Original Research Article

Design of a pineapple automatic harvesting machine based on hydraulic and mechanical transmission

Yaqing Sun

Weifang University, Weifang, Shandong, 261061, China

Abstract: This study addresses the challenges of low mechanization, high labor intensity, and low efficiency in pineapple harvesting by designing a fully automated pineapple harvester aimed at achieving automation and enhanced efficiency in the harvesting process. Based on an analysis of pineapple growth characteristics, cultivation patterns, and existing harvesting equipment, an integrated solution is proposed encompassing upright positioning, multi-stage cutting with synchronous belt transmission, lifting and conveying mechanisms, and fruit collection systems. The design process defines the operational principles and key parameters of each subsystem, accompanied by comprehensive 3D modeling. The machine adopts a hybrid hydraulic-mechanical transmission system, offering high efficiency and minimal fruit damage, while ensuring adaptability to the complex field conditions of pineapple plantations. Cost analysis indicates that the device holds considerable economic benefits and significant market potential. This research provides a practical solution for the mechanization of pineapple harvesting, contributing to reduced labor demands, improved harvesting efficiency, and the sustainable development of the pineapple industry.

Keywords: Pineapple; Complex terrain; Fully automated harvesting

1. Introduction

As one of the most important tropical fruits worldwide, pineapple plays a vital role in the tropical agricultural economy due to its high nutritional value and wide range of applications[1]. Rich in vitamins, minerals, and dietary fiber, pineapples can be consumed fresh or processed into products such as canned fruit and juice, catering to diverse market demands[2]. Major pineapple-producing countries include the Philippines, Thailand, Brazil, and the United States[3] . China, ranking as the fourth largest pineapple producer globally, has a leading position in both cultivation area and output. In southern provinces such as Hainan and Guangdong, pineapple farming has become a key pillar of the local agricultural economy[4]. However, despite the large scale of pineapple production in China, the harvesting process remains largely unmechanized and heavily reliant on manual labor. This not only increases labor intensity but also hampers improvements in production efficiency[5].

The complexity of pineapple harvesting primarily arises from the crop's unique growing conditions and fruit characteristics[6]. Pineapple leaves are tough and serrated along the edges, posing a risk of skin injuries to workers during manual harvesting[7] . Additionally, the working environment in pineapple fields is typically hot and humid, and prolonged bending during harvesting can cause physical discomfort, with potential health issues such as heatstroke and eczema[8]. Harvesting is also highly seasonal, with peak periods lasting only about two weeks; failure to harvest in a timely manner can lead to fruit overripening and decay, resulting in significant economic losses[9]. At present, no fully automated harvesting equipment capable of operating in the complex conditions of pineapple fields has been developed, leaving a critical gap in the mechanization of this sector[10]. As labor costs continue to rise and agricultural modernization accelerates, there is an urgent need for the development of efficient, low-damage pineapple harvesting machinery[11].

In recent years, the rapid advancement of agricultural mechanization technologies has laid a solid technical foundation for the development of pineapple harvesting equipment[12]. Significant progress has been made in the field of fruit and vegetable harvesting machinery, with automated harvesting systems for fruits such as apples and citrus gradually achieving commercial application[13]. However, the development of pineapple harvesting equipment still faces numerous challenges, including accommodating the irregular growth patterns of pineapple plants, achieving precise fruit cutting and low-damage transportation, and designing efficient fruit collection systems[14].

To address these challenges, this study aims to design a fully automated pineapple harvester capable of operating in the complex field conditions typical of pineapple cultivation. By integrating functions such as upright positioning, multi-stage cutting with synchronous belt transmission, lifting and conveying, and fruit collection, the proposed system seeks to achieve automation and high efficiency in the harvesting process. The overall structure of the designed harvester comprises key components including an upright positioning mechanism, a multi-stage cutting system with synchronous belt transmission, a lifting and conveying unit, and a fruit collection module. Three-dimensional modeling was employed to define the structure of each component as well as the transmission and coordination relationships among them. This study offers a feasible solution for the mechanization of pineapple harvesting, contributing to reduced labor intensity, enhanced harvesting efficiency, and the sustainable development of the pineapple industry.

2. Overall structural design of the fully automated pineapple harvester

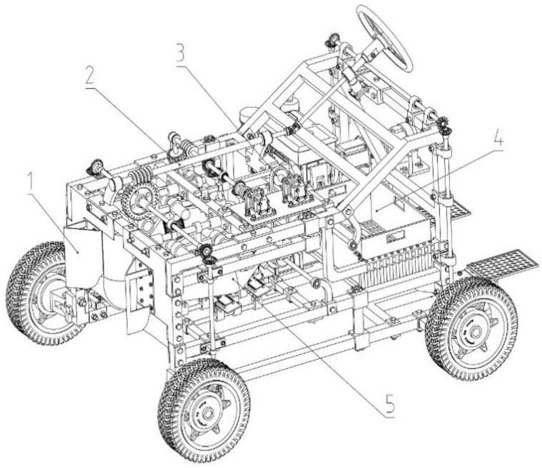
2.1. Conceptual design of the system

In this study, we designed a fully automated pineapple harvester, as illustrated in **Figure 1**, which integrates functions such as upright positioning, leaf avoidance during movement, fruit clamping and conveying, multi-stage cutting, and collection and storage. The main components of the design include the machine frame, upright positioning mechanism, multi-stage cutting system driven by synchronous belts, lifting and conveying unit, fruit collection device, steering system, and a hydraulic drive system.

The operational procedure and working principle of the proposed system are as follows: the harvesting operator stands on the foot pedal located at the rear of the machine and initiates its operation. A diesel engine continuously supplies power to the drive system, enabling the machine to advance steadily at a speed of 0.3 m/s. Motor 1 drives the synchronous belt clamping and conveying mechanism via bevel gear transmission and simultaneously powers the secondary reciprocating shear-cutting mechanism through a worm gear and belt transmission system, ensuring the desired cutting speed. Motor 2 operates the conveyor belt of the lifting and conveying unit via belt transmission.

During operation, the operator holds the steering wheel to maintain balance and control the machine's direction as it moves into the pineapple field. The center of the machine straddles a single row of pineapple plants, performing the harvesting task from above. As the machine advances, the upright positioning mechanism aligns fruits growing within a certain angular deviation and guides them toward the center of the machine. Once centralized, the pineapples are engaged by hard sponge rollers on the synchronous belt clamping system. With the combined action of the belt's clamping force and the support from an arc-shaped height-adaptive guide rail, the fruits are conveyed rearward at a uniform speed. At a designated point along the transport path, the secondary reciprocating shear-cutting mechanism located beneath the guide rail progressively severs the pineapple peduncle, leaving a residual stem length of approximately 1–2 cm—considered optimal for postharvest handling.

Subsequently, the pineapples disengage from the clamping mechanism and are transferred upward and rearward by the lifting conveyor to the fruit collection unit. A buffer slope facilitates the gentle descent of the fruits into the collection basket. The machine then proceeds to the next harvesting cycle.

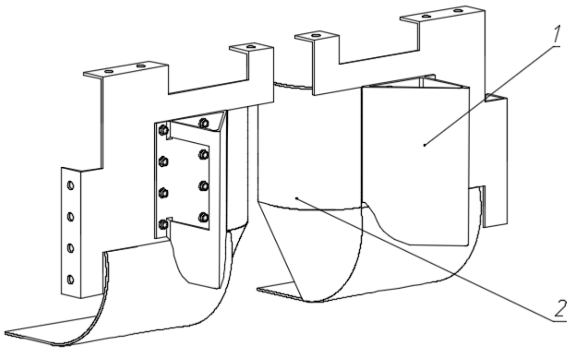


1. Upright Positioning Mechanism 2. Steering System 3. Lifting and Conveying Unit 4. Fruit Collection Device
5. Synchronous Belt Conveying and Multi-Stage Cutting System

Figure 1. Schematic diagram of the overall structure of the fully automated pineapple harvester.

2.2. Upright positioning mechanism

Pineapple cultivation is typically conducted as fieldwork, with planting done manually in rows. During planting, farmers are unable to ensure that all pineapples in the same row are perfectly vertical, resulting in a certain degree of lateral fluctuation in the growth of the pineapples. Furthermore, the slender peduncle of the pineapple is susceptible to external factors such as wind and rain, leading to tilting or lodging. According to research and relevant literature, the horizontal oscillation range of a normally growing pineapple plant's fruit is within ±25 cm. Based on this, the upright positioning mechanism was designed to ensure that pineapples within this oscillation range in the same row are aligned and gathered to the center position, allowing them to smoothly enter the subsequent work area and ensuring the successful completion of the harvesting task. Its structure is illustrated in **Figure 2**.



1. Outward Extension Clustering Mechanism 2. Inward Contraction Guiding Mechanism

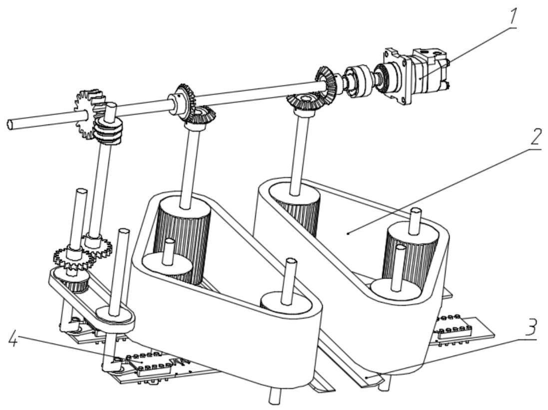
Figure 2. Schematic diagram of the structure of the upright positioning mechanism.

The upright positioning mechanism consists of two components: the outward extension clustering mechanism and the inward contraction guiding mechanism, which serve the functions of tilting correction and guiding, respectively. The outward extension clustering mechanism has a maximum opening distance of 60 cm, meeting the lateral oscillation requirements for pineapple harvesting as determined in the research. This design allows the machine to operate primarily in a straight line, thereby reducing the need for manual intervention and ensuring the reliability of the harvesting process. The lower section of the guiding mechanism is shaped to also provide a leaf-avoidance function, preventing pineapple leaves from interfering with the executing mechanisms.

2.3. Synchronic belt conveyor multi-Stage cutting system

The synchronous belt conveying and multi-stage cutting system, as designed in **Figure 3**, is the core system of this design. It consists of the synchronous belt clamping and conveying mechanism, the arc-shaped guide rail, and the secondary reciprocating shear-cutting mechanism. The synchronous belt clamping and conveying mechanism provides the clamping and conveying functions for the pineapples. The arc-shaped guide rail height adaptation device offers lifting and guiding functions for the pineapples. The secondary reciprocating shear-cutting mechanism is responsible for cutting the pineapple peduncle. These three components work in coordination to complete the critical task of detaching the pineapple fruit from the plant and continue to transport the harvested fruit to subsequent mechanisms.

To achieve optimal harvesting results, the entire system is set at an 11° angle relative to the horizontal plane. This allows the pineapple fruit to be gradually lifted during the rearward transportation process. The first function of this design is to elevate the pineapple fruit to a higher position, facilitating its entry into subsequent lifting and collection devices. This ensures that the collection device is positioned at a sufficient height to avoid interference with the pineapple plants. The second function is that, when the pineapple peduncle is not cut to the desired length after the first stage of reciprocating shear-cutting, the detached pineapple fruit will be initially conveyed horizontally over a certain distance under the influence of gravity and the friction between the belt and the fruit. After being restricted by the arc-shaped guide rail height adaptation device, the fruit is then conveyed along the guide rail direction. During this process, the excess portion of the residual peduncle extends fully into the cutting area, where it is trimmed to the optimal length by the secondary reciprocating shear-cutting mechanism.

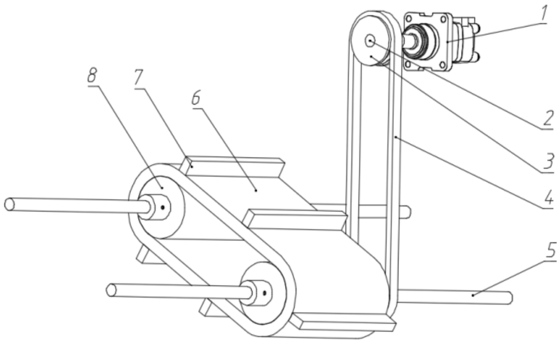


1. Hydraulic Motor 2. Synchronous Belt Clamping and Conveying Mechanism 3. Arc-Shaped Guide Rail Height Adaptation Device 4. Secondary Reciprocating Shear-Cutting Mechanism

Figure 3. Synchronous belt conveying and multi-stage cutting system.

2.4. Lifting and conveying unit

After leaving the synchronous belt conveying and multi-stage cutting system, the pineapple fruit does not reach the required height to enter the fruit collection device. Therefore, a conveyor belt with a specific inclined angle is designed behind the synchronous belt clamping and conveying mechanism. This conveyor belt moves the fruit diagonally upward, allowing the pineapple fruits that land on the lifting and conveying unit to be lifted and transported to the ideal height where they can be dropped into the fruit collection device, ensuring smooth descent into the collection basket.

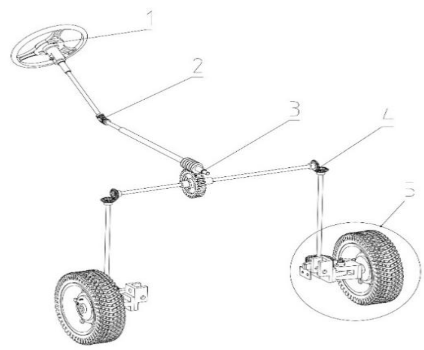


1. Hydraulic Motor 2.Hydraulic Motor Shaft 3. Drive Pulley 4. Lifting Conveyor Belt
5. Drive Shaft 6. Lifting Conveyor Belt 7. Raised Stop Block 8. Lifting Pulley

Figure 4. Schematic diagram of the structure of the synchronous belt clamping and conveying mechanism.

Figure 4 illustrates the structure of the lifting and conveying unit. The conveyor belt is made from a composite material consisting of rubber, fibers, and metal, with a layer of NBR elastomer attached to the surface. Every 15 cm along the belt, a raised stop block is placed, with a height of 3 cm. These stop blocks function to limit the position of the pineapple fruits and assist in their lifting and conveyance. The longitudinal planting spacing of pineapples is approximately 30 cm, which is nearly identical to the conveyor spacing. Therefore, after two raised stop blocks pass, approximately one pineapple fruit enters the lifting and conveying unit. The unit is designed with sufficient space to react and adjust the position of the entering fruit.

2.5. Steering mechanism



1. Steering Wheel 2. Universal Joint 3. Worm Gear and Worm Pair 4. Bevel Gear Pair 5. Wheel Steering Pair

Figure 6. Schematic diagram of the steering mechanism.

Due to the requirement that the machine must cross over the pineapple plants during the harvesting operation, the wheels cannot be directly connected by an axle. Therefore, a combination of a worm gear, multi-stage bevel gears, and a gear rack system is used to control the steering. As shown in Figure 6, the steering wheel shaft is connected to the worm wheel shaft via a universal joint. During steering, the worm wheel transmits power to the worm, whose rotation then drives the power through bevel gears to the drive shaft. The gear on the drive shaft transmits power to the rack, causing it to move in a reciprocating linear motion, which in turn drives the connecting rods to achieve synchronized steering of the two front wheels.

3. Cost and prospect analysis

Under market economic conditions, for a product to achieve favorable economic benefits, it is essential to reduce production costs, perform accurate cost accounting, and enhance profit margins.

The materials estimated for this machine are as follows:15 meters of 45 steel square steel profiles, priced at 15 yuan/m, totaling 225 yuan.8 meters of 45 steel bar shaft blanks, priced at 22 yuan/m, totaling 176 yuan.6 square meters of Q235 steel plates, priced at 10 yuan/m², totaling 60 yuan. Other parts or components require custom manufacturing or purchase: Standard components such as bolts, nuts, bearings, universal joints, etc., are estimated to cost around 100 yuan. Outsourced components, including the diesel engine, hydraulic pump, hydraulic motor, off-road tires, fuel tank, synchronous belt, and steering wheel, will cost approximately 900 yuan. Custom parts such as special connectors, collection bins, gears, racks, worm wheels, worm gears, etc., will cost about 350 yuan. The custom vehicle shell will cost around 400 yuan. The total cost for all components is approximately 2,211 yuan. After mass production, the tentative sale price is set at 7,500 yuan per unit.

Pineapple harvesting machinery has not yet appeared in the Chinese market, and there is a high demand for such machinery among fruit farmers, indicating significant market potential. After the prototype is produced, it is expected to undergo testing in the pineapple cultivation areas of Shandong Province. During the testing phase, the design will be optimized based on issues encountered during the on-site harvesting process. Following this, the machine will be introduced to pineapple planting demonstration bases, represented by Guangdong and Hainan Provinces. Once the product is fully launched, it is expected that at least 100 units will be sold annually. With a unit price of 7,500 yuan, the annual sales revenue could reach 750,000 yuan, with a sales profit of 500,000 yuan, and an additional tax contribution of over 50,000 yuan.

4. Conclusion

This study successfully designed an automatic pineapple harvester, achieving the automation and efficiency of pineapple harvesting through the integration of functions such as fruit positioning and alignment, synchronous belt conveying with multi-stage cutting, lifting conveyance, and fruit collection. The equipment adopts a combination of hydraulic and mechanical transmission, enabling it to adapt to the complex conditions of pineapple fields while significantly reducing labor intensity and harvesting damage rates. Cost analysis indicates that the equipment offers high economic benefits and substantial market potential. After the prototype is produced, it is expected to undergo testing and optimization in pineapple cultivation areas before being launched nationwide. The outcomes of this study not only provide a feasible solution for the mechanization of pineapple harvesting but also contribute to the sustainable development of the pineapple industry, supporting the national strategy for agricultural modernization and promoting the transformation and upgrading of the agricultural machinery manufacturing industry. In the future, this equipment is expected to be widely applied in pineapple-growing regions, bringing higher economic benefits and improved well-being to fruit farmers.

About the author

Sun Yaqing（2003 -）， Female, Han,　Shandong Qingdao, Research Focus: Agricultural Mechanization Engineering

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