ROBOTS FOR SPACING OF WOOD

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Abstract: Construction is of great interest for using of woodprocessing robotics. The structure, kinematic and dynamic models of robots for material location and spacing as well as woodprocessing have been considered in the paper. Taking into account specific features and dynamic characteristics of robot, the recommendations on movements planning and forming laws of control have been given. In conclusion recommendations for obtaining truthful measuring data and on the composition of robot software have been provided.

Keywords: Motion control; robot kinematics; wood processing.

1. INTRODUCTION

When producing elements of prefabricated wooden houses a great deal of work on location and spacing of wood and shaping of holes, recesses, decorative patterns is done. The projects individual peculiarities require the application of technological equipment with quick readjustment and opportunity to prepare control programs on the model during a short period of time. While solving this problem much attention is paid to the robotization of the mentioned above operations and creating robotic systems. The successful solution of robotization tasks is first connected with the development of original kinematic structures and competent structural analysis. One more significant problem of robotization of wood processing operations is setting the trajectory for cutting tool movement and provision of its purposeful movement along these trajectories with definite orientation.

2. ROBOT STRUCTURE, KINEMATICS AND DYNAMIC MODELS

The analysis of jobs connected with location and spacing of wood as well as shaping of holes and decorative patterns has shown that in the basis of the robotic system there should be a rectangular 3-coordinate gantry robot (fig.1). This cell provides the working tool movement in the plane of a working table as well as lifting, lowering and pressing of the tool. The second cell is an orienting working head providing changes in the tool position relative to the working plane or its rotation around the axis *Z*. The main kinematics relations defining the nature of the wood processing robot motions are presented by the system of the form

$$x(t) = q_1(t) + l\sin(q_4(t))\sin(q_5(t));$$
$$y(t) = q_2(t) + l\cos(q_4(t))\sin(q_5(t));$$
$$z(t) = q_3(t) + l\cos(q_5(t)),$$

where $q_i(t)$ are generalized robot's coordinates, l is the length of the end link.

The laws of changing the tool phase coordinates $x(t), y(t), z(t)$ and its orientations $\theta(t), \gamma(t)$ are determined by shape and view of the pattern being fulfilled. The angle θ specifies the tool pitch relative to the plane XY, and the angle γ - the direction of the inclination being read from the axis *X*. The values of these parameters and the laws of their change in time are formed at the stage of planning robot motions. The kinematics of orienting degrees of freedom has been chosen so that the tool pitch angles θ and the pitch directions γ are given separately by the degrees of freedom q_5 and q_4: $\theta(t) = q_5(t), \gamma(t) = q_4(t)$. In this case the laws of the generalized coordinates changes of the transportable degrees of freedom are described by the following:

$$q_1(t) = x(t) - l\sin(\theta(t))\cos(\gamma(t));$$
$$q_2(t) = y(t) - l\sin(\theta(t))\sin(\gamma(t));$$
$$q_3(t) = z(t) - l\cos(\theta(t)).$$

To simplify the controlling functions and increase the accuracy of tool positioning a special-purpose

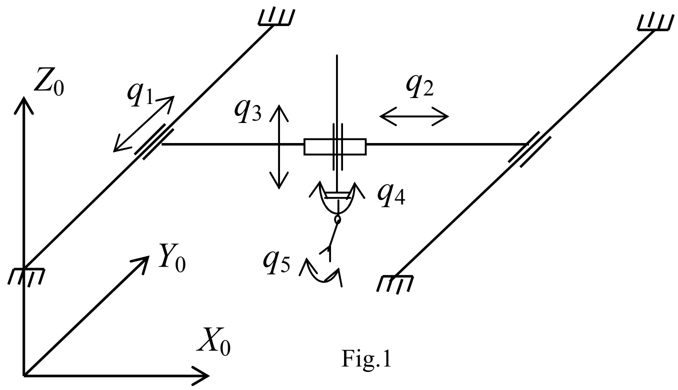

Fig.1

orienting head has been developed, its rotation axis of the last degree of freedom has been brought onto the plane of tool cutting. While rotating it allows to retain the center of the tool coordinate system on the rotation axis q_4 and obtain the main kinematics ratios of a simple kind:

$$[x(t), y(t), z(t), \theta(t), \gamma(t)] = [q_1(t), q_2(t), q_3(t), q_4(t), q_5(t)]$$

Dynamic models have been used to control robot and develop control programs. For translation degrees of freedom in the basis of dynamic models the equation for the forces balance is used

$$\sum m_i \cdot \ddot{x} = F_e - \sum F_j \ ,$$

where m_i weights of movable parts; F_e - control force of degrees of freedom; F_j - disturbing effects incorporating frictional forces in movable parts of the mechanism and load forces on the working tool. Control force F_e is connected with a moment *M*. Of the drive by the ratio $F_e = M \cdot i_r \cdot G / r$, where i_r is the drive gear ratio; *G* is the gear box efficiency; *r* is an effective radius of the mechanism transforming rotational motions into translatory ones. The drive dynamics for each degree of freedom in models is presented in a linearized form by the system of equations

$$\alpha(s) = \frac{k_m}{s(T_m s + 1)} u(s) \ ,$$

where α is the angle of the motor shaft turn; *u* is the motor control voltage.

Degree of freedom along the coordinate *Z* has double function. One of them is connected with tool lifting and lowering and second - with creating necessary pressing force on the working surface. When resolved force control is applied to drive *Z* coordinate the relationships connecting the moment and control voltage have been incorporated in the model:

$$M_m(s) = \frac{k_m s(Js + f)}{s(T_m s + 1)} \cdot u_m(s) \ ,$$

where J, T_m, k_m are inertia, time constant and gain factor of the drive.

3. MOVEMENT PLANNING AND CONTROL

The specific feature of controlling robots for location and spacing of wood is the necessity of forming programmed trajectories of cutting tool movement. On their basis the prediction of displacements according to the coordinates is made and control voltages for each of them are detemined. In the foundation of the programmed robot control is the principle of setting movement trajectories for a cutting tool and movement program with help of the pattern being performed with CorelDraw vector graphic editor. While composing patterns their accurate scaling in a special file is provided, this file is then used as an assigning file while carrying out control. On the pattern for material location and spacing or for performing decorative cutting the coordinates of the initial point, and the starting point of the process trajectory are assigned, transition lines between closed figures of the pattern are assigned as well. While processing each figure pattern scanning with digitization step *T* and read-out of information about the coordinates of the next positioning $x[kT+1], y[kT+1]$ are fulfilled. After the coordinates having been obtained control voltages are determined $u_x[kT+1]$ and $u_y[kT+1]$, and motion speeds along the coordinates *x* and *y* during the next control step are calculated as well. In order to reduce the effect of quantization as a control means in the interval $t_n \le t \le t_{n+1}$ we choose:

$$u[t_n] = 0.5[u(t_n) + u(t_{n+1})] \ .$$

This ensures minimization of maximal deviation $\overline{u}[t_n]$ from the truth-value when monotonous change $u(t)$ takes place. When applying graphical means for setting movement trajectories there appears necessity to build algorithms ensuring the proper tool orientation in each point of the trajectory. To solve this problem different kinds of interpolation have been analysed and in the algorithms of robot control a parabolic interpolation in the interval $[(n-1)T,(n+1)T]$ is selected as a basic one. In this case for the time moment $t=(n+1)T$ a predictive calculation of coordinates for the point of tool position is made and according to the coordinates of three points coefficients of an interpolating equation are defined:

$$\begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} x^2[(n-1)T] & x[(n-1)T] & 1 \\ x^2[nT] & x[nT] & 1 \\ x^2[(n+1)T] & x[(n+1)T] & 1 \end{bmatrix}^{-1} \cdot \begin{bmatrix} y[(n-1)T] \\ y[nT] \\ y[(n+1)T] \end{bmatrix}.$$

Next the obtained values of coefficients a_t are checked:

$$y[(n+1)T] = a_0 + a_1 x[(n+1)T] + a_2 x^2[(n+1)T]$$

and in case of identify the angle of normal to the trajectory in the point $t[(n+1)T]$ is calculated

$$\theta[(n+1)T] = 0.5\pi - \operatorname{arctg}(2a_0 x[(n+1)T] + a_1$$

.

After determining the vector of tool position and orienting and the vector of generalized coordinates $\overline{q}[(n+1)T]$ for the next step of control the values of tool motion speeds $\dot{x},\ \dot{y}$ and the angular speed of rotation θ are calculated. The accuracy of development of the movement trajectory depends on the accuracy of fulfilling the task mentioned above. The simplest algorithm is the linear dependence

$$v_x[(n+1)T] = (x[(n+1)T] - x[nT])/T$$
$$v_y[(n+1)T] = (y[(n+1)T] - y[nT])/T$$
$$\omega_\theta[(n+1)T] = 2\pi(\theta[(n+1)T] - \theta[nT])/360 \cdot T$$

To perform high-quality patterns we have incorporated highly precision control algorithm. For this purpose the trajectory of tool movement is interpolated by a polynomial of the 3-d degree and according to the interpolating function $S_n(T)$ the derivative $\dot{S}_n[(n+1)T]$ is determined. The obtained derivative values are applied for calculating generalized speeds:

$$v_x[(n+1)T] = \dot{q}_1[(n+1)T] =$$
$$V_o \cos(\operatorname{arctg}(\dot{S}_n[(n+1)T])),$$
$$v_y[(n+1)T] = \dot{q}_2[(n+1)T] =$$
$$V_o \sin(\operatorname{arctg}(\dot{S}_n[(n+1)T])),$$
$$\omega_\theta[(n+1)T] = \dot{q}_4[(n+1)T] =$$
$$(\dot{S}_n[(n+1)T] - \dot{S}_n[nT])/T.$$

Taking into account the fact that during the functioning of control algorithm we can form sampled-data functions $q[nT]$ describing the trajectories of links movement, then to determine derivatives in the points of tool movement trajectory it is advantageous to use control algorithms for the model. While simulating the process of motion differentiation of digital sequences is presented as a sum of the kind:

$$\dot{q}[n] = T^{-1}\sum_{k=1}^{m} K^{-1}\nabla^k q[n] = \sum a_i q[n-i],$$

where $\nabla q[n] = q[n] - q[n-1]$ - inverse difference; *m* - number of terms of a degree series; $a_i = (-1)^i \sum_{i=0}^{m} K^{-1} C_k^i$; C_k^i - binomial coefficients.

Besides the considered control method on the graphical model it is necessary to include algorithms of programmed control by the path reference point into mathematical calculations and software. In this case reference points $P[x,y]$ and angles of tool orientation in each of them are assumed. Taking into account these values we form the data base to develop the laws of generalized coordinates changes. Motions planning thus is fulfilled on the basis of interpolation with cubic splines: $S_3(t) = \sum_{k=0}^{3} a_k t^k$.

Coefficients a_k are calculated in each section of interpolation having assumed that the trajectory is continuous and smooth. Planning of robot's movement is carried out with account of limitations in degrees of freedom which are preset with reference to the table of limit values for each coordinate $q_i^{\min} \le q_i \le q_i^{\max}$.

The authenticity of the measured is of great importance for control. In the encoding position sensors being used there may be abnormal short-
Term imperfect data that can lead to short-term limit accelerations and deviations from the trajectory. Casual character of some charges of these sensors makes us to introduce predictive and correcting algorithms of simple calculating structure into the algorithms of robot control. In the applied algorithms expected values of position along the coordinates for the period of change *T* are predicted in each control step with help of *m* degree polynomial. Meanwhile we apply algorithms of single prediction, which is based on Lagrangian interpolating polynomial.

$$P(t) = \frac{1}{\tau^m} \sum P_{k-i} \prod_{j=0}^{m} \frac{k\tau + \tau r}{j-i} + \frac{M_{m+1}}{(m+1)!} \prod_{j=0}^{m} (k\tau + j\tau)$$

where *k*=1,2,3 – prediction step.
The analysis of prediction errors has shown that algorithms of double prediction should be applied for robots and values in three points (*m*=3) are to be taken. For convenience in usage of predictive expressions and reductions of calculations it is better to use recurrent form of the analysis.
A robot software solves the following problems: analog and discrete information about the parameters of robot condition is obtained, interface with drivers of analog inputs and outputs, output of discrete and analog control signals, formation of technological and emergency information, data display in real time. The programs can function in the environment of Windows and other versions and use all possibilities of this environment. Drivers for data exchange are formed as dynamic libraries DLL. The software includes robot models, which allow to carry out check of algorithm operation.

4. CONCLUSION

The material is prepared on the basis of the authors' research, which was carried out while developing robotic system for wood processing. The presented kinematic structure, algorithms of motions planning and control have been investigated on the models. Computer simulation of robot motions has shown the effectiveness of the described methods and algorithms. The obtained results of simulation were applied while developing and designing robots for cutting and spacing of wood.