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Modeling and Performance Analyzing of Helix Transmission Base on Modelica

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Abstract: Picking manipulator ontology structure used rotation and translational motion pairs to join the components together, and then a multi-joint motion mechanism was built which meet the picking space requirement. According to the characters of growth space of litchi fruit, here used helix transmission as the first axes of the picking manipulator, to achieve motion in vertical direction. This study introduces the application of multi-domain modeling and simulation when constructing and simulating a helix transmission. Use object-oriented technology, multi-domain modeling and simulation language Modelica to construct the motion system which integrates motor model, signal detection module, signal processing module and parametric screw transmission model in Dymola simulation platform. Test the helix transmission by simulation, using the mechanical structure, sensor technology, signal processing technology. Simulation results show that, the modelica can provide a valid simulation for complex electromechanical system and support for parametric design.

Introduction

With the application of multi-domain modeling language Modelica, physical system of various fields can be expressed in one form, unified modeling can be realized according to the converting relation of universal physical quantities, and hierarchical modeling can be also supported. Standard library (MSL) which involved in many fields, such as mechanics, electronics, hydraulic science, control science and thermodynamics, and expanding library are both included in Modelica for modeling as well as simulating of many complex mechanical systems, such as automobile system, aviation system and robot system. Meanwhile, simulation of discontinuous system and discrete event is also supported within the method of object-oriented system analysis and the idea of object-oriented programming [1, 2, 4].

As a kind of electromechanical system with much complexity that involves multi-disciplinary field knowledge fusion, such as mechanics, electronics, and control science, the picking manipulator adopts digital virtual design method in ensemble modeling as well as performance simulation for improving success rate of development as well as reducing [3]. The litchi picking manipulator designed in this study is a multi-joint mechanical system that composed of one moving pair and five revolute joints, providing the function of vertical elevation and horizontal rotation, and meeting the workspace requirement in picking operation. The applying of helix transmission has some beneficial features, of which includes steady transmission, significant reinforcement, easy self-locking, compact structure and low noise. By means of object-oriented language Modelica, this study presents a model construction as well as performance simulation of helix transmission and verifies the feasibility for the application of multi-domain modeling technology and simulation technology in agricultural machinery development.

Mathematical model of helix transmission

As structural performance of such helix transmission affects directly location accuracy of terminal execution body and total operational performance, spiral transmission module should have the function of self-locking and steady transmission. Helix transmission is applied to first joint of litchi picking manipulator for changing the rotary motion to linear motion, which also supports the whole weight of manipulator. The friction is produced by the contact force on contact surface. When it exceeds the pull-off force, the self-locking friction is generated and leads to a relative motionless phenomena between the two contacted objects. The helix type is SFU3205-4, with a diameter 32mm, dynamic rated load of 1450 kgf, static rated load of 4150 kgf, the screw pitch and lead both are 5mm, and radius is 15mm and θ is 3^{o}. Suppose mass of nut is m, acceleration of gravity is g, supporting force coming from screw spindle is N, the two contacting surfaces' frictional coefficient is μ, so the friction is $N\mu$. Mechanical relationship between nut and screw spindle is represent as equation 1.

$$\frac{f}{F_{mg}} = \frac{\mu mg\cos\theta}{mg\sin\theta} = \mu ctg\theta \tag{1}$$

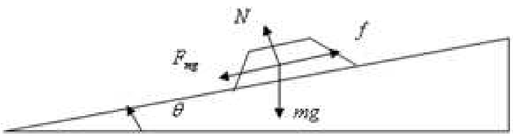

Figure 1 sketch map of a screw unwrapping

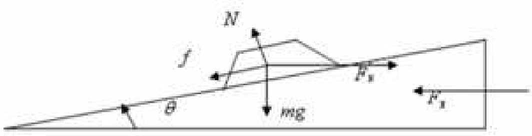

Figure 2 static analysis acting on a nut

The motion of first axes of litchi picking robot uses motor to make the screw spindle whirl, in order to let nut move in vertical direction and transfer the torque of motor into the nut lifting force. An analyzing diagram of the force acting on the nut is shown in figure 2. Equation 2 shows the mathematic relationship. Then let f equals to F, and relationship formula as equation 3. As such, suppose the direction of F_N is opposition, equation 4 is drawn. Suppose torque of a motor τ, radius r. The value of F_N is decided by τ, and the force $F_N^{'}$ that a screw spindle transferred to a nut is $-\tau / r$. The balance relationship of a helix transmission between motor torque and load is shown in equation 3 and equation 4. [5]

$$0 = \mu mg\cos\theta - mg\sin\theta \,, \quad 0 = F_N^{'}\cos\theta - \mu F_N^{'}\sin\theta \tag{2}$$

$$F_N^{'} = \frac{mg(\mu\cos\theta + \sin\theta)}{\cos\theta - \mu\sin\theta} \approx 0.205mg = -F_N \,, \quad \tau = 3.075mg \tag{3}$$

$$F_N^{'} = \frac{mg(\sin\theta - \mu\cos\theta)}{\cos\theta + \mu\sin\theta} \approx -0.096mg = -F_N \quad \tau = -1.44mg \tag{4}$$

Structure modeling of the helix transmission

Modeling of the signal detection and processing module. This helix transmission model used force sensor (called "force sensor") in modelica standard library to obtain the sum of transmission force based on the helix transmission model. But only the component force on the direction of load motion is needed and then sent to the friction module for calculating, shown in figure 3.

The mass of the model, static friction and sliding friction could be simulated by the friction arithmetic module (could also call self-locking module). But the default function only simulated with single given value, and could not change following the signal. Change the module by adding a new interface to import the data sent by force sensor and to calculate the value of real-time self-locking friction. A new one-dimensional interface is added into force sensor, because of the force sensor only sent three-dimensional signal but the friction module only treated with one-dimensional signal. The force sensor one-dimensional interface matched with the friction module interface and sent signal to it. Some of the changed codes are shown as follows.

```
model CutForce "Measure cut force vector"
    extends MultiBody.Interfaces.PartialCutForceSensor(outPort(redeclare type SignalType
= SI.Force));
  parameter Boolean animation=true   "= true, if animation shall be enabled (show arrow)";
  parameter Boolean resolveInFrame_a=true
    "= true, if force is resolved in frame_a/frame_b, otherwise in the world frame (if connector
    frame_resolve is connected, the force is resolved in frame_resolve)";
    ……
  public   Modelica.Blocks.Interfaces.OutPort outport
  equation
    if cardinality(frame_resolve) == 1 then
      force = MultiBody.Frames.resolve2(frame_resolve.R,
      MultiBody.Frames.resolve1(frame_a.R, frame_a.f))*(if positiveSign then +1 else -1);
    ……
```

Parametric design of helix transmission model. The helix transmission model is built up with the gear-rack module Modelica. Mechanics. Rotational. IdealGearR2T, positioning module MultiBody. Joints. ActuatedPrismatic, signal detection module force sensor, self-locking module friction and rotational inertia module link to the motor, showed in figure 3. Rotary-linear turning module is built up with the gear-rack module and working with the positioning module to restrict the moving range of the gear-rack mechanism. Send the component force on the load motion direction obtained by the signal detection module, to the self-locking module and it can realize the self-locking function.

The helix transmission is designed in a parametric method and the radius, screw pitch, friction coefficient, rotational inertia of the helix transmission could be changed when designing with different parameters, which could heighten the speed of modeling and rectify.

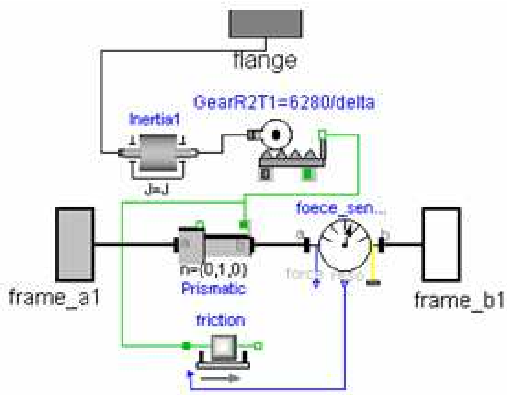

Figure 3 Helix transmission model

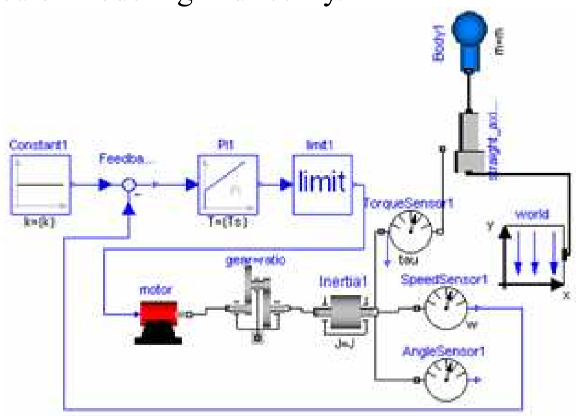

Figure 4 Simulation model of helix transmission

Simulation and analyzing of the helix transmission model

Simulation analyzing of the helix transmission mechanism depends on the first axes control system, to make the screw spindle rotating with stable speed in order to test whether the helix transmission model meet the requirement. Here use the PI controller and the "limit" module to rectify the output accordance with the feedback of the motor speed, which was measured by the speed sensor. World module provides an environment with gravity, straight axis is used as a transmission module, "body" as the load of helix transmission, and torque sensor is used to measure the torque coming from the motor[5]. The angle of motor measured by the anglesensor also could be the feedback signal. The helix transmission model is shown in figure 4.

Tested parameters are shown on the left side in figure 5 and experimental results of simulation are on the other side. The curve of torque is shown in plot1 named axisflange.tau, and curve of speed is shown in plot2 named speedsensor1.w. Suppose the test load 15kg, acceleration of gravity g is 9.81 m/s^2. Theoretical value of τ are 0.452 $N \cdot m$ and -0.212 $N \cdot m$ according to equation 3 and equation 4.

Analyzing based on the experimental results, when the motor is turning around counter clockwise with a speed of 10rad/s, the torque is 0.451 $N \cdot m$ when the motor running at the time of 0.304 second. When let the motor turn around clockwise with the same speed, the torque measured is -0.212 $N \cdot m$ when the motor running at the time of 0.274 second. Although there is a little wobble in the curve in an allowable range, the helix transmission can also reach the speed of 10rad/s in a very short time during 0.2 second.

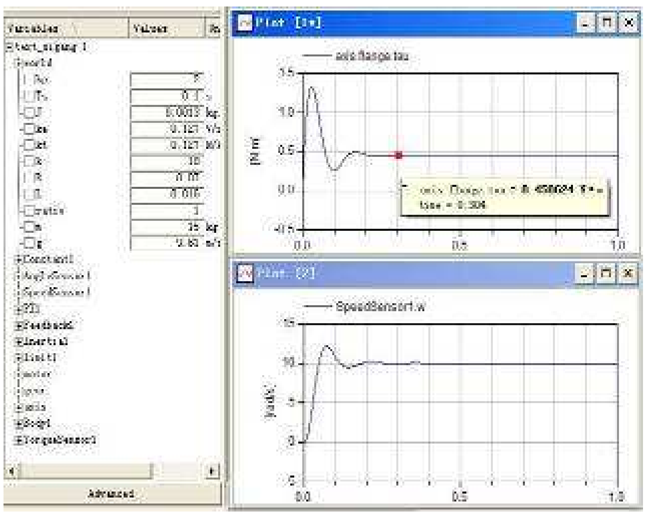

Figure 5 Simulation interface of a helix transmission (counter clockwise)

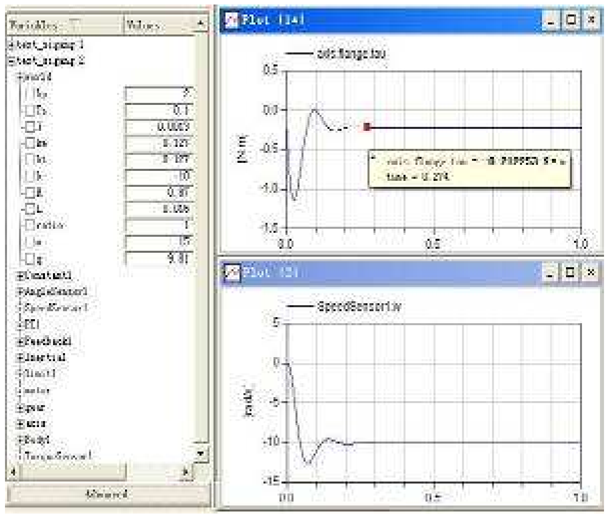

Figure 6 Simulation interface of a helix transmission (clockwise)

Conclusion

The self-locking performance and the stability of a helix transmission affect the kinematic accuracy and stability of the picking robot. The design of a helix transmission, based on modelica, integrate mechatronics, sensor and signal processing technology. Performance simulation of the helix transmission model shows that a helix transmission with parametric design meet the requirements of driving smoothly, easy self-locking and could be used in designing the whole model of the picking robot with the advantages of high reusability and convenient for extension. It's feasible and effective to design agriculture harvesting machines by using the multi-domain unified modeling and simulation technology.

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