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Design and Analysis of Hand-guided Semi-mechanized Manure Collection Vehicle for Yaks

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ABSTRACT

Yak dung has both fuel and ecological value in the plateau areas of China. However, the existing collection methods have problems such as being easily crushed or consuming a large amount of manpower. To this end, this paper designs a semi-mechanized hand-guided yak manure picking vehicle, with a focus on optimizing the picking mechanism. By constructing design variables and constraints, using Matlab to calculate key parameters, and conducting motion analysis based on SolidWorks, the picking efficiency is improved and the labor intensity is reduced.

KEYWORDS

Yak Dung Picking up; Four-bar Linkage Mechanism; Parameter Optimization; Motion Analysis.

1. INTRODUCTION

In plateau pastoral areas, cow dung is an important raw material for domestic fuel and electrode materials, and its collection is also conducive to maintaining the grassland ecology [1,2]. The existing spiral collection is prone to damaging the structure of feces [3,4,5], while the picking and throwing mechanism still relies on human labor, which consumes a lot of physical energy and is harmful to cardiac function in an oxygen-deficient environment. Therefore, this paper proposes a hand-guided semi-mechanized yak manure picking vehicle, which combines the advantages of human and mechanical labor to achieve rapid manure picking and transportation.

2. OVERALL DESIGN OF THE MAIN FACILITIES

2.1. Working Principle

The semi-mechanized hand-guided yak manure pickup vehicle mainly consists of four parts: picking up, transporting, driving and collecting. Its overall three-dimensional model is shown in Figure 1.

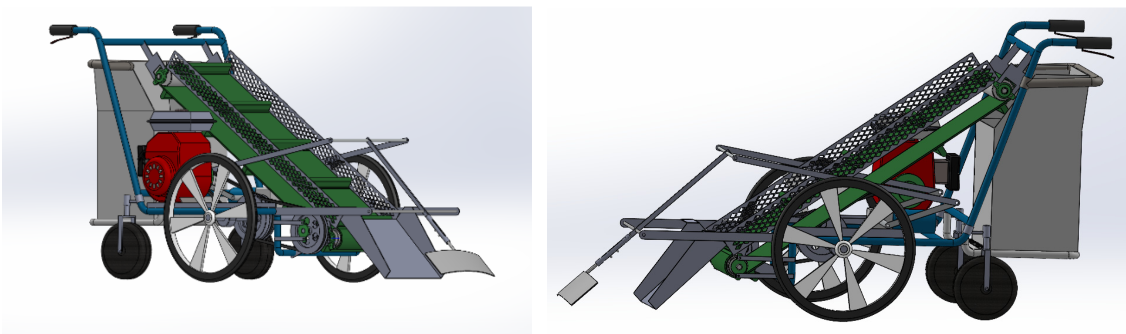

Figure 1. 3D model of the pick-up vehicle

The operator controls the vehicle's forward movement, steering and the movement of the picking mechanism through hand-held operation to achieve precise operation. The movement mode of the picking mechanism and the transmission device is intermittent movement. The power source of the transmission device is provided by a gasoline engine, and the power source of the picking mechanism is provided by a reduction motor. The collection method of the pickup truck is bagged. It is fixed when in use and the bags can be removed during transportation.

2.2. Transmission Mode Design

Compared with chain and gear transmission, belt drive operates smoothly with low noise, can buffer and absorb vibration, has a simple structure and low cost. Meanwhile, V-belt transmission has greater friction, stronger transmission capacity, a more compact structure, a larger allowable transmission ratio and higher transmission efficiency than flat belt transmission [6]. Therefore, the prime mover, traveling device and transmission device of the pickup vehicle are selected as V-belt drive. After the cow dung is picked up, it needs to be conveyed from the collection shovel to the collection container through a transmission system. Considering the convenience, safety and economy of transmission, a T-shaped conveyor belt is used for transmission.

2.3. Vehicle Body Design

The structure and material of the vehicle body will directly affect the weight of the entire picking vehicle. The structure of the vehicle body mainly considers the prime mover, picking mechanism, transmission device, traveling device and the placement of collection bags. The vehicle body material is selected as 30x30*mm* Angle steel and 25mm outer diameter and 2*mm* thick steel pipe. The vehicle body is connected by bolt connection and welding.

3. DESIGN OF PICKING MECHANISM

The picking mechanism is driven by connecting rods. When in use, it scrapes cow dung onto the collection shovel and then returns to its initial state. The simplified diagram of its motion structure is shown in Figure 2. The picking rod should be capable of effectively descending from the initial position to the lowest point during its movement to reliably pick up the feces on the ground. At the same time, during the lifting process, the stability of the feces should be maintained to ensure that they can smoothly move from the ground to the collection shovel and be transported to the conveyor belt by inertia, avoiding detachment during the transfer process.

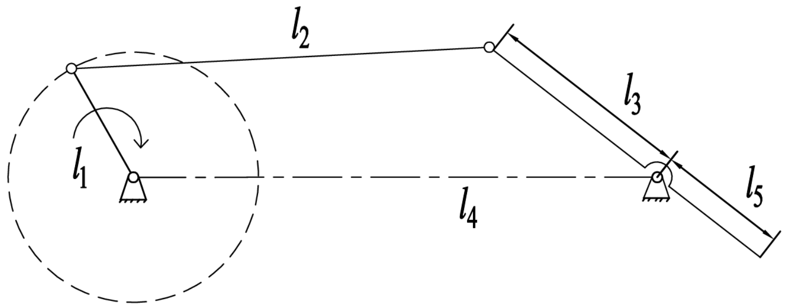

Figure 2. Simple diagram of the movement of the picking mechanism

3.1. Material Selection for Picking Institutions

The picking mechanism in this study is mainly composed of a crank mechanism and a reduction motor, etc. The crank mechanism is made up of connecting rod components such as the picking rod, connecting rod and prime mover rod. As a key component that directly contacts the material and performs the picking action, the picking rod is prone to wear at its end. Meanwhile, under reciprocating motion, it needs to have sufficient fatigue resistance to prevent fracture. Therefore, 45 steel is selected as the material. The connecting rod and the prime mover mainly serve the functions of power transmission and motion conversion. The core requirements are to ensure the rigidity necessary for the motion accuracy of the mechanism and to reduce the overall weight to lower the motor load and motion inertia. Here, Q235 common carbon structural steel is selected.

3.2. Picking Range

Through the preliminary measurement of 20 random samples of yak feces in the yak activity area of Jinzhu Town, Daocheng County, Sichuan Province, it was measured that the longest yak feces were 27.8cm, the widest 19cm, the highest 10.2cm, and the heaviest 834.5g. To ensure smooth and efficient collection and transportation of cow dung, the collection range of the collection vehicle is up to 30cm in length, 20cm in width, 12cm in height and 1kg in weight. The horizontal displacement *L* at the end of the collection rod is initially set at 40cm, and the distance *H* from the initial position to the ground is set at 15cm, as shown in Figure 3.

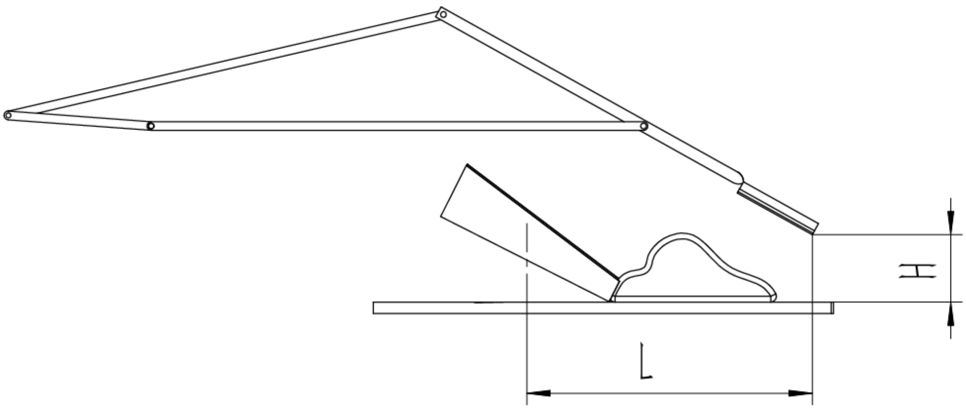

Figure 3. Schematicdiagram of cow dung collection

3.3. Optimization Design of Key Parameters

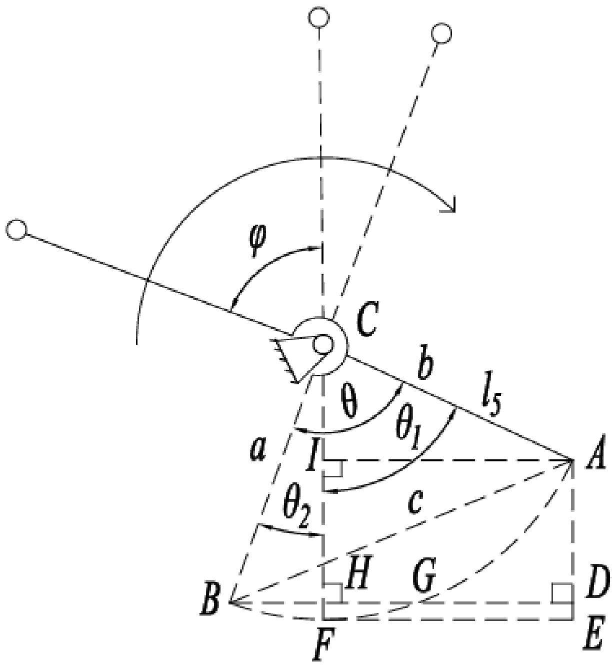

Figure 4. shows the range of motion of the picking rod

Based on the determined picking range and motion requirements mentioned above, let the length of the prime mover rod be l_1, the length of the connecting rod be l_2, and the length of the frame be l_4. The length of the picking rod is divided into two parts, l_3 and l_5 respectively, and their positional relationship is shown in Figure 2. Considering that the horizontal displacement from the end of the picking rod to the collection shovel is greater than the maximum length of the cow dung by 30cm, the initial length of l_5 is taken as 35cm. The movement trajectory of the end point of the picking rod is shown in Figure 4. The distance l_{CH} between hinge C and the ground is 30cm between the frame and the ground. Here, the straight line formed by the end of the picking rod passing through points G and B is regarded as the horizontal ground. Therefore, the vertical displacement l_{AD} of the picking rod is the height H=15cm from the initial position of the picking rod end to the ground.

Based on the above known conditions, the Angle θ that the picking rod needs to rotate when picking up cow dung can be calculated.

$$l_{AB} = \sqrt{l_{BD}^2 + l_{AD}^2} \, . \tag{1}$$

$$\cos\theta = \frac{l_{AC}^2 + l_{BC}^2 - l_{AB}^2}{2 l_{AC} l_{BC}} \, . \tag{2}$$

$$\theta = \arccos\left(\frac{l_{AC}^2 + l_{BC}^2 - l_{AB}^2}{2 l_{AC} l_{BC}}\right) . \tag{3}$$

In the formula:

l_{AC} - The length of the picking rod l_5, in cm;

l_{BC} - The length of the picking rod l_5, cm;

l_{BD} - Horizontal displacement of the picking mechanism, cm;

l_{AD} - Vertical picking range of the picking mechanism, cm.

Substitute the above values into Equations 1, 2 and 3 to obtain the rotation Angle θ of the picking rod ≈75.22°. For the convenience of subsequent design calculations, θ is taken as 76 ° here.

In conclusion, it is easy to obtain that the horizontal displacement l_{AI} from the end point A to point F of the picking rod is 31.62cm, which is greater than the longest size of the range for picking up cow dung by 30cm. Therefore, the initially set horizontal displacement L at the end of the picking rod =40cm, the distance H from the initial position of the picking rod to the ground =15cm, and the length of the picking rod l_5 is 35cm, which meet the research requirements. Since the hinge C is 30cm above the ground and the picking rod l_5 is 35cm, the picking rod l_5 adopts a telescopic structure in its design.

Now, the length dimensions of rod 1, rod 2, rod 3 and rod 4 are being optimized and designed. The transmission Angle γmin of the crank mechanism appears at one of the two positions where the driving crank AB is on the same line as the frame. In this study, the smaller transmission Angle is denoted as the minimum transmission Angle $\gamma_{\min}$, and the larger transmission Angle is denoted as the maximum transmission Angle $\gamma_{\max}$. To ensure the good force transmission performance of the picking mechanism, the transmission Angle in this study is $35° \le \gamma \le 145°$, that is, $\gamma_{\min} \ge 35°$ and $\gamma_{\max} \le 145°$.

Based on the aforementioned analysis of the four-link crank-rocker mechanism, the picking mechanism is now optimized in design.

3.3.1. Determine the Design Variables

The picking mechanism adopts a four-link crank-rocker mechanism. Considering the geometric dimensions of the frame, the lengths of the crank rod l_1 and the frame rod l_4 can be initially determined. Therefore, only l_2 and l_3 are independent variables, and the design variables are

$$\chi = (x_1 \quad x_2)^T = (l_2 \quad l_3)^T. \tag{4}$$

3.3.2. Establish the Objective Function

Based on the aforementioned analysis, the design requires that the swing Angle φ be ≥76°. Meanwhile, considering that the transmission Angle γ reflects the force transmission efficiency and motion stability of the mechanism, its ideal range is 35°≤γ≤145°. To ensure that the transmission Angle of the mechanism is as close to 90° as possible during movement (optimal force transmission), minimizing the deviation of the transmission Angle from 90° is introduced as the second objective. Therefore, the multi-objective optimization function is constructed as follows

$$\min_{l_2, l_3} F = W_1 \frac{1}{\varphi} + W_2(\gamma_{\min} - 90°)^2 + W_3(\gamma_{\max} - 90°)^2. \tag{5}$$

In the formula

W_1, W_2, W_3 - weight coefficients, determined based on the importance of the objective in the objective function, where $W_1+W_2+W_3=1$.

As the crank moves, the joystick will reach two limit positions, as shown in Figure 5.

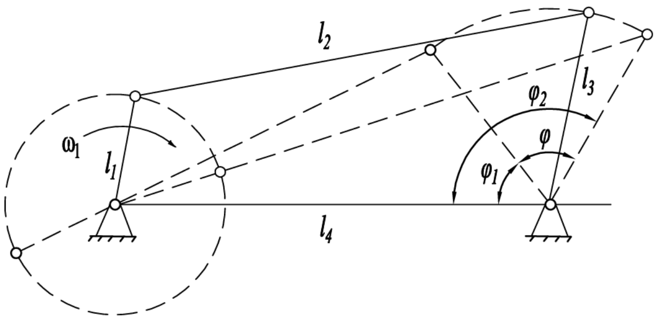

Figure 5. Limit position of crank-rocker mechanism

In Figure 5, the relationship expression between the swing Angle and the length of each rod can be obtained based on the geometric relationship, that is

$$\left.\begin{aligned} \varphi &= |\varphi_2 - \varphi_1| \\ \varphi_2 &= \arccos\frac{l_4^2 + l_3^2 - (l_1 + l_2)^2}{2l_4 l_3} \\ \varphi_1 &= \arccos\frac{l_4^2 + l_3^2 - (l_2 - l_1)^2}{2l_4 l_3} \end{aligned}\right\}. \tag{6}$$

When the picking mechanism is at the two positions as shown in Figure 6, the expression of the transmission Angle can be obtained according to the cosine theorem, that is

$$\left.\begin{aligned} \gamma_1 &= \arccos\frac{l_2^2 + l_3^2 - (l_4 - l_1)^2}{2l_2 l_3} \\ \gamma_2 &= \arccos\frac{l_2^2 + l_3^2 - (l_4 + l_1)^2}{2l_2 l_3} \\ \gamma_{\min} &= \min(\gamma_1, \ \gamma_2) \\ \gamma_{\max} &= \max(\gamma_1, \ \gamma_2) \end{aligned}\right\}. \tag{7}$$

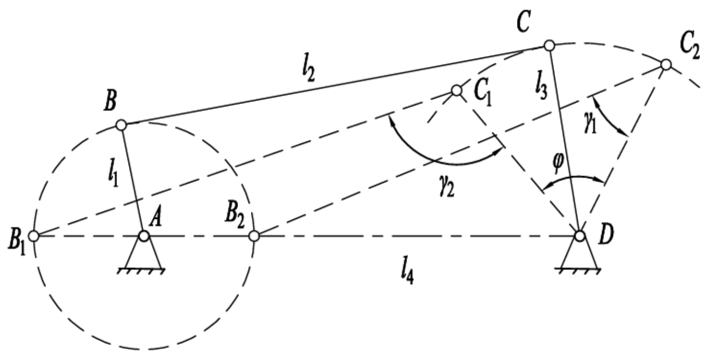

Figure 6. shows the positions of the minimum and maximum transmission angles of the crank mechanism

Since the maximum and minimum values of the transmission Angle, whether taken as γ_1 or γ_2, do not affect the value of the objective function, equations 6 and 7 can be substituted into equation 5 to obtain

$$\min_{l_2,l_3} F = W_1 \frac{1}{\sqrt{(\arccos\frac{l_4^2+l_3^2-(l_1+l_2)^2}{2l_4l_3}-\arccos\frac{l_4^2+l_3^2-(l_2-l_1)^2}{2l_4l_3})^2}} + W_2(\arccos\frac{l_2^2+l_3^2-(l_4-l_1)^2}{2l_2l_3}-90°)^2 + W_3(\arccos\frac{l_2^2+l_3^2-(l_4+l_1)^2}{2l_2l_3}-90°)^2 . \quad (8)$$

3.3.3. Determine the Constraints

1) The picking mechanism should meet the condition that a crank exists and can be obtained

$$\left.\begin{aligned} g_1(x) &= l_1 - l_2 \le 0 \\ g_2(x) &= l_1 - l_3 \le 0 \\ g_3(x) &= l_1 - l_4 \le 0 \\ g_4(x) &= l_1 + l_4 - l_2 - l_3 \le 0 \\ g_5(x) &= l_1 + l_2 - l_3 - l_4 \le 0 \\ g_6(x) &= l_1 + l_3 - l_2 - l_4 \le 0 \end{aligned}\right\} . \quad (9)$$

2) To ensure the good force transmission performance of the picking mechanism, the minimum transmission Angle $\gamma_{\min}$ of the picking mechanism is ≥35° and the maximum transmission Angle $\gamma_{\max}$ is ≤145°, which can be obtained

$$\left.\begin{aligned} g_7(x) &= 35° - \gamma_{\min} \le 0 \\ g_8(x) &= \gamma_{\max} - 145° \le 0 \end{aligned}\right\} . \quad (10)$$

3) To enhance the operational adaptability and coverage of the mechanism, the swing Angle is set as a constraint condition, that is

$$g_9(x) = \sqrt{(\arccos\frac{l_4^2+l_3^2-(l_1+l_2)^2}{2l_4l_3}-\arccos\frac{l_4^2+l_3^2-(l_2-l_1)^2}{2l_4l_3})^2} - 76° \ge 0 . \quad (11)$$

The length of the crank rod 1, the length of the frame 3.44, and the different values of W_1, W_2, and W_3 were respectively brought into the above calculation formula. The Matlab software was used for solution to obtain the values of the connecting rod l_2, rocker l_3, swing Angle φ, and the minimum and maximum transmission angles under four different weight coefficients. The specific values are shown in Table 1.

Table 1. shows the relevant parameter values obtained from different weight coefficients

Group number	The weight coefficients W_1, W_2 and W_3 are respectively taken as values	Connecting rod l_2	Joystick l_3	Swing Angle φ (degree)	Minimum transmission Angle γ_{min} (degrees)	Maximum transmission Angle γ_{max} (degrees)
1	0.8, 0.15, 0.05	3.051	1.636	75.98	52.82	140.73
2	0.7, 0.2, 0.1	3.196	1.624	76.04	48.34	131.34
3	0.6, 0.3, 0.1	3.121	1.623	76.24	50.67	136.42
4	0.5, 0.4, 0.1	2.988	1.649	75.97	54.71	144.94

As can be seen from Table 1, when the weight coefficients W_1, W_2, and W_3 are respectively 0.6, 0.3, and 0.1, the maximum swing Angle is 76.24°. According to the establishment process of the objective function, the degree of the pendulum Angle is taken as the first optimization objective. Therefore, when seeking the optimal solution, the number of pendulum angles is still the first choice. Therefore, the lengths of the crank l_1, connecting rod l_2, rocker l_3 and frame l_4 of the picking mechanism are 1, 3.121, 1.623 and 3.44 respectively. In the actual design, the length of the crank l_1 is 25cm, so the length of the connecting rod l_2 is 78.025cm, the length of the rocker is 40.575cm, and the length of the frame is 86cm. To reduce the processing and manufacturing difficulty of the crank mechanism, the lengths of each rod are taken as integers here, that is, the length of the crank l_1 is 25cm, the length of the connecting rod l_2 is 78cm, the length of the rocker l_3 is 41cm, and the length of the frame l_4 is 86cm. The relevant parameters calculated after rounding are shown in Table 2.

Table 2. shows the relevant parameters obtained after rounding each rod

	Crank l_1 (cm)	connecting rod l_2 (cm)	rocker l_3 (cm)	Frame l_4 (cm)	Swing Angle φ (degree)	Minimum transmission Angle γ_{min} (degree)	Maximum transmission Angle γ_{max} (degree)
Before rounding	25	78.025	40.575	86	76.24	50.67	136.42
After rounding off	25	78	41	86	75.27	50.78	135.42

As can be seen from Table 2, the number of swing angles obtained after rounding is less than 76°, but greater than the design requirement of 75.22°. Meanwhile, the minimum transmission Angle γ_{min} is 50.78 degrees and the maximum transmission Angle γ_{max} is 135.42°. Therefore, the dimensions of each rod after rounding meet the design requirements.

4. MOTION ANALYSIS OF THE PICKING MECHANISM

In order to verify the rationality of the design of the picking mechanism, the Motion function in SolidWorks software was utilized to analyze the motion at the end of the picking rod. It was obtained that the horizontal displacement at the end of the picking rod was 40.9cm, the vertical displacement was 17.7cm, the swing Angle of the picking rod was 77.65°, and the minimum transmission Angle was 50.77°. The maximum transmission Angle is 134.78°. Through analysis, it is found that the horizontal displacement, vertical displacement, swing Angle, minimum transmission Angle and maximum transmission Angle of the picking rod can all meet the functional requirements of the picking operation.

5. CONCLUSION

Based on the physical properties of cow dung and the operational requirements, a picking scheme centered on a four-link crank-rocker mechanism was determined. By constructing a multi-objective function aimed at optimizing the rocker swing Angle and transmission Angle, and using Matlab for optimization and solution, the optimal dimensions of each member were determined: crank 25cm, connecting rod 78cm, rocker 41cm, and frame 86cm. Verified by SolidWorks Motion simulation, the horizontal displacement of 40.9cm, the vertical displacement of 17.7cm and the swing Angle of 77.65° of the motion trajectory at the end of the picking rod are all highly consistent with the design target, proving that the mechanism design meets the requirements of picking space and motion.

The minimum transmission Angle of the optimized mechanism is 50.78°, and the maximum transmission Angle is 135.42°, always remaining within the ideal force transmission range, ensuring smooth and reliable operation of the mechanism under load. This picking mechanism is rationally designed and its performance meets expectations. It combines functionality, reliability and practicality, providing an effective semi-mechanized solution for the resourceful collection of cow dung in plateau pastoral areas and has a promising application prospect.

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