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Integrated Design of Small-Scale Machine for Chinese Chive Harvesting and Bundling

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Abstract: This paper conducts a comprehensive analysis of the current development status and market demand for Chinese chive harvesting machines. In the evolving agricultural industry, the need for efficient and practical harvesting solutions is on the rise. As farming becomes more sophisticated and productivity demands increase, advanced machinery for harvesting is crucial. In response to the specific requirements of smallholder farmers, a meticulously designed small-scale integrated machine for harvesting and bundling Chinese chive has been developed. This machine consists of several key components. The highly efficient harvesting device cuts the chives precisely with minimal damage. The reliable conveying device ensures a smooth transfer to the bundling device. The accurate bundling device creates neat bundles for easy storage and transportation. The convenient collection device simplifies the gathering process. A powerful drive device powers all these components. Along with these, there are other essential elements that enhance the functionality and durability of the machine.

1. Introduction

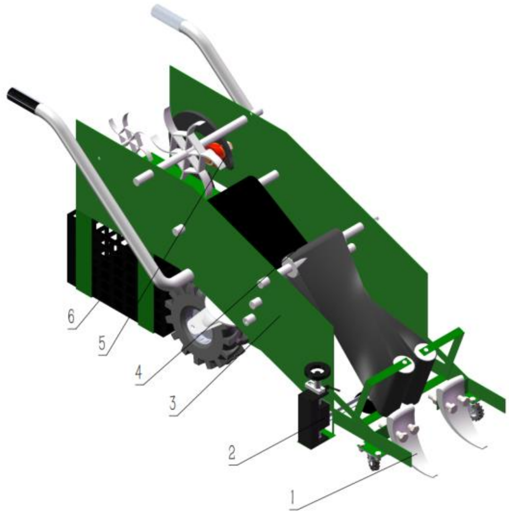
Nowadays, the planting volume of Chinese chive is increasing, with 4-5 harvests each year. The harvesting process is labor-intensive, primarily relying on manual labor, creating an urgent need for mechanization in Chinese chive harvesting[1]. Due to the complexity of harvesting process, the level of automation remains particularly low. Currently, the labor-intensive harvesting of Chinese chive in China is still mainly performed manually, resulting in high hiring costs, and occasional difficulties in finding labor even when willing to pay[2].

More importantly, manual harvesting struggles to ensure the consistent stubble height and stable harvesting quality, leading to below expected overall harvesting efficiency. Although some Chinese chive harvesters have appeared in domestic and international markets, their harvesting performance is not satisfactory, as many issues remain in key areas such as operating, conveying, and bundling[3]. Therefore, a plan is aim to design a Chinese chive harvester specifically for small-scale cultivation, capable of integrating multiple functions such as harvesting, bundling, and collecting, significantly enhancing production efficiency, reducing labor intensity, and ensuring harvesting quality.

2. Structural and System Design of the Integrated Machine

2.1. Basic Components

The designed harvesting system consists of a harvester body, a crop straightening device, two drive wheels, a harvesting device, a conveying device, a bundling device, a collection device, a control handle, and a combined drive mechanism. The harvester body is equipped with a bundling operation platform and a Chinese chive collection rack, and is capable of accommodating the crop straightening device, two drive wheels, harvesting device, conveying device, bundling device, collection device, and other equipment, providing support and stability for the harvesting system. The overall structure is shown in Figure 1.



1-crop straightening device;2-harvesting device;3-harvester body;4-conveying device;
5-bundling device;6-collection device

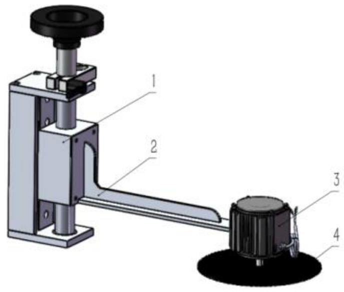
Figure 1: Overall machine structure

2.2. Structural Design

In the working state, the crop straightening device is streamlined and curved, installed at the front end of the harvester, used to upright and separate the inclined or fallen chives, ensuring they accurately enter the conveying mechanism[4]. When not in use, the user can detach the crop straightening device to facilitate the machine’s movement. The crop straightening device is shown in Figure 2.

The lifting device is fixed at the front right end of the frame and operates by turning a wheel that drives the screw rod, which moves the slider up and down, thereby controlling the lifting of the motor and the cutter blade. The locking mechanism ensures the stability of the platform at the required height, preventing slippage. The motor can adjust the speed of the cutter, allowing the Chinese chive harvester to easily handle complex terrain, thereby improving harvesting efficiency and quality. The harvesting device is shown in Figure 3.

Figure 2: Crop straightening structure

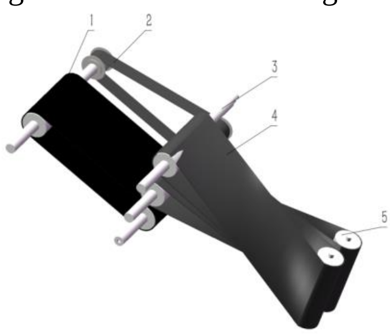


1-lifting module;2-connecting arm; 3-motor;4-cutter blade

Figure 3: Harvesting device structure

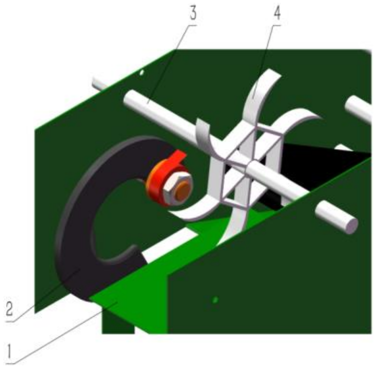
The conveying device is located in the middle section of the harvester body and consists of a double-layer flexible conveyor belt and a secondary conveyor belt. The double-layer flexible conveyor belt is mounted on two vertical round screw dies, and two horizontal round screw dies, with the vertical round screw dies installed behind the crop straightening device to facilitate the transportation of Chinese chives after cutting. The horizontal round screw dies are used to flip the Chinese chives from an upright position to a horizontal position, preventing any falling of the leaves during the conveying process. The secondary conveyor belt is set behind the double-layer flexible conveyor belt, ensuring the stable transfer of Chinese chives to the bundling operation platform. The conveying device is shown in Figure 4.

The bundling device is positioned behind the conveying device, where the winding mechanism employs an innovative planetary gear-like structure. By using the bundling wheel as the sun gear and the tape wheel axle as the planet gear, efficient automation of the bundling process is achieved. The tape wheel axle relies on the rotation of the bundling wheel and the tension of the tape, cleverly realizing both revolving and rotating functions. The bundling device is shown in Figure 5.



1-secondary conveyor belt; 2-synchronous belt; 3-horizontal round screw die; 4-flexible conveyor belt;5-belt roller

Figure 4: Conveying device structure



1-bundling operation platform; 2-winding mechanism;3-round screw die; 4-large crop guiding wheel

Figure 5: Bundling device structure

The collection device is located at the rear of the frame, featuring a removable collection frame that is easy to detach and replace for use.

2.3. Harvesting System

After the two drive motors are powered on, the rotation of the motor shafts drives the two drive wheels to move at the same speed. Subsequently, the harvesting device begins its work while the conveying device is activated simultaneously. The Chinese chives are harvested as they pass through the crop guiding device and are transported to the bundling device via the conveyor belt. After reaching a preset time, the above devices stop synchronously. Then, the bundling wheel starts to rotate, driving the tape wheel to spin, which wraps the Chinese chives with the tape. Once bundling is complete, it automatically stops. Following this, the small crop guiding wheel rotates, using the tension generated by its movement to break the tape and push the bundled Chinese chives into the collection frame, after which the small crop guiding wheel stops automatically. At this point, one cycle of automatic harvesting is complete. The Chinese chive harvester continues to operate in a preset mode for automatic harvesting.

3. Integrated Machine Parameter Calculation

To determine the operational speed, swath, tread, wheelbase, overall dimensions, and other parameters of the integrated machine for harvesting and bundling Chinese chives, it is important to note that each parameter is not independent; they are highly interconnected and mutually influential.

3.1. Operational Speed

Table 1: Empirical values of harvester operational speed[2]

Power(w)	Machine Weight(kg)	Harvester Operational Speed(m s-1)
200~300	50~100	0.1~1.0
300~400	100~300	1.0~2.0
400~600	300~500	2.0~3.0

The operational speed of the Chinese chive harvester is determined based on the previous cultivation practices, types of Chinese chives, land area, surface evenness, moisture conditions, and labor intensity associated with leafy vegetables. The empirical values of harvester operational speed are shown in Table 1.

Based on the actual conditions of the greenhouse land and the integration with the machine design, it can be concluded that: V_m=0.1~0.6(m/s).

3.2. Swath

The swath is primarily determined by the production scale of the Chinese chives, the size of the land, harvesting habits, and the motor providing power[5]. The swath is not only related to the motor and machine weight, but it must also ensure that the walking wheels of the integrated machine do not damage the unharvested Chinese chives during operation. Therefore, the swath B should satisfy:

$$B = W - 2y \tag{1}$$

In the equation: W—the linear distance from the outer sides of the two drive wheels at the rear of the machine; y—the horizontal distance from the inner side of the drive wheels to the edge of the cutting blade.

Based on the actual planting row width of 0.25 m, and considering the overall machine dimensions and row width, the swath B = 0.27m.

3.3. Wheelbase and Tread

The size of the wheelbase of the integrated machine is closely related to the terrain, and it is essential to consider the continuity and stability of the machine's operation. The designed overall dimensions of the Chinese chive harvesting and bundling integrated machine are relatively large, which not only ensures flexible operation during work but also guarantees smooth advancement. Therefore, the wheelbase is set at 95 mm.

The size of the tread of the integrated machine is influenced by the regional conditions of Chinese chive planting, and the overall width of the vehicle should be larger than that of the track width. Based on the actual width of the Chinese chive rows, the drive tread is determined to be 280 mm, and the radius of the drive wheels is 100 mm.

3.4. Overall Dimensions

Due to the limitations on dimensions imposed by the machine's maneuverability and stability, the designed overall dimensions of the vegetable harvesting and bundling integrated machine are 1200 mm in length, 570 mm in height, and 300 mm in width.

4. Design of Key Component

4.1. Design of the Cutter Blade

4.1.1. Material of the cutter blade

The root and stem parts of Chinese chive have a high moisture content. To reduce wear and dulling of the cutter blade and to protect the root stubble while cutting, the blade is made of 65Mn steel and is quenched to enhance the cutting edge[6].

4.1.2. Cutter blade rotational speed

To prevent damage to the Chinese chive during the harvesting process, the operational speed of the harvester (0.3 to 2.1 km/h) and the rotational speed for cutting Chinese chives and other leafy vegetables (25 to 30 m/s) are considered [7]. This analysis focuses on point O, where the circumferential velocity of the cutter blade is at its minimum.

By substituting the relevant data into the formula, the cutter speed can be determined as follows:

$$V_{ro} = \sqrt{V^2 - V_m^2} \tag{2}$$

$$V_{ro} = \omega r \tag{3}$$

In the equation: V_{ao}—the actual speed at point O; V_m—the operational speed of the machine; V_{ro}—the linear velocity at point O.

The calculation yields ω=20~44rad/s, corresponding to a cutter blade speed n=120~300r/min.

4.1.3. Cutter blade parameters

Based on the row spacing for planting Chinese chives in greenhouses, the diameter of the cutter blade is determined to be 250 mm. Considering that the material being cut is soft leafy vegetables, the thickness of the cutter blade is set at 5 mm. The circumference of the cutter blade is calculated to be 785 mm. Generally, the tooth spacing is between 10 and 15 mm; since a higher number of teeth improves cutting performance, a tooth spacing of 10 mm is selected, resulting in a total of 80 teeth. Experimental results indicate that the cutting blade operates effectively within a rotation speed range of 120.0 to 300.0 r/min without missing any cuts. The parameters of the cutting knife are shown in Table 2.

Table 2: Parameters of the Cutter Blade

Order	Parameter	Specific Dimensions
1	Diameter	250mm
2	Thickness	5mm
3	Number of Teeth	80
4	Blade Edge Angle	24 °
5	Cutter Blade Rotational Speed	120.0~300.0r/min

4.2. Design of the Conveying Device

4.2.1. Flexible conveyor belt

Given the relatively low resistance to compression of the stems and leaves of Chinese chive, it is essential to select a soft material for the conveyor belt to prevent damage to the vegetables. Both the inner and outer layers of the conveyor belt should be made from the same material to ensure durability and longevity. The tension of the conveyor belt must be calibrated to securely grip the Chinese chive while avoiding any harm to the plant.

Additionally, an appropriate installation angle is crucial to facilitate the smooth transportation of the vegetables while also optimizing material usage[2]. To achieve effective forward motion of the Chinese chive during operation, the structure of the vertical round screw die for gripping Chinese chive must ensure that the entry angle at the stem portion is less than the friction angle of the conveyor belt. Consequently, a rotating conveyor solution has been adopted, as illustrated in Figure 6.

(a) installation location

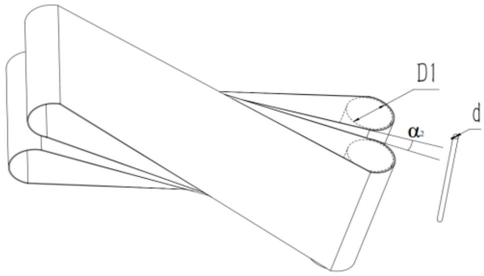


Figure 6: Structure of the Flexible Conveyor Belt

To ensure the smooth transportation of Chinese chive, the diameter of the leading vertical round screw die must meet the following requirements:

$$\alpha_2 = \arccos\frac{D_1}{D_1 + d} < \varphi \tag{4}$$

In the equation:α_2—chive stem entry angle;D_1—the diameter of the vertical round screw die; d—the diameter of the Chinese chive stem and leaf bundle(d=5-25mm);φ—the friction angle between the stem and leaf and the conveyor belt.

(b) conveyor belt speed

The speed of the conveyor belt must be determined based on the desired thickness of the layer of Chinese chive, which is influenced by the quantity of chives harvested per unit time. That is:

$$V_m B q_1 = V_s d q_2 \tag{5}$$

In the equation: V_m—operational speed (m/s); q_1—Chinese chive intensity (Chinese chive/m ^{3});B—swath (m);V_s—conveying speed of conveyor belt (m/s);D—gripping thickness of Chinese chive (mm);q_2—density of gathering chives (m/s).

The result can be derived from the above equation:

$$V_s = V_m B q_1 / d q_2 = V_m B / kd \tag{6}$$

k is the coefficient of chive gathering, k=q1/q2, Generally, the value of k is taken as 18~33, d≤60mm.

The parameters of the conveyor belt are shown in Table 3.

Table 3: Conveyor Belt Parameters

Order	Parameter	Specific Dimensions
1	Length/mm	1800
2	Width/mm	100
3	Installation Angle/°	30~40
4	Relative Linear Velocity/(m/s)	>2.25

4.2.2. Secondary layer conveyor belt

(a) installation location

The movement of the secondary conveyor belt drives the motion of the Chinese chive, and the primary force at play between them is static friction. The angle at which the secondary conveyor belt is installed significantly affects the interaction between the chives and the belt. Therefore, it is essential to conduct preliminary tests on friction characteristics to determine the optimal angle for installation [8].

Experimental material: tape measures, it is a piece of material identical to that of the conveyor belt.

A friction experiment was conducted on the Chinese chives, as shown in Figure 7. A certain number of chives were neatly placed on a material with an inclined angle α, and the angle α was gradually increased until the chives were about to slide. At this point, the values of h and d were measured, and the friction angle α was calculated based on these measurements:

$$\alpha = \arctan h/d \tag{7}$$

Based on the experimental results, the angle α was found to range between 35° and 36°. To achieve the desired conveying effect, the secondary conveyor belt was set at an inclination angle α of 30°, with dimensions of 500 × 270 mm, made from hard rubber.

(b) operational speed of conveyor belt

Due to the light weight of Chinese chives, the secondary conveyor belt will not be subjected to excessive pressure, allowing for a certain thickness of chives to be transported on it. Based on the working. Principle of the conveyor belt, the relationship between belt speed V_d and the stacking thickness of the chives can be expressed as:

$$V_d = \frac{V_s B}{kh} \tag{8}$$

In the equation: V_d—the speed of the secondary conveyor belt; h—the thickness of the Chinese chives.

In addition, to transport the Chinese chives to the bundling operation platform, the following conditions must be met, as shown in Figure 7.

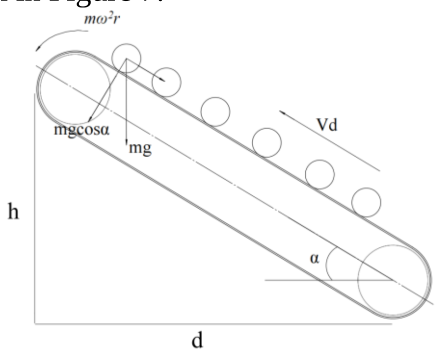


Figure 7: The Process of Transporting Chinese chives with the Secondary Conveyor Belt

$$m\omega^2 \geq mg\cos\alpha \tag{9}$$

In the equation: m—Chinese chive mass (kg); r—round screw die diameter of conveyor belt (mm); ω—round screw die angular velocity of conveyor belt (rad/s); g—gravitational acceleration (m/s^2); α—Angle of Conveyor Belt Installation Relative to the Horizontal Plane.

Therefore, we have

$$\omega \geq \sqrt{\frac{g\cos\alpha}{r}} \tag{10}$$

And

$$V_d = \omega r \tag{11}$$

Thus

$$V_d \geq \sqrt{gr\cos\alpha} \tag{12}$$

Since cos α = 1 represents the least favorable condition, the minimum speed can be determined as follows:

$$V_{\min} \geq \sqrt{gr} \tag{13}$$

Since r = 25mm, the minimum speed V_{min}=0.50m/s is obtained for the horizontal conveyor belt. In summary, $V_d > V_{min}$.

(c) power

Due to the relatively light weight of the Chinese chives, the power consumption during the transportation process is minimal. The primary power loss of the secondary conveyor belt occurs during the upward transport of the Chinese chives and the rotation of the roller that drives the conveyor belt [9]. A force analysis of the Chinese chives is illustrated in Figure 8.

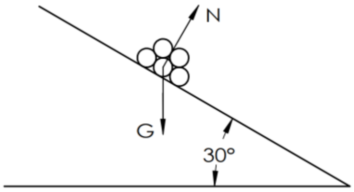


Figure 8: Force Analysis of Chinese chives on the Conveyor Belt

When fully loaded, the total weight of the leeks on the conveyor belt is approximately 3kg, thus:

$$F = G\cos 30^{\circ} \tag{14}$$

The power consumed during this process P can be expressed as:

$$P = Fv \tag{15}$$

Considering the power consumed by the roller to drive the conveyor belt, the final estimated power loss for the secondary conveyor belt is set at 25 W.

4.3. Design of the Bundling Device

4.3.1. Working principle

The bundling device for Chinese chive comprises several key components, including the large guiding wheel, the bundling operation platform, and the winding mechanism. Once the Chinese chives are transported to the bundling operation platform via the transport device, the large guiding wheel rotates to guide the Chinese chives into the bundling wheel. At this point, an operator attaches one end of the harmless adhesive tape to the Chinese chives.

The bundling wheel and the tape wheel shaft are designed using a planetary gear-like structure. After the adhesive tape is secured, the motor drives the bundling wheel to rotate clockwise. During this process, the large guiding wheel halts, creating a barrier between the Chinese chives being transported and the bundling device. As the bundling wheel turns, the tape wheel shaft also rotates due to the tension in the tape, allowing the tape to wrap around the Chinese chives multiple times. Once the bundling wheel returns to its starting position, the bundling process is complete. Following the collection of the bundled Chinese chives, the large guiding wheel resumes its rotation to initiate the next bundling cycle.

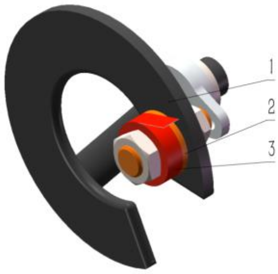
4.3.2. Design of the winding mechanism

The winding mechanism is responsible for accurately wrapping the adhesive tape around the Chinese chives. As the core component of the Chinese chive bundling machine, the design of this mechanism significantly impacts the quality of the bundled Chinese chives. Considering the importance of the winding mechanism, the following design requirements are proposed:

(a)Material Selection for Tape Wheel Shaft: The tape wheel shaft should be made of a high-hardness plastic. The surface in contact with the tape should not be overly smooth to provide sufficient friction, thereby preventing the tape from slipping during the winding process.

(b) Cooperation Between Tape Wheel Shaft and Bundling Wheel: To ensure that the tape wheel shaft can be effectively driven by the tension of the tape, the surface in contact with the bundling wheel should be sufficiently smooth. This design prevents the scenario where only the bundling wheel rotates while the tape wheel shaft remains inactive during operation[10].

The winding mechanism is illustrated in Figure 9.



1-bundling wheel; 2-tape wheel shaft; 3-adhesive tape

Figure 9: Structure Diagram of the Winding Mechanism

4.3.3. Static analysis of the winding mechanism

During the initial stage, significant reaction forces are generated by the tape and bundling wheel on the tape wheel shaft, with the primary load concentrated at the junction between the bundling wheel and the tape. To identify the potential failure points of the shaft, a comprehensive modeling and static analysis of the crankshaft was conducted[11]. In the static analysis, the fixed surface was chosen to be the axial hole that connects the bundling wheel and the tape. A torque of 1 N m was applied to the shaft at the connection point with the bundling wheel and tape, enabling a thorough static analysis, as illustrated in Figure 10.

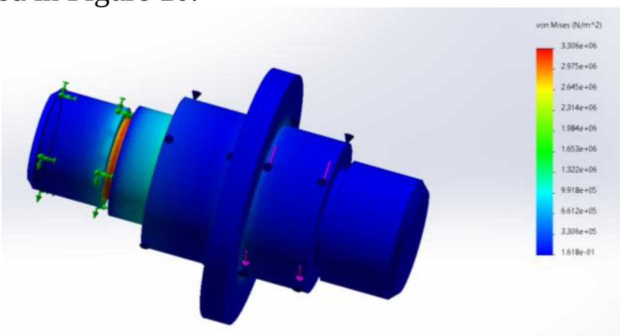


Figure 10: Static Analysis of the Tape Wheel Shaft

As shown in Figure 10, the stress at the rear recess is maximal. If a failure point occurs here, it could lead to shaft breakage. Therefore, to ensure longevity and operational efficiency, it is essential to reinforce this area and select materials with higher strength[12].

5. Conclusion

This paper introduces a small-scale integrated harvester-bundler system specifically designed for Chinese chive, demonstrating excellent adaptability for small plots and greenhouse cultivation. The system integrates harvesting, bundling, and collecting functions, thereby offering considerable advantages in labor efficiency, cost reduction, and improvements in yield and quality. Given its significant potential for enhancing agricultural productivity, it is anticipated that this small-scale integrated harvester-bundler will achieve broader application and promotion in the field, especially after further refinement and optimization.

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