THE TECHNIQUE FOR DETERMINING THE MOTION OF ROBOT MANIPULATOR MODEL ELEMENTS

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The technology of creating a motion mathematical model of an industrial robot manipulator has been proposed. Objective of the presented work is to study the motion features of industrial robot elements. The work result is a robot's computer model, which analyzes the movement elements of product moving parts.

For this purpose, a special technique of calculating the dimensional constraints of robot's elements has been developed. The technique allows to determine the permissible spatial positions of the robot elements. Taking into account possible obstacles to the movement of the robot, trajectory calculation algorithm of possible movement of robot elements has been developed.

The described technology is implemented in a robot's computer simulation using the visual design environment Autodesk Inventor. The simulation shows the movement of the robot elements, and allows to analyze the efficiency of the robot performing the specified manipulations. The program control of the simulation is performed using Autodesk Inventor API.

The developed technology is used to study the basics of robotics.

KEYWORDS

robot, trajectory, positioning, coordinates, nodal points, movable link, software

1 INTRODUCTION

The modern progress of robotics happens by the influence of a composite requirements from economy, production and health care. Among those it is possible to call a constant need in flexible industrial automation, the person-performer elimination from a direct involvement in precision or dangerous technological process, increase in an intensification of production capacities, etc.

Robotic systems implementation offers wide prospects of innovative technological processes development which application constrain by the person involvement restrictions [Makarov 2003, Monkova 2013, Mrkvica 2012, Pandova 2014, 2016, Prislupcak 2014, Brezinova 2014, Czan 2015, Lesso 2010, Gombar 2013]. These restrictions are connected to person-performer physical abilities (the loud or power capacity, speed, accuracy and recurrence of manipulations) and to working conditions. Today the direct involvement of the person-performer in production often is the principal hindrance to transition of production to better level, to development and deployment of new production technologies.

Industrial robots are widely used in different fields of economy and industry: in a research sector, in production, in transport infrastructure, in agriculture, in medicine, in a services sector. Implementation of robotic technology gives a considerable technical and economic effect of increase in productivity, technological processes, improvement of product quality and reduction of its prime cost. The positive effect from implementation of robotics also is a release the person from hard, dangerous and monotonic work for use of its creative potential in search of perspective activities. Thus, complex automation of the industry and implementation of flexible automated production is one of principal directions of development and application of robotics.

Working samples of industrial robots are very expensive in purchase and in maintenance. Therefore only some educational institutions can apply them in the educational purposes. However there is an opportunity to research controls and dynamics of the industrial robot by operation with its computer model. Such models are not exacting in service, can be changed easily and cannot be spoiled in case of execution of the wrong commands of motion. Using models it is possible to quickly optimize the operation of a prototype of the robot for application for specific objectives in certain operating conditions.

The main goal of the provided research consists in obtaining technology of development and application of computer models of controlled robots for use in educational process in subject matters of computer specialties.

The information technology of the robot computer model creation allow to research motions of links of the robot and to analyze their design features from the point of view of optimum execution of operational tasks. This technology allow to improve assimilation of basic knowledge of robotics and gives the chance to put skills of controllers programming of robots into practice.

2 OBJECT AND ENVIRONMENT OF SIMULATION

The robot-manipulator FANUC LR Mate 200iC (Fig. 1) is selected as an object for computer simulation. This compact high speed robot with acceptable accuracy of positioning is ideal as a tool for a control of a modern robotic systems study [Bouzgou 2015, Lin 2016]. Equipping of this robot by special working purpose tools allows investigating the different aspects of using of similar systems in a workplace.

The robot-manipulator is run by the R30iA controller [Kennedy 2017]. The robot represents as a closed mechanical construction with mechanisms of engines and electronic components are located inside.

Figure 1. Prototype – robot-manipulator "FANUC LR Mate 200iC"

The computer model of this robot is created by Autodesk Inventor software. This software allows to easily programming the links motions of computer models of prototypes along the specified trajectory. One of interesting features of Autodesk Inventor – is a creation of specifically software components setups which allows to automate stages of the often most carried out tasks [Kontsevich 2007]. These software components are realized on the basis of the applied programming interface (API) and allow improving simulation process.

The most effective method of creation of user applications by Autodesk Inventor is use Visual Basic for the environment API. API Autodesk Inventor defines the principles of application programming and a choice of the appropriate program opportunities of a programming environment [Kontsevich 2007, Svirnevsky 2016]. In other words, API Autodesk Inventor allows creating the optimum sequence of commands for operation with models [Svirnevsky 2016].

The simulator of the robot prototype which consists of computer model of the robot and a mathematical model of links motions control process is developed for a research of prototype motion and control.

To achieve research objectives, the following three tasks were assigned:

1. To develop a mathematical model of a robot-manipulator prototype links motions.

2. To analyze programming methods of motions of computer models by Autodesk Inventor tools.

3. To develop the motion control algorithm of the robot-manipulator prototype.

In this article the solution of the first research problem is provided [Kuznetsov 2017].

3   PHYSICAL MODEL OF PROTOTYPE MOTION

When planning trajectory of a prototype links motions the main objective is the choice of such method of control which will guarantee motion of the working tool of a prototype along a working trajectory. Before to assign a path of motion of the tool of a prototype, it is important to know [Ma 2016]:

1. Whether there are hindrances in a zone of motions of a prototype links?

2. Whether there are restrictions of mobility of a prototype links for execution of the given motion of the working tool?

When planning a trajectory of motion of the tool, one of two approaches is used:

1. For the working tool of a prototype the values of relocation, speeds and accelerations in specific (nodal) points of a working trajectory are assigned.

2. The given trajectory of motion of the working tool of a prototype is defined as analytic function.

The scheduler of trajectories selects from a class of functions (as a rule, polynomial) such functions that motions of a prototype links on the trajectory led to the given motion of the tool through the specified points. Work of the scheduler can be performed with use of the generalized coordinates of the mechanism of a prototype or the local coordinates connected to links of a prototype [Abderrahmane 2014].

Planning of a trajectory in the generalized coordinates has following advantages:

1. The changes of coordinates directly affects motion of the tool of a prototype.

2. The trajectory can be planned in real time.

3. In the generalized coordinates it is easier for present a trajectory in the form of analytic functions.

The inconvenience of use of the generalized coordinates is that it is more difficult to define the motions of a prototype links during motion process, than when using local coordinates. It is necessary for preventing of collision of links of a prototype with hindrances.

The basic algorithm for determination of nodal points on a trajectory in space of the generalized coordinates is rather simple and does not require the special description. When planning trajectory of a prototype links it is necessary to consider the following restrictions [Svirnevsky 2016]:

1. Nodal points have to be easily calculated by non-recurrent methods.

2. Position of a prototype links in certain timepoints have to be precisely set.

3. The condition of smoothness of trajectories in case of their passing through nodal points have to be met (the first and second derivatives of functions of trajectory have to be continuous).

Process of planning of trajectory in local coordinates of a prototype links consists of the following serial steps:

1. Formation of an array of nodal points on a trajectory of motion of each link of a prototype in local coordinate systems.

2. The choice of functions for connection of nodal points in a smooth trajectory of the motion of a prototype link (for example, a straight line, a circle arc, a parabola, etc.).

Such way allows receiving a fine precision positioning of a prototype working tool on the given trajectory.

However, there can be a deceleration or violation of motion of the working tool because of a time delay of a trajectory computation connected to the large counts of recalculation of a local coordinates of prototype links into a generalized coordinates of the tool. It is possible to exclude such problem by use of sensors of a prototype links position [Fang 2017].

4   SIMULATING THE GEOMETRIC AND KINEMATIC PARAMETERS OF A PROTOTYPE

For the purpose of obtaining the program of motion of a prototype in Autodesk Inventor the auxiliary (transition) geometry of API is used. The auxiliary geometry is developed to solve by means of API a row of mathematical tasks, mainly geometrical.

Links of auxiliary geometry are created by using requirements to the appropriate methods of objects and are widely used in API Autodesk Inventor. Unlike the majority of other geometrical objects of API, these objects have no visual instruments to display. Most often it is the abstract mathematical objects which are developed to control "real" geometry of Autodesk Inventor [Kontsevich 2007].

The Denavit-Hartenberg's representation is used for the description of rotational and axial joints between a adjacent prototype links. Denavit and Hartenberg offer the matrix approach of serial buildings of the coordinate systems connected to each link of the mechanism of a prototype. The sense of a Denavit-Hartenberg's representation consists in formation of the homogeneous transformation matrix to describe the position of a coordinate system of each link concerning a coordinate system of the previous link of a prototype. It gives the chance to sequentially transform coordinates of the working tool from the each link reference system to a basic link reference system which is an inertial coordinate system for a prototype [Maronek 2015].

Each coordinate system is based on the following three rules:

1. z_{i-1} an axis is directed along axis of the i-th link.

2. The axis of x_i is perpendicular to axis of z_{i-1} and directed from it.

3. The axis of y_i adds axis of x_i and z_i to the right Cartesian coordinate system.

Denavit-Hartenberg's representation of solid links depends on four geometrical parameters corresponding to each link. These four parameters completely describe any rotational or axial motion and are defined according to a figure 2 as follows:

1. ϑ_i – the associated angle on which it is necessary to turn the axis of x_{i-1} around the axis of z_{i-1} that it became a same directional with axis of x_i (the sign is defined according to the right-hand rule);

2. d_i – distance between intersection of an axis of z_{i-1} with an axis of x_i and the beginning of (i-1)-th coordinate system; it is measuring along the axis of z_{i-1};

3. a_i – distance between intersection of an axis of z_{i-1} with an axis of x_i and the beginning of i-th coordinate system; it is measuring along the axis of x_i (i.e. the shortest distance between axes of z_{i-1} and z_i);

4. α_i – an angle on which it is necessary to turn the axis of z_{i-1} around the axis of x_i that it became a same directional with axis of z_i (the sign is defined according to the right-hand rule).
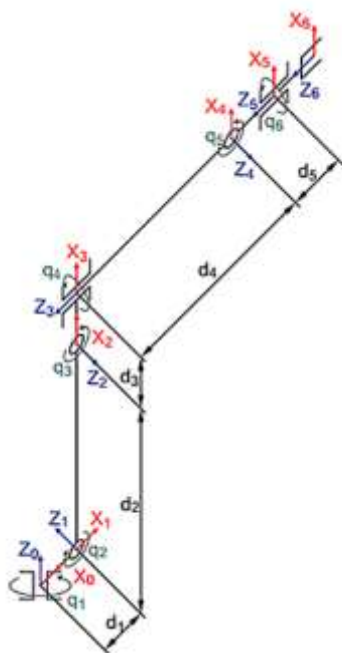

Figure 2. Kinematic chain of prototype

For rotational joints the parameters d_i, a_i and α_i are constant characteristics for this prototype. At the same time ϑ_i is the variable. It is changing in case of motion (rotation) of i-th link relative to an (i-1)-th link. For each prototype link this algorithm creates an orthonormal system of coordinates. Coordinate systems are numbered in ascending order from the base of to the working tool of a prototype. The relative positioning of adjacent links is described by a homogeneous transformation matrix (Tab. 1).

Table 1. Denavit-Hartenberg's parameters

№ link	a_i	α_i	d_i	ϑ_i
1	d_1	$-(\pi/2)$	0	q_1
2	d_2	π	0	$q_2 - (\pi/2)$
3	d_3	$-(\pi/2)$	0	$q_2 + q_3$
4	0	$\pi/2$	$-d_4$	q_4
5	0	$-(\pi/2)$	0	q_5
6	0	0	$-d_5$	q_6

The following geometric parameters of prototype links are used in Table 1:

d_1 – The offset between the coordinates of x_0, y_0, z_0 and x_1, y_1, z_1 (mm).

d_2 – Length of the first prototype link (mm).

d_3 – The offset between x_2, y_2, z_2 and x_3, y_3, z_3 (mm).

d_4 – Length of the second prototype link (mm).

d_5 – Length of the third prototype link (mm).

5 MATHEMATICAL MODEL OF PROTOTYPE MOTION

The sequence of the intermediate positions of a prototype links on the given trajectory is defined to move the prototype working tool. At first is defined an array of nodal points (coordinates of the intermediate positions of links) on motion trajectory. Then the array of rotation angles of all prototype links for each nodal point is calculated. The received coordinates have to be correspond to the current position of an link on a trajectory. The scheme of definition of corners and adjacent prototype links joint positions is presented on the Fig. 3.
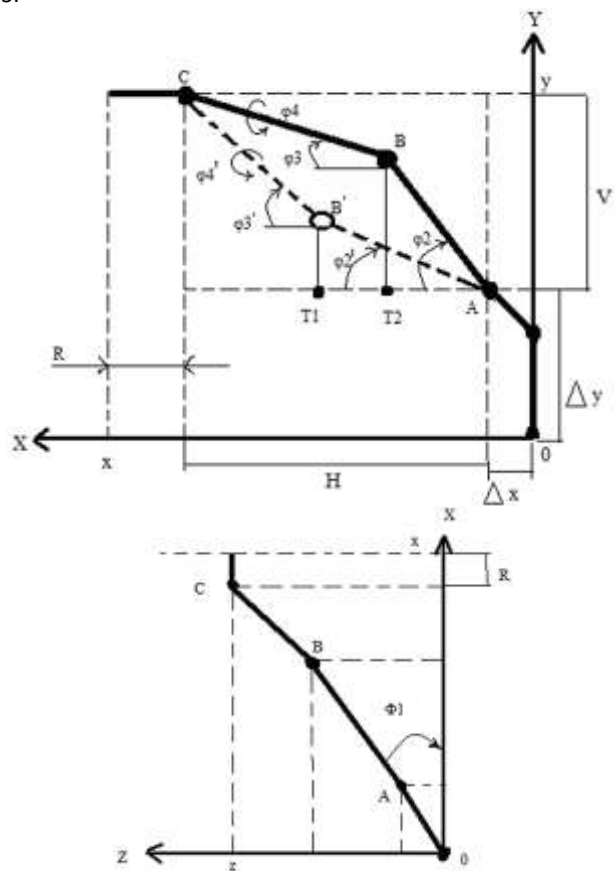

Figure 3. Rotation angle values in planes XY and XZ

For example, to define the T point location, the classical task about search of cross-point of two circles is used:

$$T = K \cdot H \pm \sqrt{K^2 H - \left(V^2 + H^2\right)\left(K^2 - (AB)^2 V^2\right)}\Big/\left(V^2 + H^2\right),$$

$$K = (AB)^2 - (BC)^2 + H^2 + V^2 / 2$$

Here H and V – is a standard position of a tool holder, and AB and BC – is a length of the corresponding prototype links.

There are two methods to make model in Autodesk Inventor: to develop application or to create a macro. It selected a method which uses writing of a macro in Visual Basic. It is connected to the fact that in Autodesk Inventor there is a built-in Visual Basic

for application interpreter and writing of a program code does not require the additional software.

6 CONCLUSIONS

During the research the analysis of the existing information technologies for control of computer models of prototypes of industrial robots is made. The functional control computer model of the industrial robot-manipulator is result of the work. Also the technology of development and use of model is result. Use of the received technology in educational process allows studying methods of control of automated systems, to test the functional capabilities of a design programming environment and to set skills of program control of a controllers system.

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