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DESIGN AND RESEARCH ON SERVOMECHANISM OF TEA PLUCKING

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Abstract.
Tea is an important cash crop in China. The contribution rate of high-quality tea is nearly 70% in tea production. The high-quality tea is harvested by hand plucking, which is inefficient and labor intensive and leads to higher costs. According to the characteristics of the tea garden and the standard of high-quality tea shoots, a tea plucking servomechanism was designed in this study. The mechanism has three degrees of freedom and can move along the direction of the X, Y, and Z axis to localize the plucking points. The components of servomechanism mainly include a frame, a three-axis truss structure, and an end effector. The virtual prototype of the three-axis truss mechanism is established through ADAMS, and the kinematics simulation is analyzed to meet the feasibility of this mechanism. It presents that there is no interference and collision between components under working conditions. The material stress analysis is applied through the ANSYS workbench. It presents the plucking process and the stress on the tea stem. These results shorten the development time and provide the theoretical basis for manufacturing the tea-picking mechanism.

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1 Introduction

Tea is the final product of tender tea shoots and has become the most popular healthy beverage world[1, 2]. In China, the total area of the tea garden is about 2.768 million hectares, and tea production is up to 2.93 million tons. The total sales reach 300 billion yuan at home and abroad per year, and the contribution rate of high-quality tea is nearly 70%. The specified morphology of high-quality tea leaves is one bud with one or two leaves(Fig.1)[3]. Additionally, the more tender the leaves are, the higher the quality and the price[4]. Besides, the plucking period is rather short, no more than one week.

In mechanical operation, tea is harvested by cutting the upper of the canopy with blades, which causes broken leaves and mixing the new and old leaves[5, 6]; furthermore, it may damage the stems and affect the germination of new shoots[7]. The mechanical harvester cannot meet the requirement of high-quality tea. Conventionally, high-quality tea is harvested by hand plucking, which is inefficient and labor-intensive and leads to higher costs[8]. Therefore, there is a growing need to design an automatic high-quality tea-plucking machine, similar to hand plucking[9]. The automation machine includes three component parts that are machine vision, servomechanism, and chassis[10, 11]. This

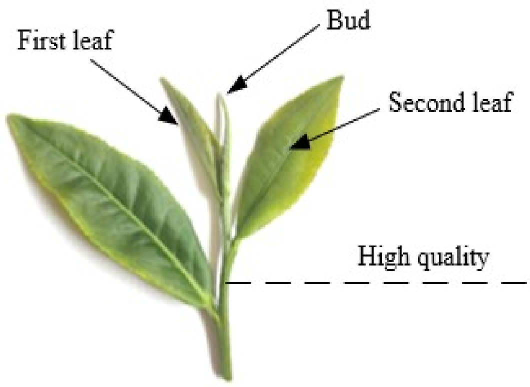

Fig. 1. Standard of high-quality tea
Рис. 1. Побег для высококачественного чая

Fig. 2. Tea garden
Рис. 2. Чайная плантация

Fig. 3. Plucking posture [12]
Рис. 3. Положение рук в процессе выщипывания

study mainly considers the design and research of the plucking servomechanism.

2 Design

2.1 General description

As shown in Fig.2, in a tea garden environment, the tea trees are planted in rows on the ground.Fig.3 presents the plucking posture[12]. In order to achieve the tea plucking servomechanism, the following specifications should be considered. Firstly, The mechanism has three degrees of freedom and can move along the direction of the X, Y, and Z axis, to localize the plucking points. Secondly, the mechanical structure should be cost-efficient and easy to maintain. Furthermore, the process of plucking should imitate the human hand plucking, which has the capability of plucking tea shoots one by one[13].

2.2 Design of main components

(1)Body frame

The breadth of the tea crown is less than or equal to 1000mm. The height of tea trees is less than or equal to 900mm. The distance between adjacent rows is about 300mm. Based on the situation of tea gardens, the installation dimensions（length×width×height）of the body frame are (1000×1100×1500)mm. The frame is made of an aluminum profile， which is easy to dismount.

(2) Triaxial truss structure

As shown in Fig. 4, the three-axis truss mechanism comprises four precision linear stages, which can realize the movement in the X, Y, and Z directions. The linear stage includes a stepping motor, nut, coupling, bearing seat, ball screw, linear guide rail, sliding block, and bedplate (Fig. 5). The ball screw is assembled with the stepping motor through the elastic coupling to convert rotational motion into linear motion of the sliding block.

(3) End effector

The experimenter took 45 samples of tender shoots, measured the different sizes of one bud with one or two leaves, and recorded the average value, as shown in Table 1. The schematic diagram of the tea sample size is shown in Fig. 6.

According to the statistics of length and width for tender shoots in Table 2.1, the working stroke of the end effector can be ascertained. In order to avoid collisions between the end effector and the tea, the vertical movement path of the end effector should be higher than 50mm, and the distance between the master arm and slave arm must be greater than 53mm when the end effector is in the open state. The end effector consists of a storage box, a stepping motor, a driving arm, and a driven arm. The top and bottom of the storage box are provided with openings (Fig. 7).

As shown in Fig. 8, The master arm and slave arm are respectively located on both sides of the tea stem. The motor drives the master arm to rotate clockwise through the gear mechanism, and the tea stem is squeezed and bent into the groove of the slave arm. The tea is broken at the clamping point. The master arm and the slave arm continue to rotate clockwise to reach the storage box and bring the tea into the storage box. The motor rotates counterclockwise, the master arm separates from the slave arm, and the tender shoots fall into the storage box to complete the tea picking action. The master

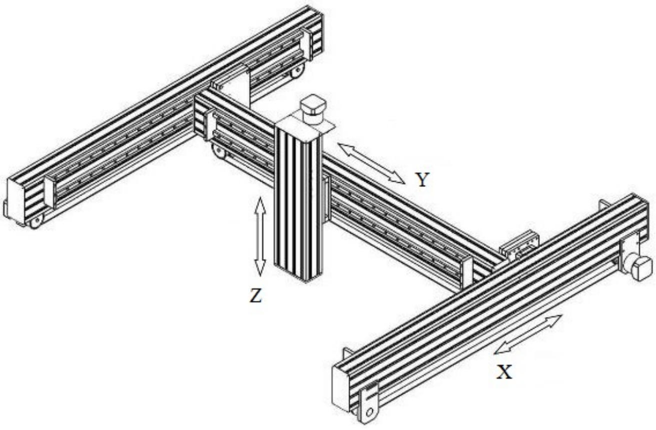

Fig. 4. Triaxial truss structure
Рис. 4. Трехосный ферменный механизм

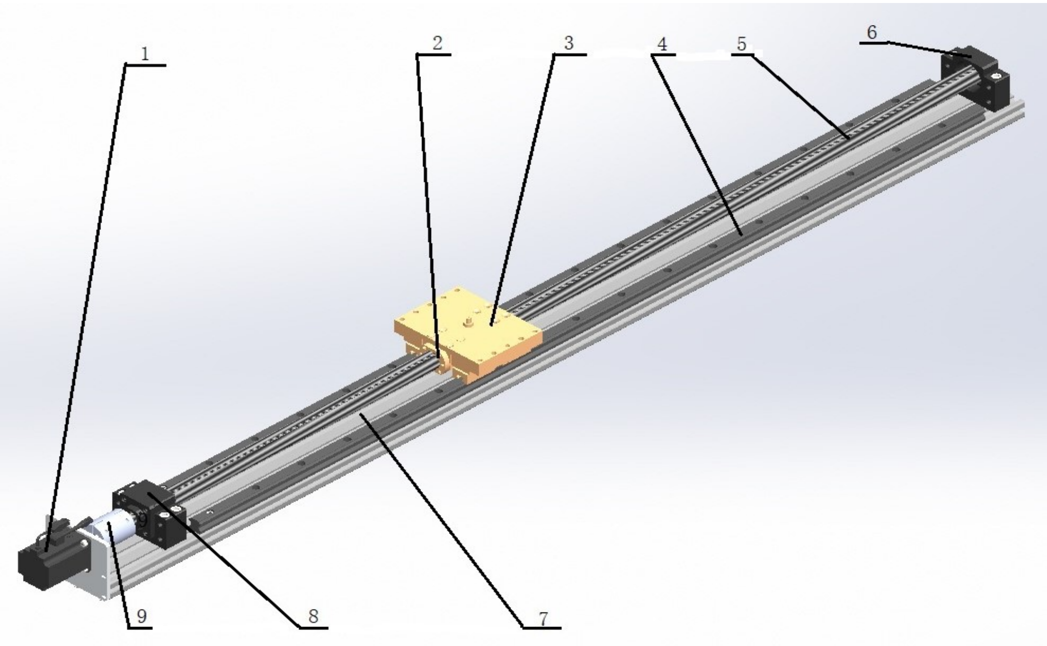

Fig. 5. Linear stage
1 – stepping motor, 2 – nut,3 – slide block,4 – linear guide rail, 5 – ball screw, 6 – bearing seat,7 – bedplate, 8 – bearing seat 9 – coupling

Рис. 5. Линейный механизм
1 – шаговый двигатель, 2 – гайка, 3 – блок скольжения, 4 – линейная направляющая, 5 – шариковый винт, 6 – посадочное место подшипника, 7 – опорная плита, 8 – посадочное место подшипника, 9 – соединительная муфта

arm returns to the initial position by motor and the driven arm by gravity.

2.3 General structure and working principle

Fig. 9 presents components of the general structure, which mainly consist of the end-effector, triaxial truss structure, and body frame. A triaxial truss structure is installed on the body frame, which is available to implement the point to the point of trajectory tracking. In x, y, and z coordinates, the end-effector is installed at the end of the Z axis. In the three-axis linkage movement, the end-effector can move along the X, Y, and Z axes to localize the picking point and pluck the tender shoots like human fingers.

3. Kinematics simulation of triaxial truss mechanism

In order to analyze the working room, the three-dimensional triaxial truss structure model established in UG is converted into Para solid(*.x_t) format and then imported into ADAMS, a virtual prototype simulation environment [14, 15]. First, setting the simulation environment, including unit, gravity, coordinate system and material properties, and so on[16]. Then, connectors of the virtual prototype, including the fixed pair, rotating pair,

Table 1. The size of tender shoots
Таблица 1. Размер молодых побегов

Morphology	Height(c)(AVG/MAX)	Width(b)(AVG/MAX)	Unit
one bud with one leaf (d_1)	27/41	32/40	mm
one bud with two leaves (d_2)	46/50	48/53	mm

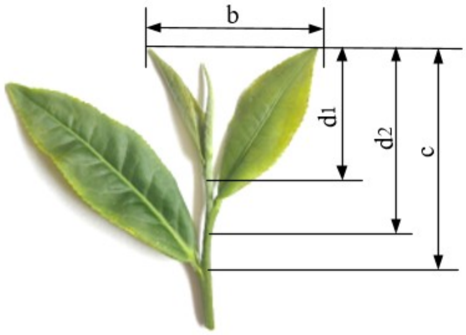

Fig. 6. Tender shoot
Рис. 6. Молодой побег

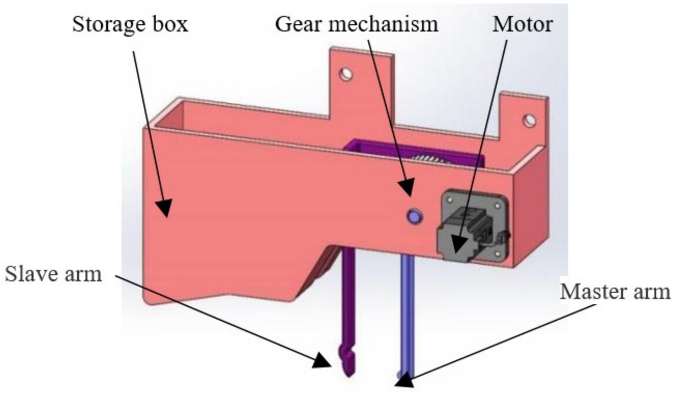

Fig. 7. The structure of the end effector
Рис. 7. Конструкция рабочего органа

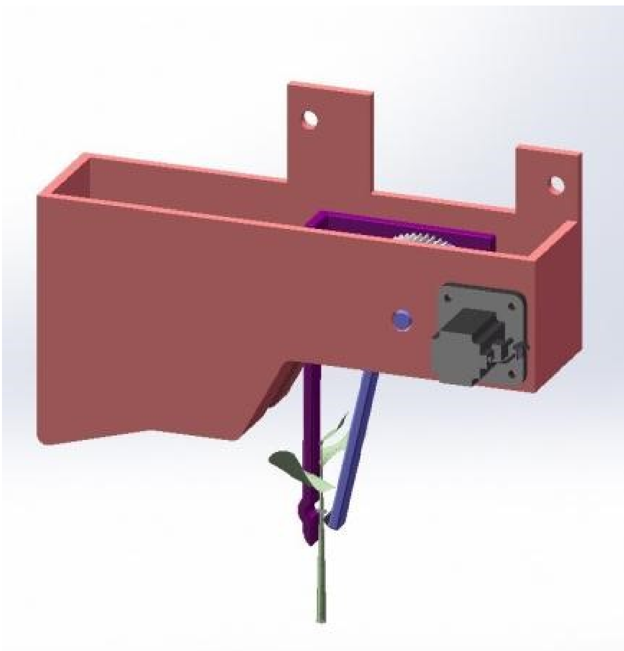

Fig. 8. Picking appearance
Рис. 8. Процесс отщипывания чайного побега

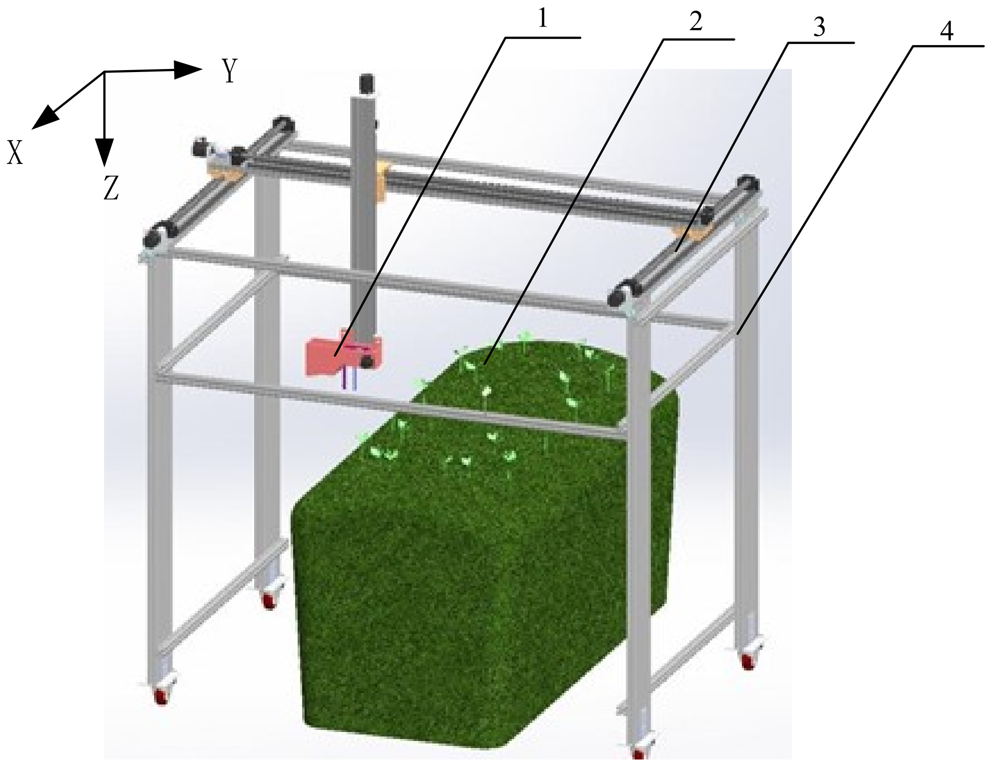

Fig. 9. The main components of the general structure
1 – end-effector, 2 – tea, 3 – triaxial truss structure, 4 – body frame
Рис. 9. Основные компоненты общей структуры
1 – рабочий орган 2 – чай, 3 – трехосный ферменный механизм, 4 – каркас основания

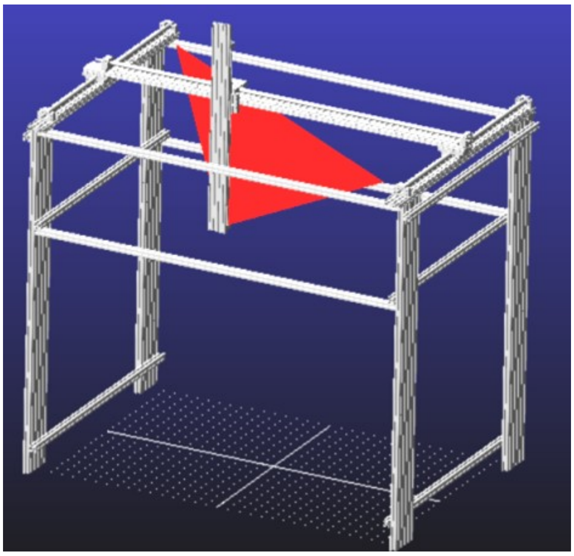

Fig. 10. Kinematics simulation
Рис. 10. Кинематическое моделирование

spiral pair, and moving pair. Finally, the rotational joint motions are added to the virtual prototype. The actuator of the virtual prototype is a step function. As shown in Fig. 9, the specified functions of the coordinate system are listed as flows:

X-axis:STEP(time , 0 ,0 , 2 , 350)+STEP(time , 2 ,0 , 6 , -900)+STEP(time , 6 ,0 , 8 , 550)

Y-axis:STEP(time , 0 ,0 , 2 , 900)+STEP(time , 2 ,0 , 6 , -1400)+STEP(time , 6 ,0 , 8 , 500)

Z-axis:STEP(time , 0 ,0 , 2 , -250)+STEP(time , 0 ,0 , 2 , 750)+STEP(time , 6 ,0 , 8 , -500)

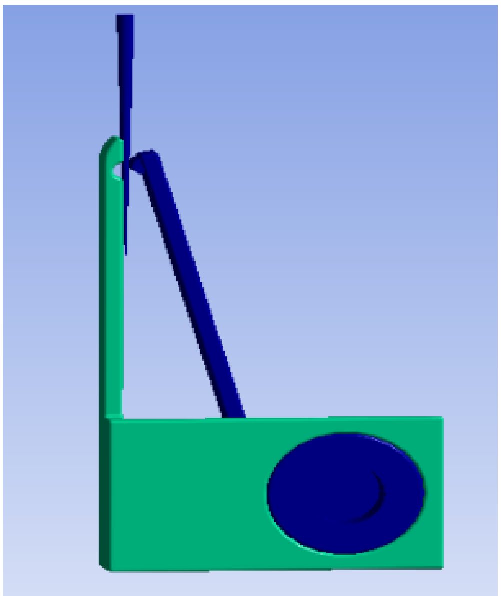

Fig. 11. Plucking model
Рис. 11. Модель процесса выщипывания

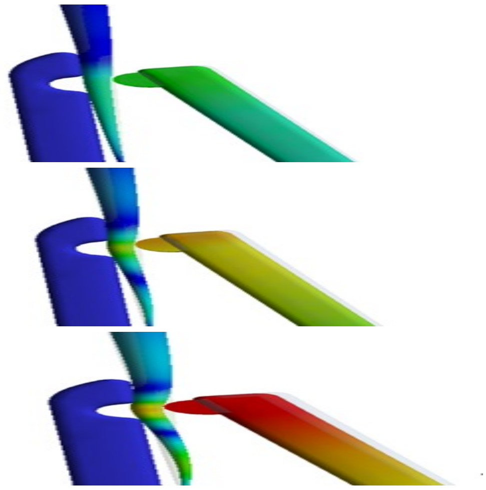

Fig. 12. Plucking process
Рис. 12. Процесс выщипывания

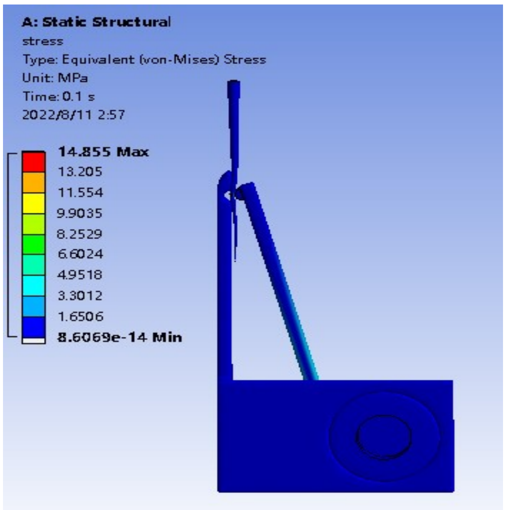

Fig. 13. Tea stem stress
Рис. 13. Напряжения в чайном стебле

The simulation result of the triaxial truss structure is analyzed to examine whether the working room fulfills the design requirements. The z-axis end trajectory is the three sides of the red triangle. It can be seen that there is no interference and collision between Z-axis and other components under working conditions.

4. Finite element analysis of tea steam based on ANSYS

The extrusion experiment of the tea stem starts with the master arm touching the stem and ends after the stem is broken off. In the extrusion process, the stem shows many physical characteristics, such as stress, strain, extrusion resistance, and extrusion power consumption. The damage to the stem will increase with force enhancement until it is broken. That is, the whole extrusion process is completed. Thus, The model characteristics of the tea team meet the following requirements:

(1) The tea stem is a homogeneous material;

(2) The interaction force between multiple stems is not considered, and only a single stem is modeled;

(3) The irregular shape of the tea stem is simplified into a cone;

(4) Length of the tea stem is set at 100 mm, the extrusion position is set at the center of the stem, and the diameter of this position is set to 2.5 mm.

In order to analyze the extrusion of the tea stem, firstly, the three-dimensional tea steam, the master arm, and slave arm are established in UG, converted into para solid (*. X_t) format, and then imported into the workbench simulation platform of ANSYS（Fig. 1）. Secondly, the material parameters of the tea stem, the master and slave arm are selected, including density, elastic modulus, Poisson's ratio, shear modulus. Thirdly, the solid models of the tea stem, the master arm, and the slave arm have meshed. Constraints are added to the tea stem, the master arm, and the slave arm. Fig. 12 presents the plucking process. Fig. 13 presents the stress on the tea stem.

5. Conclusion and future work

According to the characteristics of the tea garden and the standard of high-quality tea shoots, a tea plucking servomechanism was designed in this study. The components of servomechanism mainly include a frame, a three-axis truss structure, and an end effector. The virtual prototype of the three-axis truss mechanism is established through ADAMS, and the kinematics simulation is analyzed to meet the feasibility of this mechanism. The material stress analysis is applied through ANSYS workbench. These results shorten the development time and provide the theoretical basis for manufacturing for tea picking mechanism. Based on prior experiences, further research can be summarized as follow:

(1) When encountering steep or uneven terrain, the three-axis linkage is easy to cause the center of gravity of the tea-picking robot to move upward and cause instability. For simulation analysis of the triaxial truss mechanism studied in this paper, each

component is considered a rigid body, which has a certain deviation from the actual working condition. In order to improve plucking tea shoots' accuracy, the vibration and performance of the whole machine will be studied in the later stage.

(2) In the finite element simulation analysis of the tea stem, only the extrusion simulation analysis of a single tea stalk was carried out without considering the collision problem of multiple stalks in the working condition. Moreover, there are many kinds of tea, and the microstructure of tea stems is different. Therefore, the universality of the end effector needs to be further verified in the following research work.

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Ivan V. Chicherin – research problem statement; conceptualisation of research; drawing the conclusions; writing the text, research problem statement; scientific management; data collection; data analysis, reviewing the relevant literature; conceptualisation of research; data analysis; drawing the conclusions.
Lijun Zhao – research problem statement; conceptualisation of research; drawing the conclusions; writing the text, research problem statement; scientific management; data collection; data analysis, reviewing the relevant literature; conceptualisation of research; data analysis; drawing the conclusions.
Chanjuan Long – research problem statement; conceptualisation of research; drawing the conclusions; writing the text, research problem statement; scientific management; data collection; data analysis, reviewing the relevant literature; conceptualisation of research; data analysis; drawing the conclusions.

All authors have read and approved the final manuscript.

Научная статья

ПРОЕКТИРОВАНИЕ И ИССЛЕДОВАНИЕ МЕХАНИЗМА ДЛЯ СБОРА ЧАЯ

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высококачественный чай, сбор чая, виртуальный прототип механизма, виртуальная имитация

Аннотация.
Чай является важной товарной культурой в Китае. Доля высококачественного чая составляет почти 70% в валовом производстве чая. Высококачественный чай собирают вручную, что является неэффективным и трудоемким процессом и приводит к высоким затратам. В соответствии с характеристиками чайных кустов и стандартом высококачественных чайных побегов в этом исследовании был разработан механизм для сбора чая. Механизм имеет три степени свободы и может перемещаться вдоль направления осей X, Y и Z с целью локализации точек выщипывания подходящих чайных побегов. Компоненты механизма включают в себя раму, трехосную ферменную конструкцию и рабочий орган. Виртуальный прототип трехосного ферменного механизма разработан с помощью программной системы ADAMS, что позволило проанализировать его кинематику. На нем показано, что в рабочих условиях отсутствуют препятствия и опасность столкновений между компонентами. Анализ напряжений выполняется в программной системе ANSYS Workbench. В нем сымитирован процесс сбора чая и возникающие напряжения в чайном стебле. Полученные результаты сокращают время разработки и обеспечивают теоретическую основу для изготовления машины для сбора чая.

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