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SIMULATION AND ANALYZES OF INVERSE-KINEMATIC MODEL OF HUMANOID ROBOT HAND

Urgency of the research. *Nowadays robotics and mechatronics come to be mainstream. With development in these areas also grow computing fastidiousness. Since there is significant focus on numerical modeling and algorithmization in kinematic and dynamic modeling.*

Target setting. *Suitable approach for numerical modeling is important from the view of time consumption as well as stability of computing.*

Actual scientific researches and issues analysis. *Designing and modeling of humanoid robots have high interest in the field of robotics. The hardware and mechanical design of robots is on significantly higher level in comparison with software of robots. So, modeling and control of robots is in the interest of researchers.*

Uninvestigated parts of general matters defining. *Comparison of methods for numerical modeling of inverse kinematics.*

The research objective. *Comparing four methods from the view of performance and stability.*

The statement of basic materials. *This paper investigates the area of kinematic modeling of humanoid robot hand and simulation in MATLAB.*

Conclusions. *The paper investigated inverse kinematic model approaches. There were analyzed pseudoinverse method, transpose of Jacobian method, damped least squares method as an optimization method. The results of the simulations show the advantages of optimization method. During the simulations it never fail in comparison with other tested methods.*

Keywords: *humanoid robot hand; inverse kinematics; Jacobian; simulation.*

Fig.: 4. Table: 2. References: 15.

Introduction. Nowadays, people are in the contact with the robotic systems almost on daily base. The development in this area significantly arises. Service robots have their utilization in industrial companies, health services, military or like household robots [1]. They can be also used in medicine as prosthesis for people who lose their limbs.

This study focuses on kinematic modeling of robot hand. One of the first works in this research are [2] and [3]. Several researches are focused on modeling of human robot locomotion [4] and [5], some of them deal with modeling of robot hand [1][6][7]. This paper studies inverse kinematic models, simulate them and compare from the view of simulation speed and stability.

The paper is divided as follows. The second chapter deals with biomechanics of human hand describing the joints and bones. Based on biological human hand, the concept of robot hand is designed with corresponding DOF. Next chapter presents iteration methods for inverse kinematic modeling. The inverse kinematic model of robot hand is established and simulated in MATLAB. In the conclusion the methods are compared and the results are discussed.

Biomechanics. This section discusses about human hand. Fig. 1 shows particular bones and joints of a human finger. As can be seen in the Fig. 1, human hand consists of 14 phalanges, 5 splint bones as well as 8 wrist bones, see also Fig. 2.

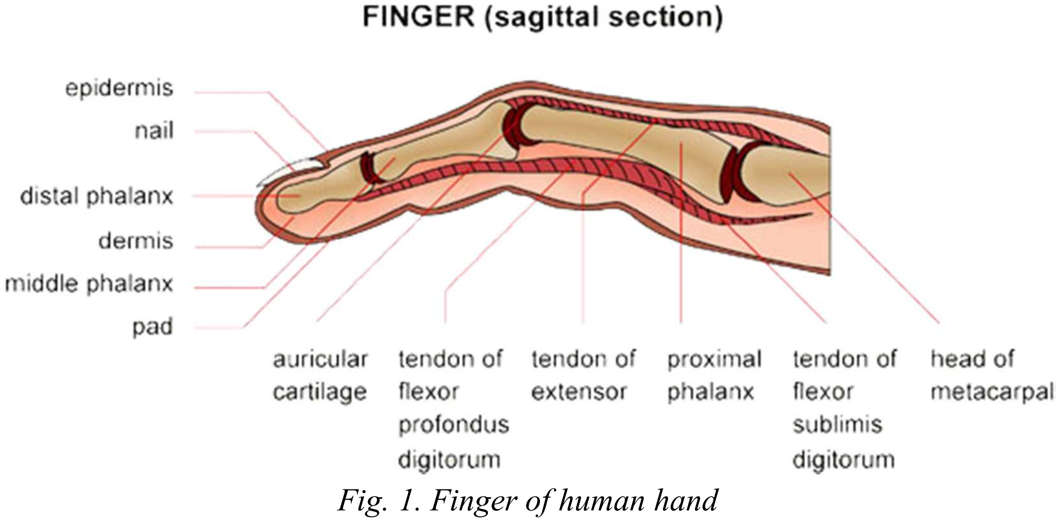

Fig. 1. Finger of human hand

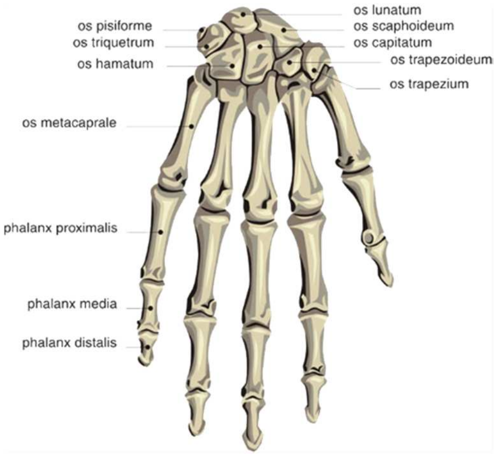

Fig. 2. Bones and joints of human hand

Hand is connected to forearm through carpal bones. For the purposes of kinematic model design it can be neglected. Metacarpal bones form a palm of hand by their arcuate shape and their motion is limited. Carpometalcarpal, proximal interphalangeal and distal interphalangeal joints can be considered as revolute joints and metacarpophalangeal joint as ball-joint. A thumb is different from other fingers because it does not have second phalangeal bone and its metacarpophalangeal joint gives it significant opportunity of motion [14]. When the carpal bones are neglected the human hand has 24 + 6 DOF, 24 for hand and 6 for placement in 3D space.

The range of motion of particular joints in the Tab. 1 are shown.

Table 1

Human hand joints description

Joint position	Kind of joint	Motion	Range
Wrist	Elliptical	Flexion, Duction	120°, 20°
Carpal – thumb	Cylindrical	Flexion	90°
Metacarpal – thumb	Saddle	Duction, Opposition	50°, 60°
Metacarpal – fingers	Spherical	Flexion, Duction	90°, 30°
Middle – thumb	Cylindrical	Flextion	20°
Middle – fingers	Cylindrical	Flexion	100°
Terminal – thumb	Cylindrical	Flexion	90°
Terminal – fingers	Cylindrical	Flexion	80°

Mathematical model of humanoid robot hand. The aim of inverse kinematic model is to find generalized variables $\mathbf{q} = [q_1, q_2, \dots, q_n]^T \in \mathbb{R}^n$, where n is number of DOF. The end-effector coordinates is $\mathbf{x} \in \mathbb{R}^m$, where m represents number of task. Considering inverse kinematic model, finding the solution is significantly more difficult task in comparison with direct kinematic model. Numerical solution arises from basic term

$$\mathbf{x}_k = f(\mathbf{q}_k)$$

By iteration of following term can be solved inverse kinematic model

$$\mathbf{q}_{k+1} = \mathbf{q}_k + \mathbf{J}^{-1}(\mathbf{x}_p - \mathbf{x}_k)$$

Where $\mathbf{x}_p$ is vector of desired position and $\mathbf{x}_k$ is vector of actual position. Considering n number of DOF is higher than number of performed task m we can speak about kinematically redundant mechanism. In this case we can you for example pseudoinverse arising from

$$\Delta\mathbf{q} = \mathbf{J}_P \Delta\mathbf{x}$$

Since Jacobian is no symmetric matrix we can use following equation

$$\mathbf{J}_P = \mathbf{J}^T(\mathbf{J}\mathbf{J}^T)^{-1}$$

Considering the case when $n < m$, Jacobian is expressed as

$$\mathbf{J}_P = (\mathbf{J}^T\mathbf{J})^{-1}\mathbf{J}^T$$

Next frequently used method for inverse kinematic is method based on transposed of Jacobian. This method was firstly used in the works [12] and [13]. The method is based on idea of replacing Jacobian inversion by transpose of Jacobian. It can be expressed as

$$\Delta\mathbf{q} = \delta\mathbf{J}^T\Delta\mathbf{x}$$

where δ is scalar value defined by user.

Next considered method is damped least squares (DLS). DLS assume with finding such $\Delta\mathbf{q}$ that minimizes following equation

$$||\mathbf{J}\Delta\mathbf{q} - \Delta\mathbf{x}||^2 + \lambda||\Delta\mathbf{q}||^2$$

where λ is damping constant. By mathematical operations can be last mentioned term adjust as

$$\Delta\mathbf{q} = \mathbf{J}^T(\mathbf{J}\mathbf{J}^T + \lambda^2\mathbf{I})^{-1}\Delta\mathbf{x}$$

where **I** is unit matrix.

With three mentioned methods will be also considered method which lies in optimization process. For optimization method the function *fmincon* is used in software MATLAB. This function tries to find minimum of scalar function of variables. For simulation has to be set the set of initial guess of variables.

$$\min f(x)\ for \begin{cases} c(x) \leq 0 \\ ceq(x) = 0 \\ Ax \leq b \\ Aeqx = beq \\ lb \leq x \leq ub \end{cases}$$

where x is vector of independent variables, lb is vector of lower boundary values, ub is vector upper boundary values, c(x) and ceq(x) are functions of x for conditions of equality and inequality, A and Aeq are matrices of parameters for conditions of linear equality and inequality, b and beq are vectors of parameters of right sides of conditions of linear equality and inequality, f(x) is objective function of independent variables x, from which the extreme is searched [15]. Function *fmincon* is gradient-based method.

Numerical simulations. All mentioned methods in the previous chapter will be now simulated in order to find the best approach. The simulations in the software MATLAB are done. The parameters for simulations arise from biomechanics of human hand. So particular part of the simulated finger has following length: l_1=79,16 mm; l_2=67,5 mm; l_3=30,43 mm; l_4 = 15,81 mm. Tolerance of inverse kinematic solution is set to be 0,01 mm. The simulation are evaluated from the two aspects. The first is the time of simulation and the second is number of iteration necessary for finding of solution.

Table 2

Results of the simulations

Method	**Point [mm]**	**Solution**	**Time [s]**	**Number of iterations**
1	2	3	4	5
Damped least squares	[80 150 45]	found	1,858877	543
	[40 220 20]	not found	>10	–
	[80 140 80]	found	1,795458	538
	[50 90 80]	found	1,735288	509
	[30 200 -5]	not found	>10	–
Method	**Point [mm]**	**Solution**	**Time [s]**	**Number of iterations**
Pseudoinversion of Jacobian	[80 150 45]	found	1,816513	542
	[40 220 20]	not found	>10	–
	[80 140 80]	found	1,763199	538
	[50 90 80]	found	1,665617	509
	[30 200 -5]	not found	>10	–

End Table 2

1	2	3	4	5
Method	**Point [mm]**	**Solution**	**Time [s]**	**Number of iterations**
Transpose of Jacobian	[80 150 45]	found	1,058998	295
	[40 220 20]	not found	>10	–
	[80 140 80]	found	1,20205	361
	[50 90 80]	found	0,24794	75
	[30 200 -5]	not found	>10	–
Method	**Point [mm]**	**Solution**	**Time [s]**	**Number of iterations**
Optimization method	[80 150 45]	found	0,138819	77
	[40 220 20]	found	0,186186	111
	[80 140 80]	found	0,131314	93
	[50 90 80]	found	0,191943	133
	[30 200 -5]	found	0,17053	89

As can be seen from the Tab. 2, there are some cases when the simulations fail. However, using optimization method the solution were found always. The advantage of this method is in non Jacobian based approach. In the following figures are some examples of optimization method for particular humanoid robot hand tasks.

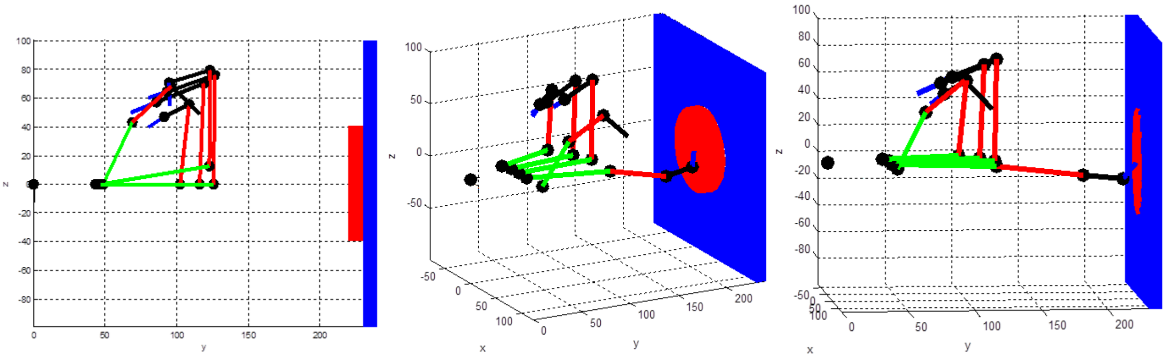

Fig. 3. Pushing of the button by finger

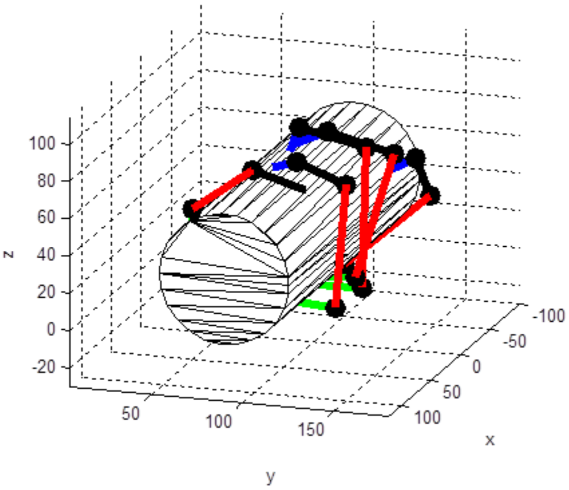

Fig. 4. Grasping task

Conclusions. The paper investigated inverse kinematic model approaches. There were analyzed pseudoinverse method, transpose of Jacobian method, damped least squares method as well as optimization method. The results of the simulations show the advantages of optimization method. During the simulations it never fail in comparison with other tested methods.

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МОДЕЛЮВАННЯ ТА АНАЛІЗ ЗВОРОТНОЇ КІНЕМАТИЧНОЇ МОДЕЛІ РУКИ ЛЮДИНОПОДІБНОГО РОБОТА

Актуальність теми дослідження. *На сьогодні робототехніка та мехатроніка стали основними напрямками. З розвитком цих галузей також зростають обчислювальні можливості. Тому в кінематичному та динамічному моделюванні приділяється значна увага чисельному моделюванню та алгоритмізації.*

Постановка проблеми. *Відповідний підхід для чисельного моделювання важливий з огляду на витрату часу, а також стабільність обчислень.*

Аналіз останніх досліджень і публікацій. *Проектування та моделювання людиноподібних роботів представляє значний інтерес у галузі робототехніки. Апаратна та механічна частина конструкції роботів знаходиться на значно вищому рівні порівняно з програмним забезпеченням роботів. Отже, моделювання та управління роботами лежить у полі інтересів дослідників.*

Виділення недосліджених частин загальної проблеми. *Порівняння методів чисельного моделювання зворотної кінематики.*

Постановка завдання. *Порівняння чотирьох методів з точки зору продуктивності та стабільності.*

Виклад основного матеріалу. *У цій роботі досліджено область кінематичного моделювання руки людиноподібного робота та моделювання в MATLAB.*

Висновки відповідно до статті. *У роботі досліджено зворотні кінематичні підходи до моделі. Були проаналізовані псевдоінверсний метод, транспонування методом Якобі, метод найменших квадратів в якості методу оп-*

тимізації. Результати моделювання показують переваги методу оптимізації. Під час моделювання цей метод ніколи не відмовляє порівняно з іншими перевіреними методами.

Ключові слова: *рука людиноподібних роботів; зворотна кінематика; якобіан; моделювання.*

Рис.: 4. Табл.: 2. Бібл.: 15.

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