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A Bionic Pelican-based Rice Field Channeled Applesnail Egg Removal Robot

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Abstract: This study introduces a biomimetic robotic solution for automatically removing golden apple snail eggs from rice plants. Inspired by the pelican, the robot integrates an intelligent recognition module, a motion module, and a biomimetic cleaning module. Using image recognition and water propulsion, the robot locates and removes snail eggs efficiently.

1. Introduction

A robotic solution inspired by the pelican for removing attached golden apple snail eggs from plant stems and leaves has been designed to address the difficulty of removal. The robot consists of an intelligent recognition module, a motion module, and a biomimetic cleaning module. The intelligent recognition module utilizes image recognition and distance measurement to locate the pink golden apple snail eggs on the stems and leaves. The motion module employs the webbed feet of a pelican and utilizes the reactive force of water to propel the device forward. The biomimetic cleaning module comprises three steps: grasping, scraping, and collecting. With the assistance of the positioning device, the grasping arm of the biomimetic pelican controls the stems and leaves, utilizing the periodic motion of the crank-slider mechanism to scrape the eggs repeatedly. The dropped golden apple snail eggs are collected and processed in the collection bag under the lower jaw of the biomimetic pelican. This device achieves automatic removal of golden apple snail eggs in rice fields, maintaining field safety and reducing the inconvenience of manual removal of invasive golden apple snail eggs, thereby demonstrating practical application value[1-3].

2. Research Objective

The golden apple snail, as one of the highly invasive alien species in recent years in China, has caused significant harm due to its strong adaptability, rapid growth and reproduction, wide-ranging diet, and strong survival and competitive abilities. It has already become a serious problem in many parts of southern China, severely affecting local ecological balance and the growth of aquatic plants, thereby seriously impacting the safety of aquatic food crops, especially rice. On May 31, 2022, several relevant departments in China jointly reviewed and promulgated the "Management Measures for

Invasive Alien Species," highlighting the control of golden apple snail eggs as a key issue, as shown in Figure 1.

Figure 1: Images of golden apple snail eggs on rice stems and the pelican.

3. Design of the Solution

3.1 Device Design

The robot primarily biomimics the biological characteristics of pelicans and is designed with an intelligent recognition module, biomimetic webbed feet motion module, and biomimetic cleaning module. The intelligent recognition module comprises image recognition device and distance measurement device; the biomimetic webbed feet motion module utilizes the form of pelican's webbed feet to propel the device forward through water displacement; the biomimetic cleaning module mainly consists of a gripping device, scraper, and collection device. The overall device achieves the processing and recovery of attached golden apple snail eggs.

3.2 Intelligent Recognition Module

The intelligent recognition module utilizes cameras on both sides of the device to capture image information, which is then processed by the internal information processing control unit. Employing a sequential method of image processing, it distinguishes between rice seedlings and golden apple snail eggs. Additionally, it incorporates distance measurement for the gripping device and recognition block, as well as obstacle avoidance functionality during device operation.

This module mainly consists of an image recognition device and a distance measurement device. As golden apple snail eggs typically adhere to crop stems in irregular clusters, a sequential algorithm is applied for image processing. Initially, the algorithm scans to identify pixels with grayscale differences meeting predefined threshold values. In a subsequent scan, normalized processing is applied to locked pixels, with calculations performed on each matching difference pixel point selected randomly. This process continues until the cumulative difference exceeds another threshold, effectively identifying golden apple snail eggs within the range.

For distance measurement, image-based ranging is employed. Analysis is conducted by capturing images of the same location at two different times, leveraging the device's smooth movement on the water surface. With the two cameras approximated as two parallel optical axes, changes in the vertical angle relative to the direction of travel are utilized to calculate distance[4-6].

3.3 Biomimetic Webbed Feet Motion Module

This module replicates the motion characteristics of a pelican's webbed feet and comprises biomimetic webbed feet, stepper motors, waterproof dual-axis servos, and related structures. The overall structure utilizes high-strength, water-resistant POM plastic, known for its hydrophobic properties and low friction coefficient, effectively reducing water resistance and enhancing propulsion efficiency to some extent.

The dual-axis servos are connected in a manner that ensures synchronous movement of the webbed feet mounting brackets, preventing potential instability in the device's heading due to variations in motor frequency and minimizing the risk of damaging crops in the field. The webbed feet are designed with an inverted cup structure, facilitating the assembly of smooth, high-strength rubber skins in an inverted configuration to enhance forward propulsion, as shown in Figure 2.

Figure 2: Images of Biomimetic Webbed Feet Motion Module.

This device addresses the issues encountered with previous field devices that used track mechanisms, which suffered from rapid wear due to water exposure and the risk of getting stuck in mud and water. Additionally, it resolves issues related to changes in device movement caused by shifting centers of gravity during operation. As the device moves, the biomimetic webbed feet adjust their angles for propulsion or halt, while stepper motors at the base of the legs control their movements for steering purposes.

3.4 Biomimetic Cleaning Module

The biomimetic cleaning module is primarily inspired by the upper body of a pelican, mimicking its upper and lower jaws. It utilizes a gripping device to stabilize rice stems and leaves, while a linkage mechanism composed of crank-slider structures enables the repetitive scraping action of dual-directional blades. This scraping action dislodges golden apple snail eggs, causing them to fall into a "collection bag" mimicking the pelican's lower jaw, thus facilitating their retrieval.

The overall device consists mainly of a worm gear, vertical rotation shaft, hydraulic rod, scraping platform, biomimetic collection bag, planar four-bar linkage, gripping platform, and gripping hands.

When the intelligent recognition module identifies the location of golden apple snail eggs through image recognition and distance measurement, a motor drives the worm gear to rotate, thereby rotating the worm wheel. Once the rotation reaches the required angle, another motor drives the vertical rotation shaft to rotate the entire device within the vertical plane. The directional rotation of the vertical rotation shaft aligns the gripping hands with the targeted stems or leaves. Meanwhile, the hydraulic rod adjusts vertically, positioning the gripping device 3-5cm above the targeted area. With the arms adjusted using screws, the gripping device laterally grasps the stems or leaves.

After gripping the targeted area, a motor on the scraping platform drives gears to rotate, activating the reciprocating motion of dual-directional blades on the crank-slider mechanism. This motion enables the scraping of golden apple snail eggs, which then fall into the biomimetic collection bag located under the pelican's lower jaw, completing the collection process.

3.5 Gripping Device

The gripping device section is primarily inspired by the way a pelican's upper jaw grasps fish, designed for grasping rice stems and leaves. This gripping device mainly consists of a hydraulic rod, gripping platform, motor, gripping arms, and shock-absorbing support arms.

To ensure the stability of rice stems or leaves and prevent difficulties in force application due to the softness of leaves, a top-down gripping method is employed. Using information from the intelligent recognition module regarding the distribution of golden apple snail eggs on a whole stem, a point approximately 3-5cm below the topmost egg is selected for gripping. The hydraulic rod ensures alignment, and then a motor on the gripping platform drives a clockwise screw rotation. The gears symmetrically mesh with the screw, controlling the arms to extend forward and open outward through four linkages, as shown in Figure 3.

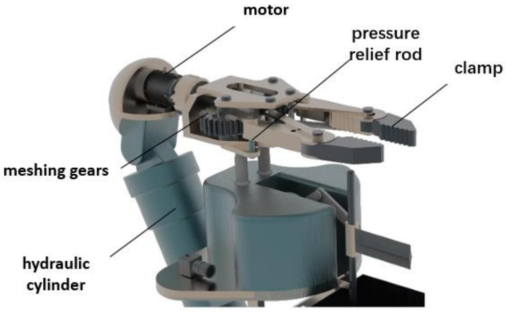

Figure 3: Images of Scraping Device

As the stem or leaf enters the central region between the two gripping arms, the motor drives the screw counterclockwise, closing the arms. Rubber soft layers are installed inside the gripping arms to prevent damage to plants. The required gripping force can be determined through experiments to achieve a certain degree of stiffness while ensuring that the leaves are not damaged. The shock-absorbing support arms, connected to the scraping platform via telescopic piston rods, are used to cushion the inertia generated when the vertical rotation shaft stops rotating.

3.6 Scraping Device

The scraping device section is primarily inspired by the hook-like part of a pelican's upper jaw used to capture fish. It is designed as a scraping device driven by a crank-slider mechanism. The device mainly consists of a scraping platform, welding rods, motor, crank-slider mechanism, dual-directional blades, planar four-bar linkage, slider fixing rod, camera, and other components.

The scraping platform is connected to the hydraulic rod via welding rods, enabling both vertical and vertical-plane movement. A planar four-bar linkage structure beneath the scraping platform provides support and facilitates its up-and-down movement. As the hydraulic rod moves downward, it drives the scraping platform downward, exerting force on the connecting rods below. This force causes the planar four-bar linkage structure to flatten, providing support while allowing the platform to move up and down.

Internally, the scraping platform consists mainly of the crank-slider mechanism and a motor. The crank-slider mechanism is positioned approximately 2cm below the gripping mouth and initially held above the slider rod by a limiting block. Once the gripping device is secured, the limiting block is released, allowing the motor to rotate the gear, which in turn rotates the disk. This rotation causes the fixed linkages on the disk to rotate, driving the connecting rods to move the slider up and down. As a result, the dual-directional blades on the slider move up and down, performing a reciprocating motion 3-5 times before stopping. The slider then moves back to the top, and the limiting block closes. This process is repeated by the up-and-down movement of the hydraulic rod, enabling the removal of golden apple snail eggs beneath the stems or leaves.

3.7 Collection Device

The collection device primarily mimics the "collection bag" formed by the lower jaw of a pelican, designed to collect the golden apple snail eggs removed by the scraping device for the extraction of astaxanthin. The collection bag consists of two layers: an outer layer made of organic gelatinous material, which forms wrinkles as it expands and contracts, and an inner layer made of PE plastic bags. The inner layer allows for easy replacement when collecting golden apple snail eggs, ensuring convenient handling of the collected material, as shown in Figure 4.

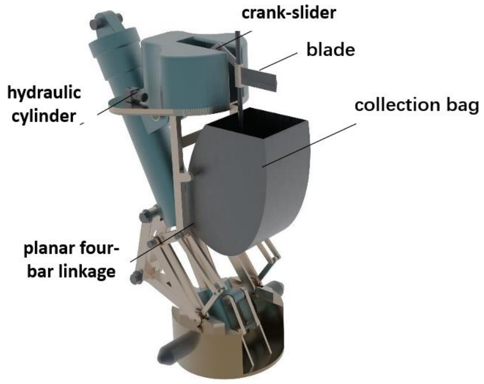

Figure 4: Images of collection device

4. Feasibility Analysis

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

4.1 Analysis of the Intelligent Recognition Module

According to the Young-Helmholtz theory, the three primary colors have a high color resolution. In practical application scenarios, the main body of the golden apple snail eggs is red, while the hatching part is pink or white, creating a significant contrast with the green color of rice seedlings. Therefore, when estimating grayscale values, there is a significant difference between the grayscale values of red and green, making the identification of golden apple snail eggs simpler and more accurate. By leveraging this color contrast, rice seedlings can be effectively distinguished from golden apple snail eggs, achieving the goal of localization.

In contrast to measuring the distance to rice seedlings with golden apple snail eggs in rice fields, a tree image-based distance measurement method using binocular vision is employed. This device utilizes two horizontally aligned cameras of equal height, converting the vertical plane coordinate system into a horizontal Cartesian coordinate system. By applying a similar process to the original measurement method, the algorithm is adapted for use in this device.

The following formula represents the correlation formula obtained through image recognition:

$$R(a,b)=\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}X_{ij}Y(a,b)_{ij}}{\sqrt{\sum_{i=1}^{m}\sum_{i=1}^{n}X_{ij}^{2}}\sqrt{\sum_{i=1}^{m}\sum_{i=1}^{n}Y^{2}(a,b)_{ij}}} \tag{1}$$

In the formula, X_{ij} and Y_{ij} represent the pixel points of the reference image, ranging from $m\times n$ to $M\times N$ ($M>m$, $N>n$);

In the formula, (a,b) represents a randomly selected center point.

Wherein, when $R(a,b)$ exceeds the specified threshold, the block stops marking, and the area beyond the correlated pixel points is identified as the attachment area of the golden apple snail eggs, and marked as the clearance area.

4.2 Biomimetic Flippers Motion Module Analysis

The thin membrane of the flipper in this device is made of elastic and flexible material, facilitating fine adjustments of the flipper's claw. The following equation represents the control equation for the flipper's claw [7]:

$$H(t) = h\sin(2\pi f t) \tag{2}$$

$$M(t) = J\theta \tag{3}$$

In the equation:

(t) represents the vertical distance of the device relative to the pivot axis, measured in meters (m).

h represents the maximum distance the flipper can float upwards, measured in meters (m).

t represents the running time, measured in seconds (s).

J represents the rotational inertia of the flipper, measured in kilograms times meters squared (kg m ^{2}).

θ represents the angular velocity of the flipper, measured in radians per second squared (rad/s ^{2}).

M(t) represents the torque generated by hydrodynamic forces acting on the flipper.

This equation is utilized to design the fiber bending of the flipper using dual-axis servo motors. It ensures that there is a limit to the bending angle when the flipper rotates. When the torque starts to reverse, the servo motor reverses, and the entire locomotion structure enters the recovery phase. With reference to biomimetic gaits, the swinging angle is controlled to be around 90°, with an upward amplitude of approximately 5cm.

The following equation describes the relationship between the overall size of the foot and the maximum propulsion force generated by the fluid [8]:

$$F_{\text{[illegible]}} = 0.5\rho C_D \int_0^l c\sin\alpha_1(\omega r)dr \tag{4}$$

$$F_{\text{[illegible]}} = 0.5\rho C_D \int_0^L \left(\frac{b-a}{L}\right) r\sin\alpha_2(\omega r)dr \tag{5}$$

In the equation:

represents the density of water, measured in kg/m ^{3}.

represents the drag coefficient.

l represents the length of the flipper frame, measured in meters (m).

c represents the width of the flipper frame, measured in meters (m).

α_i represents the angle of attack of the surface, measured in radians (rad).

L represents the length of the flipper, measured in meters (m).

a and b represent the narrowest and widest distances of the flipper, measured in meters (m).

ω represents the angular velocity relative to the pivot axis, measured in radians per second (rad/s).

According to the above formula, in steady gait locomotion, the device experiences a maximum propulsion force of approximately 1N, and during the recovery process, the net force exerted on the device is approximately 0.25N. Acceleration and recovery times are assumed to be equal. Hence, the device can maintain accelerated movement at the initial stage of operation. Considering a complete device operation cycle of

T=2s and employing a synchronized swinging biomimetic gait, the device can achieve a displacement of approximately 0.084m per cycle, with a maximum velocity of around 0.11m/s.

4.3 Biomimetic Cleaning Module Analysis

Degree of Freedom Analysis

$$F = 3n - 2P_l - P_h \tag{6}$$

In the equation:
F represents the degrees of freedom (DoF).
n represents the number of active components.
Pl represents the number of lower pair connections.
Ph represents the number of higher pair connections.
For the crank-slider mechanism:
n=3, Pl=4, Ph=0. Thus, F=1,which corresponds to the driven motion by the motor.
For the planar four-bar linkage:
n=5,n=5, Pl=7,
Ph=0. Hence, F=1, which corresponds to the downward motion of the scraping platform, forming the extension and retraction of the linkage.

4.4 Clamping Motion Analysis

For the clamping device, the motor drives the worm gear to rotate, causing the two external meshing gears to rotate in opposite directions. When the worm gear rotates clockwise, the left gear of the external meshing gears rotates counterclockwise, while the right gear rotates clockwise. The linkage above the gears is connected to the bottom end of the clamping arm through a circular shaft and a connecting rod. When the gears rotate, the linkage pushes the clamping arm outward. The front end of the clamping arm is connected to the outer casing through the linkage, increasing stability. The trajectories of the two linkages are similar, pushing the clamping arm outward or retracting it inward. The force generated by the motor is approximately 0.05N.

4.5 Crank-Slider Transmission Analysis

According to reference, selecting the stroke ratio coefficient K=1.20 and the stroke of the slider H=10cm, the minimum transmission angle is 47.21°, which satisfies the requirement of the minimum transmission angle being greater than 40°, ensuring good transmission performance. At this point, the extreme angle is 16°, with a crank length of 3.7cm, a connecting rod length of 10.8cm, and an eccentricity of 3.6cm.

4.6 Innovations and Project Features

1) Application Innovation: This device applies the biological features of a pelican's beak and webbed feet to a robot designed to remove apple snail eggs from rice plant stems, enabling the robot's movement and egg removal.

2) Structural Innovation: The device mimics a pelican's structure, incorporating features such as hydraulic extension, crank-slider mechanisms, and planar four-bar linkages, enabling effective removal of apple snail eggs.

3) Integration Innovation: By combining the clamping and scraping mechanisms, with the clamping device providing support for the scraping mechanism, the success rate of egg removal is increased.

5. Conclusion

Through this study, we have successfully designed and validated a novel device for removing apple snail eggs in rice fields. By integrating biomimetic technology with robotics into agricultural ecosystems, we have provided a new solution for the biological control of apple snail eggs. Our findings not only demonstrate innovation in biomimetic structural design but also show significant effectiveness in practical applications. We believe that this research is of great significance for addressing the issue of apple snail eggs in Chinese rice field ecosystems and provides valuable insights and experiences for solving similar ecological problems in the future.

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