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Design of Gravity Compensation Based on Rope Pulley Mechanism Using in Pineapple Harvesting

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***Abstract*—Objective: Aiming at compensating the gravity, a passive gravity compensation system is designed. In order to verify the practicability, it has been applied in the pineapple harvesting. Utilizing the disc cam and tension spring mechanism, the system can implement gravity compensation within any angle in operation. Methods: It establishes a mechanical model of static balance system of manipulator, and obtains the contour of the cam by deducing the relationship between angle and the arm of force by considering the angle between the flexing rope and vertical direction. Results: The system works ideally meets the anticipation. Conclusion: Aiming at putting the gravity compensation into the miniature hand construction machinery and agricultural machinery, the cost of the whole gravity compensation is very low and significantly useful in labor-saving in the testing working conditions.**

Keywords—Gravity Compensation, Rope Pulley Mechanism, Pineapple Harvesting

I. Introduction

For the miniature hand construction machinery and agricultural machinery, the axis of their manipulator is not perpendicular to the ground, which exist a gravity moment. In practical production, not only the arm of force can be very long, but the weight of the workpiece which on the extremity of the manipulator can also be quite heavy. Therefore, the gravity moment would be extremely large, which will lead to low dynamic features. Gravity compensation method has already adopted in the commercial industry robots, by putting the real time gravity compensation into the PD control [1,2]. However, not only the PD control with real time gravity compensation is too expensive to practice when introduced to the miniature hand construction machinery and agricultural machinery, but it will also increase the whole system's complexity [3]. As a result, in the use of the miniature hand construction machinery and agricultural machinery, the gravity is still compensated by manpower. For instance, the equipment that used for sprinkling pesticide [4], and those used for picking the fruits that grow on the tall trees like apples or oranges [5,6]. Continuous work with heavy machinery without gravity compensation will result in serious arm-ache, and the efficiency of work will be enormously decreased. Most research nowadays just give the gravity a linear compensation, however, with the changing of the angle, the changing of the torque is nonlinear. That will lead to incompletion and instability in the compensation. This paper proposes a gravity compensation based on rope pulley mechanism, which can counteract the torque ideally while the total weight changes very little. Moreover, in consider of the total price of miniature hand construction machinery and agricultural machinery, the cost of the compensation system is minimized in a very small range.

II. Design of the Cam and Tension Spring Mechanism

The main structure of the gravity compensation system includes cam, hinged-support, crown block and tension spring. When the system works, the torque produced by the manipulator will be compensated through flexing rope which is connected to the tension spring. The crown block is used to change the direction of the flexing rope, and the pulling force among the rope will change at the same time. When the manipulator rotates, the flexing rope will roll with the cam, which is fixed with the manipulator. Then there will be a new torque, which can counteract the former that produced by the manipulator and the workpiece. By designing the spring stiffness coefficient and the contour of the cam, every point in the work can achieve the gravity compensation, and the work efficiency will be improved.

Deduction of the Cam Contour

First of all, simplify the gravity compensation system and draw the free body diagram in the Fig. 1. Point O is the central of the cam, L is the distance that from manipulator to point O. Point A is barycenter of the manipulator, Point B is barycenter of the workpiece that on the extremity of the manipulator. r is the distance that from the central of the cam to the central of the flexing rope.

Secondly, choose the horizontal as initial state, and analyze the system's stress condition, we can obtain:

$$MgL\sin\alpha = Fr \tag{1}$$

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In Eq.1, M----equivalent mass of manipulator and workpiece to point O

And according to the Hooke’s law, Eq.1 equals to:

$$MgL\sin\alpha = kxr \tag{2}$$

In Eq.2, k----composite stiffness coefficient of the spring and the flexing rope

x----spring’s displacement from the initial state.

For there are three variables in the Eq.2, and we hope to obtain an equation about α and r, so here we have an approximate analysis, according to the arc length formula,

$$x = r\alpha \tag{3}$$

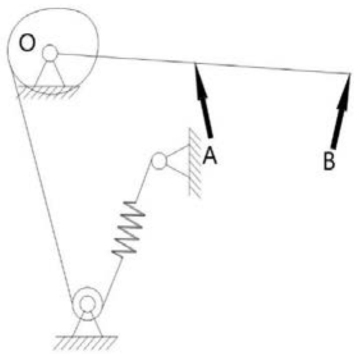
And because in the cam we are going to use the range of the r which is not so large, then the arc length formula is useable. So we put the Eq,3 into Eq.2,

$$MgL\sin\alpha = kr^2\alpha \tag{4}$$

Simplifying the Eq.4, the r is a dependent variable and the α is an independent variable,

$$r = \sqrt{\frac{MgL\sin\alpha}{k\alpha}} \tag{5}$$

Eq.5 is the equation about contour of the cam we want, but there is an absolute error and we need to revise it, according to Fig. 2.



Figue.1 Free body diagram

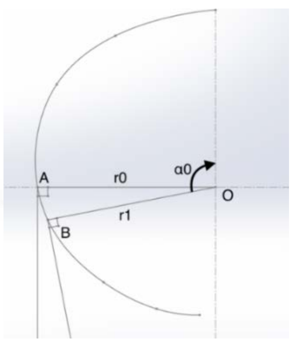


Figure2. Actual rope and the idealization rope

During the deducing, we regard that the direction of the pulling force in the flexing rope is perpendicular to the horizontal plane, in other words, the default wrap angle is 90°, but actually the wrap angle cannot be 90° and will change with the r in the Eq.5. Then the absolute error appears. The r related to the wrap angle is the real r.

First of all, we assume that the diameter of the crown block is d_0, and the center-distance between crown block and the cam is a, according to the geometrical relationship, the wrap angel of the flexing rope in the cam is:

$$90^\circ + \frac{r-d_0}{2a}\times 57.3^\circ \tag{6}$$

When the cam turns to α_0, actual r should add the addition r relative to the increment of wrap angle that compare to the horizontal state.

$$r(\alpha_0) = \sqrt{\frac{MgL\sin\left(\alpha_0 + \frac{\delta d}{2a}\times 57.3^\circ\right)}{k\left(\alpha_0 + \frac{\delta d}{2a}\times 57.3^\circ\right)}} \tag{7}$$

In the Eq.7, δd ---- $2\times\sqrt{\frac{MgL\sin\alpha_0}{k\alpha_0}}-d_0$ is the difference of r and d_0 [7].

From the Eq.7, we can obtain that choose a large a and d_0 is helpful in reducing the influence from wrap angle to r.

Besides, another absolute error of r is the influence from the radius of the flexing rope, finally we can deduce the equation of r and α

$$r=\sqrt{\frac{MgL\sin\left(\alpha+\frac{\delta d}{2a}\times57.3^\circ\right)}{k\left(\alpha+\frac{\delta d}{2a}\times57.3^\circ\right)}}-r_r \tag{8}$$

In the Eq.8, r_r is the radius of the flexing rope.

III. Validation and Application of the Gravity Compensation System

After deducing the contour of the cam, we need to validate the system and make sure that it can perform well. Here we decide to applying the system in the pineapple harvesting.

Production practice shows that the main cost in pineapple planting is harvesting, that is because you have to bend down in order to gather them. In consider that the pineapple mechanization is still in the initial stage of the development situation [8]. Based on the gravity compensation system, a labor-saving mechanism is designed.

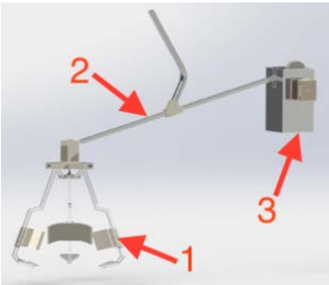


Figure 3 Model of the equipment


Figure 4. Model of the system

In the Fig. 3 arrow 1 is the grabber, arrow 2 is the manipulator, and arrow 3 is the gravity

compensation, and the inside structure is showed in the Fig. 4. The parameters are listed below. The total mass of manipulator is $m_1 = 0.7$kg, the mass of grabber is $m_2 = 0.1$kg, and the length of manipulator is 0.7m. Many cultivars are known, varieties include “Hilo” 1.0- to 1.5-Kg, “Natal queen”, at 1.0 to 1.5Kg, “Pernambuco”, weights 1-2 Kg, “Red Spanish”, at 1-2 Kg [9,10]. So here we suppose the pineapple weights 1.5 Kg.

The whole mechanism should not be too large to operate manually. Therefore, we set the parameter a to 200mm, the d_0=10mm. The standard parts are selected to reduce the cost of the spring.

According to the GB/T1239.1-2009, the wire diameter is 2mm, the mean coil diameter of the spring is 9mm, the active coil number is 28, then we can calculate the k is 7.74N/mm.

After obtaining the k, we can start to design the cam, the equivalent mass of manipulator and workpiece to point O is 1.95Kg, the radium of the flexing rope we choose is 0.467mm, and considering that the k_2 is far too bigger than k_1, then the k_2 can neglect. Programming in the Matlab, set the step size t = 0.01, the Fig. 5 shows the contour of the cam.

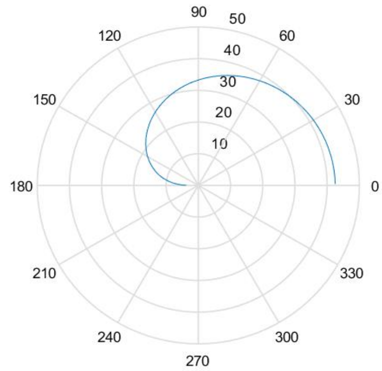


Figure.5 Contour of the cam

Because the mechanism only turns about 0~π/3, then only keeps the curve form 0~π/3, we imported it to the CREO, established the model like Fig. 6, and used the SLA (Stereo Lithography Appearance) to build it, showed in Fig. 7.

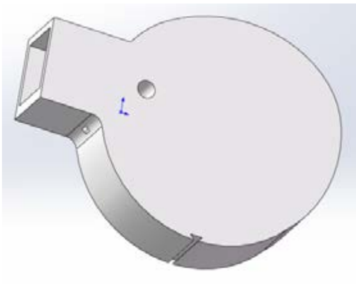


Figure 6. Model of the cam

Figure 7. Cam in kind

In order to feel the gravity compensation effect more patently, we take off the flexing rope, then the compensation system turns invalid. Though the whole harvesting mechanism can still work, the arm falls into serious fatigue in no more than 5 minutes. Putting back the flexing rope, the gravity compensation system gets back to work, and the arm feels at ease in continuous working.

IV. Conclusion

The present study proposes a novel design of gravity compensation. From the point of pineapple harvesting mechanism, it seems feasible to construct an effective gravity compensation system based on the cam and tension spring mechanism, which releases the arm from supporting the extra torque. For the miniature hand construction machinery and agricultural machinery applications, the gravity compensation scheme is cost-effective and significantly useful in labor-saving in the testing working conditions.

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