Designing drives of a medical robot actuator

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Abstract. The paper presents the results of a study that makes it possible to calculate power of drives in the degree of freedom of a medical robot with regard of dynamics of its actuator. Kinematic scheme of the robot is proposed, shown as a direct graph that contains no cycles. Values of the Denavit–Hartenberg parameters and reachability matrix have been obtained. The SolidWorks design system, elements of robot's design were developed, and values of masses, Torques of inertia, center of mass coordinates and other parameters of its main units required for simulation were obtained. Using an application specially developed in the MATLAB software package, a simulation was made, and numerical values of the matrix elements that are included into equation of the robot dynamics, as well as values of drives power in degrees of freedom were obtained.

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Introduction

When studying and designing robots, developers use various methods of building mathematical models of their actuators [1,2,3,4,5]. It is advisable to select methods that make it possible to analyze the diversity of robots' kinematic structures, have good software for researching and designing them and make it possible to synthesize algorithms of controlling their movement.

One such method has been proposed in work [6]. It is based on sharing the d'Alembert principle, matrix theory (4x4) that have been widely used in robototronics [3], and graph theory [7]. The method makes it possible to obtain the mathematical model of the robot's actuator with an arbitrary kinematic tree structure. This takes into account its movableness on a stationary base and availability of external disturbing forces and Torques applied to the actuator. The software developed makes it possible to determine numerical values of matrix coefficients of robot dynamics, power of drives in the degree of freedom, forces and Torques of links reaction imposed on a tree actuator [8,9].

Main part

Selecting the kinematic scheme of a medical robot

During medical operations [10] robot's gripper should be able not only to move the tool, but also to orientate it in space, i.e. have the necessary value of coefficient of service [1]. Created by nature and developed in the course of working practice, the human (surgeon's) hand has coefficient of service ranging from zero (at the border of the work area) to unity in some areas of the working zone.

Upon selecting the kinematic scheme (KS) of a medical robot, a human hand is taken as the biological prototype. Using the method described in [11], we obtain the seven-degree structure with rotational kinematic pairs. Such a structure makes it possible to obtain the necessary amount of working area and an acceptable coefficient of service. However, such structures have a significant error of gripper positioning, which can be mitigated by using precision drives in robot's degrees of freedom [2]. In order to select drives, one has to know the required values of torque and power in degrees of freedom calculated basing on dynamics robot actuator.

Let us use the method of building mathematical models proposed in [6], which makes it possible to analyze the kinematics and dynamics of robots with arbitrary kinematic structure. The resulting KS of a robot built by Denavit–Hartenberg rules [3], is shown in Fig. 1. It can also be represented as a direct graph where actuator links are considered vertices, and their joints are considered edges [7]. Vertices of the graph are connected in series, as any of them will have no more than two adjacent vertices (Fig. 2)

Let's choose vertex "0" as root, since the zero element is the fixed rack. Edges of the tree are oriented in such a way that each vertex has a direct path from the root. Thus, the resulting reachability graph represents an outgoing oriented root tree and reflects the order of the links of the mechanism and their mutual reachability. Using the graph, it is easy to determine the number of father link for link i-parameter f(i) and parameter ns (i), showing what the sibling count of link i to link f(i) is [6].

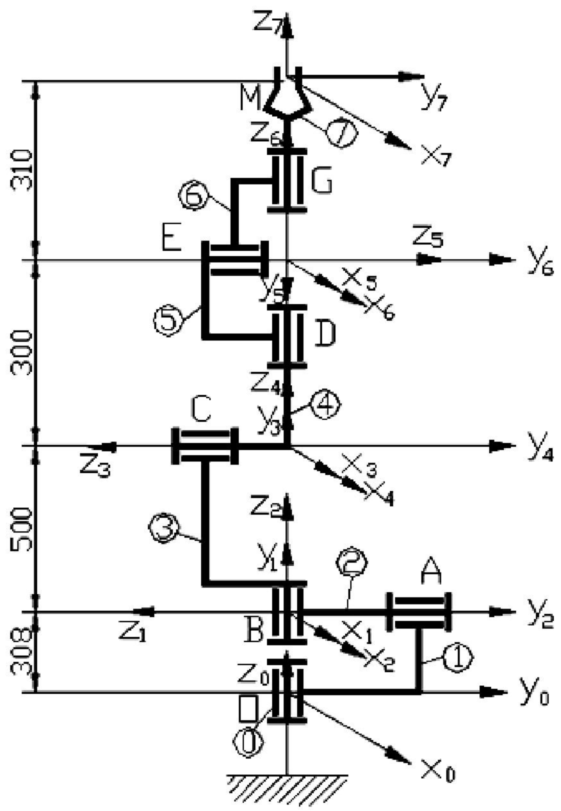

Fig. 1. KS of a medical robot with designated Denavit-Hartenberg coordinate systems

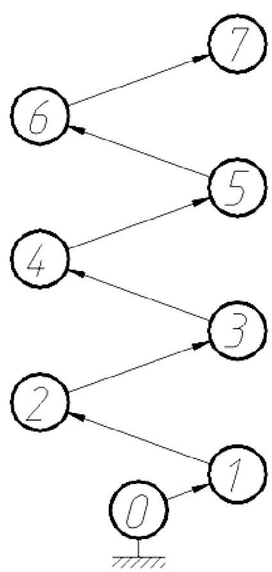

Fig. 2. Medical robot actuator reachability direct graph

In Fig. 1 the following designations are adopted:

0 - fixed link; 1 - rotation link; 2 - shoulder swing link; 3 - shoulder; 4 -forearm; 5 - wrist; 6 - gripper swing link; 7 - gripper rotation link.

Values of Denavit-Hartenberg parameters, as well as f(i) and ns(i) are shown in Table 1.

Table 1. Denavit-Hartenberg parameters for KS of robot's actuator links

KS No.	θ, rad	d, m	a, m	α, rad	f(i)	ns(i)
1	0	0.308	0	π/2	0	1
2	0	0	0	- π/2	1	1
3	0	0.500	0	π/2	2	1
4	0	0	0	- π/2	3	1
5	0	0.300	0	- π/2	4	1
6	0	0	0	π/2	5	1
7	0	0.310	0	0	6	1

Using direct graph, let us define the reachability matrix D, which describes its kinematic structure. The considered robot has open (linear) kinematic circuit, so the matrix D (7x7) will be a diagonal unity matrix [7].

2. Medical robot actuator design engineering

The robot was designed in SolidWorks environment in accordance with the developed KS. Robot general drawing was obtained as well as assembly drawings of individual actuator links. Table 2 shows weights and coordinates of links' centers of mass, and Table 3 shows Torques of inertia of actuator links.

Table 2. Weights and centers of mass coordinates of robot's actuator links

Link No.	Xc, m	Yc, m	Zc, m	m, kg
1 (Corner housing of 1 shoulder drive)	-0.0063568	-0.2011614	0.0386116	4.6997359
2 (Corner housing of 2 shoulder drive)	0.0000043	0.0913715	-0.0642970	0.8620324
3 (Shoulder)	-0.0000010	-0.1776811	0.0610229	8.0002017
4 (Fore arm)	-0.0000312	0.0391551	0.0411657	1.4001713
5 (Wrist)	-0.0000569	0.0840126	-0.0412516	0.4601126
6 (Gripper swing link)	-0.0033596	0.0004326	0.0056797	1.7000187
7 (Gripper rotation link)	-0.0002287	-0.0108403	-0.1151995	1.3999679

Table 3. Torques of inertia of robot's actuator links

Link	Jx, kg·m2	Jy, kg·m2	Jz, kg·m2	Jxy, kg·m2	Jxz, kg·m2	Jyz, kg·m2
1	0.0504795	0.0316253	0.0402522	-0.0000005	0.0000005	-0.0006825
2	0.0048232	0.0035800	0.0032698	-0.0000001	0.0000001	-0.0012453
3	0.1678987	0.0546003	0.1450103	0.0000005	-0.0000036	0.0293670
4	0.0062266	0.0059742	0.0025119	0.0000008	-0.000050	0.0003820
5	0.0020688	0.0004466	0.0019076	-0.0000005	-0.0000004	0.0003481
6	0.0102681	0.0096634	0.0026581	0.0000090	-0.0000307	-0.0000201
7	0.0069446	0.0069301	0.0009581	0.0000046	-0.0000135	-0.0000930

Equation of robot actuators dynamics

Let's write robot actuator dynamics equation in the following form [6]:

$$A(\mathrm{q})\cdot\ddot{\mathrm{q}}+B(\mathrm{q},\dot{\mathrm{q}})-C(\mathrm{q})\cdot\mathrm{f}_{\text{в}}^{0}-H(\mathrm{q})\cdot\mathrm{n}_{\text{в}}^{0}=\tau \quad , \qquad (1)$$

where q is the vector of generalized coordinates of the actuator;

τ [Tetha] - is column-vector of Torques developed by robot's actuators;

f_B^0 и n_B^0 - block matrices of external forces and Torques applied to links from environment;

Matrix coefficients $A(q)$, $B(q,\dot{q})$, $C(q)$ and $H(q)$ are calculated in accordance with [6].

If manipulator gripper or any actuator link has external connections, the actuator dynamic equation can be written as [8].

$$\begin{pmatrix} A(q) - & J_{VR(q)}^T \\ J_{t(q)} & 0 \end{pmatrix}\begin{pmatrix} \ddot{q} \\ {}^{\circ}R_f \end{pmatrix} + \begin{pmatrix} B(q,\dot{q}) \\ P(q) \end{pmatrix} - \begin{pmatrix} L(q)^{o}Fb \\ 0 \end{pmatrix} = \begin{pmatrix} \tau \\ 0 \end{pmatrix} \quad (2)$$

Matrix coefficients A(q), B(q, $\dot{q}$), Jt(q), J_{VR}^T (q), ${}^{\circ}R_f$, P(q), ${}^{\circ}F_b$ are defined in accordance with [9]. Equation (2) makes it possible to determine the motion of the robot's actuator with an arbitrary kinematic tree structure with imposed kinematic connections and arising from this reaction forces and Torques of these connections.

3. Calculation of robot's actuator drives power

The calculation was made by simulation in MATLAB environment using a specially designed set of procedures written as m-files. The advantage of this set of procedures is that it is applicable for studying the actuator with an arbitrary kinematic structure. Feature for a specific KS is reflected in the content of the start-up file that stores information about Denavit–Hartenberg parameters, weights, Torques of inertia, center of mass coordinates, etc. [9].

Table 4. Torques and power by robot's degrees of freedom

Joint No.	Torque, $H \cdot м$	Power, W
1	110.087310617755	1073.14136329531
2	-306.887028235873	747.890837760127
3	72.0143015652822	675.965956061798
4	-52.0112859030801	244.103308907383
5	-23.2388385812687	185.554635920445
6	-35.8166571725831	174.572055994377
7	-1.90885632943510	18.6077093918440

By simulation results, numeric values of matrix elements $A(q)$ (7x7), $B(q,\dot{q})$ (7x1), $C(q)$ (7x7) и $H(q)$ (7x7) in equation (1) were obtained. The maximum values of the column-vector [tau] (7x1) of torques developed by robot's actuators and values of power N in robot's degrees of freedom are presented in Table 4.

Conclusion

The paper describes the main stages of designing medical robot actuator drives. It is shown that choice of robot's KS should be performed taking into account peculiarities of the operations that it will perform. To derive kinematics and dynamics equations of the robot's actuator, the method based on the shared use of d'Alembert principle, matrix theory (4x4) and graph theory is recommended. A 3D model of robot's activator has been developed, and its mass and inertial characteristics have been calculated.

Numeric values of matrix elements in robot's dynamics equation have been obtained, as well as the torque values and power by degrees of freedom.

The work results are the basis for further research in order to create a medical robot.

Conclusions

In course of designing medical robot's drives, its actuator dynamics should be considered. Using the method of building equations of kinematics and dynamics developed for actuators of robots with tree KS, for robots with linear (open) kinematic circuit, makes it possible for the designer to analyze various KS and to choose the best option.

The software simulation suite developed in the MATLAB environment can be used for studying dynamics of robot's actuator with an arbitrary KS, including a linear one. Information about specific KS parameters is contained in program start-up file. It makes it possible at the design stage to explore a variety of actuator KS versions, changing only the data in the startup file.

Such an approach makes it possible to optimize choice of KS and to considerably reduce duration of robot actuators design.

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References

1. Kobrinsky, A.A. and A.E.Kobrinsky, 1988. Manipulating systems of robots. Moscow: Nauka. Ch. Ed. of physical and mathematical literature, pp: 344.
2. Vorobyov, E.I., et al, 1988. Mechanics of robots (in 3 books). Textbook for universities. Eds., Frolov, K.V. and E.I. Vorobyov. Moscow: Vyshcha Skola, pp: 304.
3. Zenkevich, S.L. and A.S.Yushchenko, 2004. Fundamentals of controlling manipulator robots. Moscow: Publishing House of Bauman MSTU, pp: 480.
4. Roy, S.S. and D.K. Pratihar, 2011. Dynamic Modeling and Energy Consumption Analysis of Crab. In the Proceedings of the ICMAE 2011 International Conference on Mechanical and Aerospace Engineering (issue 110-116), Trans Tech Publications, Switzerland. Date Views 19.02.2014 www.scientific.net/AMM.110-116.2730.
5. Xie, X., Q. Sun, X. Yu and R. Du, 2011. Research on Coordinated Simulation of Medical Robot Arm Based on Simulink and RecurDyn. Applied Mechanics and Materials, 58-60. Date Views 19.02.2014 www.scientific.net/AMM. 58-60.1300.
6. Kovalchuk, A.K., D.B.Kulakov and S.E.Semenov, 2008. Block-matrix equations of motion if actuators of robots with tree kinematic structure. Bulletin of higher educational institutions. Mechanic Engineering, 12: 5-21.
7. Alekseeva, A.A. and V.A.Talanov, 2006. Graphs and algorithms. Data Structures. Models of calculation. Moscow: Binomial Publishing House, pp: 319.
8. Kovalchuk, A.K., L.A. Karginov, D.B. Kulakov et al, 2012.Walking robots' tree actuators simulation program. Certificate of PC program registration No. 2012610398 dated 10.01.2012
9. Kovalchuk, A.K., D.B.Kulakov and S.E.Semenov, 2007. Control of executive systems of two-legged walking robots. Theory and algorithms. Eds., Kovalchuk,A.K. Moscow: Publishing House of the Moscow State Open University, pp: 160.
10. Speich, J.E. and J. Rosen, 2013. Medical Robotics. Encyclopedia of Biomaterials and Biomedical Engineering, 12. Date Views 19.02.2014 www.tandfonline.com/doi/pdf/10.1081/E-EBBE-120024154#.UwTk1ClWFeU.
11. Pupkov, K.A., A.K. Kovalchuk and B.B. Kulakov, 2009.Usage of Biological Prototypes for Kinematical Scheme Construction of Modern Robots. In the Proceedings of the 13thIFAC Symposium on Information Control Problems in Manufacturing, Moscow, pp: 1829-1834.

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