Formation of the Method of Description and Control of the Relative Position of the Gripper Phalanges for Anthropomorphic Robot

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Abstract

The structural and design features and methods of description and improvement of both the mechanical design of grippers of anthropomorphic robots or prosthesis and the methods of model formation and improvement are analyzed. It is proposed to use a stepper motor, an additional brake and rods to drive the phalanges. A combined model of the drive, brakes and tractions has been created. The conducted modeling mostly concerns the drive of the links and the structure of the joints, which involves sensitization of the fingers and the skin of the palm and the skin in general. Formed as a result of recurrent approximation, the model demonstrates how combining modern analytical research methods for automatic control of robots with new distributed sensors improves their technological capabilities. The solution methodology, the system of nonlinear differential equations with additional models of traction and brake elements allowed to introduce design changes to eliminate dead zones. The obtained model methods and impact data are suitable for designing and modeling intelligent robotics and automation systems.

Keywords

Anthropomorphic grips, prostheses, models, drive, brake, recurrent approximation of models.

1. Introduction

The development of industrial robots, automated areas of various types of production requires expanding the functions of structural elements and revising the requirements for their characteristics. At the same time, the growing demand for anthropomorphic devices that partially functionally reproduce the movements of the upper limbs has been growing rapidly in the last decade. The reason for this is military actions and their consequences: ruptures of unexploded mines, grenades and other undisarmed weapons. The consolidated development of robotics [1], sensitized grippers [2], electromechanical [3,4,5] and pneumatic drives [6] together with the advances in electronics and single-board microcontrollers and artificial intelligence (AI) [7] requires a revision of the concept of modern prosthetics. However, such a review should be preceded by a comparative analysis of the characteristics of optimal technical solutions, which is not possible without a review of the achievements of robotics and model building and simulation modeling.

In connection with the emergence of new types of actuators with simple physical principles and new properties [8], prospects for the construction of new prostheses are opening up, which requires the creation of models suitable for comparative analysis and standards [9, 10 12].

2. Analysis of recent publications

Most modern prostheses are equipped with external electrical power sources, which primarily determines the shape and structural essence of the structural elements of the device as a whole. In this regard, one of the principles of organizing the operation of prostheses is based on the effect of electromyography [13]. However, as shown in [14], one of the main problems is the limited number of muscle zones that are suitable for the formation of a myographic signal,

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which limits the number of movements of the prosthesis that can be controlled. The potential difference from two electrodes is used to proportionally control the opening and closing of the prosthesis [15]. As shown in [16], this very limitation determined the manufacture of prostheses with only one degree of freedom. In work [17] it was established that the preliminary tension, which is formed on the surface of the palm, is the most often used as a standard when grasping or manipulating objects, most control systems are designed to perform grasping with a specified force. All fingers have the same appearance, but not all are active, for example, the middle, ring, or little finger [18]. Such hand prostheses, as a rule, use two-point potential control. One control signal initiates the opening of the palm, and the other causes clenching [19]. Thus, most people with amputation of the upper limbs use prostheses that only open and close. This limited function is one of the reasons leading to rejection of the prosthesis [19]. Many different estimates have been made, but according to most surveys, failure rates are high and reach 75% [19]. Recently, one of the most recent surveys showed that almost 70% of people who abandoned or rejected the use of a prosthesis stated that with the improvement of technology and control, it is more likely that they will reconsider the decision and choose a prosthesis [19].
In connection with the stated problem of unattractiveness to use, many researchers are searching for methods of improving both the mechanical design of the prosthesis and the control method. The indicated to a greater extent concerns the drive of the links and the structure of the joints, the sensitivity of the fingers and the skin of the palm and the skin in general. It is obvious that the Newton`s mechanistic paradigm is not able to meet the requirements of effective control of upper limb prostheses, as it relies on direct methods of model construction [20]. The authors of the work [21] demonstrate how combining modern methods of computational intelligence for automatic control of robots with new distributed sensors improves their technological capabilities. Transformation methodologies that can be applied to the modeling of intelligent robotics and automation systems transform various implicit forms of models into recurrent converging sequences [22]. Their progressiveness lies in the additional increase of informative components. An estimate of the maximum possible error and the value of the iteration number are added to the analytical expression of the transformed model, starting from which the relative error becomes less than the specified one [22]. Attempts to solve these problems by means of AI are reduced to statistical generalization of simulation experiments in virtual reality systems using matrix algebra operations and neural networks [23]. The use of calibration together with the use of a recurrent network as shown in [24] opens up new possibilities for model correction. Interactive interaction allows fragmented representations and image processing, which obviously simplifies the process as a whole [24]. Recurrent approximation and transformation of the model, which forms an analytical convergent sequence, allows considering the dynamics of the elements of a mobile robot, manipulator, prosthesis in an inertial or quasi-inertial base coordinate system [25]. As the results of the study demonstrate, the influence of the choice of the coordinate system for modern speeds and accelerations is estimated to have an error of up to 30 percent [25]. Equally important and practically useful for the description of dynamics is the application of transformation operations on fuzzy sets for solving problems of optimal movement without operator robots [26]. The analytical form of the structure of the membership function based on the data of experts' assessments allowed the search for optimal solutions to be reduced to operations of mathematical analysis [26].

The search for new operating principles of actuators in the conditions of interactive interaction stimulates their review and comparison. One of the drives that is promising due to its high initial torque and precise movement is the stepper motor (SM) [27]. The Simulink structure of the Matlab model and the one proposed by the authors in the form of equations of electric, magnetic and mechanical quantities for a hybrid engine was studied in [27]. The simulation results were compared with the results obtained by the Simulink model in the Matlab library, and it was demonstrated that they need to be and how can be adjusted [27]. The authors of the work [28] conclude that the development of the physical hand and virtual control algorithms will be carried out in a consolidated manner in order to achieve the two main goals of a socially affordable price and openness of the software code.

Thus, the main unsolved problem in the innovative design of links of the upper limbs of the grippers of an anthropomorphic robot is the formation of the modeling method for the description and control of the relative position and functioning.

3. The purpose and objectives of the research

The aim of the work is to improve the quality of the model, which describes the relative positions of the prosthesis links and the position of the prosthesis in relation to the subject of articulation.
To achieve this goal, we will set the following tasks:
- Develop a model of the dynamics of the movement of the finger's upper phalanx of the upper limbs in the inertial coordinate system;
- carry out modeling of the step drive of the prosthesis links, which includes an adjustable brake;
- to present an approximate analytical model of motion based on a stepper motor with a brake.

4. Model of the dynamics of movement of the phalanges of the upper limbs in the inertial coordinate system of the stepper drive with a brake

An anthropomorphic gripper or a prosthesis of the upper limbs of the arm with the same kinematic scheme was considered. The diagram of the articulation of the first two phalanges of the fingers of an anthropomorphic robot, as a basic standard element, is presented in Figure 1.

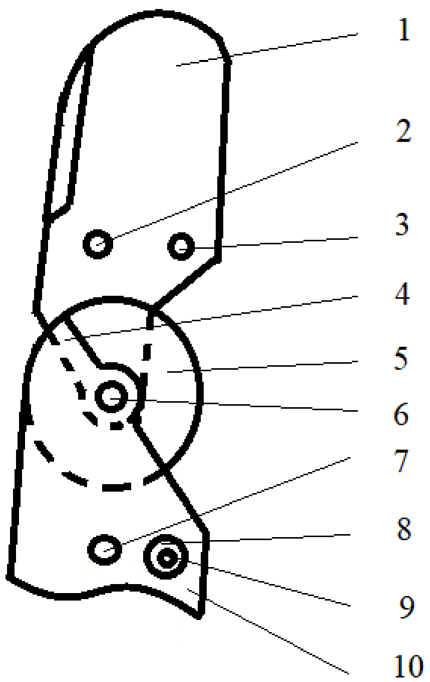

Figure 1 : Schematic representation of the kinematic diagram of articulation of the phalanges of the prosthetic finger

1 - phalanx body; 2 - the thrust pin of the reverse movement of the phalanx; 3- thrust pin of the relative bending of the phalanx; 4 corps of the second articulated phalanx; 5 auxiliary disk; 6 hinge axis; 7 - thrust pin of the reverse movement of the phalanx; 8 – pulley bearing housing; 9-pulley axis; 10, the lower body plate of the second articulated phalanx, the upper one is conditionally removed for ease of display.

Assume that the basic coordinate system is rigidly connected to another phalanx, and the origin of the half-connected and connected coordinate systems is located in the center of the hinge axis 6. Under these conditions, the displacement of the center of the thrust pin of the relative bending of the phalanx 1 is equal to the angular displacement of the drive shaft, which is multiplied by the radius of the pulley.

Also, a SM was chosen as the drive, the rotor of which is additionally braked by an electric brake.

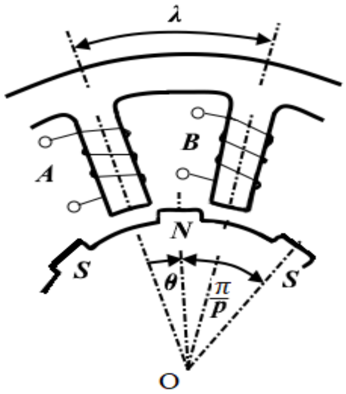

Figure 2 : Structural model of a SM fragment

Stepwise jump-like changes in angular positions form the basis of all operating modes of the SM. By its very nature, jump-like turns are its main feature, which determines the similar nature of changes and all parameters to be measured. This becomes obvious after solving the mathematical model of the SM, which is a system of nonlinear differential equations [27]:

$$\begin{cases} J\dfrac{d^2\theta}{dt^2}+D\dfrac{d\theta}{dt}+pn\Phi_m i_A\sin\left(p\theta\right)+pn\Phi_m i_B\sin\left(p\left(\theta-\lambda\right)\right)+M_{fr}=0, \\ V_{gA}-r\cdot i_a-L\cdot\dfrac{di_A}{dt}-M\dfrac{di_B}{dt}+\dfrac{d}{dt}\left[n\Phi_m\cos\left(p\theta\right)\right]=0, \\ V_{gB}-r\cdot i_b-L\cdot\dfrac{di_B}{dt}-M\dfrac{di_A}{dt}+\dfrac{d}{dt}\left[n\Phi_m\cos\left(p\left(\theta-\lambda\right)\right)\right]=0, \\ M_{em}=-nN_r\Phi_M\cdot\left[i_A\cdot\sin\left(N_r\cdot\theta\right)+i_B\cdot\cos\left(N_r\cdot\theta\right)\right], \\ dl=r_1 d\varphi=r_d d\theta \end{cases}, \quad (1)$$

where: V_{gA}, V_{gB} – supply voltage, respectively phases A and B;

L – is the inherent inductance of each phase;

M – mutual inductance;

r – is the resistance of the stator winding circuit;

Nr – is the number of rotor teeth;

J – moment of inertia;

D – is the coefficient of viscous friction;

θ – is the rotation angle of the SM rotor relative to the stator;

p – is the number of pole pairs of the SM stator;

n – the number of winding turns;

Φ_m – coefficient of mutual induction;

i_A, i_B – current in the windings of phases A and B, respectively;

λ – is the pitch of the SM stator teeth.

One of the methods of solving the system (1) is to reduce the nonlinear differential equations to linear ones, in this way the linearized mathematical model of SM is actually derived. However, then it becomes impossible to find the error and pre-evaluate the adequacy of the obtained model. The system (1) for a two-phase SM of the M35SP-6 type was constructed using the decomposition of nonlinearities by the method of recurrent approximation:

$$\begin{aligned}
&\sin(p\theta) = \sin(p\theta_n) + p\cos(p\theta_n)(\theta_{n+1} - \theta_n);\\
&\sin(p(\theta-\lambda)) = \sin(p(\theta_n-\lambda)) + p\cos(p(\theta_n-\lambda))(\theta_{n+1} - \theta_n);\\
&\theta_n = 0; \qquad \sin(p\theta) = p\theta_{n+1};\\
&\sin(p(\theta-\lambda)) = -\sin(\pi) + p\theta_{n+1}\cos(\pi) = -p\theta_{n+1}\ .
\end{aligned} \tag{2}$$

Substitution results of application recurrent approximation for non-linear multipliers of terms into the equations (1) after simple algebraic transformations reduce it to the system:

$$\begin{cases}
J\dfrac{d^2\theta_{n+1}}{dt^2} + D\dfrac{d\theta_{n+1}}{dt} + p^2 n\Phi_m(i_A - i_B)\theta_{n+1} + M_{fr} = 0,\\
V_{gA} - V_{gB} - 2p^2 n\Phi_m\dfrac{d\theta_{n+1}}{dt}\theta_{n+1} = (L-M)\cdot\dfrac{d(i_A - i_B)}{dt} + r\cdot(i_a - i_b),\\
M_{ем} = -npN_r\Phi_M\cdot[i_A - i_B]\theta_{n+1},\\
dl = r_1 d\varphi = r_d d\theta.
\end{cases} \tag{3}$$

For the formation of the transfer function, the Laplace transformation was applied to the system (3). The Laplace transform of the product of the functions into the third term of the first equation is determined by integration by parts and by the similarity method:

$$\int_0^\infty e^{-st}(i_A - i_B)\theta_{n+1}dt = \frac{\omega}{(s-1)}(\tilde{i}_A - \tilde{i}_B). \tag{4}$$

Due to this result system (3) can be rewritten in Laplace transforms as follows:

$$\begin{cases}
Js^2\tilde{\theta}_{n+1} + Ds\tilde{\theta}_{n+1} + \dfrac{p^2 n\Phi_m\omega}{(s-1)}(\tilde{i}_A - \tilde{i}_B) + \tilde{M}_{fr} = 0;\\
\tilde{V}_{gA} - \tilde{V}_{gB} - 2p^2 n\Phi_m\dfrac{d\theta_{n+1}}{dt}\tilde{\theta}_{n+1} = (L-M)\cdot\dfrac{d(\tilde{i}_A - \tilde{i}_B)}{dt} + r\cdot(\tilde{i}_a - \tilde{i}_b),
\end{cases}, \tag{5}$$

and its rotation angle and voltage difference, as functions of the currents transformed according to Laplace, under $\tilde{M}_{fr} = 0$ we present :

$$\begin{cases}
\tilde{\theta}_{n+1} = -\dfrac{p^2 n\Phi_m\omega}{(Js^2 + Ds)(s-1)}(\tilde{i}_A - \tilde{i}_B);\\
\tilde{V}_{gA} - \tilde{V}_{gB} = 2p^2 n\Phi_m\omega\tilde{\theta}_{n+1} + (L-M)\cdot s(\tilde{i}_A - \tilde{i}_B) + r\cdot(\tilde{i}_a - \tilde{i}_b).
\end{cases}. \tag{6}$$

The expressions of the system (5) allow you to build a transfer function and, together with the equations of system (3), to determine current and moments and to model the dynamics of the phalanxes of an anthropomorphic gripper containing drive stepper motors and a brake.

Usually, the drive brakes keep the rotor shaft from spinning when the voltage is turned off. Structurally, the brakes of the manipulator drive are made as disc or drum type. A section of the engine for an disc-type brake is presented in Fig. 2. Body parts of the engine and the electromagnet casing are not shown in the figure. Figure 8 also shows the rotor of the electric motor and the end brake with an electromagnet, the rotor is mounted on two ball bearings, the gearbox and the housing of the motor and electromagnet are conventionally not shown. In the disabled state, fig. 7, the spring 4 presses the brake disk 2 against the end surface of the brake disk of the rotor of the electric motor 1. As a result of applying voltage to the stator winding, it is also supplied to the solenoid winding 6 in parallel, due to which a force is formed that retracts the rod 3 and separates the brake surfaces of the disk 2 and the rotor 1.

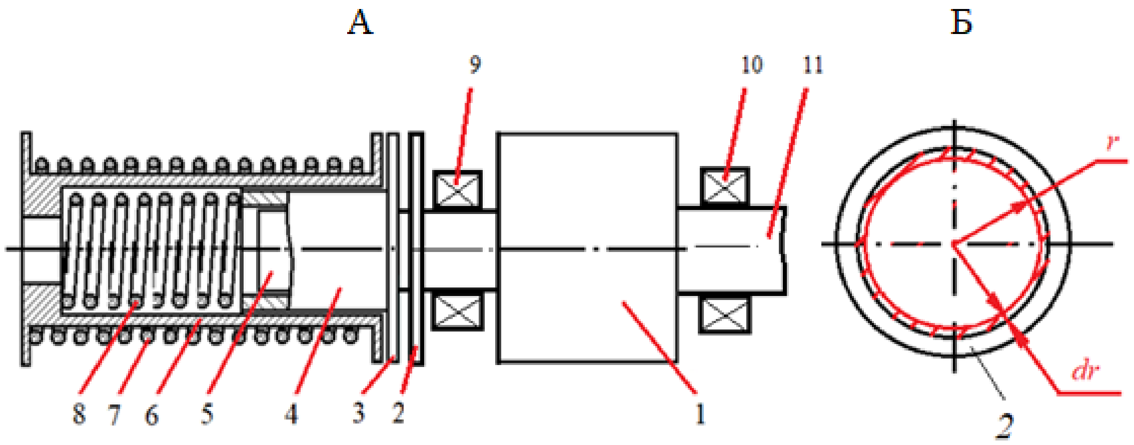

Figure 3: Schematic representation of the elements of the engine brake assembly (stator elements are not conventionally shown). A-section of the engine and brake along the rotor axis; B - a view of the surface of the brake disc. 1- rotor assembly; 2 - rotor brake disc; 3 – electromagnet brake disk; 4 – guide sleeve of the spring stop; 5 – rod of the electromagnet brake disk; 6 - electromagnet coil frame; 7 – electromagnet winding; 8 – compression spring; 9, 10 – support-thrust bearings of the engine rotor; 11 – motor rotor shaft.

We determine M_{fr} - the moment of brake friction force acting on disc - 2 in the braked state (static). Based on the distributed dry friction force - $f_{dfr}p\pi rdr$ acting on the elementary surface of the disc πrdr with *Rint*, *Rout* - inter and outer radius accordingly after integration can be written, if a friction coefficient - f_{dfr} is a constant:

$$M_{fr} = \int_{R\mathrm{int}}^{Rout} f_{dfr} p\pi r^2 dr = \frac{\pi p f_{dfr}}{3}\left(R_{out}^3 - R_{int}^3\right).$$

The torque of the engine brake friction force during its rotation is derived from the conditions of constant pressure distribution p over the area of the brake disk and the coefficient of viscos friction f_{vfr} proportional to the speed:

$$M_{fr} = \int_{R\mathrm{int}}^{Rout} f_{vfr} p'\pi v r^2 dr = \frac{\pi p'\omega f_{vfr}}{4}\left(R_{out}^4 - R_{int}^4\right),$$

where the value of the hydrostatic pressure in the interdisc gap is indicated p'. The compression force - F_{st} can be calculate by characteristic of the spring from its deformation. We find the deformation of the spring or by the size of the gap - h and rigidness of spring - k, then we calculate the force:

$$F_{st} = kh.$$

The value of hydrostatic pressure in the disc gap we calculate:

$$p' = \frac{F - F_{st}}{\pi\left(R_{out}^2 - R_{int}^2\right)}.$$

Thus, we calculate the moment of brake friction forces in the braked static state:

$$M_{fr} = \frac{\pi p' f_{dfr}}{3}\left(R_{out}^3 - R_{int}^3\right) = \frac{f_{dfr}}{3}\frac{(F - F_{st})\left(R_{out}^2 + R_{out}R_{int} + R_{int}^2\right)}{\left(R_{out} + R_{int}\right)}.$$

Energy losses per unit of time can be calculated as the work of the moment of friction forces multiplied by the angular velocity and the time interval, if the moment of forces does not depend on time or if it does, then:

$$Q = \int_0^t M_{fr} \omega dt = \frac{\pi p' f_{vfr}}{4}\left(R_{out}^4 - R_{int}^4\right)\int_0^t \omega dt \,.$$

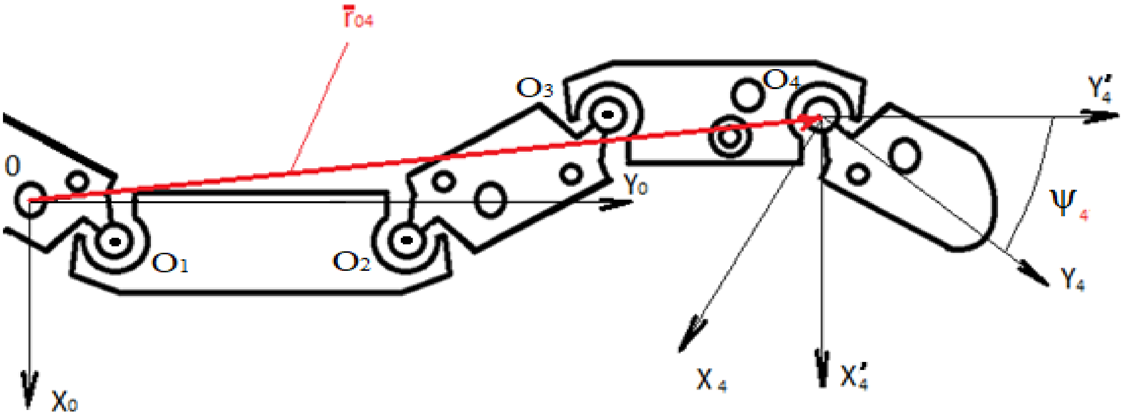

Figure 4: Kinematic diagram of articulations of the phalanges of one finger with elements of the palm of an anthropomorphic prosthesis

It was assumed that the base coordinate system of the gripper is related to the zero link, which in turn is related to the first, second, third, and fourth phalanges. Let`s mark $\overline{r}_{oji}$ - radius vectors the centers of the articulation of *j*-th joints of the *i*-th link are set relatively to point *O*. The vector of the angle of rotation of the axes of the connected coordinate system $O_4X_4Y_4Z_4$ are marked $\overline{\psi}_{j,i}$ and radius vectors the ordinary point *k* relatively to *j*-th joints - $\overline{r}_{jik}$, then the radius vector of it will obtain relatively to point O:

$$\overline{r}_{oik} = \overline{r}_{oji} + \overline{\psi}_{j,i} \times \overline{r}_{jik}; \quad i = \overline{1,4}; \quad j = \overline{0,4}.$$

Thus, if the drive rod hooked to the pin 6 shifts by the amount Δl, the phalanges will turn to the angle $\overline{\psi}_{j,i}$. To ensure the high-quality work of the gripper, it was constructively provided that the phalanx was returned to the initial value of the angle. The dynamics of the movement of a separate phalanx in the basic coordinate system $OX_0Y_0Z_0$ is described by the system in general:

$$\begin{cases} \dfrac{d\overline{K}}{dt} + \overline{\Omega} \times \overline{K} = \overline{R}; \\ \dfrac{d\overline{L}}{dt} + \overline{\Omega} \times \overline{L} + \overline{v}_o \times \overline{K} = \overline{M}. \end{cases} \tag{7}$$

The vectors $\overline{v}_o, \overline{\Omega}$ - linear and angular velocity of the center of mass in the coupled $O_4X_4Y_4Z_4$ coordinate system of equation (7) are determined through the coupling matrices as follows:

$$\begin{bmatrix} \dot{x}_o \\ \dot{y}_o \\ \dot{z}_0 \end{bmatrix} = \begin{bmatrix} \cos\varphi\cos\psi, (\sin\varphi\sin\theta - \cos\varphi\sin\psi\cos\theta), (\cos\varphi\sin\psi\sin\theta + \sin\varphi\cos\theta) \\ \sin\psi, \qquad \cos\psi\cos\theta, \qquad -\cos\psi\sin\theta \\ -\sin\varphi\cos\psi, (\sin\varphi\sin\psi\cos\theta + \cos\varphi\sin\theta), (\cos\varphi\cos\theta - \sin\varphi\sin\psi\sin\theta) \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix}; \tag{8}$$

$$\begin{bmatrix} \omega_{ix} \\ \omega_{iy} \\ \omega_{iz} \end{bmatrix} = \begin{bmatrix} 1, \sin\psi_i, 0 \\ 0, \cos\theta_i\cos\psi_i, \sin\theta_i \\ 0, -\sin\theta_i\cos\psi_i, \cos\theta_i \end{bmatrix} \begin{bmatrix} \dot{\theta}_i \\ \dot{\varphi}_i \\ \dot{\psi}_i \end{bmatrix}. \tag{9}$$

Determination of forces and moments of forces by equation (3) together with a linear and angular velocity of the center of mass described by the system (7) – (9) can determine the coordinates and angular position of phalanges finger with elements of the palm of an anthropomorphic prosthesis.

5. Simulation of the joint operation of the actuator, phalanx rotation, and force sensor.

To confirm the effectiveness of the applied recurrent approximation, we will present a simulation of the approximation process. Table 1 presents nine values of angles and two consecutive approximations, determined according to schedule (2).

Table 1
Estimation of the rate of convergence of two successive recurrent approximations

№	$p\theta_n$	$\sin(p\theta_n)$	$p\theta_{n+1}$	ε, %
1	0,015708	0,015706904	0,015706904	0,008224254
2	0,031415	0,031409933	0,031412516	0,009595359
3	0,047123	0,047105212	0,047109733	0,010281236
4	0,06283	0,06278887	0,062795326	0,010693028
5	0,078538	0,078457036	0,078465426	0,010967781
6	0,094245	0,094105845	0,094116167	0,011164225
7	0,109953	0,109731436	0,109743688	0,011311728
8	0,12566	0,125329953	0,125344132	0,011426603
9	0,141368	0,14089755	0,156448404	0,01151864

The analysis of the data in Table 1 shows that thanks to the recurrent approximation, the value of the hundredth part of a percent is achieved. Thus, the use of such an approximation leads system (1) to a model that will ensure high accuracy of solutions. The results of the simulation of the holding force with the help of an additional brake ensured that an object with a mass suitable for holding a gripper up to 20-25 kg was kept in the brake. Data for calculating the braking torque are presented in Table 2

Table 2
Moments of frictional forces developing an additional brake

n	$R_{int}\ 10^2$, m	$R_{out}\ 10^2$, m	$M_{fr} 10^2$, Nm
1	0,5	2	-236,25
2	0,5	2,25	-337,969
3	0,5	2,5	-465
4	0,75	2	-227,344
5	0,75	2,25	-329,063
6	0,75	2,5	-456,094

As evidenced by the data in Table 2, an increase in the outer diameter of the brake disc by 1.25 increases the braking torque almost twice. The determined values of forces and moments make it possible to form requirements for force sensors from one to 150 N. The choice of initial angles between phalanges from 15 to 25 degrees reduces the dead zone and shortens the working range of force sensors. The proposed model made it possible to carry out modeling and determine the design parameters of various working options, which simplifies the analysis. However, the main problem is to determine the accuracy and prove the reliability of the models, because as well as in Simulink, the Matlab model requires an experimental test with a justified methodical error.

Conclusions

1. Recurrent approximation simplified the presentation of the nonlinear model of the movement of the phalanges, rods and additional brake of the stepper motor. The new expressions of the solution dynamic and electric system allow the building of a transfer function, determining current and moments, and modeling the dynamics of the phalanxes of an anthropomorphic gripper containing drive stepper motors and a brake.
2. According to the simulation results, the ranges of changes in the braking torque of the additional brake are determined from 200 Nm 10^{-2} to 450 Nm 10^{-2}, and the initial angle between the phalanges is changed in range from 15 to 25 degrees

Reference

[1] Modeling and Simulation of Robotic Finger Powered by Nylon Artificial Muscles. Lokesh Saharan, Lianjun Wu, Yonas Tadesse. Journal of Mechanisms and Robotics Copyright © 2019 by ASME FEBRUARY 2020, Vol. 12 / 014501 pp.1-11

[2] Trounov, A. N. (1984). Application of sensory modules for adaptive robots.IFS Publication.Robot Vision and Sensory Control, p.285–294.

[3] Naoki Uchiyama, Yuichi Osugi, Yuichiro Kajita, Shigenori Sano, Shoji Takagi, "Model Reference Control for Collision Avoidance of a HumanOperated Robotic Manipulator", International Review of Automatic Control, Vol. 3. n. 2, pp 219-225, March 2011.

[4] Ouamri Bachir, Ahmed-Foitih Zoubir, "Computed Torque Control of a Puma 600 Robot by using Fuzzy Logic", International Review of Automatic Control, Vol. 4. n. 2, pp 248-252, March 2011.

[5] BionicSoft Hand Pneumatic robot hand with artificial intelligence. www.festo.com/net/SupportPortal/ Files/597078/Festo_BionicSoft Hand_en.pdf.

[6] Faix V., Lückfeldt S., Ostertag A. Pneumatic robotics meets artificial intelligence. Bionic projects 2019

[7] Amran Mohd Zaid, M. Atif Yaqub, Mohd Rizal Arshad, Md Saidin Wahab "UTHM Hand: Mechanics Behind The Dexterous Anthropomorphic Hand", World Academy Of Science, Engineering And Technology, Vol.74, Pages.154-158, February 2011.

[8] Amran Mohd Zaid, M. Atif Yaqub "UTHM Hand: Design of Dexterous Anthropomorphic Hand", International Review of Automatic Control, Vol.4,N. 6, Pages.969-976, November 2011

[9] Nili E. Krausz, Ronald A. L. Rorrer, and Richard F. ff. Weir. Design and Fabrication of a Six Degree-ofFreedom Open Source Hand IEEE Trans Neural Syst Rehabil Eng. 2016 May;24(5): pp. 562-72. doi://10.1109/TNSRE.2015.2440177. Epub 2015 Jun 15.

[10] Wu and Wen Zheng *A Modeling of Twisted and Coiled Polymer Artificial Muscles Based on Elastic Rod Theory Chunbing. Actuators 2020, 9, 25; P 14. www.mdpi.com/journal/actuators doi:10.3390/act9020025

[11] Park, H., Kim, M., Lee, B., Kim, D. Design and Experiment of an Anthropomorphic Robot Hand for Variable Grasping Stiffness. IEEE Accessthis link is disabled, 2021, 9, pp. 99467–99479, 9469870

[12] D.S. Childress and R.F. Weir, "Control of limb prostheses," in Atlas of Amputations and Limb Deficiencies, vol. 3, D.G. Smith, J.W. Michael, and J.H. Bowker, Eds. Rosemont, IL: American Academy of Orthopaedic Surgeons, 2004, pp. 173-193.

[13] T.R. Farrell, R.F. Weir, "A comparison of the effects of electrode implantation and targeting on pattern classification accuracy for prosthesis control," IEEE Transactions on Biomedical Engineering, vol. 55, no. 9, pp. 2198-2211, Sep. 2008. DOI: 10.1109/TBME.2008.923917

[14] Billock J.N. “Upper limb prosthetic terminal devices: hands versus hooks,” Clinical Prosthetics and Orthotics, vol. 10, no. 2, pp. 57-65, 1986.

[15] Weir R.F., “Design of artificial arms and hands for prosthetic applications,” in Standard Handbook of Biomedical Engineering and Design, M. Kutz, Ed., New York, NY: McGraw Hill, 2003, pp. 32.1-32.61.

[16] Bolu Ajiboye Richard F. ff. Weir. A Heuristic Fuzzy Logic Approach to EMG Pattern Recognition for Multifunctional Prosthesis Control IEEE transactions on neural systems and rehabilitation engineering: a publication of the IEEE Engineering in Medicine and Biology Society . October 2005. 13(3):280-91. DOI:10.1109/TNSRE.2005.847357 Source PubMed

[17] Pezzin L. E., et al., “Use and satisfaction with prosthetic limb devices and related services,” Archives of Physical Medicine and Rehabilitation, vol. 85, no. 5, pp. 723–729, May 2004. DOI: 10.1016/j.apmr.2003.06.002

[18] Biddiss, Elaine A., and Chau Tom T. “Upper limb prosthesis use and abandonment: A survey of the last 25 years.” Prosthetics and orthotics international 31.3 (2007): 236-257.

[19] Resnik L., et al., “Advanced Upper Limb Prosthetic Devices: Implications for Upper Limb Prosthetic Rehabilitation,” Archives of Physical Medicine and Rehabilitation, vol. 93, no. 4, pp. 710–717, Apr. 2012.

[20] Open source hand. A 6 Degree-Of-Freedom Open Source Prosthetic Hand www.opensourcehand.wordpress.com.

[21] Kondratenko, Y.; Duro, R. (Eds.) Advances in Intelligent Robotics and Collaborative Automation; River Publishers: Aalborg, Denmark, 2015; ISBN 9788793237032.

[22] Trunov, A. (2019) Forming a мetodology for transforming a model as the basis for expanding its informativeness. №.5/4 (101), 2019, pp. 34-43. DOI: https://doi.org/10.15587/1729-4061.2019.181866

[23] Fisun, M., Smith, W., Trunov, A. The vector rotor as instrument of image segmentation for sensors of automated system of technological control. *Proceedings of the 12th International Scientific and Technical Conference on Computer Sciences and Information Technologies, CSIT 2017*, 2017, 1, страницы 458–463, **DOI:** 10.1109/STC-CSIT.2017.8098828

[24] Trunov, A., Fisun, M., Malcheniuk, A. The processing of hyperspectral images as matrix algebra operations 14th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering, TCSET 2018 - Proceedings, 2018, 2018-April, pp. 738–742. **DOI:** 10.1109/TCSET.2018.8336305

[25] Trunov, A. Recurrent transformation of the dynamics model for autonomous underwater vehicle in the inertial coordinate system Eastern-European Journal of Enterprise Technologies, 2017, 2(4-86), pp. 39–47. DOI: 10.15587/1729-4061.2017.95783

[26] Trunov, A. Transformation of operations with fuzzy sets for solving the problems on optimal motion of crewless unmanned vehicles. Eastern-European Journal of Enterprise Technologies, 2018, 4(4-94), pp. 43–50. DOI: https://doi.org/10.15587/1729-4061.2018.140641

[27] Iqteit, N.A.; Yahya, K.; Makahleh, F.M.; Attar, H.; Amer, A.; Solyman, A.A.A.; Qudaimat, A.; Tamizi, K. Simple Mathematical and Simulink Model of Stepper Motor. Energies 2022, 15, 6159. https:// doi.org/10.3390/en15176159

[28] Kõiva, R., Hilsenbeck, B. & Castellini, C. Evaluating subsampling strategies for sEMG-based prediction of voluntary muscle contractions. Proc. Int. Conf. Rehabil. Robot 1–7 (2013).