Research and design of automatic silkworm cocoon harvester for plastic collapsible mountage

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ABSTRACT: Silkworm cocoon harvesting manually from the plastic collapsible mountage is laborious, time consuming and inefficient, to overcome the present situation of cocoon harvesting, a novel automatic cocoon harvester with dual harvesting roller rotating in opposite direction for plastic mountage was designed. By analyzing the force on cocoon harvested with the harvesting roller, conditional equation of cocoon separated from plastic mountage was obtained, when the pressure on cocoon acted by the harvesting roller was lowest. The parameters that achieved efficient cocoon harvesting were:(1) the gap between the two harvesting rollers was 3 mm;(2) the diameter of the harvesting roller was 47.7 mm. When the harvesting roller speed was 700 r/min, 1100 r/min, 1500 r/min, one-hour continuous cocoon harvesting test was carried out. According to the experiment result, the cocoon harvester efficiency was about 8.7 times the efficiency of manual harvesting for the plastic mountage. The novel cocoon harvester can be promoted and used in sericulture areas.

1. Introduction
In 2018, the area of mulberry gardens was 790,000 hm², with an annual output of about 679,000 tons of cocoons in China [1][2]. The plastic mountage is a wave-shaped collapsible sericulture tool made of high-density polyethylene. It is one of the most widely used cocooning devices for sericulture [3]. Some kind of automatic cocoon harvester had been developed in China [4]. Wang designed a cocoon harvester for the cardboard mountage, using ejector pins to detach the cocoons from the cardboard mountage. but due to the cardboard mountage was easily deformed in the use process and it could not ensure that each ejector pin and square hole of the cardboard mountage were completely well matched, which would cause secondary damage to the deformed cardboard mountage and could not work continuously [5]. Liu developed a Cartesian coordinate automatic cocoon harvesting machine based on computer vision, which could non-destructively harvest cocoons for different type of cardboard mountages or even deformed...
ones and could identify and remove the contaminated cocoons during the cocoon harvesting process, but the cocoon harvesting efficiency of the harvester was low [6], [7], [8].

Cocoon harvesting machine for cardboard mountage had been researched and designed. But there was few relevant research and report on cocoon harvester for plastic collapsible mountage. A dual roller automatic cocoon harvester for plastic mountage was designed and developed in the paper in order to improve the cocoon harvesting efficiency for plastic mountage, reduce the labor cost, and increase the income of sericulture farmers, whose key cocoon harvesting part comprised of two rollers rotating in opposite direction[9], [10].

2. Materials and Methods

2.1. Mechanical analysis of cocoon harvesting

2.1.1. Silkworm cocoon and plastic mountage
The plastic mountage cocooning silkworm cocoons was shown in Fig.1. And the cocoons were bound on the uniform corrugation by cocoon floss.

Figure 1. Silkworm cocoons on the plastic mountage

The schematic diagram of the dual counter-rotating roller for cocoon harvesting from the plastic mountage is shown in Fig.2. The two rollers rotation speed is \( n \) in opposite direction. The speed of the flattened plastic mountage passing through the two rollers is \( v \). The tangential force of the roller on the cocoon makes the cocoon roll when cocoons move with the mountage and come into contact with the rotating roller. The cocoon rolling direction is opposite to the direction of the mountage movement so that the cocoon would be separated from the mountage and not damaged by the rotating roller squeeze.

Figure 2. Diagram of dual counter-rotating roller silkworm cocoon harvester for plastic mountage

2.1.2. Dynamics analysis of cocoon harvesting
Assuming that the flattened plastic mountage is located in the middle of the two rollers and is not in contact with the roller during the cocoon harvesting process. Therefore, there is no direct contact force between the roller and the mountage. If the long axis of cocoon is parallel to the axis of the harvesting roller, the diagram of the dynamic analysis of the cocoon harvesting is shown in Fig.3. The axial of the rollers is perpendicular to the \( xy \) plane. The gap between the plastic mountage and the roller is \( d \). The mountage moves in the \( x \) direction. The roller I rotates clockwise. The roller II rotates anticlockwise. The side of the mountage facing the roller I is referred to side A, so the roller I harvests cocoons on the side A of the plastic mountage and the roller II harvests cocoon on the other side. When the mountage passes through the dual roller, the cocoon on the side A touches the rotating roller I. The cocoon moves with the mountage when the external forces on the cocoon is less than the moment of the cocoon floss drag force during the process of cocoon harvesting. When the moment of the external forces on the cocoon is greater than that of floss drag force, the cocoon begins to roll on the mountage.
$F_c$ have no moment about lever arm OP. The instantaneous rotation center of the cocoon is the point O. When the rolling cocoon satisfies (1), the force binding cocoon on mountage by the cocoon floss reaches the maximum tensile strength so that the floss will be broken. Then, the cocoon is separated from the mountage and falls under the action of gravity.

\[ F_{n1} \sin \phi + F_{f1} \cos \phi \cdot l \geq M_{c_{\text{max}}} \]  

where $F_{n1}$ is the pressure acting on the cocoon caused by the rotating roller I, N; $F_{f1}$ is the friction between the surfaces of the cocoon and the rotating roller I, N; $l$ is the length of lever arm OP, mm; $\phi$ is the angel between $F_{n1}$ and the lever arm OP, rad; $M_{c_{\text{max}}}$ is the maximum of the moment of the cocoon floss drag force, N·mm.

$F_{f1}$ can be calculated according to (2):
\[ F_{f1} = \mu F_{n1} \]  

where $\mu$ is sliding friction coefficient.

The lever arm $l$ is expressed as:
\[ l = \sqrt{2b^2 - 2b^2 \cos(\pi - 2\phi)} \]  

where $b$ is short axis radius of cocoon, mm.

$M_{c_{\text{max}}}$ can be calculated according to (4):
\[ M_{c_{\text{max}}} = \frac{T}{2}b \]  

where $T$ is maximum force of cocoon bound on the mountage by cocoon floss.

Substituting (2), (3), and (4) into (1):
\[ F_{n1} \sin 2\phi + F_{f1} \cos 2\phi \cdot l \geq \frac{T}{2} \]  

When the force $F_{n1}$ is smaller, the force $F_{f1}$ and the mechanical power consumption of cocoon harvesting are smaller. The mechanical damage to cocoons will be smaller. It is to say that the condition of the smallest mechanical damage and the lowest power consumption is that the function $f(\phi)$ gets the maximum value when the silkworm cocoon is harvested from the mountage. According to (5), $f(\phi)$ is expressed as:
\[ f(\phi) = \sin 2\phi + \mu(1 + \cos 2\phi) \]  

The derivative of $f(\phi)$ is:
\[ f'(\phi) = 2 \cos 2\phi + 2 \mu \sin 2\phi \]  

Let $f'(\phi) = 0$, then:
\[ \phi = \frac{1}{2} \arctan \frac{1}{\mu} \]  

In addition, it can be observed from Fig.3 that $0 < \phi < \frac{\pi}{2}$, $\theta_1 = 2\phi$, and Equation (9):
\[
\frac{b}{\cos \theta} \frac{a}{c + \frac{b}{\cos \theta}} = \frac{b}{a + \frac{c - d}{2}}
\]

where \(a\) is radius of harvesting roller, mm; \(c\) is the gap between the two roller, mm; \(d\) is the thickness of mountage, mm; \(\theta\) is the angle between the line connecting the roller axis center and the cocoon’s geometry center and the negative direction of the \(y\) axis, rad.

Equation (9) can be arranged as follows:

\[
a = \frac{2b(1 + \cos 2\varphi) + d - c}{2(1 - \cos 2\varphi)}
\]

According to (8) and (10), when \(\mu\), \(b\), \(c\) and \(d\) are known, the optimal structure parameters of the radius of the cocoon harvesting roller and the distance between the two rollers can be obtained.

2.2 Overall scheme design of automatic cocoon harvester

2.2.1. Mechanical structure design

The cocoon harvester was mainly composed a fixed cocoon harvesting roller, a movable cocoon harvesting roller, an electric linear actuator, a control system, etc. The mechanical structure is shown in Fig.4.

The cocoon collecting pallet was fixed at the front of the cocoon harvester. The infrared light curtain was installed the back side. One of the harvesting rollers was fixed. The movable roller could slide on track under the push-pull action of the electric linear actuator. When the infrared light curtain does not detect the mountage, the motors for driving the harvesting rollers will be powered off, and the electric linear actuator pushes away the movable harvesting roller to prepare for feeding the mountage into the gap between the rollers. One of the operators standing in front of the harvester feeds vertically the mountage mounting cocoons into the harvester. When the infrared light curtain detects the mountage, the electric linear actuator pulls back the movable harvesting roller, the two motors power on and the two harvesting rollers rotate synchronously in different directions. At the same time, another operator standing at the back side of the harvester pulls out the mountage from the harvester. When the mountage is passing through the harvester, the cocoon contacting the cocoon picking roller rolls on the mountage under the action of the harvesting roller rotating friction force. Then the cocoon floss will be broken and falls into the cocoon collecting pallet. When the mountage is draw out the gap between the rollers, the mountage signal detected by the infrared light curtain disappears. The driving motors for the harvesting rollers will be powered off and stop. The electric linear actuator pushes away the movable harvesting roller to prepare for the next harvesting.
2.2.2. Design of automatic cocoon harvesting control system

The block diagram of the automatic harvesting control system based on STM32 controller is shown in Fig.5. The cocoon harvesting roller is powered by a 120 Watts AC220 V electric motor. The two pairs of infrared light curtains installed on the upper and lower parts of the cocoon harvester respectively detect the upper and lower edges of the plastic mountage fed to the harvester. The STM32 controller reads the detection signals of two pairs of infrared light curtains in real time. According to the signal state, controls the electric linear actuator, the two cocoon harvesting rollers to achieve automatic harvesting for the plastic mountage. The automatic cocoon harvesting control system workflow chart is shown in Fig.6.

![Figure 5. Diagram of control system](image1)

![Figure 6. Control system workflow chart](image2)

3. Results & Discussion

On October 3, 2018, the cocoon harvesting test was carried out at Tai’an Mazhuang Experiment Station of the Shandong Agricultural Industry Technology System, Shandong, China. The harvesting roller speed of the harvester was set to 700 r/min, 1100 r/min and 1500 r/min respectively. And cocoon was harvested for one hour at each speed. The cocoon harvesting data was shown in Table 1.

| Harvesting roller rotating speed (r/min) | Number of the mountage harvested for one hour | Cocoon harvested weight (kg) | Average harvesting time per mountage (s) |
|-----------------------------------------|-----------------------------------------------|-----------------------------|----------------------------------------|
| 700                                     | 203                                           | 106                         | 17.7                                   |
| 1100                                    | 209                                           | 110                         | 17.2                                   |
| 1500                                    | 212                                           | 108                         | 17.0                                   |

It could be seen from Table 1 that there was no significant difference on the cocoon harvesting efficiency when continuous cocoon harvesting tests were carried out for one hour at the different roller speeds. In other word, the rotating speed of harvesting roller had no significant effect on the cocoon harvesting efficiency. The whole process from taking a mountage to the completion of harvesting took an average of 17.3 seconds, while a skilled worker took an average of about 5 minutes to harvest manually cocoons from a plastic mountage. The average harvesting efficiency of the harvester was about 8.7 times the efficiency of manual harvesting.

4. Conclusions

Taking the minimum pressure force on the cocoon as the constraint condition and the highest cocoon...
harvesting efficiency as the design goal, the key component parameters of the cocoon harvesting roller with the diameter of 47.7 mm and the harvesting rollers gap of 3 mm were obtained by using the cocoon harvesting mechanical analysis and numerical simulation method. It was found that the dual counter-rotating roller cocoon harvesting mechanism could achieve efficient and non-destructive cocoon harvesting for the plastic mountage by analyzing the results obtained with the high speed camera experiment of cocoon harvesting. The cocoon moving manner on the surface of the plastic mountage during the cocoon harvesting was consistent with the kinetic analysis of the cocoon. The high speed camera experiment verified the correctness of theoretical design and digital simulation analysis of the cocoon harvesting mechanism for the plastic mountage.

The automatic silkworm cocoon harvester for plastic collapsible mountage improve the cocoon harvesting efficiency for plastic mountage and reduce the labor cost. It also achieve the mechanized harvest of plastic collapsible mountage. But there are still some problems that need to be perfected.

1) The automatic silkworm cocoon harvester is operated by two people. The feeding and pulling device can be designed to make the machine more labor-saving.

2) The entangled frison wound by the cocoon picking roller in the working process of machine need to be manually removed, leading to the low harvesting efficiency. A device for automatically rejecting cocoons can be designed to improve efficiency.

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