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An Intelligent Lotus Root Harvesting Equipment

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Abstract. A fully hydraulic intelligent lotus root harvester has been designed to solve the difficult problem in the harsh muddy water environment of the lotus pond. Power distribution is achieved through proportional hydraulic pumps, proportional speed control valves, directional valves, and low speed high torque motors, Forward and reverse control and hydraulic flow adjustment to achieve speed changes such as forward, backward, and turning of the machine. Accurately regulate speed and direction to meet the walking and transition requirements of Lotus Pond; Innovatively designed a chassis structure with the core of "wide rubber track +buoyancy box+ four point linkage lifting device", which can adapt to different operating water depths; Hydraulic, pneumatic, and electric joint control, Realize remote control of low-pressure and high flow jet, The chain reversing and swinging mechanism integrates chain reversing, lifting, and jetting to achieve swinging jetting, Dynamically adjusting the distance between the jet unit and the mud surface, Vigorously improving the efficiency of low-pressure and high-flow jet.

Keywords. Intelligent Lotus Root Harvester; Hydraulic, pneumatic, and electric joint control; Remote control.

1 Introduction

Lotus root is an important aquatic cash crop that is easy to grow and difficult to harvest, and has been cultivated and eaten in China for more than 3,000 years [1]. The main production areas are distributed in North China, South China, Southwest China and the Yangtze River Basin, with the gradual expansion of lotus root planting areas in China, many areas have formed large-scale lotus root planting bases, and the lotus root planting area has also shown a steady growth trend[2-4].

In the early harvest, the harvest of lotus roots mainly used artificial water gun excavation[5]. However, due to the fact that the jet pressure is not well controlled, it is easy to cause damage to the peel of the lotus root [6]. Only a few foreign countries have studied the lotus root excavator, and the DLX-31 lotus root excavator developed in Japan is mainly composed of a crawler platform, a rocker arm, etc., and a hydraulic scouring rocker arm is mounted on the crawler platform [7]. South Korea has developed a track-type lotus root harvester that uses high-pressure gas jetted from the field to the culture soil [8]. In China, Gao Xuefeng et al. proposed a high-power lotus root harvester that

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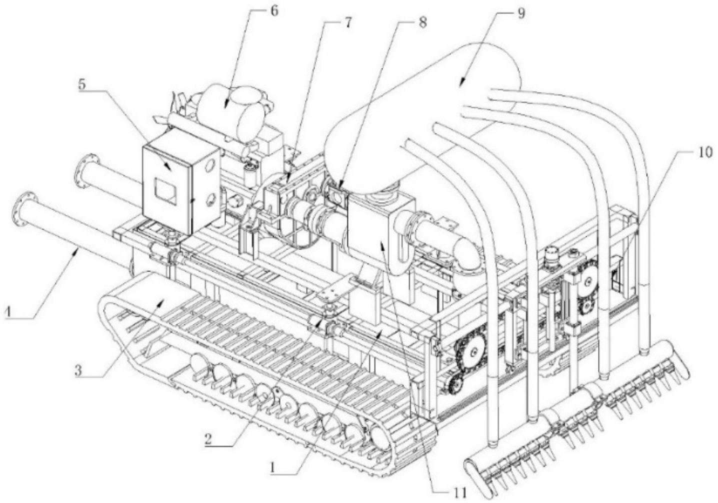
combines two types of root harvesting methods, shovel type and jet type [9]. Feng Chuangchuang, Liu Yan et al. designed a spiral propeller digging machine [10,11]. Bai Guorui et al. designed a crawler pontoon type digging machine [12]. Cheng Ying designed a cutter for bucket conveying mechanism [13]. Wu Hao developed a spin jet type lotus digging machine, which analyzed the principle of action between high-pressure water jet and soil through EDEM-CFD coupling simulation, which provided a theoretical basis for the development of the digging machine [14]. In addition, such as Jiao Jun, Wang Wenli and others studied the nozzle simulation and nozzle flow field study of the digging machine [15,16]. Zhang Xiang carried out the design research of the key components of the excavation excavator [17]. Huang Lin carried out the structural design and research of the hand-held digging machine [18]. At present, the lotus root mining and harvesting machinery that can be vigorously promoted and widely used in China is almost blank, and it is urgent to carry out research on the mining mechanism of intelligent lotus root.

2 Basic Structure and Working Principle of Intelligent Lotus Root Harvester



1.Buoyancy box 2. Four linked lifting device 3. Wide rubber engineering track 4. Back flushing device
5. Electric control box 6. Diesel engine 7. Transfer box 8. Hydraulic pump 9. Water distribution bag
10. Chain swinging jet mechanism 11. Sewage pump

Figure 1. Structure of the Intelligent Lotus Root Harvester

The lower mechanism of the machine is consists of rubber track and dual hydraulic motors, forming a walking module. In order to reduce the weight of the machine body and improve the efficiency of underwater operations, the buoyancy box is added to the lower frame. The upper structure is a working module, including a power drive module composed of a diesel engine, its accessories, and a transfer box, The sewage pump, chain swing jet mechanism, pipeline, water distribution bag, etc. constitute the jet working module, and the suction pipeline, filter pipe, backwash device and four linkage lifting device form the suction pipeline module, The chassis adopts hydraulic driven track integrated design, and the track adopts wide rubber track, Width 450mm to increase the contact area with lotus root mud and meet the requirements of working in loose lotus root mud underwater. The upper mechanism of the entire machine is installed on the main beam of the walking mechanism through a four linkage lifting device, achieving the lifting and lowering of the upper body to meet the requirements of different water depth operations. The travel module realizes the whole machine walking and steering, and can provide three steering methods: rapid steering; quick turns; Larger diameter turns. The proportional speed regulating valve controls the forward and backward speed changes through flow adjustment, and if one in and one retreat can achieve a small diameter turn, the double travel motor rotates synchronously when working. The transfer box is a self-made three-axis transfer box, which is connected to a large displacement sewage pump port with an integrated pneumatic clutch. The sewage pump is driven by a pneumatic clutch to ensure a smooth start and stop of the sewage pump during the working process. By adjusting a number of analog quantities and on-off quantities, the remote control of the whole machine is realized, the remote control sends the control signal, the receiver receives the signal input to the PLC, and the PLC realizes the control of the executive element. The remote control adopts touch screen mode. Power drive module, jet working module, suction pipeline module, hydraulic system module, remote control module and air system module are integrated and integrated on the base, hydraulic drive, liquid-gas and electric joint control remote control, high degree of automation. The specific structure is shown in Figure 1.

3 Key Institutional Design and Main Technical Indicators

3.1 Main technical indicators

The working environment of muddy water in the lotus pond requires the lotus root harvester to have strong adaptability to harsh environments, as well as certain land walking functions and the ability to freely walk at the bottom of the lotus pond. The chassis adopts a track type+ buoyancy box structure to reduce ground pressure, increase adhesion, and reduce slip rate. The low-pressure and high flow jet of the self priming sewage pump improves the lotus root harvesting rate, and the multi-channel hydraulic system does not interfere with each other, facilitating the normal operation of the harvester in the complex working environment of lotus root fields. The main structural parameters and performance of the lotus root picking machine are shown in Table 1.

Table 1. Structural performance parameters of intelligent lotus root picking machine

parameter	numerical value
Overall size/(mm ×mm× mm)	5000×2485×2347
Diesel engine power/KW	121
Track size /(mm ×mm× mm)	2900×2485×520
Sewage pump displacement/(m^3/t)	260
Sewage pump shaft power/KW	78
Outlet pressure/MPa	> 0.5
Maximum walking speed on land/(m/h)	5000
Operation walking speed/(m/h)	100-600
Operating water depth/m	0.3-1
Maximum operating water depth/m	1.2
Job width/m	3.5
Climbing ability/°	35°
Slope walking slope/°	25°
Operation efficiency/(mu/h)	1 mu /h

3.2 Design and selection calculation of tracked walking mechanism

The track type driving mechanism uses tracks wrapped around the driving wheel and a series of rollers to prevent the wheels from directly contacting the ground of the coupling pool. The design of wide rubber engineering track and box buoyancy avoids sinking into mud and crushing lotus roots; The wide rubber engineering track has a width of 450mm, which is beneficial for reducing travel resistance; The ground pressure is between two feet and one foot grounding; The climbing ability can steadily walk at an angle of 35 º to the horizontal line, and can walk on a slope of 25 º. The track pitch is determined by the mass of the entire machine, and the pitch varies depending on the mass of the machine.[19-21] The calculation formula is:

$$t_0 = (15\sim17.5)\sqrt[4]{G} \tag{1}$$

In the formula, G is the overall weight, the unit is kg, and t_0 is the track pitch, the unit is mm, G takes 2000 ,$t_0 = 10.305\sim117.022$

The calculation formula for track shoe width b is:

$$b = (0.9\sim1.1) \times 209 \times \sqrt[3]{G \times 10^{-3}} = 510.503\sim623.926 \tag{2}$$

In the formula, b is the width of the track shoe, the unit is mm.

The formula for calculating the number of teeth on the driving wheel is:

$$Z = 2Z' = 2(12\sim15) = 24\sim30 \tag{3}$$

Considering the service life of the driving wheel, an odd number is generally preferred.

The calculation formula for the pitch diameter of the driving wheel is:

$$D_k = \frac{t_0}{sin\left(\frac{180}{Z'}\right)} \tag{4}$$

In the equation, D_k is the pitch diameter of the driving wheel, the unit is mm, and Z' is the number of teeth on the driving wheel. Based on the parameters of this mechanism, the pitch diameter of the driving wheel is selected and calculated to be 530mm.

According to the standard requirements of GB/T 7586-2008 Test Methods for Hydraulic Excavators, the fuselage is prone to sinking into soft soil due to its own weight, and the addition of tracks increases the contact area with the ground and reduces the pressure; The formula for ground pressure is:

$$E_a = \frac{gM}{2000b\,L} \tag{5}$$

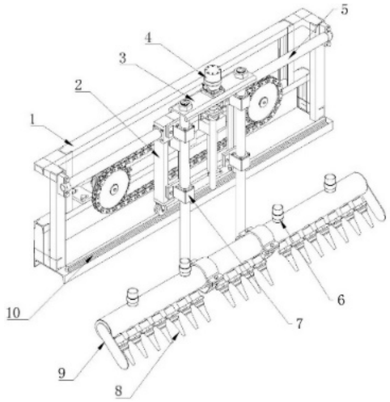
In the equation, E_a is the ground pressure, unit is Kpa, L is track grounding length, unit is m, take 1.6m here, g is the standard gravitational acceleration, 9.8m/s^2, M is the working mass, unit is kg, where 1900Kg is taken, b is the width of the track shoe, unit is meters, taken as 0.5m. After calculation, the ground specific voltage is 11.6 Kpa. The pressure of a person on the ground is approximately 3.5 Kpa when landing on a single foot and 17 Kpa when landing on both feet. Under this working condition, the specific pressure of the track to ground is between that of a single foot and that of both feet, meeting the requirements.

The traction force required for a single track based on a maximum climbing angle of 30 ° is:

$$N > \frac{G \sin\theta}{2} \times 9.8 = \frac{2000 \sin 30}{2} \times 9.8 = 4900 \quad (6)$$

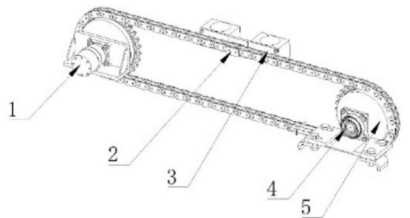
The required traction force for climbing the entire machine is 4900x2=9800N.

3.3 Jet swinging mechanism



1.Jet mechanism frame 2. swing frame 3. lifting guide mechanism 4. lifting motor 5. left and right moving guide rod 6. water separator 7. lifting guide rod sleeve seat 8. jet nozzle 9. baffle 10. guide rail

Figure 2. Structure diagram of jet swinging mechanism



1. Swing motor 2. Connecting pin shaft 3. Sliding bearing assembly 4. Driven wheel support seat 5. Sprocket chain assembly

Figure 3. Sprocket Chain Drive Mechanism Diagram

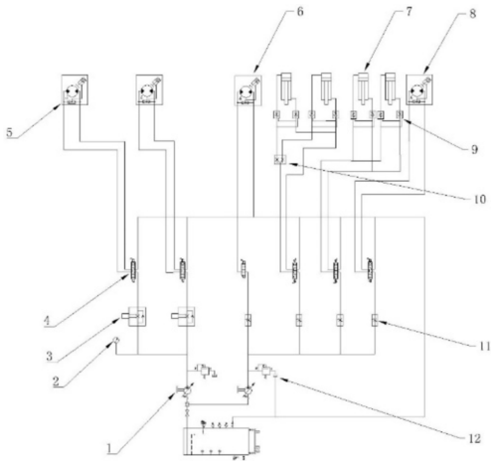
Figure 2 shows the structural diagram of the jet swinging mechanism, The swinging motor of the jet mechanism can drive the jet unit to move back and forth in the left and right directions, thereby increasing the coverage area of the jet and improving the recovery efficiency. The reciprocating movement not only increases the breaking force of the jet, but also avoids sludge backflow and improves the excavation rate. The actual implementation mechanism is shown in Figure 3. The lifting structure can achieve adjustable jet height to meet the operational requirements of different water depths. The lifting motor can adjust the height of the lifting guide mechanism to change the angle of the jet nozzle, which can avoid the spray unit from falling into the lotus pond and realize the harvesting of the lotus root growing obliquely.

3.4 Control System

The control module includes diesel engine start stop and speed control, hydraulic system control, and transfer case pneumatic clutch start stop control. The diesel engine is powered on to start, with one on-off control for start and stop, and one on-off control for emergency or full stop; Diesel engine speed control is an analog quantity. Adopting electric regulation control speed regulator, 24V DC input power supply, voltage signal 0-5V input control. The speed control method is proportional controlled through a proportional speed control valve.

The pneumatic system module provides power for the integrated pneumatic clutch of the transfer case, The diesel engine comes with an air pump, which is filtered by a triple valve and then fed into the air storage tank, connected to the transfer case air guide faucet, The air faucet is connected to the air circuit switch to control the start and stop of the transfer case pneumatic tire clutch. When the speed ratio between the transfer box and the hydraulic pump output port is 1.2:1, decelerate; When the speed ratio to the output port of the sewage pump is 1:1.16, it is the growth rate.

The hydraulic system includes left and right track hydraulic motor circuits, four linkage lifting hydraulic cylinder circuits for the entire machine, jet module swing circuit, jet module lifting circuit, etc. Hydraulic, pneumatic, and electric joint control, remote control for synchronous lifting and turning of the entire machine, suitable for operations in different water depths, especially shallow water areas. Three steering modes of the entire machine can be achieved through proportional speed control valve for speed regulation. Realize sharp turns, fast turns, and larger radius turns. The PLC integrated touch screen and RF module can achieve manual remote control of touch screen operations at a distance of 1000m, dynamically adjusting the harvesting process. The schematic diagram of the hydraulic system is shown in Figure 4.



1. Variable displacement plunger pump 2. pressure gauge 3. proportional speed control valve 4. three-position four-way electromagnetic directional valve 5. left and right moving motor 6. chain swing motor 7. four linked lifting hydraulic cylinder 8. jet mechanism lifting motor 9. hydraulic control one-way valve 10. diversion valve 11. manual speed control valve 12. overflow valve

Figure 4. Principle of hydraulic system

4 Test and Result Analysis

4.1 Simulation analysis

The process of CFD simulation analysis is as follows: using the Fluent software DM module to establish a two-dimensional model of jet simulation, draw the air and soil parts, divide the geometry module into the phase domain, and then mesh it. The solution process is set: the initial conditional period T=360 time step and water velocity v=15m/s are set, the key moments in the cycle are simulated and analyzed, and the velocity flow field and pressure are analyzed at nine times of time of time of T = 10, T = 50, T = 90, T = 130, T = 170, T = 210, T = 250, T = 290, T = 330. When T = 130, the velocity begins to decay, and when T = 210, the vortex phenomenon begins to appear. The pressure at the inlet is large, and the area with the greatest pressure is concentrated at the nozzle flow channel inlet. As shown in Figures 5 to 7, the jet of water produces a vortex phenomenon in the soil, which is conducive to agitating the soil, so that the soil around the lotus root is better separated from the lotus root, thereby improving the harvesting efficiency and digging rate of the lotus root.

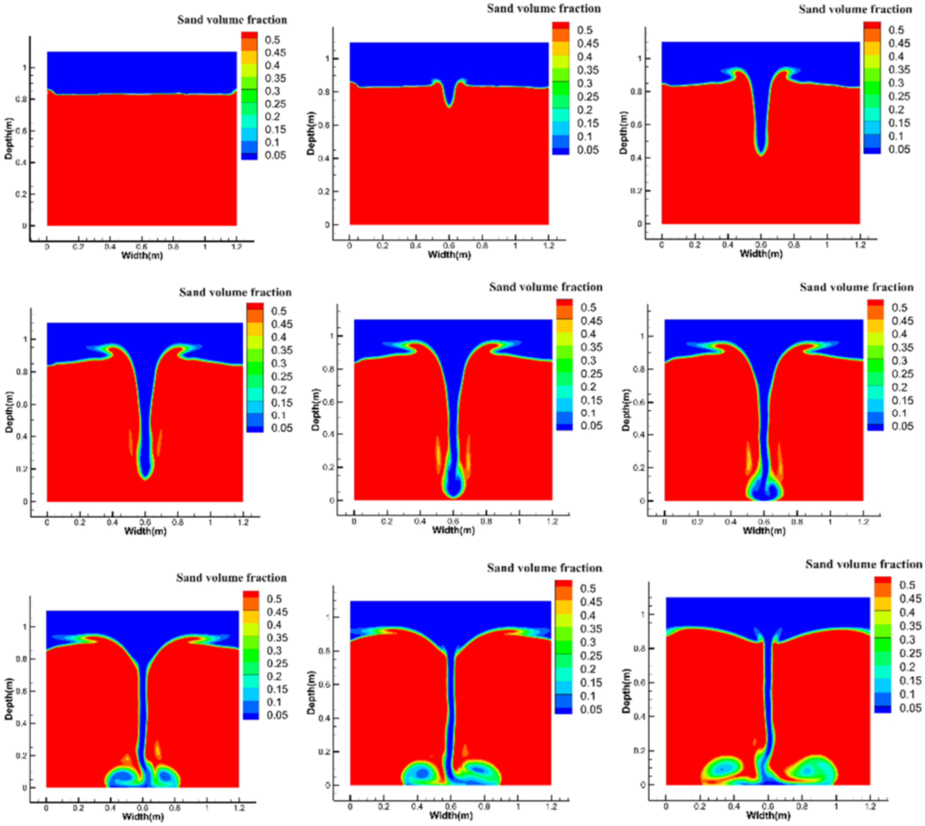


Figure 5. Diagram of spray sediment state at different time

As shown in Figure 6 water velocity vector, the jet water flow forms a water flow that diverges to both sides, the water flow is vertically downward, and it presents a vortex-like flow state driven by pressure, which reduces the adhesion force on the internal surface of the soil and achieves the purpose of dispersing the soil particles. Figure 7 is a schematic diagram of the water velocity vector at different time steps of the sediment horizontal line of the injection unit. 0.6m is the central axis of the incidence, when the time step T = 10, the overall horizontal line from a relatively stable state began to change, with the increase of time step, when the time step T = 50, the horizontal line occurs large oscillations, can be seen from the shape of the curve at different moments, in the time step T = 130, the speed begins to attenuate, when T = 210, the vortex phenomenon begins to appear. Its speed shows a tendency to increase and then decrease, and then oscillate in a relatively stable range. Among them, the characteristics of the shape change of the central axis can clearly distinguish the relative time range of the beginning of the vortex.

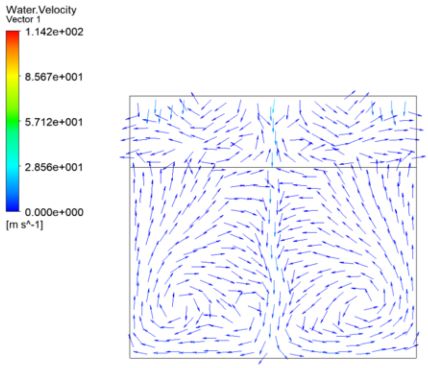


Figure 6. Flow velocity vector

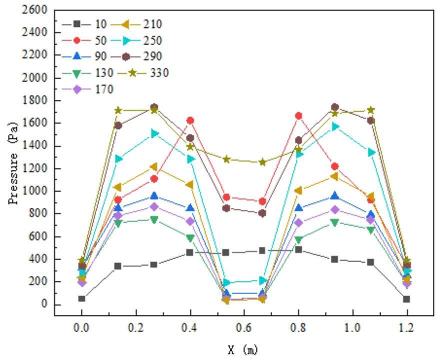


Figure 7. Sediment horizontal line pressure vector with different time steps

4.2 Field trials

In order to verify the actual field performance of the lotus root harvester, a lotus root field harvesting experiment was conducted in Huanghekou Town, Dongying City, taking the net rate, damage rate and fuel consumption rate of lotus root as the main performance indexes. Figure 8 shows the field experiment, During the experiment, two adjacent and similar lotus pond were used to dig lotus root with artificial water gun and machine simultaneously to carry out man-machine war. At the end, the excavation efficiency and damage rate of the two groups were compared. The working efficiency of the lotus root harvester is eight times that of manual harvesting, but the cost is not half of the cost of the manual team, and the damage rate of lotus root is less than that of manual harvesting. This verified the practicality and efficiency of the intelligent lotus root harvester. The comparison of the results between the two groups of experiments is shown in Table 2.

Table 2. Cost accounting of intelligent lotus harvester

project	Joint team	Lotus root extractor
Job labor	5	1
Labor cost (Yuan /h)	50	50
Working hours (h)	0.5	0.5
Electricity/Fuel (Yuan)	5	60
Quantity of lotus root (kg)	102.95	155.50
Damage rate (%)	5%	1.5%
Cost of picking lotus root (Yuan /kg)	1.26	0.55
Efficiency (kg/h)	40.80	311
Total cost (Yuan)	130	85

Figure 8. Field Lotus Root Harvesting Experiment

5 Conclusion

A fully hydraulic intelligent lotus root harvester was designed to address the harsh working environment of muddy water in the lotus pond. It uses a proportional hydraulic pump, proportional speed control valve, directional valve, and low-speed high torque motor, Forward and reverse control and hydraulic flow adjustment control achieve forward, backward, turning, and speed changes, accurately adjust speed and direction, and no crawling at low speeds.

Wide rubber engineering track+ box buoyancy+ linkage lifting device. The buoyancy box provides buoyancy to avoid damaging the lotus root and sinking the entire machine. It has a bottom supporting function. The wide rubber engineering track reduces the grounding pressure, and the linkage lifting device lifts the buoyancy box, making it suitable for obstacle crossing.

Hydraulic, pneumatic, and electric joint control, remote control of low-pressure and high flow jet, chain reversing jet swing mechanism to achieve swinging jet, integrating chain reversing, lifting, and jet, The conical nozzle can rotate the jet, and through field experiments in lotus ponds, the harvesting depth can reach 0.3 to 1.2m, the operating speed in lotus fields can reach 1.6 m/min to 8m/min, and the average working efficiency is 1 mu/h, which is eight times the efficiency of manual lotus root harvesting. The lotus root harvesting rate of the lotus root harvesting machine is greater than 95%, and the damage rate of lotus root is less than that of artificial harvesting. The lotus root picking machine has excellent results in lotus field experiments and stable working performance.

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