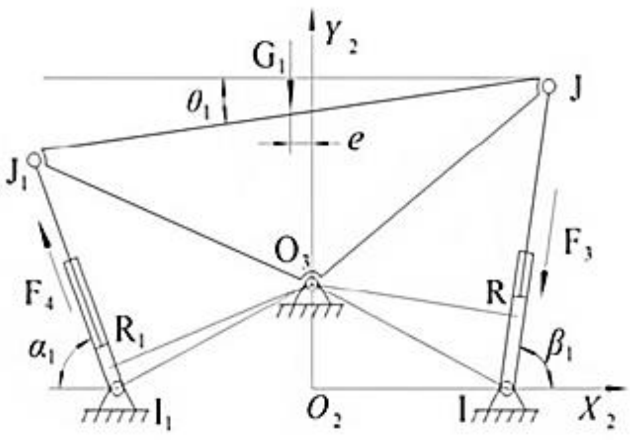


Fig. 3 - Horizontal leveling structure diagram

The hydraulic cylinder I_1J_1 the opposite movement of the *IJ*, the frame rotates around the O_3 point, and the worktable tilts at a certain angle θ_1 to achieve the purpose of roll leveling.

$$\begin{cases} \angle IO_3R = \beta_1 - \angle IO_3O_2 \\ L_{O_3R} = L_{IO_3}\cos\angle IO_3R \\ \angle I_1O_3R_1 = \alpha_1 - \angle I_1O_3O_2 \\ L_{O_3R_1} = L_{I_1O_3}\cos\angle I_1O_3R_1 \\ F_3 \cdot L_{O_3R} + F_4 \cdot L_{O_3R_1} = G_1 e \end{cases} \tag{6}$$

where: F_3 and F_4 are the thrust of the roll hydraulic cylinder.

According to the selected cylinder, $1.45F_3 = F_4$ is obtained, therefore:

$$F_4 = G_1 \frac{0.6e}{L_{IO_3}\cos(\beta_1 - \angle IO_3O_2) + L_{I_1O_3}\cos(\alpha_1 - \angle I_1O_3O_2)} \tag{7}$$

It can be seen from the formula that: the increase of the hydraulic cylinder will lead to the increase of the hydraulic cylinder thrust. In the design of the workbench components, the center of gravity is reduced to reduce the required thrust of the hydraulic cylinder, and the roll stability of the platform can also be increased.

Increasing L_{IO3} and L_{I1O3} will reduce the thrust required by the hydraulic cylinder, but too much L_{IO3} and L_{I1O3} will lead to insufficient stroke of the hydraulic cylinder, which cannot meet the leveling requirements of the design. It is necessary to select an appropriate value for the structural parameters, which can not only reduce the thrust required by the hydraulic cylinder, but also make the structure more reasonable and meet the design requirements.

The specific dimensions are shown in Table 3.

$$\begin{cases} X_{JJ_1} = L_{l_1J_1}\cos\alpha_1 + L_{I_1I} + L_{LJ}\cos\beta_1 \\ Y_{J_1} = L_{LJ}\cos\beta_1 - L_{I_1J_1}\cos\alpha_1 \end{cases} \tag{8}$$

Horizontal adjustable table angle:

$$\begin{cases} X_{JJ_1} = L_{l_1J_1}\cos\alpha_1 + L_{I_1I} + L_{LJ}\cos\beta_1 \\ Y_{J_1} = L_{LJ}\cos\beta_1 - L_{I_1J_1}\cos\alpha_1 \end{cases} \tag{9}$$

$$\theta_1 = \arctan\frac{L_{LJ}\sin\beta_1 - L_{I_1J_1}\sin\alpha_1}{L_{I_1J_1}\cos\alpha_1 + L_{l_1l} + L_{LJ}\cos\beta_1} \tag{10}$$

The installation position, installation size and stroke of hydraulic cylinder are directly related to the transverse adjustable angle. The installation position and installation size are affected by the frame structure. Considering the design requirements of the horizontal leveling angle, the hydraulic cylinder with the stroke amount is selected, and the appropriate size is selected for other structures according to the design requirements and structural characteristics. The specific size is shown in Table 3.

Table 3

Basic parameters of horizontal leveling structure

Argument	Unit	Numerical value
α_1	°	$28 \sim 70.5$
L_{IO_3}	mm	264
L_{IJ}	mm	$320 \sim 390$
L_{I_1I}	mm	373

ANSYS finite element analysis of leveling structures

According to the actual force and constraints of the frame, the frame is constrained and loaded 3000 N, as shown in Figure 4. Because the horizontal leveling hydraulic rod is not the main force component, only the finite element analysis of the shear fork lifting structure and the longitudinal leveling hydraulic rod is needed.

The designed platform material uses Q235, and its mechanical properties parameters are shown in Table 4.

Table 4

Q235 material mechanical performance parameters

Type of material	Modulus of elasticity (GPa)	Density (kg/m3)	Yield strength (MPa)	Tensile strength (MPa)	Poisson's ratio
Q235	210	7800	235	400	0.28

The distribution of stress and deformation, the maximum stress and deformation position can be obtained by simulation, and whether the structure meets the strength requirements can be obtained by referring to the parameter table.

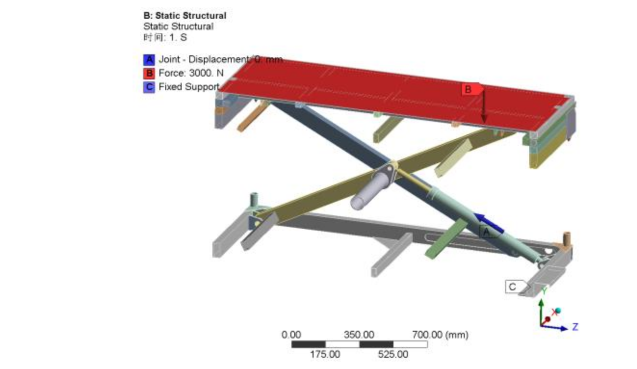


Fig. 4 - Load, constraint add diagram

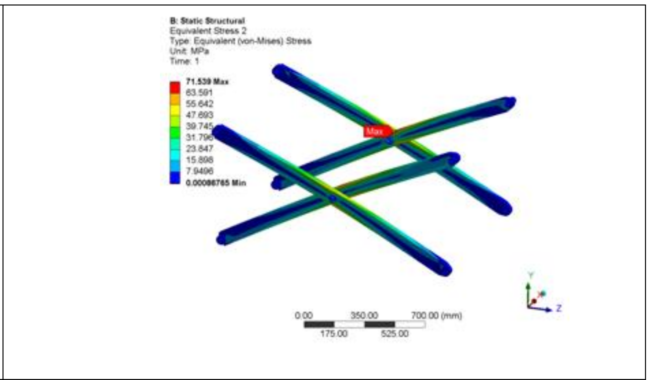


Fig. 5 - Shear fork structure stress distribution diagram

According to the stress distribution of the diagonal support and support rod of the scissor structure. The maximum stress on the system is calculated to be 71.539 MPa, as shown in Figures 5 and 6, observed in Part B. The load acting on the cylinder causes a lower stress on the lower scissor section A.

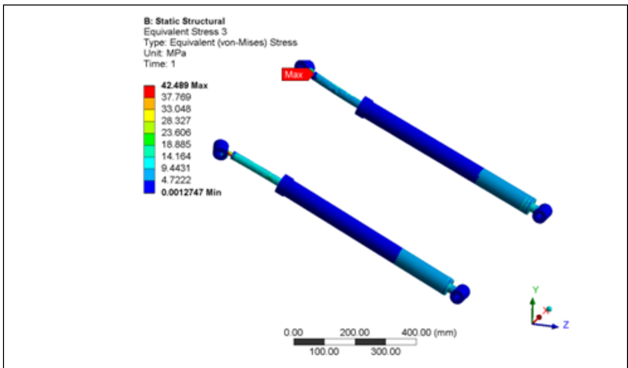


Fig. 6 - Support rod stress distribution diagram

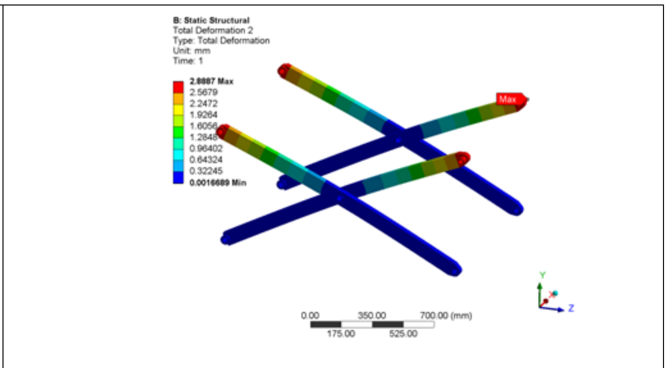


Fig. 7 - Shear fork structure deformation distribution diagram

Figure 7 shows the deformation of the upper table and the upper splicing head under load. The calculated deformation is 0.1173 mm under no-load condition. When the maximum load is applied to the platform, the deformation is 0.694 mm, which is a six-fold increase in deformation. The analysis results show that when the scissors profile is made of Q235 material, the lowest safety factor observed at the joint of the scissors is 4.3, and the safety factor of the pin made of Q235 material is 6.5, both of which are greater than 3. Therefore, the safety factor is within the acceptable range of the system to be designed.

Design of double circuit hydraulic system

The basic configuration circuit is shown in Figure 8. The relief valve, check valve, hydraulic lock and other basic hydraulic circuits are configured. With the introduction of the automatic leveling system, the configuration of the hydraulic circuit has been partially changed.

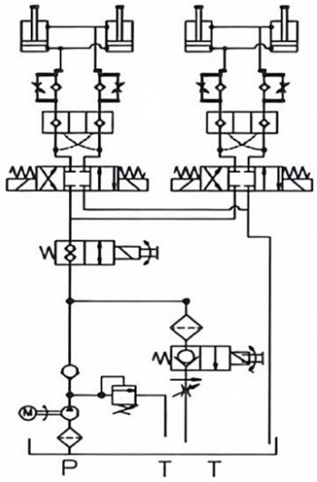
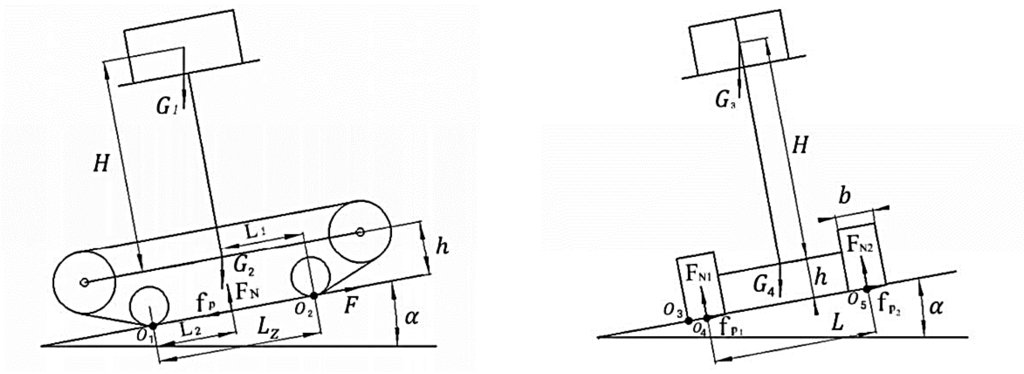


Fig. 8 - Hydraulic system basic schematic diagram

Mechanical analysis of tipping factors

The orchard platform on the slope is divided into three kinds of posture: longitudinal, oblique and transverse. In order to determine the factors affecting the tipping angle, the slope mechanics of the platform was analyzed. Figure 9 shows the stress diagram of the orchard operating platform under longitudinal and transverse attitude.

Where: G_1 - total platform weight; G_2 - total load weight; H - linear distance between platform center of mass and load center of mass; h - height of platform center of mass; L_1, L_2 - respectively, the distance from the center of the front and rear support wheels to the center of the platform along the slope; L_Z - track grounding length; F - driving force; α - slope angle; f_p - the frictional resistance of the slope against the platform; b - track width; L - two track distance; O_1, O_2, O_3, O_4, O_5 - they are respectively the rear support wheel, front support wheel, left track edge, left track, right track and slope contact points.



(a) The platform is longitudinal to the slope (b) The platform is transverse to the slope

Fig. 9 - Force diagram under two slope attitudes

When the platform is longitudinal on the slope, the force analysis shows that with the increase of slope Angle, the platform will tip over along the O_1 point, and the torque equilibrium equation $\sum M_{O_1} = 0$ can be obtained:

$$G_1 \cos\alpha\,(L_1 - L_2) - G_1 \sin\alpha\,(\mathrm{H} + \mathrm{h}) + G_2 \cos\alpha\,(L_1 - L_2) - G_z \sin\alpha\,\mathrm{h} - F_N L_2 = 0 \tag{11}$$

When the slope Angle α gradually increases, the supporting force F_N of the slope towards the track gradually moves to O_2 point. When F_N fully acts on the support wheel of the track, that is, $L_2 = 0$, the critical tipping state occurs. Therefore, the condition that the platform does not roll over vertically is $L_2 \geq 0$. Therefore:

$$\alpha \leq arctan\frac{(G_1+G_2)(L_Z-L_1)}{G_1(H+h)+G_2 h} \tag{12}$$

As can be seen from the above formula, the platform tipping Angle is related to the total weight of the machine, the height of the load center of mass and the load position.

When the platform is transversally on the slope, with the increase of the slope Angle, the platform turns transversally along the O_1 point, and the moment equilibrium equation $\sum M_{O_3} = 0$ can be obtained:

$$G_2 \cos\alpha\left(\frac{L+b}{2}\right) - G_2 \sin\alpha\, b + G_1 \cos\alpha\left(\frac{L+b}{2}\right) - G_3 \sin\alpha\,(H + h) - P_{N_1}\frac{b}{2} - F_{N_2}\left(\frac{b}{2} + L\right) = 0 \tag{13}$$

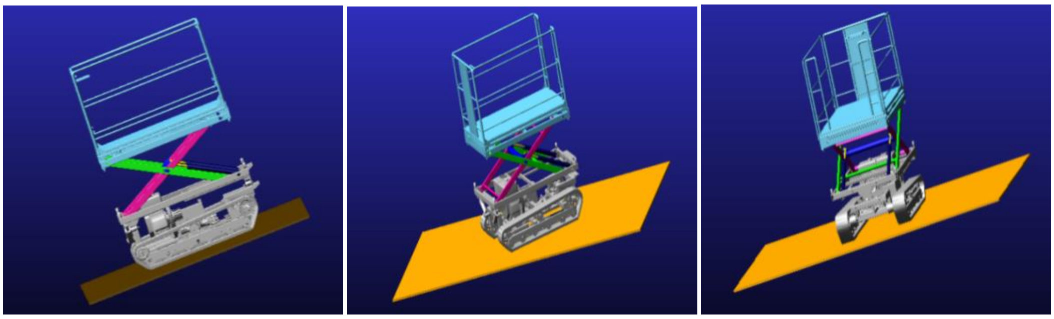
When the platform is in a critical tipping state, both F_{N1} and F_{N2} are 0, so the conditions for not tipping are $F_{N_1} \geq 0$ and $F_{N2} \geq 0$. Therefore:

$$\alpha \leq \arctan\frac{(G_1+G_2)\left(\frac{\mathrm{L+b}}{2}\right)}{G_1(\mathrm{H+h})+G_2\mathrm{h}} \tag{14}$$

It is concluded that the lateral slope of the platform is related to the total weight of the load, the height of the centroid of the load and the position of the load. When the table is inclined to the slope, the tipping slope is between the longitudinal tipping slope and the transverse tipping slope under the condition that the load, load height and load position are unchanged.

Dynamic simulation optimization analysis

According to the above force analysis, it can be seen that the tipping slope of the orchard platform should be tested by comprehensively considering the different posture of the platform on different slopes (the Angle between the track and the ground in the direction of the platform is divided into three cases: 0°, 45° and 90°) load size, load height and load position. Therefore, the tilting test bench is set up in ADAMS, as shown in Figure 10.



(a) (b) (c)

Fig. 10 - Simulation process diagram of orchard platform

(a) 0°; (b) 45°; (c) 90°

The test bench *(Chinese research criteria, 2011)* rotates at a certain angular speed and performs simulation under different loads of 1200, 1420, 1640, 1860, 2080 and 2300 mm at different stroke elevations and 0, 50, 100, 150, 200, 250 and 300 kg at three different poses. When the supporting force of the track is 0, the inclination Angle of the test stand is recorded as the tipping slope. As the test bench is turned over, the longitudinal or transverse structure begins to level until the limit position is reached, as shown in Figure 11.

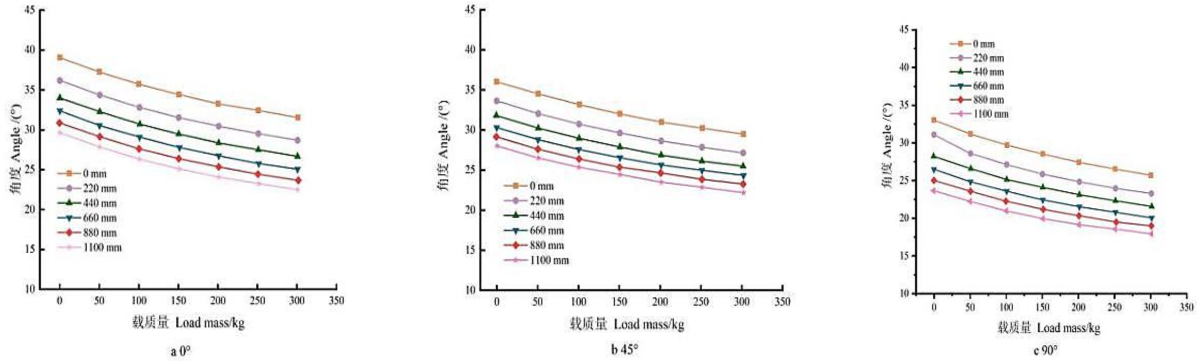


Fig. 11 - Simulation results of orchard platform tipping

(a) 0°; (b) 45°; (c) 90°

It can be seen from the simulation results that, when the lifting height and load are constant, the ultimate tipping slope of the platform in the vertical, oblique and transverse posture gradually decreases. In addition, under the three attitudes, the lifting height and load increase, and the extreme limit tipping slope of the platform will decrease. Shear-fork structure levelling raises the work platform, allowing the center of gravity of the platform to move along the slope, which is beneficial for improving the vertical anti-overturning ability of the platform. Because both oblique and lateral attitude leveling require the involvement of the roll leveling mechanism, which improves the anti-roll ability of the platform.

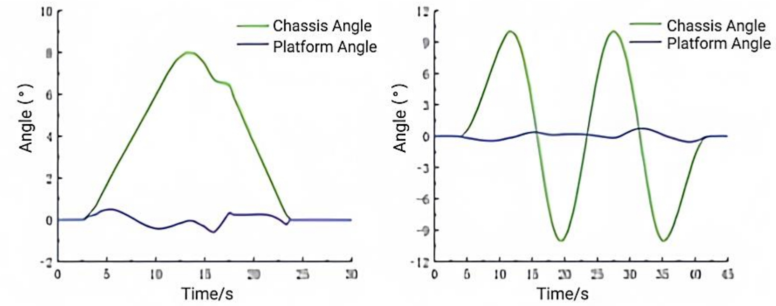
Overall, the maximum ultimate tipping slope was reduced by 1.3%, and the minimum ultimate tipping slope was increased by 15.1%, which significantly improved the safety of the platform.

Dynamic walking simulation analysis

In order to verify that the platform can be levelled according to the levelling design requirements when it passes the uneven road surface *(Liu et al.,2009)*, different obstacle roads can be set up in ADAMS to simulate and analyze the dynamic levelling performance of the workbench. After analyzing the basic characteristics of orchard pavement, it can be simplified into two kinds of obstacle pavement: single wave and continuous wave.

The slow running speed of agricultural machinery during operation is generally lower than 2 km/h, and the minimum speed can reach 0.2 km/h. Due to the large amount of orchard work and the slow running speed of the platform, the simulation speed is set to 0.72 km/h and the STEP function is used to control the platform.

Track chassis inclination and table inclination are measured. Track chassis inclination reflects the influence of road surface changes on the platform, and table inclination reflects the degree of leveling to offset the influence of road surface. By comparing the two, it is possible to obtain the leveling performance of the platform when passing different obstacles. Fig.12 shows the simulation results.



(b) (b)

Fig. 12 - Simulation results of dynamic leveling

a) Single waveform; (b) Continuous waveform

It can be seen from the figure that under a single waveform obstacle, the chassis Angle changes with the change of the obstacle, the maximum roll is 8°, and the workbench Angle fluctuates to a certain extent, but it is always maintained within the range of 0.75°. Since the two sides of the track are rigidly connected together, when passing a single waveform obstacle, there will be a corner hanging, and there will be fluctuations at 16s.

However, when encountering fluctuations, the angle of the platform is still maintained near 0°, showing better leveling performance. Under continuous waveform fault, the Angle of the chassis fluctuates with the change of the waveform, the change range is ±10°, the Angle of the platform is floating in the range of 0.73°, and the longitudinal leveling performance is good. It can be seen that the terrain change has a great impact on the orchard platform, but the leveling can effectively reduce this impact, so that the workbench is stable and maintained near 0°, which can meet the requirements of orchard operation in hilly and mountainous areas.

RESULTS

Platform field test

The prototype of orchard multifunctional automatic leveling operation platform is shown in Figure 13.

Fig. 13 - Working platform prototype

Build a leveling test site, design different gradients, and test the dynamic leveling performance of the operating platform during the ramp driving. The operating platform is uphill at a speed of 1km/h, and the Angle value of the platform is recorded in real time by the inclination sensor. Each slope Angle was tested four times respectively, and the recorded data were shown in Table 5.

Table 5

Dynamic leveling performance test

Slope Angle / (°)		Platform no-load		Platform full load	
Longitudinal Angle / (°)	Transverse Angle / (°)	Leveling time / s	Leveling error/s	Leveling time / s	Leveling error / s
0	0	0	0	0	0
	5	1.04	0.64	1.16	0.58
	10	1.18	0.78	1.25	0.95
	15	1.30	0.82	1.33	1.05
7	0	1.36	0.47	1.28	0.62
	5	2.02	0.60	2.20	0.97
	10	2.20	0.63	2.35	1.06
	15	2.42	0.80	2.58	1.12
14	0	1.63	0.62	1.79	0.73
	5	2.49	0.74	2.70	1.09
	10	2.60	0.80	2.78	1.20
	15	2.77	0.85	2.99	1.30
21	0	1.20	0.64	3.00	0.85
	5	2.83	0.79	3.35	1.20
	10	3.05	0.86	3.44	1.28
	15	3.33	0.89	3.60	1.34
30	0	2.57	0.62	3.12	0.93
	5	3.45	0.80	3.94	1.32
	10	3.78	0.82	4.30	1.40
	15	3.90	0.93	4.33	1.43

The test results of leveling performance are shown in Table 5. When the platform is fully loaded, the average value of the platform leveling error is within 0°~1.5°, and the dynamic leveling time has a certain relationship with the ramp and load mass. When the transverse Angle is within 15°and the longitudinal Angle is within 30°, the leveling time is less than 4.5 s. It can realize the horizontal state of the operating platform during the ramp driving and maintain the stability of goods transportation.

CONCLUSIONS

(1) In this paper, the scheme of horizontal and vertical leveling of orchard operation platform is designed. The longitudinal leveling structure is improved on the basis of the shear fork lifting structure, which will not add too much structure. The simulation analysis is carried out, and according to the simulation results, the structure is further optimized to improve its safety strength.

(2) The static analysis of the platform was carried out, and the dynamic simulation optimization was carried out in ADAMS. The tilting test platform was established, and the leveling accuracy and walking stability of the platform under different attitude, slope and load were analyzed and verified.

(3) The dynamic leveling performance of the platform prototype is tested to check the horizontal state and transportation stability of the platform on the ramp.

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