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Design and Simulation of a Handling Robot for Bagged Agricultural Materials

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Abstract: Loading and unloading agriculture bags manually in the train, is labor intensive and inefficient, thus a handling robot for bagged agricultural materials has been designed to address the problem. Aimed at the tightly stacked, largely deformed and easily damaged agricultural bags, a grabbing mechanism has been designed with stable and reliable capturing performance. And statical analysis of the grabbing mechanism has been conducted. The kinematical model was established in a Denavit-Hartenberg coordinate system and solutions of the forward kinematics analysis were calculated to analyze the kinematics of the handling robot. The simulation model was built with ADAMS and the results have approved the kinematic equations as well as the good feasibility of the handling robot. Therefore, the overall design met the operational requirements.

Keywords: handling robot, stacked agricultural bags, structural design, kinematics analysis, simulation

1. INTRODUCTION

Currently, agriculture in China is developing rapidly and the demand of agricultural materials is increasing. The total food output is 601.935 million tons in 2013, and food production has been growing for ten consecutive years. Accordingly, production of fertilizers is 71.537 million tons in 2012 with a growth rate of 4.89%. The majority of food, fertilizers, feed and other powdered agricultural products are transported through bags in the train. Now, most bags are loaded and unloaded manually in China, it is regarded as one of the most labor intensive operations. As shown in Fig.1, manual handling method is low-efficient, which will directly increase the overall costs. On the other hand, some Bagged Agricultural Materials are chemical corrosive, which are harmful to human health.

Fig.1. Comparison of the efficiency between the handling robot and manual method during loading and unloading

Nowadays more and more automatic applications have been observed in agriculture. In developed countries, handling robots have already been widely used in food, fertilizers and other industry. Japan, Germany, the United States, and Sweden have equipped with a lot of handling robots for assembly line production in the factory.

Tanner et al. (2001) investigated a multiple mobile manipulator system handling a deformable object during an agricultural task and the robot can handle a variety of agricultural products. Caffaz and Cannata (1998) proposed the first prototype of the DIST-Hand dextrous gripper which is a 4-fingered tendon driven device with 16 degrees of freedom. Park et al. (2003) developed a robotic gripper to enable control of both shape and vibration of thin-walled flexible payloads. The gripper was configured with multiple actuated fingers, which are comprised of linear actuators with DC motors and laser proximity sensors. Lee et al. (2009) presented a service robot gripper which has a miniaturized fingertip pressure sensor, a thumb, and two fingers. Ali et al. (2011) designed a smart gripper with vision sensor for industrial applications. In order to control the applied force, the gripper has two fingers with force sensor mounted. Hatano(2007) investigated an advanced autonomous rescue robot with force sensors attached on fingertips to avoid breaking down rubbles during operating. Sam and Nefti (2011) developed a flexible robotic gripper to handle food products. Therefore, there are no relevant studies on handling robots for the bagged agricultural material. Because these bags are tightly stacked, it's hard to complete the grabbing task without any damage of the other bags. Furthermore, the

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largely deformed and easily damaged characters of the bags make it difficult to handling them. Moreover, the narrow space of the train carriage is another challenge for the handling robot.

In this paper, a handling robot for bagged agricultural materials had been designed specifically for the working scenario in the train to improve the working efficiency and reduce the human contact with dangerous agricultural material. Since the agricultural bags are tightly stacked, largely deformed and easily damaged, a special grabbing mechanism has been designed to complete the grabbing task. And the statical analysis of the grabbing mechanism has been conducted. The kinematical model of the handling robot was established in a Denavit-Hartenberg coordinate system and solutions of the forward kinematics analysis were calculated. In addition, kinematical simulation was presented with ADAMS.

2. DESIGN OF THE HANDLING ROBOT

2.1 Structural Design of the Handling Robot

The handling robot developed in this paper was specifically used in train wagon. At present, the common size of the train wagon in China was shown in Table 1.

Table 1. Related parameters of the train wagon(mm)

Long	Wide	High	Size of the door	Stacking height
15478	2800	2855	2539*2946	1600-1800

Because the handling robot was designed for train wagon, where bagged agricultural materials were placed irregularly, the robot movement should be made as flexible as possible. Thus, a motor-driven programme of five degrees of freedom (DOF) structure was utilized for a good accessibility of the robot.

According to the work space in a train wagon, basic parameters of the robot arm were determined, including the length of the upper and lower arm and the maximum swinging angle. The position diagram of the three DOF handling robot was shown in Fig. 2. The whole model was established in a coordinate system OXYZ with coordinate origin O serving as its base center. Firstly, the robot was located in the workspace of Planar XOZ. Then the whole robot workspace is achieved by rotating the workspace in the Planar XOZ around the z axis by θ_0 .

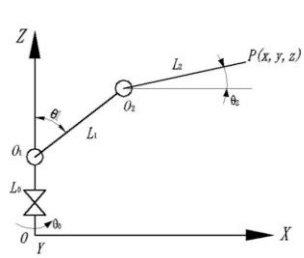

Fig.2. Position diagram of the handling robot

The maximum space of the end point P(x, y, z) on the handling robot is the robot's largest workspace. From the diagram above, coordinate P(x, y, z) can be expressed as:

$$x = L_1 \sin\theta_1 + L_2 \cos\theta_2 \tag{1}$$

Where

L_1 is the length of the upper arm

L_2 is the length of the front arm

$$z = L_0 + L_1 \cos\theta_1 + L_2 \sin\theta_2 \tag{2}$$

Where

L_0 is the height of the pedestal

θ_1 is the upper arm pitching angle

θ_2 is the front arm pitching angle

$$y = 0 \tag{3}$$

Fig. 3 shows the handling robot workspace in plane XOZ formed by the four curves. Among them, P_1P_2 is the curve when $\theta_2=\theta_{2max}$, θ_1 changes from θ_{1max} to θ_{1min}; P_2P_3 is the curve when $\theta_1=\theta_{1min}$, θ_2 changes from θ_{2max} to θ_{2min}; P_3P_4 is the curve when $\theta_2=\theta_{2min}$, θ_1 changes from θ_{1min} to θ_{1max}; P_4P_1 is the curve when $\theta_1=\theta_{1max}$, θ_2 changes from θ_{2min} to θ_{2max}.

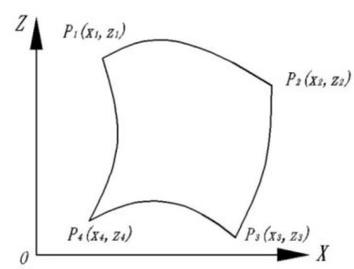

Fig.3. Boundary of the handling robot workspace in plane XOZ

The coordinate values of P_1, P_2, P_3 accorded with (1) and (2), and then following equations were formulated:

$$x_1 = -L_1 \sin\theta_{1max} + L_2 \cos\theta_{2max} \tag{4}$$

$$z_1 = L_0 + L_1 \cos\theta_{1max} + L_2 \sin\theta_{2max} \tag{5}$$

$$x_2 = -L_1 \sin\theta_{1min} + L_2 \cos\theta_{2max} \tag{6}$$

$$z_2 = L_0 + L_1 \cos\theta_{1min} + L_2 \sin\theta_{2max} \tag{7}$$

$$x_3 = -L_1 \sin\theta_{1min} + L_2 \cos\theta_{2min} \tag{8}$$

$$z_1 = L_0 + L_1 \cos\theta_{1min} + L_2 \sin\theta_{2min} \tag{9}$$

Set the height of the pedestal as L_0=0.7m , coordinates of three border points were shown as below:

$$P_1(x_1, z_1) = (1.0,1.8)$$
$$P_2(x_2, z_2) = (2.2,1.6)$$
$$P_3(x_3, z_3) = (1.6,0.3)$$

Set the coordinates into (4) to (9), the results after rounded were:

L_1=1100m; L_2=1300m

$\theta_0 \sim (0-360°)$; $\theta_{1min} = -70°$

$\theta_{1max} = 30°$; $\theta_{2min} = -100°$; $\theta_{2max} = 20°$