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Mechanism Design and Kinematics Analysis of Display Bracket Based on Adams

Li Song[1], Huang Li Xin[2]
(College of Mechanical Engineering, Shanghai University of Engineering Science, China)

ABSTRACT: *In view of the problem of conventional display support equipment which has a poor intelligent, low technological level, easy to cause the body with sub-health, and can't meet the needs of high level office, designed a new type of display bracket mechanism. The principle and force analysis was carried out on the display bracket mechanism, and to simplify the original mechanism with three linkages for facilitating analysis and simulation. Forward kinematics analysis was carried out on the bracket mechanism based on DH method and obtained pose transformation matrix between each joint coordinate, and expressed the relationship between the end speed and the velocity of each joint by using Jacobian matrix. Establishing simplified virtual prototype and kinematics simulation was carried out on displacement, velocity, acceleration, angular velocity and acceleration of bracket mechanism based on the software of ADAMS which verified the correctness of theoretical analysis. The simulation results showed that the design of bracket mechanism complied with the requirements of free readjustment of display. Realizing the combination between high-tech and high emotion, improving the body with sub-health at the present situation of office, and meet the needs of advanced intelligent office by using the new display bracket mechanism.*

Keywords: *DH method, Display bracket, Kinematics, Software of ADAMS*

I. INTRODUCTION

With the production of artificial intelligence and the commercial Internet under the circumstances of the development of science and technology, this promoted SOHO business model of the modern office. The design of office furniture products also will cooperate with the development of the digital become more intelligent with the functions of network communication transmission, consulting, and so on. So, the application of wireless network and artificial intelligence on the design of office furniture has become a necessary thinking direction[1]. Nowadays the way of society office that produced the problem of sub-health, the problems of the waist and the cervical vertebra discomfort many people because of the long time operation on the computer, which cause many diseases such as Lumbar disc bulge, lumbar muscle degeneration, Benign Prostatic Hyperplasia, cervical hyperplasia and so on[2], especially people watch a fixed angle of the computer screen for a long time, many office equipment are increased bracket which can be manually adjust the angle of display. But most of these products are achieved the adjustment of the lift height, distance and the pitch Angle and so on of the display by artificial, and the product does not meet the needs of the future high-level market also cannot achieve the ideal effect of man-machine engineering,. In order to improve the degree of equipment automation and improve the flexibility of equipment, it needs to use to some mechanical devices such as robots, lifting mechanism[3], etc. Therefore this paper aim to discuss how to make the adjustment of the display can be more intelligent from the aspects of structure, at the same time can achieve the desired position. For this goal a display bracket mechanism is designed. First design the structure of display bracket and analyses its principle. Secondly analyses the kinematics and calculated the Jacobian matrix. Finally design the virtual prototype of display bracket and the motion simulation analysis was carried out based on ADAMS.

II. MECHANISM DESIGN OF DISPLAY BRACKET

2.1 Structure design and principle

Fig.1 showed the structure of display bracket. It mainly consists of base 1, fixed bracket 2, rotary bracket 3, handspike device 4, active bracket 5, display connection device 6 and other components. The principle for its application: first, fixing the bracket system to a certain range thickness of the table by base 1 and fixed bracket 2, using cylindrical vice between rotary bracket 3 and fixed bracket 2, to realize freely adjust of bracket system by rotating rotary bracket 3, adjusting the angle of elevation of activity bracket 5 by handspike device 4, then moving upward along a circular trajectory around the hinged point between rotary bracket 3 and activity bracket 5 until the angle of elevation of activity bracket 5 to the right size in order to realize freedom control of the height of display connection device 6. Then adjusting the state of pitch angle of display connection device 6 by rotating rotary the hinged point between activity bracket 5 and display connection device 6, the display is fixed in the connection device 6, then the freedom adjustment of display can be realized.

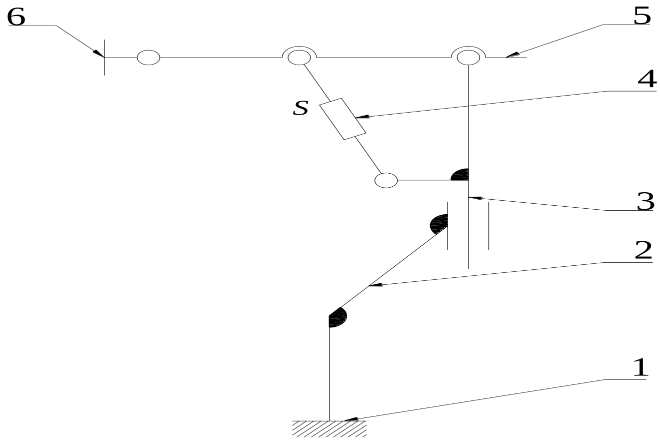

Fig.1 Structure diagram of display bracket mechanism

2.2 Force analysis and structure simplified

Fig.2 showed the force analysis of the structure of display bracket.

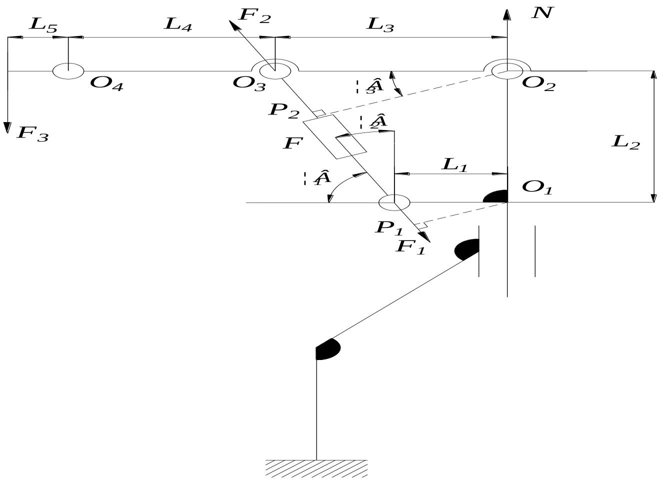

Fig.2 Analysis of forces

To be convenient for proceeding the simulation and kinematics analysis by simplifying the structure of display bracket, fig.2 showed the simplified force system.

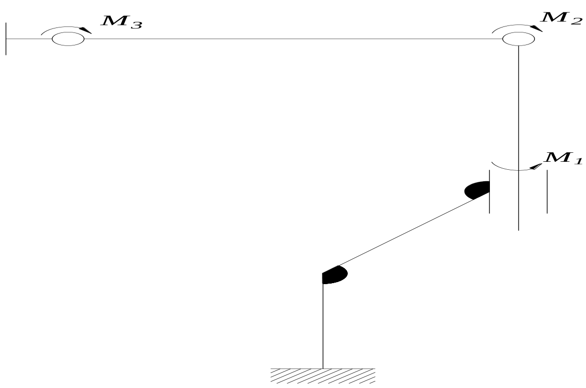

Fig.3 The simplified force system

The thrust generated by the handspike device and the applied force of the connection device generated by the display both simplified toward the center of the joint, respectively, making the bracket joints are only existed torque of couple. The positive is clockwise direction and the simplified force system as follows:

$M_2 = F_2 L_{o_2 p_2} - F_1 L_{o_1 p_1}$, $M_3 = F_4 L_5$, $L_{o_1 p_1} = L_1 \sin\beta_1$, $L_{o_2 p_2} = L_3 \cos\beta_3$, in the formula: L_i is the

length of connecting rod of each part, mm, $i = 1, 2, 3, 4, 5$; F_j is the force of connecting rod of each part, N, $j = 1, 2, 3$; β_i is the deflection angle of connecting rods, °, $i = 1, 2, 3$; $L_{o_1 p_1}$ is the vertical distance from point O_1 to P_1,mm; $L_{o_2 p_2}$ is the vertical distance from point O_2 to P_2,mm; M_i is the torque of couple of the joints, $N \cdot mm$, $i = 1, 2, 3$.

III. KINEMATICS ANALYSIS

Fig.3 showed the display bracket mechanism becomes three linkages by simplifying the force system, including three revolute pairs and involving in the problem of the relationship between the translation and rotation in two-dimensional space. In order to describe the relationship between adjacent linkages, a matrix analysis method is proposed by Denavit and Hartenberg[4]. Therefore, setting a coordinate system to each linkage to describe the position of each joint, then the DH method carries on the kinematics analysis.

Set up a DH coordinate system of the display bracket mechanism under the laws of DH matrix. Fig.4 showed the coordinate system of DH. Due to relative position between the rotary bracket and the fixed base is not change, the coordinate system origin O can choose in the intersection point between z_0 and z_1. Tab.1 showed DH parameters of display bracket mechanism.

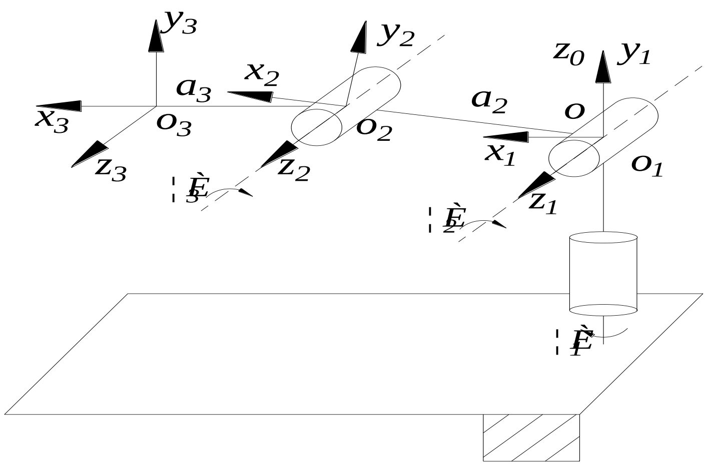

Fig.4 Coordinate system of DH

Table 1 DH parameters

Linkage	a_i	α_i	d_i	θ_i
1	0	$\pi/2$	0	θ_1
2	a_2	0	0	θ_2
3	a_3	0	0	θ_3

In the table 1, a_i is the distance from point O_i and O_{i-1}; d_i is the coordinate of θ_i along z_{i-1},and $d_i = 0$; α_i is the angle between axis z_{i-1} and z_i, the positive is clockwise direction around axis x_i; θ_i is the angle between axis x_{i-1} and x_i, the positive is clockwise direction around axis z_{i-1}.

3.1 Forward kinematics analysis

The transformation matrix from coordinate $\{i-1\}$ to coordinate $\{i\}$ is:

$$ {}^{i-1}T_i(q_i) = \begin{pmatrix} c_{\theta_i} & -s_{\theta_i}c_{\alpha_i} & s_{\theta_i}c_{\alpha_i} & a_i c_{\theta_i} \\ s_{\theta_i} & c_{\theta_i}c_{\alpha_i} & -c_{\theta_i}s_{\alpha_i} & a_i s_{\theta_i} \\ 0 & s_{\alpha_i} & c_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{1} $$

In the equation (1), q_i is the joint angle, $i = 1,2,3$.

According to the equation (1), the forward kinematics formula of bracket mechanism is derived as follows:

$$ {}^0T_3(q) = {}^0T_1(q_1)\,{}^1T_2(q_2)\,{}^2T_3(q_3) = \begin{pmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{2} $$

In the equation (2):

$n_x = c_1c_{23}$, $n_y = s_1c_{23}$, $n_z = s_{23}$, $o_x = -c_1s_{23}$, $o_y = -s_1s_{23}$, $o_z = c_{23}$, $a_x = s_1$, $a_y = -c_1$, $a_z = 0$, $p_x = c_1(a_2c_2 + a_3c_{23})$, $p_y = s_1(a_2c_2 + a_3c_{23})$, $p_z = a_2s_2 + a_3s_{23}$, $s_i = \sin(\theta_i)$, $c_i = \cos(\theta_i)$, $s_{ij} = \sin(\theta_i + \theta_j)$, $i, j = 1,2,3$.

Put the initial value $\theta_1 = \theta_2 = \theta_3 = 0$ into the equation (2) and multiplied by $\begin{pmatrix} 0 & 0 & 0 & 1 \end{pmatrix}^{\mathrm{T}}$, the coordinate of $\{3\}$ in the coordinate $\{0\}$ is $\begin{pmatrix} a_2 + a_3 & 0 & 0 \end{pmatrix}$. The results show that the initial condition for display bracket is the axes of display connection device and activity bracket are both parallel to the base, which consist with the actual situation.

3.2 The calculation of Jacobian matrix[5]

Computation of the unit vectors of revolute joint axes gives as follows:

$$ z_0 = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, z_1 = z_2 = \begin{bmatrix} s_1 \\ -c_1 \\ 0 \end{bmatrix} \tag{3} $$

Computation of the position vectors of the various links gives as follows:

$$ p_0 = p_1 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, p_2 = \begin{bmatrix} a_2c_1c_2 \\ a_2c_2s_1 \\ a_2s_2 \end{bmatrix}, p_3 = \begin{bmatrix} c_1(a_2c_2 + a_3c_{23}) \\ s_1(a_2c_2 + a_3c_{23}) \\ a_2s_2 + a_3s_{23} \end{bmatrix} \tag{4} $$

The angular velocity of each joint is:

$$ \omega_i = q_i z_{i-1} \tag{5} $$

The linear velocity of each joint is derived as follows:

$$ v_i = \omega_i(p_i - p_{i-1}) = z_{i-1}(p_i - p_{i-1})q_i \tag{6} $$

The velocity vector joint is derived by merging the equation (5) and (6):

$$ \begin{bmatrix} v_i \\ \omega_i \end{bmatrix} = \begin{bmatrix} z_{i-1}(p_i - p_{i-1}) \\ z_{i-1} \end{bmatrix} q_i $$

The *i* column of Jacobian matrix can be expressed as follows:

$$ J_i = \begin{bmatrix} z_{i-1}(p_3 - p_{i-1}) \\ z_{i-1} \end{bmatrix} \tag{7} $$

The Jacobian matrix of each revolute joint can be obtained by commutating the equation (5), (6) and (7):

$$J_1=\begin{bmatrix} z_0(p_3-p_0) \\ z_0 \end{bmatrix}, J_2=\begin{bmatrix} z_1(p_3-p_1) \\ z_1 \end{bmatrix}, J_3=\begin{bmatrix} z_2(p_3-p_2) \\ z_2 \end{bmatrix}$$

The form of Jacobian matrix can be expressed as:

$$J=\begin{bmatrix} J_1 & J_2 & J_3 \end{bmatrix}=\begin{bmatrix} -s_1(a_2c_2+a_3c_{23}) & -c_1(a_2s_2+a_3s_{23}) & -a_3c_1s_{23} \\ c_1(a_2c_2+a_3c_{23}) & -s_1(a_2s_2+a_3s_{23}) & -a_2s_1s_{23} \\ 0 & a_2c_2+a_3c_{23} & a_3c_{23} \\ 0 & s_1 & s_1 \\ 0 & -c_1 & -c_1 \\ 1 & 0 & 0 \end{bmatrix}$$

IV. THE MOVEMENT SIMULATION

4.1 The simulation process and results

Set up a simplified three link model of display bracket in the software of Solidworks, and then import in the software of ADAMS[6-7]. In order to measure the motion curve of the end, establishing a Marker tag in the center of the display connection device, and setting a Marker tag in the center of mass of rotary bracket as the reference coordinate system. The direction for z and y axis of the reference coordinate system is the same as the fig.4; the direction for x axis is opposite to fig.4; the initial posture of bracket is the same as the fig.3. Then add the rotation constraints and driver on each joint, the driving mode are as follows:

Motion_1 : STEP(time , 0 , 0 , 2 , -45d) ;

Motion_2 : STEP(time , 0 , 0 , 2 , 0)+STEP(time , 2 , 0 , 4 , 23d)+STEP(time , 4 , 0 , 6 , -48d)+STEP(time , 6 , 0 , 8 , 25d) ;

Motion_3 : STEP(time , 0 , 0 , 2 , 0)+STEP(time , 2 , 0 , 4 , 23d)+STEP(time , 4 , 0 , 6 , -48d)+STEP(time , 6 , 0 , 8 , 25d)+STEP(time , 8 , 0 , 9 , 10d).

Motion_1 is the driver of the revolute pair between fixed bracket and rotary bracket; Motion_2 is the driver of the revolute pair between active bracket and rotary bracket; Motion_3 is the driver of the revolute pair between display connection device and active bracket.

Set up 9 s simulation time and 500 steps, to measure displacement, velocity, acceleration and angular velocity and angular acceleration of the end Marker tag, respectively, and generate the curve charts. Processing the curve charts in the Adams/Postprocessor[8-9]. Fig.6 to Fig.9 showed the curve charts.

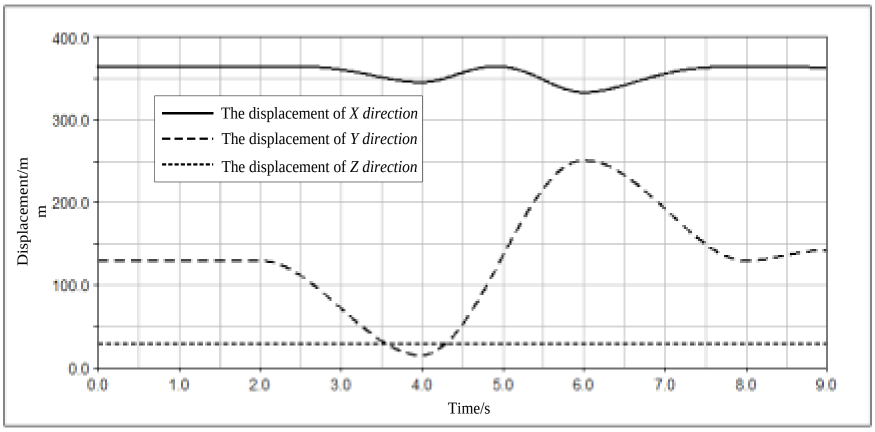

Fig.6 Displacement curves of the marker point of the end

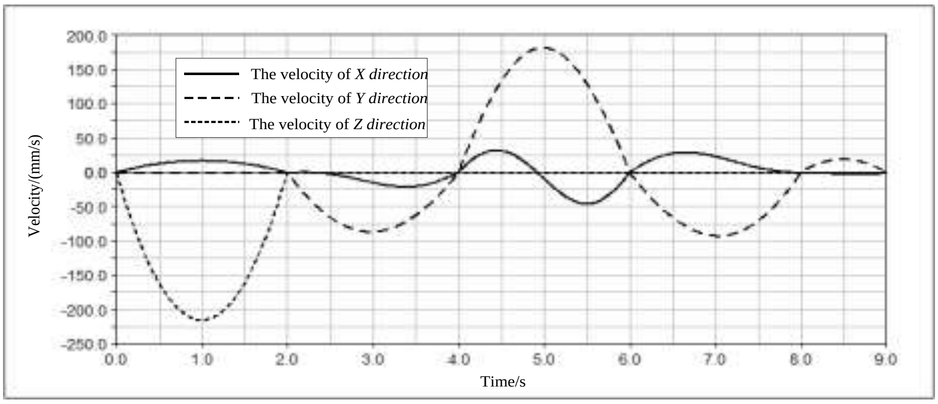

Fig.7 Velocity curves of the marker point of the end

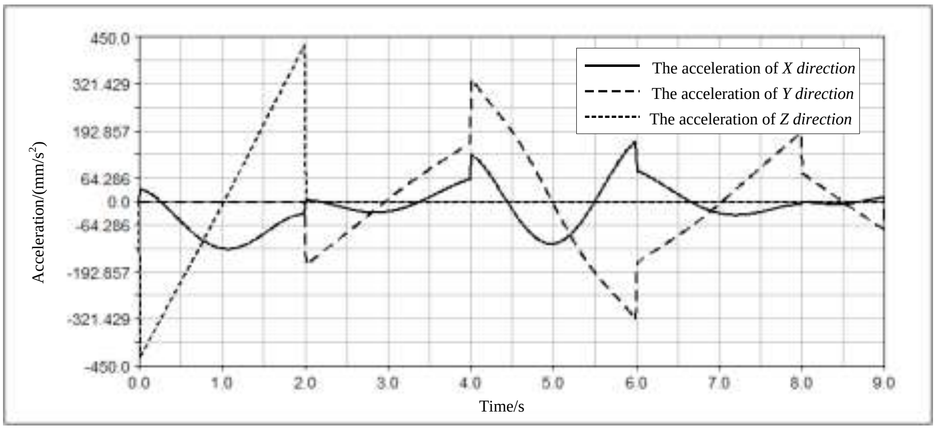

Fig.8 Acceleration curves of the marker point of the end

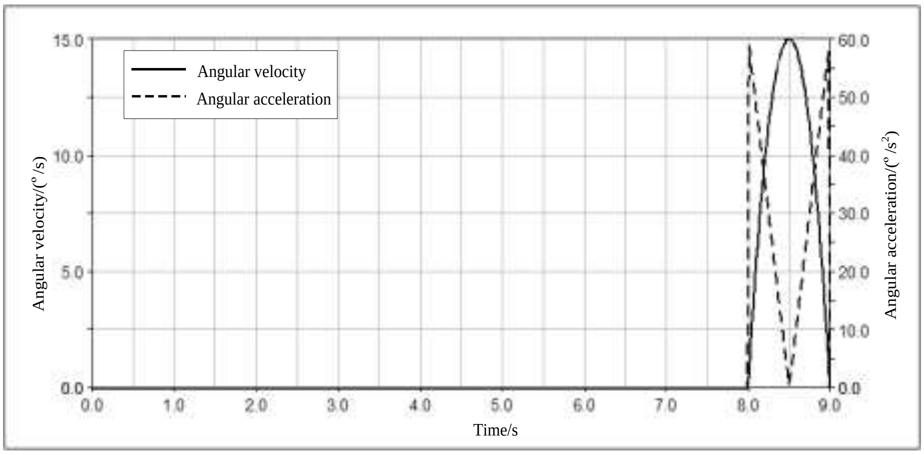

Fig.9 Angular velocity and acceleration curves of the marker point of the end

4.2 Results analysis

1) According to the loaded driver function of each joint, refer to fig.4, it is observed that the displacement of the direction for Z axis of the end of display bracket has fixed value in the range of 0 ~ 9 s, and the angular velocity and the acceleration of the end are both zero in the range of 0 ~ 8 s; The bracket overall rotated -45º, and the variation of the end versus the reference coordinate system mainly in the X axis and Z axis in the range of 0 ~ 2 s; The joint 2 and the joint 3 rotate at the same time, and great changes have taken place in displacement, velocity and acceleration, and the velocity and the acceleration are both zero in the direction of Z axis in the range of 2 ~ 8 s; The variation of the displacement, velocity and acceleration of the end is not obvious, and the angular acceleration is obvious in the range of 8 ~ 9 s.

2) The reason for the displacement of the direction for Z axis of the end has fixed value in the range of 0 ~ 9 s is that the end has the initial value in the direction of Z axis after the joint 1 rotated -45º in the range of 0 ~ 2 s, which shown that the rotation achieved the angle adjustment function of the whole bracket; The variation

of the displacement, velocity and acceleration of the end is obvious in the range of 2 ~ 8 s, and the displacement of the direction for X axis has little change, and the displacements of the direction for Y axis are reached maximum value, the instantaneous velocities are zero, the instantaneous accelerations are maximum, which implemented the height adjustment of up and down for the bracket. The angular acceleration of the end is obvious in the range of 8 ~ 9 s, which implemented the adjustment of the pitch angle of display for the rotation of joint 3, but the angular velocity and acceleration has smaller value, and the impact is not big, which reduce the demand of motor for joint 3 and eliminate the cost.

V. CONCLUSION

In this paper, actual application demand is analyzed of the display, and a display bracket mechanism is designed. The force of the new structure for display bracket is analyzed. To be convenient for proceeding the simulation and kinematics analysis by simplifying the structure of display bracket. The establishment of the kinematic model is the premise and foundation for the study of the space trajectory planning and control strategy of display bracket. The simulation results show that the machine running well and has a good running smoothness.

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