ATLANTIS
PRESS

Method of Planning the Trajectory of an Anthropomorphic Manipulator With a Copying Control With Haptic Gloves

Vyacheslav Petrenko
Institute of Information Technology and Telecommunications
Department of Organization and Technology of Information Protection
North Caucasus Federal University
Stavropol, Russian Federation
vip.petrenko@gmail.com

Vladimir Antonov
Institute of Information Technology and Telecommunications
Department of Applied Mathematics and Computer Security
North Caucasus Federal University
Stavropol, Russian Federation
ant.vl.02@gmail.com

Fariza Tebueva*
Institute of Information Technology and Telecommunications
Department of Applied Mathematics and Computer Security
North Caucasus Federal University
Stavropol, Russian Federation
fariza.teb@gmail.com

Artem Apurin
Institute of Information Technology and Telecommunications
Department of Organization and Technology of Information Protection
North Caucasus Federal University
Stavropol, Russian Federation
apurin.a@icloud.com

Abstract—**The article presents the development of a method for planning the trajectory of motion of the joints of an anthropomorphic manipulator in virtual reality with copy control with haptic gloves based on the method of calculating the position of the operator's hands. The article discusses the existing development of haptic gloves, analyzes the scientific publications on this topic, which showed a variety of technical solutions. Two methods for the implementation of haptic gloves are indicated, for which the calculation of the path of movement of the robot arm is performed. The method of planning the trajectory of motion of the joints of the anthropomorphic manipulator with copy control using haptic gloves is based on the Denavit-Hartenberg representation and the developed method and calculating the position of the operator's hands in virtual reality.**

Keywords—haptic glove, virtual reality, copy control, anthropomorphic manipulator, motion control

I. INTRODUCTION

Increasingly, the need arises to perform tasks in places where the presence of a person is difficult, risky or even impossible. In such dangerous situations, the use of anthropomorphic manipulators (the structure consists of 3 units of 6–7 degrees of mobility) is effective. For remote control of the manipulator, a haptic glove worn by the operator can be used. Haptic gloves significantly expand the possibilities of plausible immersion, allowing you to feel virtual objects by affecting the tactile sensations of a person for greater dexterity and control during operations. This can be an advantage not only during rescue operations, but also in the energy and construction sectors, medicine, and industry.

The aim of this work is to develop a method for planning the trajectory of motion of the joints of an anthropomorphic manipulator with copy control using haptic gloves. To achieve this goal, literary sources were analyzed in which existing haptic gloves and existing methods for planning the trajectory of movement of the manipulator are presented.

A method for planning the trajectory of motion of the joints of an anthropomorphic manipulator with copy control using haptic gloves on absolute orientation sensors and bend sensors is proposed, the software architecture is presented, as well as methods for calculating the position of the operator's hands in virtual reality.

II. ANALYTICAL REVIEW OF CURRENT DEVELOPMENTS OF HAPTIC GLOVES AND METHODS OF PLANNING A TRAJECTORY OF MOTION OF JOINS OF MANIPULATORS

As part of the work, an analysis of systems and mechanisms developed in recent years has been made. These systems are used to build haptic gloves. There is a general trend for all developments, which consists in the desire to reduce the weight of the structure for the possibility of more comfortable and long-term use, as well as moving towards a cheaper design.

The papers [1–9] describe the current developments of haptic gloves. The devices considered are shown in Fig. 1. The input parameters for controlling the anthropomorphic manipulators of the robot should be data on the angles of rotation of the fingers, the orientation of the hand in space and its relative distance from the target point.

Let us consider a gloves device for generating input data. In [1–2, 4, 6–8], a pneumatic or electric drive is used for the haptic glove to read out the angles of rotation of the fingers of the operator's hand and provide feedback. The position in space is realized by inertial sensors (accelerometers) measuring the tilt of the operator's hand.

In articles [3;5;9], worm-geared motors or brake mechanisms are used to provide feedback; accelerometers

are used to register the position of the glove in space. Bend sensors can be used to calculate finger angles.
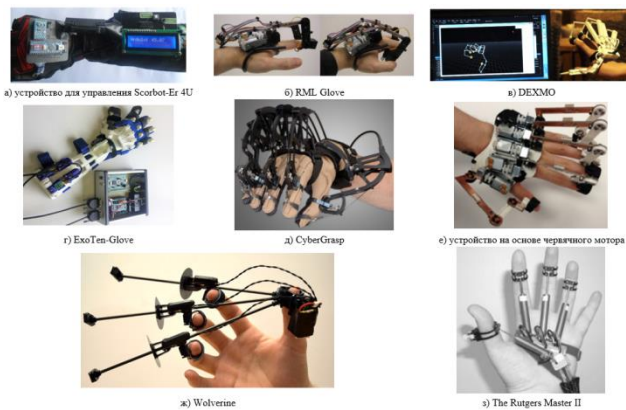

Fig.1 Existing Haptic Gloves Prototypes: a) – Scorbot-Er 4u; б)– RMLGlove; в) – DEXMO; г) – ExoTen-Glove; д) – CyberGrasp; е) – haptic gloves based on a worm-geared motor; ж) – Wolverine; з) – The Rutgers Master II

This article proposes two options for the implementation of haptic gloves, based on absolute orientation sensors (inertial) and on the basis of bend sensors, for subsequent control of robotic arms. The functional diagram of the haptic gloves is shown in Fig. 2. Input data are generated using motion sensors and transmitted to the actuator through the communication module.
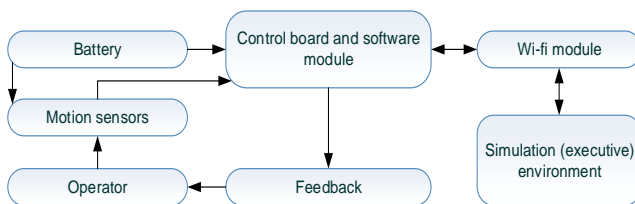

Fig.2.Functional diagram of the haptic glove

To plan the path of movement of the robot arms, input data on the angles of rotation of the fingers (which must be calculated when processing data from inertial sensors), the orientation of the hand in space and its relative distance from the target point are required. The output data is a set (table) of discrete values of generalized variables that determine the position of the manipulator in space. There are 2 main approaches to solving the problem of planning the path of movement of the robot manipulator: Sample-based (feasible solution based on probabilistic configurations) and the combinatorial approach (numerical and analytical methods). The non-deterministic configuration space, the high available computational complexity and the need to search for a complete solution and evidence of its presence allow us to conclude the prospect of using analytical methods for calculating the angle of rotation of the manipulator in this article. The need to find a complete solution is associated with the possible use of anthropomorphic robots in collaboration with humans [10-12]. In this case, the robot should be able to manipulate the manipulators to avoid collisions or optimize the performance of targeted operations.

Based on the existing methods for solving kinematics problems (graph-analytical methods, genetic algorithms, machine learning, fuzzy logic, spline interpolation), it is proposed to use the Denavit-Hartenberg representation and

the approach to calculating the rotation angles of the operator's hand described in [13-16].

To implement the method of planning the trajectory of motion of the joints of the anthropomorphic manipulator with copy control using haptic gloves, it is necessary to develop a method for calculating the position of the operator's hands in VR, which will allow obtaining data on the rotation angles of the operator's fingers and the position of the hand in space by processing information from inertial sensors of the haptic glove.

III. METHOD FOR CALCULATING THE OPERATOR'S HAND POSITION IN VIRTUAL REALITY

This section deals only with the left hand of the operator. The calculations for the right hand of the operator are similar. The purpose of the calculation is to determine the Cartesian coordinates x_h', y_h', z_h' and Euler angles α', β', γ' of the operator's virtual brush relative to the operator's center of vision (Fig. 3), as well as rotation angles $\boldsymbol{\theta}'$ in the joints of the fingers of the operator's virtual hand [16-19].
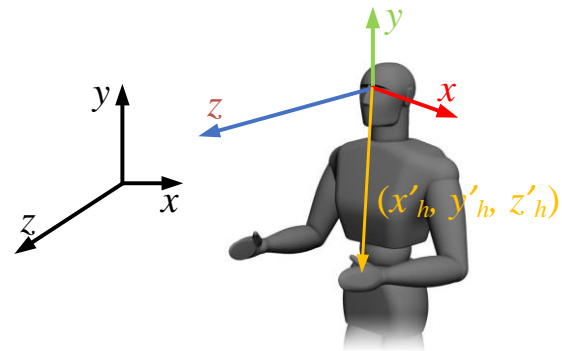

Fig. 3. Coordinate system associated with the operator's center of vision

- The initial data for the calculation are:
- Cartesian coordinates x_h, y_h, z_h of the center of the hand of the operator, calculated relative to the center of vision of the operator;
- Eulerangles α, β, γ of the operator's hand relative to the coordinate system associated with the operator;
- Cartesian coordinates of the ends of the fingers of the operator relative to the center of his hand in the case of a haptic glove based on inertial sensors;
- measurement results of a bend sensors in the case of a haptic glove based on bend sensors.

Cartesian coordinates x_h, y_h, z_h and Euler angles of the operator's hand can be displayed in virtual space without changes:

$$< x_h', y_h', z_h', \alpha', \beta', \gamma' > = < x_h, y_h, z_h, \alpha, \beta, \gamma >.$$

The rotation angles $\boldsymbol{\theta}$ in the joints of the fingers of the operator's hand cannot be mapped into the angles of rotation $\boldsymbol{\theta}'$ in the joints of the fingers of the virtual arm of the operator without transformations, since in the general case the lengths of the phalanges of the fingers of the operator's hand differ from the lengths of the phalanges of its virtual model. It is possible to implement a custom virtual model of the operator's hand, in which the phalanx lengths will coincide with the lengths of the operator's phalanges,

however, this will require a rather laborious operation to measure the lengths of the operator's phalanges. Consider the individual finger i. In fig. 4 shows various positions of the operator's finger. For the j−th position of the i-th finger $A_{i,j}$ denotes the center of the joint between the metacarpal bone and the proximal phalanx, point $B_{i,j}$ the center of the joint between the proximal and middle phalanx, point $C_{i,j}$ the center of the joint between the middle and distal phalanx, point $D_{i,j}$ the end of the finger. When the finger is naturally bent, the radius vector $\boldsymbol{r_i}$ of its end describes in space a certain curve e_i (Fig. 4).
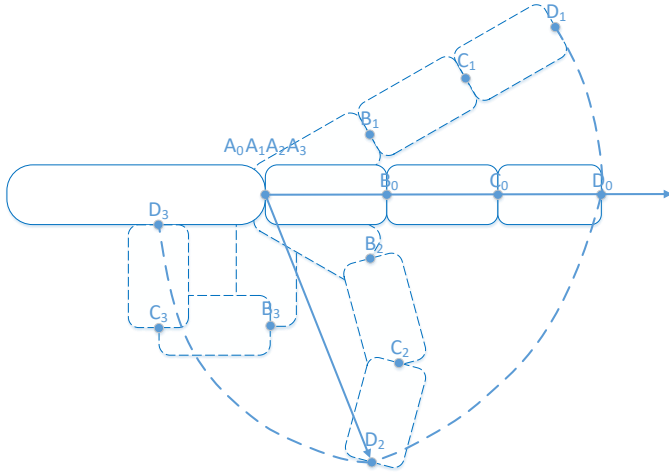

Fig. 4. The trajectory of the end of the finger when it is bent

When bending the finger of the virtual model of the operator's hand, the radius vector $\boldsymbol{r_i'}$ of its end likewise describes a certain curve e_i'. This article proposes to transform the position of the finger of the operator's hand into the position of the finger of the virtual model of the operator's hand as follows. For the operator's hand and its virtual model, a polar coordinate system is introduced, the axis of which is directed along the position of the straightened finger (Fig. 4, Fig. 5). In these polar coordinate systems, the radius vectors $\boldsymbol{r_i}$ and $\boldsymbol{r_i'}$ have the coordinates $r_i(\varphi_i, \rho_i)$ and $r_i'(\varphi_i', \rho_i')$. The peculiarity of the curves e_i and e_i' is that the position of the points on these curves is uniquely determined by the angles φ_i and φ_i'. The paper proposes to transform the position of the operator's finger into the position of the finger of the virtual model so that the angle φ_i' is equal to the angle φ_i. For the human-like motion of the fingers of the virtual model, it is assumed that the bending angles θ_i' in each finger joint are equal to each other (Fig. 5).

The value of the angle φ_i in the case of using inertial sensors can be found by the formula:

$$\varphi_i = \text{atan2}(D_{ix}, D_{iy}), \qquad (1)$$

Where $\text{atan2}()$ – arctangent function taking into account the quadrant of the angle; D_{ix}, D_{iy} – Cartesian coordinates of the end of the finger of the operator D_i.

In the case of using bend sensors, the angle φ_i is a function of the sensor reading $\varphi_i(a)$, which can be approximated by some polynomial based on experimental studies.
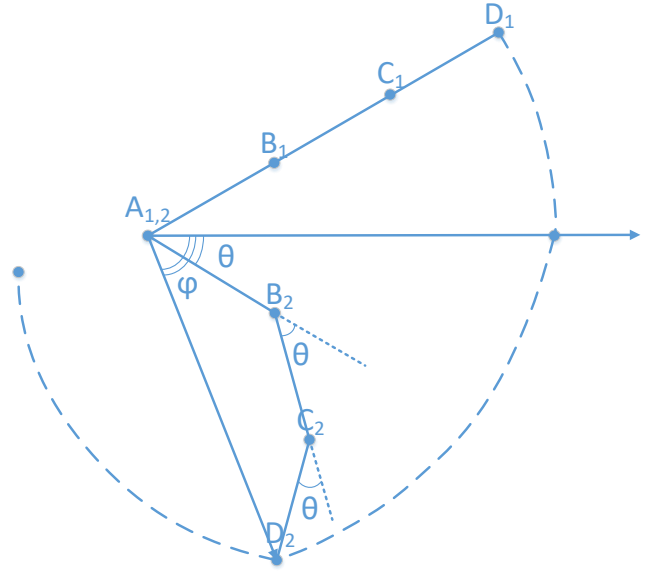

Fig. 5. Calculation of the bending angles θ_i' in the finger joints of a virtual model

The direct kinematics problem for the finger of a virtual model is solved as follows:

$$\tan\varphi_i' = \frac{l_{i1}'\sin\theta_i' + l_{i2}'\sin 2\theta_i' + l_{i3}'\sin 3\theta_i'}{l_{i1}'\cos\theta_i' + l_{i2}'\cos 2\theta_i' + l_{i3}'\cos 3\theta_i'}, \qquad (2)$$

Where l_{i1}', l_{i2}', l_{i3}' – the lengths of the proximal, middle and distal phalanges of the finger of the virtual model, respectively.

The desired bending angles θ_i'' in the finger joints of the virtual model can be found by numerically solving an equation with one unknown:

$$l_{i1}'\sin\theta_i' + l_{i2}'\sin 2\theta_i' + l_{i3}'\sin 3\theta_i' - \tan\varphi_i'\left(l_{i1}'\cos\theta_i' + l_{i2}'\cos 2\theta_i' + l_{i3}'\cos 3\theta_i'\right) = 0. \qquad (3)$$

IV. METHOD OF PLANNING A TRAJECTORY OF MOVEMENT OF JOINTS OF ANTHROPOMORPHIC MANIPULATOR

The kinematic diagram of the manipulator with 7 degrees of mobility is shown in Fig. 6.

The following designations are given in the current diagram: B_1, B_2, B_3, B_4 – humeral, ulnar, wrist nodes and working end; $A_1 - A_7$ – rotational degrees of mobility of the manipulator, A_8 – the center of the working end of the manipulator; l_{B1-B2}, l_{B2-B3}, l_{B3-B4} – the length of the links of the manipulator; $\boldsymbol{\theta} = \{\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6, \theta_7\}$ – are the angles of rotation of the links of the manipulator.

The solution of the inverse kinematics problem for planning the trajectory of the joints of the anthropomorphic manipulator with copy control using haptic gloves consists in the coalescence of the method of calculating the position of the operator's hands in virtual reality and searching for such a value of the attached coordinates $\alpha_A, \beta_A, \gamma_A, \alpha_B, \alpha_C, \beta_C, \gamma_C$, at where the manipulator effector will be at the target point D. The methods for finding

generalized coordinates (the inverse kinematics problem) for anthropomorphic manipulators are very diverse and deeply studied In this regard, a ready-made mathematical apparatus was used, the representation of Denavit-Hartenberg. When repeating this implementation, any other methods may be used.
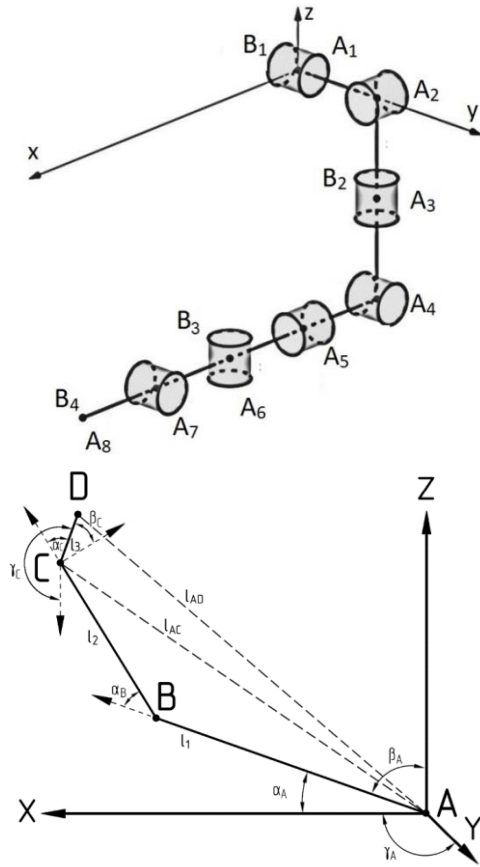

Fig. 6 – Kinematic diagram of an anthropomorphic robot manipulator with 7 degrees of mobility: a) - mmm; b) - ppp

The mathematical model of the problem of searching for generalized coordinates for manipulator engines has the form: $\overrightarrow{AD} = A_A^0 A_B^A A_C^B * \overrightarrow{CD}$, where matrices of the form A_I^J are transformation matrices obtained from the Denavit-Hartenberg representation (formulas 4-6), where $\alpha_A, \beta_A, \gamma_A, \alpha_B, \alpha_C, \beta_C, \gamma_C$ are the angles of rotation of the manipulator links for up to D.

V. SOFTWARE

To implement the presented method of planning the trajectory of motion of the joints of the anthropomorphic manipulator with copy control using haptic gloves, software was developed, a model was created in the Unity development platform, the calculations were performed in the C # package (Fig. 7). The software allows you to display in real time each recorded movement of the fingers and hands of the operator and calculate the angles of rotation of the operator's hands.
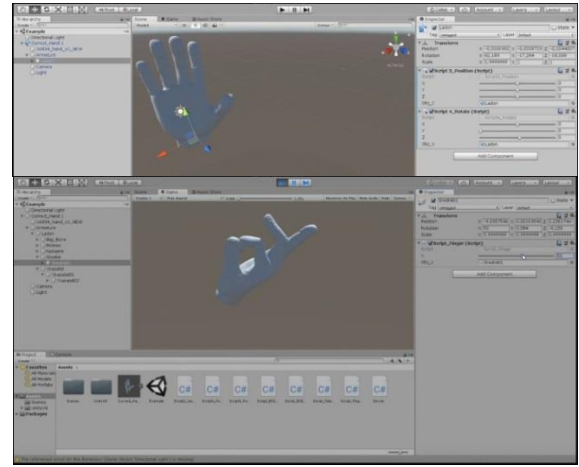

Fig. 7. Virtual model of the operator's hand

Fig. 8. Repetition of movements behind a virtual model of the operator's hand with the manipulator of the anthropomorphic robot AR-601

$$A_A^0 = \begin{bmatrix} \cos(\alpha_A)\cos(\gamma_A) - \sin(\alpha_A)\cos(\beta_A)\sin(\gamma_A) & -\cos(\alpha_A)\sin(\gamma_A) - \sin(\alpha_A)\cos(\beta_A)\cos(\gamma_A) & \sin(\alpha_A)\sin(\beta_A) & 0 \\ \sin(\alpha_A)\cos(\gamma_A) + \cos(\alpha_A)\cos(\beta_A)\sin(\gamma_A) & -\sin(\alpha_A)\sin(\gamma_A) + \cos(\alpha_A)\cos(\beta_A)\cos(\gamma_A) & -\cos(\alpha_A)\sin(\beta_A) & 0 \\ \sin(\beta_A)\sin(\gamma_A) & \sin(\beta_A)\cos(\gamma_A) & \cos(\beta_A) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$A_B^A = \begin{bmatrix} \cos(\gamma_B) & -\sin(\gamma_B) & 0 & l_{AB} \\ \sin(\gamma_B) & \cos(\gamma_B) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

$$A_C^B = \begin{bmatrix} \cos(\beta_C)\cos(\gamma_C) & -\cos(\beta_C)\sin(\gamma_C) & \sin(\beta_C) & 0 \\ -\sin(\alpha_C)\sin(\beta_C)\cos(\gamma_C) + \cos(\alpha_C)\sin(\gamma_C) & \sin(\alpha_C)\sin(\beta_C)\sin(\gamma_C) + \cos(\alpha_C)\cos(\gamma_C) & -\sin(\alpha_C)\cos(\beta_C) & 0 \\ -\cos(\alpha_C)\sin(\beta_C)\cos(\gamma_C) + \sin(\alpha_C)\sin(\gamma_C) & \cos(\alpha_C)\sin(\beta_C)\sin(\gamma_C) + \sin(\alpha_C)\cos(\gamma_C) & -\cos(\alpha_C)\cos(\beta_C) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

Using the Wi-Fi module, the haptic glove connects to the computer on which the software is installed. Absolute orientation sensors transmit measurements of tangential acceleration, rotational acceleration, and local magnetic field strength, and bend sensors transmit values from 0 to 1023, depending on the degree of bending.

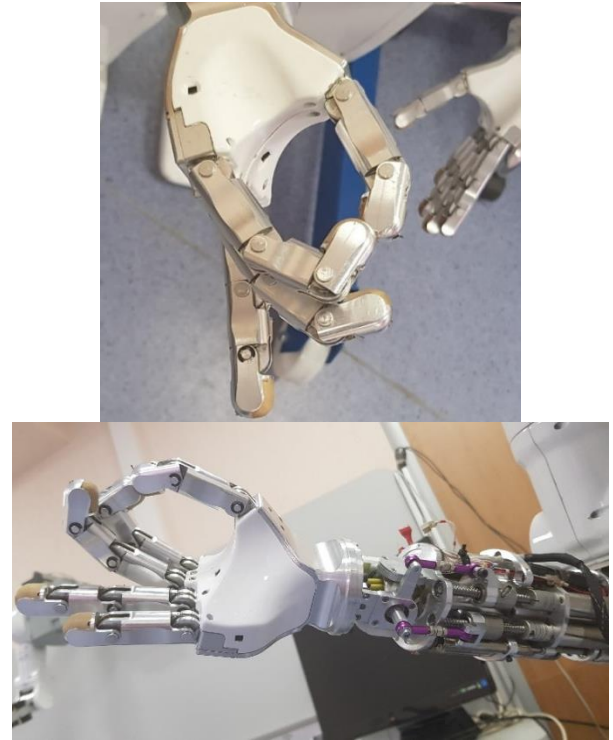Practical implementation was carried out on the manipulator of the anthropomorphic robot AR-601 from JSC NPO Android Technika. The test result is shown in Fig. 8. The figure shows the repetition of movements behind the virtual model of the operator's hand with the manipulator of the anthropomorphic robot AR-601.

VI. CONCLUSION

The article presents the development of a method for planning the trajectory of motion of the joints of an anthropomorphic manipulator in virtual reality with copy control from haptic gloves based on the method of calculating the position of the operator's hands. The article discusses the existing development of haptic gloves, analyzes the scientific publications on this topic, which showed a variety of technical solutions. According to this analysis, it was concluded that the input data for controlling the manipulator from the hapic glove are data from inertial sensors. A method of processing information from inertial sensors to calculate the position of the hands of the operator in virtual reality relative to the point of view of the operator is developed. Based on this method and the method for solving the inverse kinematics problem based on the Denavit-Hartenberg representation, a method for planning the trajectory of the joints of an anthropomorphic manipulator was developed.

Software was developed to test the workability of the method, a simulation model was created in the Unity cross-platform development environment. The calculations for the planning method are carried out in the C # package. The figures of operability and coincidence of the results of the rotation angles of the operator's hand are given.

In the future, the team is faced with the task of constructing a model of processing information from inertial sensors of the haptic glove and, on its basis, developing a system of copying motion control by a robot manipulator with feedback.

REFERENCES

[1] A. Talhan and H. Kim and S. Kumar and A. Raza and S. Jeon. Pneumatic Actuated Haptic Glove to Interact with the Virtual Human. 2019

[2] Anjos, Genival & Santos, Gabriel & Amado, Jose & Marques, João. Haptic glove development for passive control of a robotic arm, 2016

[3] Ma, Zhou & Ben-Tzvi, Pinhas. Design and Optimization of a Five-Finger Haptic Glove Mechanism. Journal of Mechanisms and Robotics. 2015

[4] Hosseini, Mohssen & Sengül, Ali & Pane, Yudha & Schutter, Joris & Bruyninckx, Herman. ExoTen-Glove: A Force-Feedback Haptic Glove Based on Twisted String Actuation System, 2018

[5] Z. Ma and P. Ben-Tzvi. RML Glove – An Exoskeleton Glove Mechanism with Haptics Feedback. IEEE/ASME Transactions on Mechatronics. 2014

[6] "Cybergrasp," http://www.cyberglovesystems.com

[7] X. Gu, Y. Zhang, W. Sun, Y. Bian, D. Zhou, and P. O. Kristensson, "Dexmo: An inexpensive and lightweight mechanical exoskeleton for motion capture and force feedback in vr," in Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, ser. CHI '16. New York, NY, USA: ACM, 2016, pp. 1991–1995. [Online].

[8] M. Bouzit and G. Burdea and G. Popescu and R. Boian. The Rutgers Master II-New Design force-feedback glove. Mechatronics, IEEE/ASME Transactions on. 7. 256 - 263. 2002

[9] I. Choi, E. W. Hawkes, D. L. Christensen, C. J. Ploch, and S. Follmer, "Wolverine: A wearable haptic interface for grasping in virtual reality," in Intelligent Robots and Systems (IROS), 2016 IEEE/RSJ International Conference on. IEEE, 2016, pp. 986–993.

[10] A. A. Bogdanov, A. F. Permyakov and I. M. Kutlubaev, "Basic Principles of an Exoskeleton Construction for an Anthropomorphic Manipulator Control," 2019 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), Vladivostok, Russia, 2019, pp. 1-4. doi: 10.1109/FarEastCon.2019.8934739

[11] E. Magrini, F. Ferraguti, A. J. Ronga, F. Pini, A. De Luca, F. Leali, Human-robot coexistence and interaction in open industrial cells, Robotics and Computer-Integrated Manufacturing, Volume 61, 2020,

[12] E. Magrini and A. De Luca, "Human-robot coexistence and contact handling with redundant robots," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, 2017. doi: 10.1109/IROS.2017.8206331.

[13] Petrenko V., Tebueva F., Antonov, V., Gurchinskiy, M., Pavlov, A., Sergey, R, Shutova,Y. Analysis of the Effectiveness Path Planning Methods and Algorithm for the Anthropomorphic Robot Manipulator// International Siberian Conference on Control and Communications, SIBCON 2019 - Proceedings (2019), IEEE. doi: 10.1109/SIBCON.2019.8729657

[14] Worn, H; Gonchar, LE; Yussupova, NI; Shakhmametova, GR. Collision avoidance path planning for multi-links manipulators in uncertain environment // 6th International Conference on Intelligent Autonomous Systems (IAS-6) VENICE, ITALY JUL 25-27 2000. P. 1025-1030, 2000.

[15] Kovács, G., Yussupova, N., Rizvanov, D. Resource management simulation using multi-agent approach and semantic constraints // Pollack Periodica Vol. 12, Issue 1, 2017, P. 45-58.

[16] Petrenko, V., Tebueva, F., Gyrchinsky, M., Antonov, V., Shutova, J. The method of forming a geometric solution of the inverse kinematics problem for chains with kinematic pairs of rotational type only // IX International Multidisciplinary Scientific and Research Conference Modern Issues in Science and Technology / Workshop Advanced Technologies in Aerospace, Mechanical and Automation Engineering. IOP Conference Series: Materials Science and Engineering (2018). doi: 10.1088/1757-899X/450/4/042016

[17] Vyacheslav Petrenko, Fariza Tebueva, Vladimir Antonov, Nikolay Untewsky, Mikhail Gurchinsky. Energy-Efficient Path Planning: Designed Software Implementation // Proceedings of the 7th Scientific Conference on Information Technologies for Intelligent Decision Making Support (ITIDS 2019). Series:Advances in Intelligent Systems Research. doi: https://doi.org/10.2991/itids-19.2019.30

[18] Vyacheslav Petrenko, Fariza Tebueva, Mikhail Gurchinsky, Sergey Ryabtsev, Nikolay Svistunov. The Study of the Problems of the Master-Slave Teleoperation Control Anthropomorphic Manipulator // Proceedings of the 7th Scientific Conference on Information Technologies for Intelligent Decision Making Support (ITIDS 2019). Series:Advances in Intelligent Systems Research. doi: https://doi.org/10.2991/itids-19.2019.29

[19] Vyacheslav Petrenko, Fariza Tebueva, Mikhail Gurchinsky, Sergey Ryabtsev, Olga Trofimuk. Exoskeleton for Operator's Motion Capture With Master-Slave Control // Proceedings of the 7th Scientific Conference on Information Technologies for Intelligent Decision Making Support (ITIDS 2019). Series:Advances in Intelligent Systems Research. doi: https://doi.org/10.2991/itids-19.2019.28