fusals and 9 – are transitions of restorations, 22 – are external and 9 – are internal. The decision of system of the differential equations will allow to define probabilities of finding of open pit trucks in various technological conditions, intensity of transitions between them and to correct operating system of maintenance operation rationally.

Conclusions

Within the developed mathematical model the analysis of streams of the events formed by transitions between technological conditions of open pit trucks of the Krivorozhsky iron ore pool is made.

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Optimizing Industrial Robot for Picking Liquid Glass

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Abstract
In order to optimize the design, a five-degree virtual prototype robot with easy structure is presented dedicated to picking liquid glass. With D-H method, a theoretical kinematics mathematics model is established, the forward and inverse kinematics of the robot is analyzed to get the expression of the end effector of the robot. Then, based on the 3D model established with UG, the rotation matrix and translation matrix of the robot can be calculated future. Following, the process of automatic feeding of the robot imported to ADMAS is simulated. Through simulation graphs: the result tested and verified is consistent with the actual situation of the working process. Finally, the research has provided some references for future study of the picking liquid glass robot.
Key words: PICKING GLASS ROBOT, MECHANICAL STRUCTURE, VIRTUAL PROTOTYPE.

1. Introduction

With the development of the modern industry automaticity level, the status of robot in the modern industrial manufacturing is meant to become more and more important, they take place of workers to complete the hard and dangerous jobs, however, today's standard robotic systems often do not meet the industry's demands for accurate high-speed robotic applications[1]. In this paper, creating an autonomous robot that can understand the basis of human interaction with the environment in order to make the robot acting in a similar manner to what people do while moving and interacting across their space [2].

Currently, our country has made great progress in the field of robot, but the research in the field of glass processing of manipulator is less, most of the domestic glass processing small medium enterprise is still given priority to artificial feeding, only a small part of the large enterprises choose to introduce foreign manipulators[3]. In abroad, intelligent robot has become the trend of the development, they can understand instructions, perception environment, planning its procedures to complete the tasks, however, the transmission and control structure is complex, which is unfavorable for the protection maintenance.

So in order to meet the job requirements, a five-DOF robot dedicated to taking liquid glass is designed, which can realize space translation, rotation, pitch, at the same time, the flexibility, range and bearing capacity of the robot are given full consideration[4]. Firstly, the feature of the robot should be taken into account to define the model volume to achieve the motion at the beginning and the end region[5]. The following step is to check if the part of the robot has interference region with other volumes to ensure the implement of the orders, subsequently, kinematics analysis of the base, arm, forearm, wrist and end executor of the robot is carried out to confirm that the end of the actuator position expression T is right. At last, the trajectory simulation will be shown to prove the effective of the design. Traditional industries have to manually remove the liquid glass from the furnace, high risk, low working efficiency, on the contrast, the liquid glass removed from the high temperature furnace using the robot can ensure the safety of the workers, improving work efficiency and product quality.

2.Kinematics theoretical model

2.1 The establishment of the D-H coordinate system

In recent years, many advanced algorithms have been designed and developed by different researchers [6,7], D-H model uses 4x4 homogeneous transformation matrix to describe space position relations between the robot adjacent bar to simplify the complex kinematics. Figure 1, the linkage system of the five-degree robot according to the D-H coordinate system.

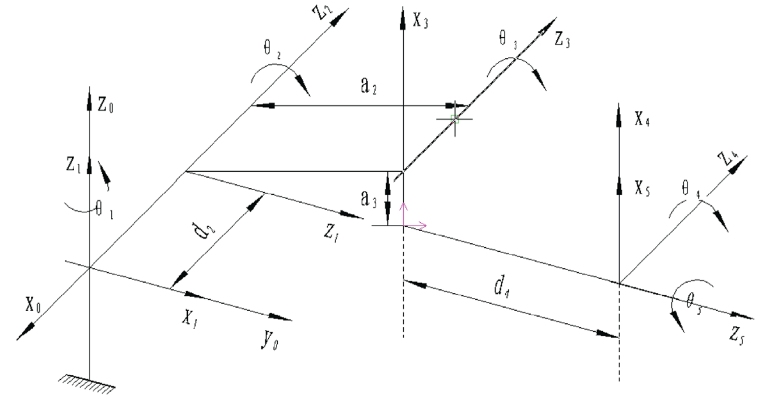

Figure 1. The connecting rod coordinate system

According to figure 1, the linkage parameters can be achieved, as shown in table 1.

Table 1. Linkage parameters

linkage i	variable θ_i	α_{i-1}	a_{i-1}	d_i
1	θ_1 $(\pi/2)$	0	0	0
2	θ_2 (0)	$-\pi/2$	0	d_2
3	θ_3 $(-\pi/2)$	0	a_2	0
4	θ_4 (0)	0	a_3	d_4
5	θ_5 (0)	$-\pi/2$	0	0

θ_i is the axis x_{i-1} transformation to the axis x_i rotation angel around shaft z_i; d_i is the translation distance between axis x_{i-1} and axis x_i along shaft z_i; a_{i-1} is the translation distance between axis z_{i-1} and axis z_i along shaft x_{i-1}; α_{i-1} is the axis z_{i-1} transformation to the axis z_i rotation angel around shaft x_{i-1}.

d_1 is the height of the base ,329mm; d_2 is the big arm length,389mm;a_2 is the length of the forearm,436mm;d_4 is the wrist length,389mm;the length of the end actuator is 600mm.

2.2 Kinematics positive solution

The kinematics problem is known the bars' joint variables and geometric parameters to achieve the position of the actuator in the given coordinate system. Homogeneous transformation matrix expression Ti [8] is as follows;

$$\mathbf{T}_i = Rot(x_i,\alpha_{i-1})Trans(x_i,a_{i-1})Trans(z_i,d_i)Rot(z_i,\theta_i)$$

$$= \begin{bmatrix} c\theta_i & -s\theta_i c\alpha_{i-1} & s\theta_i s\alpha_{i-1} & a_{i-1}c\theta_i \\ s\theta_i & c\theta_i c\alpha_{i-1} & -c\theta_i s\alpha_{i-1} & a_{i-1}s\theta_i \\ 0 & s\alpha_{i-1} & c\alpha_{i-1} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$c\theta_i = \cos(\theta_i)\ s\theta_i = \sin(\theta_i)$$

Put the link parameters in table 1, and the joint variables into the formula (1), each connecting rod transformation matrix can be obtained as follows;

$${}^0T_1 = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & 0 \\ s\theta_1 & c\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_2^1 = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & 0 \\ 0 & 0 & 1 & d_2 \\ -s\theta_2 & -c\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_3^2 = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & a_2 \\ s\theta_3 & c\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_4^3 = \begin{bmatrix} c\theta_4 & -s\theta_4 & 0 & a_3 \\ s\theta_4 & c\theta_4 & 0 & 0 \\ 0 & 0 & 1 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_5^4 = \begin{bmatrix} c\theta_5 & -s\theta_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -s\theta_5 & -c\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

By the connecting rod matrix multiplication, total transformation matrix of the robot is as follows, which indicates the position of the end actuator.

$${}^0T_5 = {}^0T_1(\theta_1)\,{}^1T_2(\theta_2)\,{}^2T_3(\theta_3)\,{}^3T_4(\theta_4)\,{}^4T_5(\theta_5) = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

2.3 Kinematics inverse solution

Expectations for the position of the end executor, how to solve the problem of each joint variable is known as the kinematics of the second question [9,10], also known as the joint Angle of inverse transformation. In order to solve the robot inverse kinematics solution, this paper adopts ${}^0T_i^{-1}$ and matrix ${}^0T_5$ multiplication, the results are as follows;

$$\theta_1 = \arctan\left(\frac{p_y}{p_x}\right) - \arctan\left(\frac{d_2 + d_4}{\pm\sqrt{p_x^2 + p_y^2 - (d_2 + d_4)^2}}\right)$$

$$\theta_2 = \theta_3 - \theta_3 = \arctan\frac{-(a_3 + a_2 c_3)p_z + (c_1 p_x + s_1 p_y)a_2 s_3}{a_2 s_3 p_z + (c_1 p_x + s_1 p_y)(a_2 c_3 + a_3)}$$

$$- \arccos\left(\frac{p_x^2 + p_y^2 + p_z^2 - a_2^2 - a_3^2 - (d_2 + d_4)^2}{2a_2 a_3}\right)$$

$$\theta_3 = \arccos\left(\frac{p_x^2 + p_y^2 + p_z^2 - a_2^2 - a_3^2 - (d_2 + d_4)^2}{2a_2 a_3}\right)$$

$$\theta_4 = \arctan\frac{(c_1 c_3\ a_x + s_1 c_3\ a_y - s_3\ a_z)}{c_1 s_3\ a_x + s_1 s_3\ a_y + c_3\ a_z}$$

$$\theta_5 = \arctan\frac{c_1 c_3\ o_x + s_1 s_3\ o_y - s_3\ o_z}{c_4(-s_1 o_x + c_1 o_y)}$$

Each joint angel is not unique, so what you should do is to select the optimal solution according to the actual requirements of the work.

2.4 Differential transform Jacobi matrix

Robot Jacobi matrix is the study of the linear transmission relation of the end actuator in the coordinate system between the generalized velocity vector $\dot{x}$ and the joint torsional angular velocity vector $\dot{q}$.

$\dot{x} = J(q)\dot{q}$

The robot talked about contains of five joints, so the Jacobi matrix is 6x5 order matrix.

$$^{T}J(q) = \begin{bmatrix} (p \times n)_z \\ (p \times o)_z \\ (p \times a)_z \\ n_z \\ o_z \\ a_z \end{bmatrix} \mathbf{d}\theta_i \qquad (3)$$

According to type (3) and the transformation matrix $^{i}T_5$, we can obtain the linear velocity ratio and the angular velocity ratio of each link. The results are as follows;

$$^{T}J_1(q) = \begin{bmatrix} ^{T}J_{1x} \\ ^{T}J_{1y} \\ ^{T}J_{1z} \\ -s_2(c_3c_4c_5 - s_3s_4s_5) - c_2(s_3c_4c_5 + c_3s_4c_5) \\ -s_2(-c_3c_4s_5 - s_3s_4s_5) + c_2(s_3c_4s_5 + c_3s_4s_5) \\ s_2(c_3s_4 + s_3c_4) - c_2(-s_3s_4 + c_3c_4) \end{bmatrix}$$

$$^{T}J_{1x} = -(d_2 + d_4)[c_2(c_3c_4c_5 - s_3s_4s_5) - s_2(s_3c_4c_5 + c_3s_4c_5)] + a_3s_2s_3s_5 - c_2s_5(a_3c_3 + a_2)$$

$$^{T}J_{1y} = -(d_2 + d_4)[c_2(-c_3c_4s_5 - s_3s_4s_5) + s_2(s_3c_4s_5 + c_3s_4s_5)] + a_3s_2s_3c_5 - c_2c_5(a_3c_3 + a_2)$$

$$^{T}J_{1z} = (d_2 + d_4)[c_2(c_3s_4 + s_3c_4) - s_2(-s_3s_4 + c_3c_4)]$$

$$^{T}J_2(q)=\begin{bmatrix} -a_3s_3(c_3c_4c_5-s_3s_4c_5)+(a_3c_3+a_2)(s_3c_4c_5+c_3s_4s_5) \\ -a_3s_3(-c_3c_4s_5+s_3s_4s_5)+(a_3c_3+a_2)(-s_3c_4s_5-c_3s_4s_5) \\ a_3s_3(c_3s_4+s_3c_4)+(a_3c_3+a_2)(-s_3s_4+c_3c_4) \\ -s_5 \\ -c_5 \\ 0 \end{bmatrix}$$

$$^{T}J_3(q)=\begin{bmatrix} a_3s_4c_5 \\ -c_3s_4s_5 \\ a_3c_4 \\ -s_5 \\ -c_5 \\ 0 \end{bmatrix} \quad ^{T}J_4(q)=\begin{bmatrix} 0 \\ 0 \\ 0 \\ -s_5 \\ -c_5 \\ 0 \end{bmatrix} \quad ^{T}J_5(q)=\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

3.The 3-D model

The body structure of the five degrees of freedom robot used to picking liquid glass is composed of base, waist between the base and the turntable, arm connecting the shoulder and the turntable, elbow between the upper and low arm, wrist connecting forearm and end effector and actuator. Among them, the rotation of the turntable, arm, forearm bobbing up and down control the working space of the actuator, the pitch of the wrist controls the working attitude of the end effector. Therefore, the 3-D simulation model established by UG software is shown in figure 2.

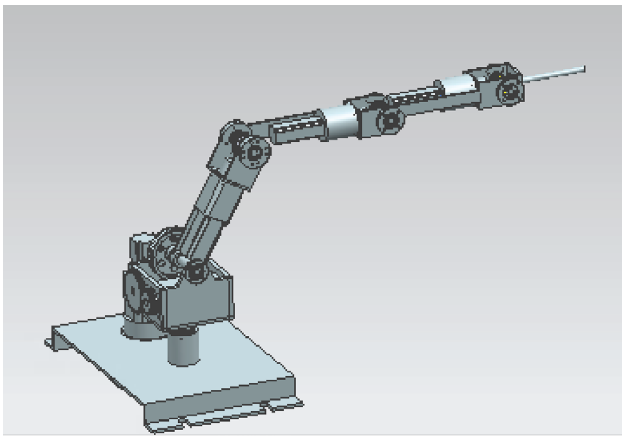

Figure2. 3-D simulation model

4.Motion simulations

4.1 Pre-treatment simulation

In order to further verify the rationality of the robot designed and simulate the trajectory, the ADMAS software is used. The model in UG is saved as a parasolid format, and imported into the ADMAS/View, then add rotation deputy and driver to each building including base, arm, forearm, wrist and end executor. Virtual prototype model of the robot is shown in figure 3.

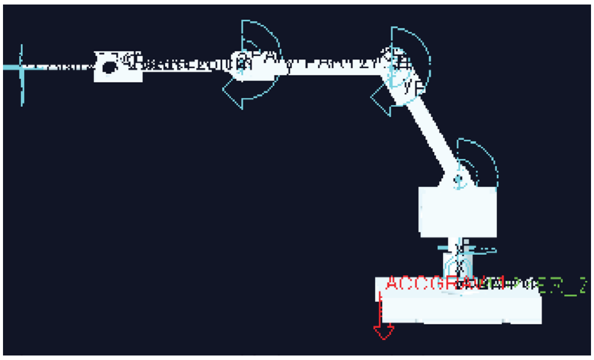

Figure 3. Virtual prototype model

Mark-15 in the center of the mass of the end actuator, as the research object, is studied the relative to the base (fixed coordinate system) of the trajectory and the speed curve. Set the simulation time for 10 seconds, the simulation steps for 500, processed track by ADMAS is shown in figure 4.

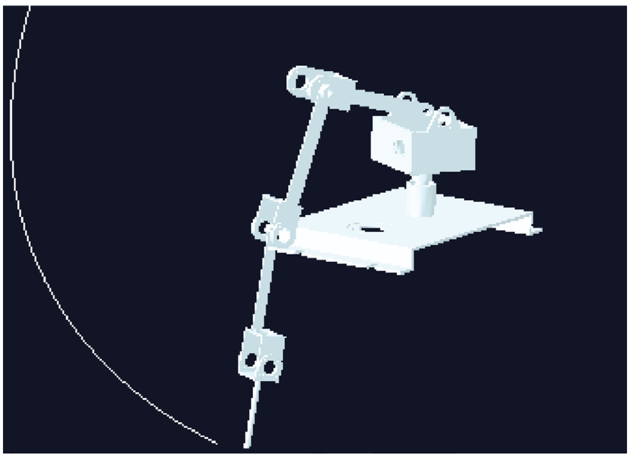

Figure 4. Simulation trajectory

Speed curve along the X, Y, Z axis is shown in figure 5.

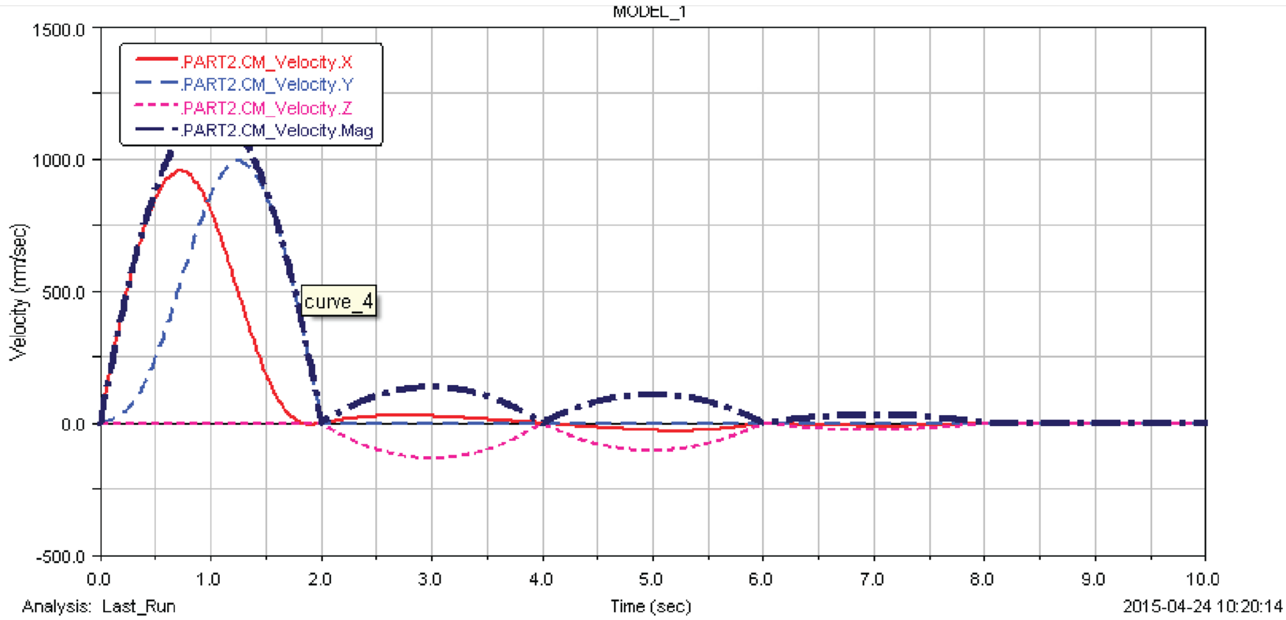

Figure 5. Speed curve

As can be seen from the figure 5, in the first 2s, the speed of mark-15 in the direction of X, Y accelerate to the max, then decelerate to zero, the speed in the direction of Z is zero, the time between 2s and 8s, the speed in X axis is zero, the velocity along Y is very slow, the mainly movement is the radial motion along Z. The last two seconds, the end actuator does uniform rotation. The robot's motion simulation is consistent with the design concept.

4.Conclusions

In this paper, various methods are presented to optimize the design to improve the overall performance of the robot. The simulation results have been shown that the robot is capable of satisfying the working requirements. The value of this paper is that the amount of degrees of freedom and the overall design are redesigned to improve the flexibility and extend the working space. It is important to know that a more precise control system should be developed to cope with the complex trajectory optimization, as a consequence, fuzzy-neural control can be used to improve the robustness [11] because of its special advantages.

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