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Structure Design and Multi-Domain Modeling for a Picking Banana Manipulator

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Abstract. Based on agronomic and harvest characteristic analysis for bananas, according to bionic principle, a mechanism of picking banana manipulator simulating action of a person manually picking bananas was proposed, which was consisted of rotary mechanism, lifting mechanism, and shift mechanism, the body mechanical model of the picking banana manipulator was established. The multi-domain uniform model of a picking banana manipulator was developed employing the virtual simulation and modeling language Modelica. A body structure model for picking banana manipulator was established based on component models in DriveLib model library. Motion control's mathematic models for picking banana manipulator were analyzed according to drive motor performance for the body structure, the simulation model of a mechanical motion control for the picking banana manipulator were realized in Dymola simulation platform. The validity models could provide a theoretical basis for picking banana manipulator primary design.

Introduction

With developing of robotization technology and cost reducing of mechanical equipments, the cost of picking work using robot equipments is lower than manual work, agricultural picking robots was becoming study focus in agricultural engineering areas. Up to now, many automatic picking types of equipment have been reported [1, 2]; a 5-DOF robot using hydraulic driving was developed in Japan, which was used to harvest watermelons; a 3-DOF manipulator driven by servo motor was used to harvest pimientos in United States; the picking apple robot was researched in Kyungpook University in Korea; the picking mushroom robot was developed in Silsoe academe in Britain. In China, harvesting strawberry robots and harvesting aubergine robots were developed in China Agricultural University [3], the picking cucumber manipulator was study in Nanjing. Agricultural University [4], and the harvesting tomato robot based on binocular vision was researched in Jiangsu University [5]. Agricultural picking manipulators were simulated and analyzed applying the multi-domain simulation language Modelica in South China Agricultural University [6, 7].

Banana is one of the four major fruits in the world. Its yield and planting area are increased year by year. But the present statue of picking bananas is still rest on the phase of relatively backward artificial mode, of which the disadvantages contain larger labor amount; lower efficiency and higher picking costs, as well as bringing body hurt to the picking people, injury to banana epidermis, and affecting seriously the banana harvest quality. The development of picking banana manipulator has broad prospects.

Based on agronomic and harvest characteristic analysis for bananas, a picking banana manipulator was researched in this paper, which can simulate action of a person manually pick bananas. The multi-domain uniform model of a picking banana manipulator was developed employing the virtual simulation and modeling language Modelica. The simulation model of a mechanical motion control was realized in Dymola simulation platform, the model was testified being validity in a picking banana manipulator.

Structure Synthesis for the Picking Banana Manipulator

The Agronomic and Harvest Characteristic Analysis for Bananas. Banana distributes serially in pedicel, and the weight of each series is about 25~40 kg. The average distance from its location to the ground is about 1.6~ 3 meters and bunch distributes randomly in crown. The agronomic parameter of banana is shown in table 1.

Table 1 the agronomic parameter of banana

Cutting height of banana bunch	Row spacing	Plant spacing	Diameter of banana stalk	Length of banana bunch	Weight of banana bunch	Diameter of banana body
2.2~3.0m	1.9m	1.6m	60~120mm	0.7~1.2m	25~50kg	0.4~0.7m

When a person picked bananas, a banana bunch whose stalk is low from ground was cut directly; a banana bunch whose stalk is high from ground need be cut in middle of the stalk, when the stem drooped, then total banana bunch was cut. Generally, two persons cooperated with each other to complete picking action; one person cut a banana stalk, other person lift banana bunch with hands.

Mechanical synthesis for a picking banana manipulator. Work space is a main motion parameters

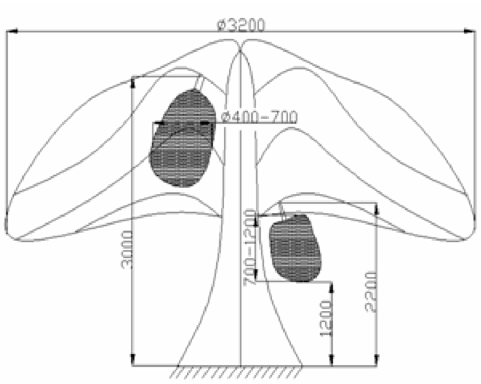

Fig. 1 projection diagram of banana grown space

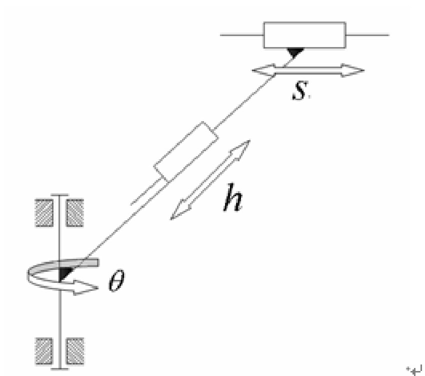

Fig. 2 structural diagram of the manipulator

indicating work capability viewing to geometry, and is an important reference of designing manipulator, the design mechanism of a manipulator first satisfy work space requirement. According to agronomic characteristic of bananas, banana trees can be handled as a turning with coronary leaves and stock axes, the diagram of bananas grown space projecting on vertical plane is shown in figure 1.

The picking manipulator possess three motion variables, which are lifting or drooping in vertical direction, return shifting in horizontal direction, and rotating around a vertical axis, their changeable scope were given as table 2.

Table.2 changeable scope of motion variables

	variables	changeable scope
1	θ_1	$-90^\circ \sim 90^\circ$
2	h_2	1700~2500mm
3	s_3	400~700mm

Considering picking banana manipulators were mainly used to replace peoples to act as picking banana in order to reduce strength of labor, the body structure of manipulator was designed to process 3-DOF (degree of free) in a cylindrical coordinate system, its lifter and rotary mechanism were used to collaboratively locate the object, its shift motion mechanism complete to clamp and cut banana pedicel.

The picking banana manipulator consists of five parts, which are lifter, rotary mechanism, clamping mechanism, cutting mechanism, and control system. At first, orientation of actuator is adjusted by rotary mechanism and height of actuator is adjusted by lifter, thus the location of banana for manipulator is realized. Then clamping mechanism enclasp automatically banana stalk to initiate the cutter head rotation of cutting mechanism, as to the achievement for separation of banana bunch and banana stalk, and then banana is collected into fruit cases by lifter. These series actions are controlled automatically by control system. The control system consists mainly of MCU and limit switch, and completes the picking process, such as clamping, cutting, reciprocating motion and so on. Figure 2 is the structural diagram of picking banana manipulator.

A 3-DOF picking banana manipulator can rotate freely within 180 degree range in vertical planar. That is, it can climb straightly or decrease straightly along the inclined direction of lifter, and move straightly in horizontal direction. The first DOF lies in base rotary mechanism, which is droved by DC servo motor model after deceleration and increasing moment of reducer. It fixes boom in lifter by two fixed points, so that the rotation action of clamping and cutting mechanism can be accomplished. The second DOF realizes bio-level lifting with expansion link. That is, firstly, gear and rack mechanism is droved by DC servo motor to accomplish the translation of telescopic boom one in the fixed boom direction, and then telescopic boom two is droved by chain transmission to realize bio-level lifting. The third DOF accomplishes automatically clamping and unclamping action by the driving of top DC servo motor to screw mechanism, which then drives the linkage mechanism.

Structural Modeling for the Picking Banana Manipulator Based on Modelica

Multi-domain physical modeling integrates multi- discipline models belonging to mechanism, control, electron, hydraulic pressure, air pressure, and software to a unitary model in order to simulating total performances of a complex system. Simulation language Modelica is important sign in multi-domain modeling and simulating, which is object oriented physical simulation language based on C high level language, and possess many extension mathematic models. Its standard model library includes electric component module, one- dimension translation module, one-dimension revolved module, and three-dimension mechanical module etc. Structure models for the picking banana manipulator can be established by modules in Dymola software platform being changed, such as Multibody, Electrical etc. Model library consists mainly of manipulator body, control system, mechanical transmission system, and driving motor and so on. Element in DriveLib library has the characteristics of correspondence and generality with manipulator body, as well as the characteristics of reusability and standardization. In the following model building process, users need only to find the necessary model in this model library, and then connect them to change parameter; even they do not know the concrete implementation principle and method of model.

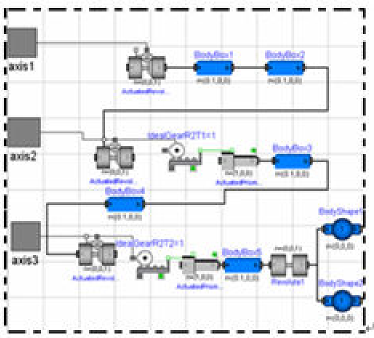

Fig. 3 the manipulator model of based on Modelica

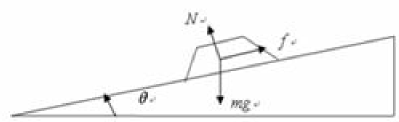

Fig. 4 sketch map of a screw unwrapping

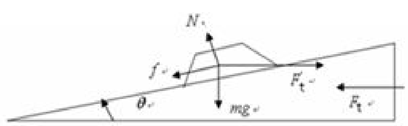

Fig. 5 static analysis acting on a nut

According to action behavior of all mechanisms, the body structural model of the picking banana manipulator was built with Modelica. Rotary mechanism consists of driver, rotary shaft, bearing and so on. Lifter consists of driver, fixed boom, telescopic boom and pulley. Shift mechanism consists of driver, screw pole, fixed turnbuckle, connection rod, hinge and spring. According to grammar and symbol standard of Modelica, the established model of the picking banana manipulator is show in figure 3. After being established, these models are encapsulated into reusable element form which then is added into the user-defined DriveLib model library.

Mathematical Model of the Helix Transmission Mechanism

The helix transmission mechanism locating at top of the picking banana manipulator can be driven by DC servo to implement return shifting in horizontal direction and drive linkage mechanism to fulfill clamping and unclamping banana stalk. Unwrapping diagram of a screw thread for a helix transmission with ball bearing is shown in figure 4, suppose slope indicates screw spindle and glide block indicates nut.

In figure 4, suppose mass of nut is *m*, acceleration of gravity is *g*, the gravity acting on nut is *mg*, supporting force coming from screw spindle is *N*, there is a friction between nut and screw spindle. According to physics knowledge, a friction is related with frictional coefficient μ and positive press *N* between two contacting surfaces, its magnitude is μN . Mechanical relationship between nut and screw spindle can be represent as equation 1.

$$\frac{f}{F_{mg}} = \frac{\mu mg\cos\theta}{mg\sin\theta} = \mu ctg\theta \qquad (1)$$

When a motor drives screw spindle turning, a torque coming from the motor transform a driving force to impel a nut ascending, a screw spindle convert the torque to a force perpendicular to axes of the screw spindle, as well as the nut generates an action force, whose magnitude equals to the force acting on a screw spindle and direction is opposition with the force acting on a screw spindle. An analyzing diagram of the force acting on a nut is shown figure 4, their mathematic relationship is described as equation 2.

$$\begin{cases} 0 = \mu mg\cos\theta - mg\sin\theta \\ 0 = F_t'\cos\theta - \mu F_t'\sin\theta \end{cases} \qquad (2)$$

Suppose the friction could keep balance with drive force, the nut would move equably. Place μ , $\cos\theta$, and $\sin\theta$ into equation (1), let *f* equals to *F*, then relationship formula as follow will be drawn.

$$F_t' = \frac{mg(\mu\cos\theta + \sin\theta)}{(\cos\theta - \mu\sin\theta)} \approx 0.205mg = -F_t \qquad (3)$$

As such, suppose the direction of F_t is opposition, and it will drive a nut descending, the result is described as follow formula (4).

$$F_t' = \frac{mg(\sin\theta - \mu\cos\theta)}{(\cos\theta + \mu\sin\theta)} \approx -0.096mg = -F_t \qquad (4)$$

The value of F_t is decided by torque of a motor τ , the force F_t' that a screw spindle transferred to a nut can be represented as equation (5):

$$F_t' = -\tau / r \qquad (5)$$

Here *r* is radio of a screw spindle. Then the balance relationship of a helix transmission between motor torque and load is given by equation (6).

$$\tau = 3.075mg \text{ or } \tau = -1.44mg \qquad (6)$$

Motion Simulation for a Helix Transmission Mechanism

Simulation analyzing of a helix transmission mechanism depends on a uniaxial control system to make a screw spindle turning with constant speed, which can test if the model of a helix transmission is right. Speed feedback can make a motor to generate a constant rev acting as reference of the helix transmission, World module provides gravity, straight axis is transmission module, body supply a load acting as the helix transmission, and torque sensor measure the torque imported by a motor.

Let load equals 10*kg*, acceleration of gravity is 9.81m/s^2, according to equation (6), the theory torque τ of a motor equal separately to 0.3*N.m* (while a motor is turning around counter clockwise) and -1.41*N.m* (while a motor is turning around clockwise).

The simulation interface when a motor is turning around counter clockwise is shown in figure 6. Based on the figure, it can be seen that the torque of a motor transfer to a screw spindle is 0.300376*N.m* when time of a motor running is 0.318 *seconds*.

Then let a motor turn around clockwise, the simulation interface is shown in figure 7. In the same way, it can be seen that the torque of a motor transfer to a screw spindle is -0.141555*N.m* when time of a motor running is 0.278 *seconds*.

Making a comprehensive view above description, the simulation results are accord with theory computation. The simulation model is availability.

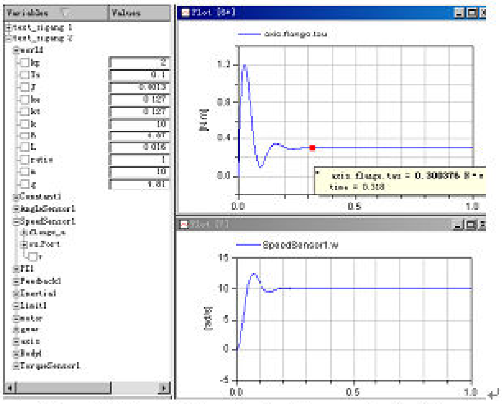

Fig. 6 simulation interface of a helix transmission (counter clockwise)

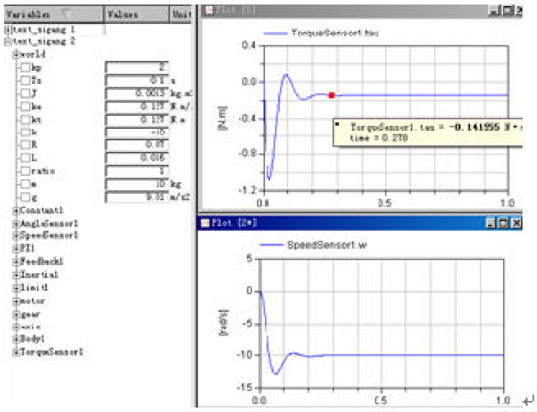

Fig. 7 simulation interface of a helix transmission (clockwise)

Conclusion

Picking banana manipulators are a complex electro- mechanism system integrating multi-discipline knowledge including mechanism, control, and electron, which can be simulated employing multi-domain physical system modeling language Modelica. Based on agronomic and harvest characteristic analysis for bananas, a picking banana manipulator was researched in this paper, which can simulate action of a person manually pick bananas. The multi-domain uniform model of a picking banana manipulator was developed employing the virtual simulation and modeling language Modelica. The simulation model of a mechanical motion control was realized in Dymola simulation platform, the model was testified being validity in a picking banana manipulator.

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