Modelling of the end effector movement of the SCARA-module taking into account the characteristics of the drives

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Abstract. The functioning of the multifunctional module based on the SCARA type manipulator (Selective Compliance Articulated Robot Arm) is considered, its characteristics and possible areas of use are described. The model, determining the trajectories of movement of the module end effector with known dimensions of its links and specified control moment is developed in MapleSim. Carrying out such an analysis allows planning the movements of the module. The results of modelling for given parameters of module links and prospects for further research are presented.

1. Introduction
In modern production, the means of automation of technological processes are widely used, allowing improving the various characteristics of products. One of these means is industrial robots - specialized devices designed to perform specific operations, such as welding, assembling threaded connections, etc. In this paper, it is proposed to consider the operation of a rapidly readjusted module for performing various technological operations.

The scheme on the basis of which this module is developed is the kinematics of SCARA type manipulators (Selective Compliance Articulated Robot Arm). This kinematics is based on a lever system that provides the last link movement in the plane due to the rotation of two levers of the mechanism. These structures provide industrial robots with high handling and a large service angle, but they also have a number of shortcomings such as low index of carrying / weight of the manipulator and relatively low stiffness.

There are several kinematic schemes for SCARA manipulators. Consider one of them, shown in Figure 1. To analyse the functioning of the developed device, it is necessary to solve the problems of kinematics, which consist in establishing links between the values of the generalized coordinates and the position of its end effector [1-8]. The direct and inverse kinematic problems were solved for a multifunctional rapidly readjusted module earlier [9].

The coordinates of point P (end effector) for the kinematic scheme shown in Figures 1, are determined by the system of equations:

\[
\begin{align*}
x_p &= l_p \cos \phi_{32} \cos \phi_{43} - l_p \sin \phi_{32} \sin \phi_{43} + l_3 \cos \phi_{32} + l_2 \\
y_p &= l_p \sin \phi_{32} \cos \phi_{43} + l_p \cos \phi_{32} \sin \phi_{43} + l_3 \sin \phi_{32} \\
z_p &= l_4 + l_5 + l_6 + l_1
\end{align*}
\]  

(1)
In the work [9], the research of the movement of the end effector was carried out only taking into account the structure of the mechanism and the geometric relationships between the dimensions of its links, and the acting forces and moments were not taken into account. To account the effects of forces and moments, a dynamic analysis is carried out. One of the objectives of this analysis is to study the mode of motion of the mechanism under the action of given forces and moments, and the establishment of ways to ensure given modes of its movement.

In solving the above problem, the main attention should be paid to the movement of the end effector in the XY plane, which is provided by two kinematic pairs of the 5th class. Then, in accordance with expression (1), the equations for determining the position of the end effector in the XY plane are described by the system:

\[
\begin{align*}
    x_p &= l_p \cos \varphi_{32} \cos \varphi_{43} - l_p \sin \varphi_{32} \sin \varphi_{43} + l_3 \cos \varphi_{32} + l_2 \\
    y_p &= l_p \sin \varphi_{32} \cos \varphi_{43} + l_p \cos \varphi_{32} \sin \varphi_{43} + l_3 \sin \varphi_{32}
\end{align*}
\]

The purpose of this work is to develop a model of the end effector movement of a multifunctional rapidly readjusted module, taking into account the dynamic characteristics of its drives.

2. Model of the SCARA-module movement

The authors formulate the problem of dynamic analysis as follows: to determine the trajectories of movement of the end effector of a multifunctional rapidly readjusted module with known dimensions of its links and specified control moments.

There are many different ways to solve dynamic analysis problems. With the development of modern computing systems, specialized software is emerging that allows modeling of complex systems taking
into account the dynamics. MapleSim is a physical modeling tool that significantly reduces model development time. Building a model in this environment is to create a block diagram.

The principles of constructing a module model in MapleSim for the given scheme in Figure 1 are described in the work [10]. The block diagram of the module model and its visual display in MapleSim are presented in Figures 2 and 3. The model uses Applied Moment blocks, which allow setting the moment values for each of the coordinates.

Figure 2. Block diagram of the module model: 1 - the system of hinge moments input; 2 - Applied Moment block; 3 - rotational kinematic pair of the 5th class; 4 - centres of mass; 5 - subsystem for determining the characteristics of the movement of the end effector

Figure 3. Visual display of the module model in MapleSim

After inputting the dependence of the control moments on time, the angles of rotation of the individual drives are determined. The use of the Euler Angles block followed by the entrance to the Real Demultiplexer block of subsystem 5 allows obtaining three flat angles from the spatial Euler’s angle. These angles are the initial data for solving the direct problem of kinematics.
Entering the system of equations (2) in MapleSim occurs using the Signal Blocks library. The speeds and accelerations of the module end effector are determined by differentiating the expression (2) for each of the coordinates using blocks of the specified library.

3. Simulation results
The module construction assumes the use of stepper motors with a torque up to 6 Nm. Graphs of the supposed changes of the control moments on time at the first and second hinges are shown in Figure 4. The input geometric parameters and masses of the module links used in the simulation are shown in Table 1. The graphs of the changes of positions, speeds and accelerations of the module end effector are shown in Figures 5-7.

![Graphs of the control moments](image)

**Figure 4.** Specification of the hinges moments: a – moments of the first hinge; b – moments of the second hinge

| Name | Description | Value | Units |
|------|-------------|-------|-------|
| Sx1  | Distance from the feet up to the first hinge | 0.05  | m     |
| Sx2  | Distance from the first hinge to the center of mass between the hinges | 0.075 | m     |
| Sx3  | Distance from the center of mass between the hinges to the second hinge | 0.075 | m     |
| Sx4  | Distance from the second hinge to the center of mass between the second hinge and end effector | 0.075 | m     |
| Sx5  | Distance from the center of mass between the second hinge and end effector to the end effector | 0.075 | m     |
| m1   | The mass of the first lever | 0.4   | kg    |
| m2   | The mass of the second lever | 0.4   | kg    |
| m3   | The mass of the end effector | 0.5   | kg    |
| m11  | The mass of the first hinge with motor | 3     | kg    |
| m22  | The mass of the second hinge with motor | 3     | kg    |
Figure 5. Graphs of changes in the position of the end effector in different coordinates: a) x coordinate; b) y coordinate

Figure 6. Graphs of changes of the end effector speed in different coordinates: a) x-axis speed; b) y-axis speed

Figure 7. Graphs of changes of the end effector acceleration in different coordinates: a) x-axis acceleration; b) y-axis acceleration
4. Conclusion
This research allows estimating the dynamic characteristics of the end effector movement of a multifunctional rapidly readjusted module, taking into account the applied moments created by the drives. Carrying out such an analysis allows planning the movements of the module. The prospects of further research are the choice of the optimal design of the multifunctional module and the determination of its precision characteristics.

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