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Bionic soil deep pine robot

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Abstract: *Addressing the issue where the current soil deep loosening machines fall short in performance, leading to the need for multiple machines to operate collectively and consequently reducing work efficiency, a bionic soil deep loosening robot has been innovatively designed. This robot is inspired by nature's principles and is intended to optimize the soil tilling process, enhancing productivity and minimizing the need for multiple machines to work in tandem. By incorporating bionic elements, it aims to revolutionize agricultural soil preparation.*

Keywords: *bionic elements, soil deep loosening, robot*

1. Introduction

In view of the problem that the farmland effect is not ideal when the existing soil deep loosening machine cultivates, a bionic soil deep loosening robot is designed. Through the combined movement of the ring oid and longitudinal muscle structure, and the control device of the robot, use the surface structure of sand fish and earthworm, the physiological structure of the surface, and reduce the surface wear of the device, and plan the route with the RRT algorithm to ensure that the robot does not collide with the hard foreign body during the operation, causing the damage to the deep loose head[1].

2. Purpose of research

Due to the incorrect use of chemical fertilizer in the past production process and the unreasonable tillage mode, the soil was damaged, and the tillage layer became shallow and the plough layer hardened. Now, the national government vigorously promotes the effect of mechanical deep loosening to loosen soil, retain water and moisture, and promote the root growth of crops. As illustrated in Figure 1, the area undergoing deep loosening has been expanding year by year. To further encourage this practice, the government has also introduced corresponding subsidy policies.

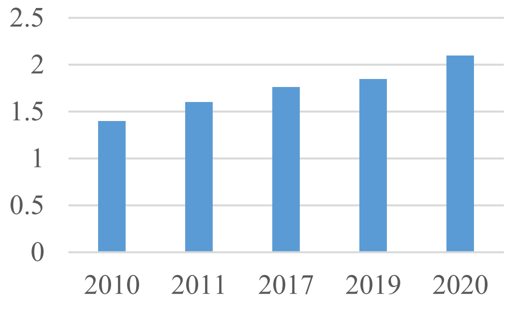

Figure 1: 2010-2020 Deep loosening area (100 million mu)

As a tillage technology to break the plough layer and improve the tillage structure by conveying soil, the purpose is to improve the ability of soil water storage and soil moisture conservation, and then boost the crop cost saving and income increase, stable yield, and help the grain storage in the ground and grain storage in the technology. Deep loosening refers to the soil loosening in 30-50cm soil layer, which can be divided into partial deep loosening and all-directional deep loosening. Comprehensive deep loosening is mainly applicable to farmland capital construction, and this paper mainly involves partial deep loosening with a wider range of application.

At present, the technical public relations of deep loosening machine is not mature enough, and can

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not achieve the sowing state of flat ground level. At the same time, because the machine is facing more wet soil, resulting in resistance at work, and there is a problem of not fully loosening the soil. In addition, because the deep pine shovel causes 25-35cm deep ditch after tillage, it is necessary to combine with other machines for shallow tillage and sowing.

3. Overall Scheme Design

The bionic robot designed based on the principles of earthworms, sandfish skinks, and rhinoceros beetles is mainly composed of a deep loose head module, drive module, loose soil sowing module, unicorn fairy bionic module, and control module. Figure 2 depicts the overall model of this innovative robotic system. Among them, the soil sowing module includes imitation digestion device and sowing device, and the deep loosening head module is divided into feeding device and rotating device.

Figure 2: Overall model diagram of the bionic earthworm robot

When the device is in normal operation, most of the soil is swallowed through the feeding device of the deep loose head, and a small part of the soil is pushed around. Most of the soil enters the intestinal imitation device, loosening the soil and removing the soil through the rotation of the head and the driving module.

3.1 Driver module

The module is mainly composed of ring muscle-like devices and longitudinal muscle-like devices. During movement, the earthworm propels itself through the soil by the coordinated action of its ring muscles and longitudinal muscles. The non-smooth ripple structure on its surface further enhances its mobility by effectively reducing resistance in the soil. The specific structural design of this module is illustrated in Figure 3.

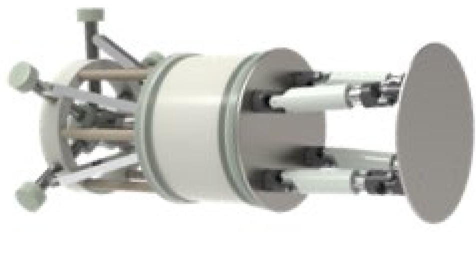

Figure 3: Drive cell model Fig

The designed cricoid device is mainly composed of drive module, vavault, support rod, slide and spring, in which the spring plays a limiting role in the device. The drive module drives the bevel gear through the rotation of the motor to the silk shaft slide bar. The rotation of the slide rod makes the slide shift in the horizontal direction, and then drives the support rod movement and the spring act together to make the support pole pop out or go back down.

The designed longitudinal muscle-like device is mainly composed of universal joints and telescopic rod, and the two ends of the telescopic rod are connected with universal joints, and the universal joints are connected to both ends of the drive compartment. Through the coordinated movement of the four telescopic rods, the earthworm moves forward and turns.

In the process of the movement of the bionic robot, the soil will be arched, and the promotion of the cricoid device will push the soil twice to achieve the effect of loose soil.

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3.2 Deep loose head module

The deep pine head module uses the bionic earthworm robot head positive prism structure to break through the soil. During the movement, the bionic earthworm robot body is twisted, and the inverted diamond structure located in the head is used to cut the soil layer around the head. The machine population rolls outward to swallow the soil and transport it to the subsequent soil loosening plant. The specific structural design of this module is illustrated in Figure 4.

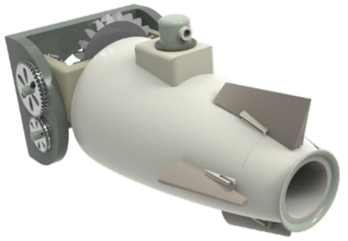

Figure 4: Structural diagram of the deep loose head module

The head of the bionic earthworm robot is designed with a fixed structure, and the prism cutting structure is fixed on the head of the robot through a slot structure similar to the mortise and tenon. The top of the prism structure changes the tip to the flat end to reduce the friction caused by the soil layer and extend the replacement cycle of the prism structure.

3.3 The monoglin module

The fiber stacking structure and hollow columella structure of the rhinoceros beetle forewing can improve the strength and rigidity of the head structure of the bionic earthworm robot, and reduce the possibility of damaging the peristalsis head of the robot to a certain extent. The specific structural design of this module is illustrated in Figure 5.

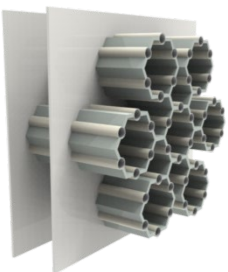

Figure 5: Schematic diagram of the microstructure of the unicorn

The internal structure of the head of the bionic earthworm robot consists of many layers, and each layer is composed of a large number of bionic small units. The units in the adjacent layer will appear a certain amount of dislocations, forming a trapezoidal structure. Each small cell contains six columella structures, which are distributed on the wall surface of the honeycomb structure. The columella structures are connected by the honeycomb surface. The ratio of the side length of the honeycomb cell and the outer radius of the columella is 4.

3.4 Pine soil sowing module

Through the movement of the head to swallow the soil into the intestinal imitation device, mainly composed of hoses and pushing mechanism. Considering that the intestinal peristalsis of the earthworm's digestive system can crush the soil, a push ring is now designed to connect the slide with a slightly smaller diameter than the hose, and the motor drives the slide by moving on the hose.

The push ring is controlled by the electromagnetic device, a section is installed with a permanent magnet, and a section is installed with a permanent magnet that can control the positive and negative magnetism. When the push ring pushes it to the end, the reverse magnetic force will push the ring to release. Through the motor movement, the forward magnetism will push the ring closure.

A seeding device is installed at the end of the bionic robot, which consists of a seed storage box, pipes and two layers of sieve mesh. The size of the pipeline is slightly larger than a seed, and the baffle is controlled by the control module and the seed outflow is controlled. When the seeds flow from the pipeline to the six-hole sieve plate, conduct one screening, and then fall into the lower one-hole sieve plate for secondary screening to ensure that only one seed falls into the soil for sowing.

3.5 Control module

During the normal operation of the device, the deep loose head is controlled to make the bionic robot spiral movement. The positioning device is set inside the device. When the robot is found to reach the highest point, the seeding device is controlled to open the baffle and sow the seeds.

Considering the possible presence of stones in the cultivated soil, induction devices were installed inside the deep pine head. When there is no pressure in the imitation intestinal structure, it means that the device has not swallowed the soil.

4. Feasibility analysis

4.1 Surface-blocked analysis of biomimetic robots

The structure form of the bionic robot consists of support structure, driving structure, control structure and sensing system. The connection between the joints is made together with rubber protective sleeve to prevent sediment and water from entering the structure and ensure the normal operation of the bionic robot. The surface of the robot adopts the corrugated non-smooth structure of the bionic earthworm surface, and the link structure in the middle design forms a macro non-smooth structure; a large number of staggered fine pattern structures are distributed between the links to form a secondary corrugated non-smooth structure, reducing the resistance [2] during the robot operation.

The effect of earthworm surface is: contraction state, resting state and diastolic state. After wrapping the joints with rubber on the surface of the robot, the body shrinkage pattern is reduced by 29% and the head shrinkage pattern by 39% compared with the steel pattern [3].

4.2 Force analysis of head drilling structure

Each small unit contains six columella structures, which are distributed on the wall surface of the honeycomb structure. The columella structures are connected by the honeycomb surface. The ratio of the side length of the honeycomb cell to the outer radius of the small pillar is 4. At this time, the columella structure is distributed in the middle part of the original honeycomb wall to produce the maximum deformation of the honeycomb wall; the wall structure improves the torsional deformation resistance of the unit. The honeycomb wall provides a lateral support for the columella to prevent the columella from breaking [4-6] due to the large bearing force.

$$U_C = \frac{\int_0^D \sigma A d\delta}{V_c} \tag{1}$$

$$\delta = \varepsilon h \tag{2}$$

Where: U_c is the deformation energy per unit volume of the core layer, J;

σ Is the average stress of the core layer, and N;

A is the section area of the plate core layer, m^2;

δ The longitudinal deformation of the core layer;

h is the core layer height, m;

D is the corresponding displacement of the stress of the core layer to 85%, m;

V_c is the volume of the core layer, m^3.

From the above formula: [7], the compressive strength of the core layer is about 151MPa, and the energy consumption per unit volume of the core layer is about 13.1MJ/m^3.

It can be seen from the literature data [8] that the bionic robot receives the maximum shear force at 300-500mm. When the robot moves, the head structure stress analysis in the soil layer is illustrated in

Figure 6.

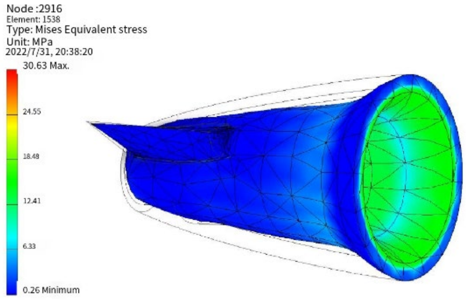

Figure 6: Analysis of stress stress of robot earth-breaking module in deep soil motion

4.3 Analysis of the robotic soil-loosening efficiency

The robot mimics the digestion mechanism of the earthworm, which uses the extrusion, opening and closing of the electromagnet and the vibration generated by the robot movement to achieve the effect of loose soil. Earthworms mainly rely on the interaction of cyclic muscles and longitudinal muscles to make the body peristalsis crawl, and can retreat in the opposite direction, periodically repeating the above movements to control the body to advance and retreat. The bionic earthworm robot uses the motor to drive the bical gear through the drive module, and the bical gear drives the wire rod. The reciprocating motion drives the robot to move between the soil layer, constantly drilling and cutting the soil and swallowing the soil into the imitation digestion device for further extrusion and loosening.

The robot imitation digestion device consists of stomach bag and electromagnetic extrusion. When the robot moves, the deep loose head structure on the head constantly cuts the soil, and the robot is constantly moving[9].

$$F = \frac{SB^2}{2\mu} \tag{3}$$

Where: F is the magnetic field force, and N;

B is the magnetic induction intensity of the air gap, T;

μ Is the magnetoresistance, and the H/m.

From the above formula: when μ is $4\pi\times10^{-7}$ H/m, S is $0.1m^2$, and B is 0.013T, the magnetic field force of the extrusion soil is 13.46N.

The robot moves 12 times per minute, each time moving 0.2-0.3m. The robot can move 144-216m per hour, and the cross-sectional area of the bionic robot is $0.06m^2$. It is calculated that each bionic robot can use the stomach bag to loosen the soil of $1.628\text{-}2.442m^3$ per hour.

4.4 Feasibility analysis of obstacle avoidance control

In the process of deep soil loosening, the surface soil layer of the soil is often used. In this part, there are often some hard foreign bodies such as metals, stones or semi-buried obstacles, which will cause serious damage to the farming machine. The feeling part of the design of this device is the NDT technology.

The GPR technology is used not to detect the underground hard objects by the high-frequency radio in the 10MHz~2.6GHz range. This technology mainly uses the basic theory of electromagnetic wave, which can be expressed by the Maxwell system of equations:

$$\nabla \times E = -\frac{\partial B}{\partial t} \tag{4}$$

$$\nabla \times H = \frac{\partial D}{\partial t} + J \tag{5}$$

$$\nabla \cdot D = \rho \tag{6}$$

$$\nabla \cdot B = 0 \tag{7}$$

Where: E is the electric field intensity vector, V / m;

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B is the magnetic induction intensity vector, T;

H is the magnetic field strength vector, A/m;

D is the electric displacement vector, C/m2;

J is the current density vector, and A/m;

ρ Is the charge density, and C/m3;

t is time, s;

∇ is the del vector operation, called the gradient operator.

Through the above system of equations, the kinematics and dynamics of the electromagnetic field can be roughly determined, but the limited relationship between the elder brother field quantity and the field quantity is not determined, and the following formula is applied:

$$D = \varepsilon E \tag{8}$$

$$J = \sigma E \tag{9}$$

$$B = \mu H \tag{10}$$

Where ε, σ, and μ represent the dielectric constant (farah per meter, F/m), electrical conductivity (Siemens per meter, S/m), and magnetic conductivity (Henry per meter, H/m) of the material, respectively.

After finishing, it can be obtained from:

$$\nabla \times \nabla \times E + \mu\sigma \frac{\partial E}{\partial t} + \mu\varepsilon \frac{\partial^2 E}{\partial t^2} = 0 \tag{11}$$

$$\nabla \times \nabla \times H + \mu\sigma \frac{\partial E}{\partial t} + \mu\varepsilon \frac{\partial^2 E}{\partial t^2} = 0 \tag{12}$$

Thus, the formula of the electromagnetic wave propagation law is obtained. For the GPR system, the antenna is the bo source. With the change of the current density in the antenna, the electromagnetic wave is constantly generated and radiated outward, and the propagation speed of the electromagnetic wave is:

$$v = \frac{1}{\sqrt{\mu\varepsilon}} \tag{13}$$

The current density in the line changes, constantly generating electromagnetic waves and radiating outward, and the propagation speed of the electromagnetic wave is calculated using the algorithm depicted in Figure 7.

Figure 7: A Schematic representation of the gprMax runs based on the Python environment

Finally, it is found that the size has a great influence on the detection. The larger the size of the hard foreign body, the stronger the reflection model is. At the same time, with the increase of the burial depth, the reflection signal decreases, but it can work well in the spherical area of 0.1-3m. As can be seen from the above, GPR technology can be used to generate the soil condition in the deep loosening area, and plan the operation route for the robot in advance.

5. There is already a foundation

Based on the current situation of soil remediation work in China, this project designed a bionic soil deep loosening robot. At present, there is a deep loosening machine to complete the deep soil loosening,

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but it needs to work with other machines, and the operation cannot be automated. The whole process is inefficient and the existing machines do not pay attention to the design structure to extend the service life of the device. In this project, we consulted relevant materials, combined with a variety of mechanical structures and control methods, and finally designed this bionic soil deep loosening robot.

Existing conditions: at present, the motion part of the device is based on the soft robot, and its relevant control operation code is relatively mature, which has been used in the field for many times.

Lack conditions: lack of field investigation, further access to relevant information, and in-depth field investigation, further optimize the design machinery, to match the working environment, to achieve better working results.

6. Conclusions

The bionic earthworm peristaltic forward mode of this device can be applied not only in the underground moving mode of deep soil loosening, but also in the transportation field. In the field and other fields of chemical engineering, the auxiliary transportation of liquid in the device can also play a stable role, ensuring that the transportation process is more stable, more safe, more rapid, and improving the overall transportation efficiency.

If appropriate improvements are made, the infrared detector and the surface hardness will be improved, and the motion module of the device will be used for the detection of the disaster relief site to assist the process of disaster relief and rescue. The internal structure of the deep loose head module can be used for robot lightweight or aerospace material improvement.

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