АҚПАРАТТЫҚ ЖҮЙЕЛЕР
ИНФОРМАЦИОННЫЕ СИСТЕМЫ
INFORMATION SYSTEMS

DOI 10.51885/1561-4212_2024_2_134
IRSTI 28.23.27

I. Karymsakova[1], **N. Denissova**[2], **A. Kaliyeva**[1], **D. Kozhakhmetova**[1], **R. Bekbayeva**[1]
[1]Shakarim University, Semey, Kazakhstan
*E-mail: karymsakova.indira@mail.ru**
E-mail: aliyabekenqyzy@gmail.com
E-mail: dinarakozhakhmetova@mail.ru
E-mail: 31-roza@mail.ru
[2]D. Serikbayev East Kazakhstan technical university, Ust-Kamenogorsk, Kazakhstan
E-mail: ndenisova@ektu.kz

DEVELOPMENT OF AN INFORMATION SYSTEM FOR MODELING TRAJECTORIES FOR SPRAYING IMPLANTS

ИМПЛАНТТАРДЫ БҮРКУ ҮШІН ТРАЕКТОРИЯЛАРДЫ МОДЕЛЬДЕУДІҢ АҚПАРАТТЫҚ ЖҮЙЕСІН ӘЗІРЛЕУ

РАЗРАБОТКА ИНФОРМАЦИОННОЙ СИСТЕМЫ МОДЕЛИРОВАНИЯ ТРАЕКТОРИЙ ДЛЯ НАПЫЛЕНИЯ ИМПЛАНТОВ

Abstract. *The article aims to create an information system for modeling trajectories for subsequent microplasma spraying using a robotic complex. The research results proposed in the article are focused on the practical use of methods for further construction of robot movement. The proposed approach using Hermite splines of the third and fourth orders makes it possible to construct motion trajectories taking into account speed. Various trajectories of movement construction were considered. An algorithm for constructing a spline was shown. Trajectories for splines of the third and fourth orders were constructed in the Matlab environment. To construct the trajectories of the robot's movement, a fourth-order Hermite spline was chosen, which satisfies the condition of passing along the selected trajectory with certain speeds and has minimal offsets.*

Keywords: *Hermite spline, program trajectories, smoothness of functions, interpolation, construction of trajectories*

Аңдатпа. *Мақалада роботты кешеннің көмегімен кейінгі микроплазмалық бүрку үшін траекторияларды модельдеудің ақпараттық жүйесін құру мақсаты қойылған. Мақалада ұсынылған зерттеу нәтижелері Робот қозғалысын одан әрі құру әдістерін практикалық қолдануға бағытталған. Үшінші және төртінші ретті эрмит сплайндарын қолдану арқылы ұсынылған тәсіл жылдамдықты ескере отырып қозғалыс траекториясын құруға мүмкіндік береді. Қозғалыс құрылысының әртүрлі траекториялары қарастырылды. Сплайн құру алгоритмі көрсетілді. Матлаб ортасында үшінші және төртінші ретті сплайндарға арналған траекториялар салынды. Роботтың қозғалыс траекториясын құру үшін Төртінші ретті эрмит сплайн таңдалды, ол таңдалған траектория бойынша белгілі бір жылдамдықпен жүру шартын қанағаттандырады және минималды ауытқуларға ие.*

Түйін сөздер: *эрмит сплайн, бағдарламалық траектория, функцияның тегістігі, интерполяция, траектория құру.*

Аннотация. *В статье поставлена цель создания информационной системы моделирования траекторий для последущего микроплазменного напыления при помощи роботизированного комплекса. Результаты исследований, предлагаемые в статье, ориентированы на практическое использование методов для дальнейшего построения движения робота. Предлагаемый подход с использованием сплайнов Эрмита третьего и четвертого порядков позволяет построить траектории движения с учетом скорости. Были рассмотрены различные траектории построения движений. Был показан алгоритм построения сплайна. В среде Матлаб были построены траектории для сплайнов третьего и четвертого порядков. Для построения* *траекторий движения робота был выбран сплайн Эрмита четвертого порядка, который удовлетворяет условию прохождения по выбранной траектории с определенными скоростями и имеет минимальные отколнения.*

Ключевые слова: *сплайн Эрмита, программные траектории, гладкость функций, интерполирование, построение траекторий*

Introduction. The use of robots for microplasma spraying of titanium implants is one of the most important tasks. To date, it has not been possible to create a manipulator that will fully perform the functions of human limbs.

The production of endoprostheses is one of the most difficult tasks. These endoprostheses must be fully compatible with human organs. Robotic systems are used to obtain high-precision endoprostheses.

For spraying using a robotic complex, limb endoprostheses will be used: hip endoprosthesis, lower leg endoprosthesis, knee endoprosthesis, spinal implant, shoulder endoprosthesis, joint endoprosthesis.

Literature review.

Endoprostheses are products that are used to replace damaged human organs.

The existing classifications of endoprostheses have been analyzed.

In the work of Imanbayeva M.B., Zubi Yu.Kh., Izbaskanova A.S. Endoprostheses are classified according to the friction pair of the constituent elements.

In the work of Dzhaksybaev M.N., Zhumagulov M.O. endoprostheses are classified according to the design of the constituent elements.

In the work of Williams D., Roof R., endoprostheses are classified by composition and design, by the duration of functioning, by the degree of immersion in the body.

In the work of Kirpichev I.V., Aliev A.G., Kovalenko A.N., Ambrosenkov A.V. endoprostheses are classified according to the number of components.

In the work of Mironov R.A., Osmanov A.M., Ustazov K.A., Aslamkhanov S.R. endoprostheses are classified depending on the design principle.

In the work of Chirkov N.N., Nikolaev N.S., Gorbatov R.O., Klemenova I.A., Novikov A.V., Zinoviev S.V., Kazakov A.A. endoprostheses are classified according to the method of fixation, according to the design.

In the work of S. N. Nekhlopochin, A. S. Nekhlopochin, and A. I. Shvets, endoprostheses are classified according to the design of the elements.

In the work of Adamova A.A., Shvedova A.G., Chudovsky I.V. endoprostheses are classified according to their various characteristics: scope, method of suturing to organic tissues [1-3].

Materials and research methods. To develop an information system for modeling trajectories for subsequent microplasma spraying using a robotic complex, it is necessary to perform several stages: stage 1 - classification of spray objects, stage 2 - analysis of methods for mathematical modeling of the robot's trajectory, stage 3 - development of a mathematical model, stage 4 - development of architecture IS, stage 5 - development of algorithms and program code for a robot movement simulator.

Let's look at each of these steps:

Stage 1- Classification.

For the selection of endoprostheses for the possibility of spraying with the help of robots, implants must be classified. To do this, we first analyzed various classifications of endoprostheses (Table 1).

Classification is an optimization task in which it is necessary to attribute elements to different classes according to some characteristics.

Table 1. Different classifications of endoprostheses

№	Classification
1	By friction pair
2	By design
3	By composition and structure, by the time of functioning, by the degree of introduction into the body
4	By the number of components, depending on the design principle
5	By the method of fixation, by design
6	According to other characteristics: areas of use, methods of implantation to human tissues

To optimize the spraying trajectory, it is more expedient to use the parametric method for classifying endoprostheses (Table 2)

Table 2. Parametric classification method

Class	Parameter values by class (mm)										
	Length	Diameter	Width	Arc length	Clamp length	Clamp diameter	Rectangle length	Height	Proximal stem length	Distal stem length	Stem diameter
1	150-400	15-35	30-50	50-70	160-200	10-20	15-20	15-20	15-20	15-20	15-20
2	15-150	5-15	5-30	10-50	10-160	5-10	10-15	10-15	10-15	10-15	10-15
3	0-15	0-5	0-5	0-10	0-10	0-5	0-10	0-10	0-10	0-10	0-10

1st class: endoprostheses that optimally match the limiting parameters of spraying;
2nd class: endoprostheses that meet the limiting parameters of spraying;
3rd class: endoprostheses that do not meet the limiting spraying parameters.
The classification is shown in Figure 1.

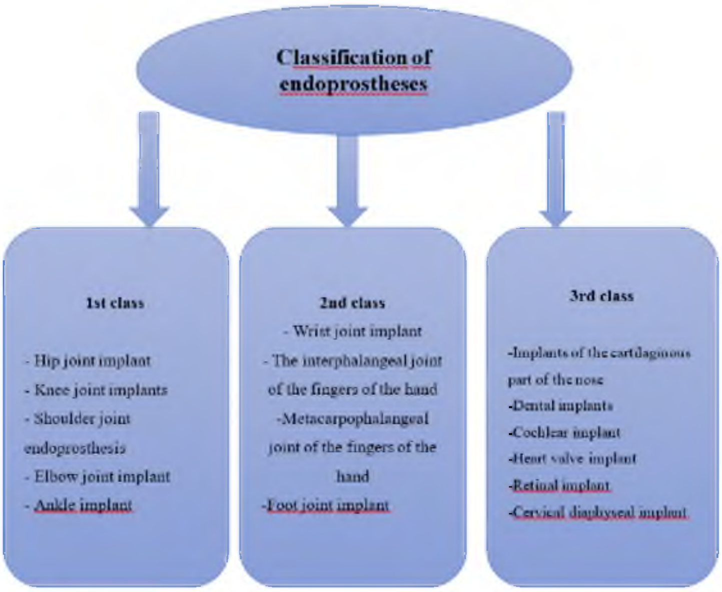

Figure 1. Classification of implants

Stage 2 – analysis of methods for mathematical modeling of the trajectory of the robot. To build a mathematical model of the robot's motion during spraying, it is necessary to choose a method for constructing the motion trajectory. For this, the existing methods were considered (Table 3).

Table 3. Methods for constructing the trajectory of movement

№	The method of constructing the trajectory of movement	Advantages	Disadvantages
1	Interpolation using polynomials	Flexible movement of the robot arm grip	The condition of continuity of the second order derivative is not fulfilled
2	The method of connected graphs	The transformation of the coordinates of the grip	The condition of continuity of the second order derivative is not fulfilled
3	Interpolation by third and fourth order polynomials	Flexible movement of the robot arm grip	
4	Interpolation using the Lagrange-Euler model	Flexible movement of the robot arm grip	The condition of continuity of the second order derivative is not fulfilled
5	Multigraph concept motion problems	Deterministic discretization of the space of angles	Irregular structure of neighboring elements of the multigraph
6	Methods of integral manifolds	Motion along an optimal trajectory	
7	Trajectory graph generation method	Flexible movement of the robot arm grip	The condition of continuity of the second order derivative is not fulfilled

The obtained analysis showed that for the formation of the trajectory of movement of manipulative robots, the conditions for the smoothness of the function and the continuity of the second derivative are important. For our classes of endoprostheses, the spline method will be used to construct the trajectory.

To simulate the trajectory of movement, it is necessary to first create a 3D model of the implant. The existing methods for creating 3D models are shown in Figure 2[4-9].

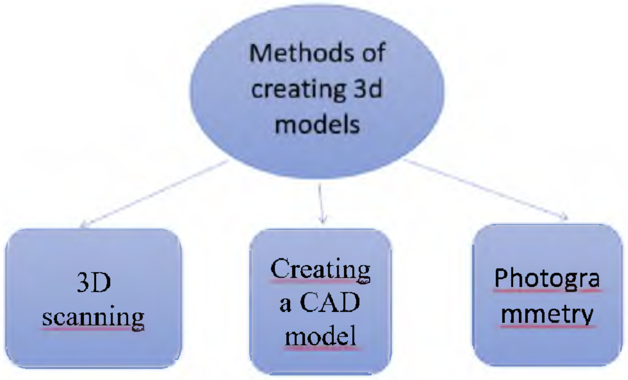

Figure 2. Methods for creating 3D models

Stage 3 – Mathematical modeling of the spraying trajectory.

Splines are used to interpolate mechanical motions

$$q_i(t)=\sum_{l=0}^{3} a_i^{(l)}(t_{i+1}-t)^l \qquad (1)$$

where t is the given time intervals (nodes), qi(t) is a polynomial.

Splines satisfying conditions (2) are called Hermitian

$$q_i(t_i)=\theta_i;\ q_i(t_{i+1})=\theta_{i+1};$$

$$\dot{q}_i(t_i)=v_i;\dot{q}_i(t_{i+1})=v_{i+1}, i=\overline{1,n-1} \qquad (2)$$

where qi(t) is a polynomial, $\theta(t_i)=\theta_i$ are generalized coordinates, $v_i=v(t_i)$ is the speed of passage [10, 11].

The process of spraying endoprostheses by a robot can be defined as follows (Fig. 3)

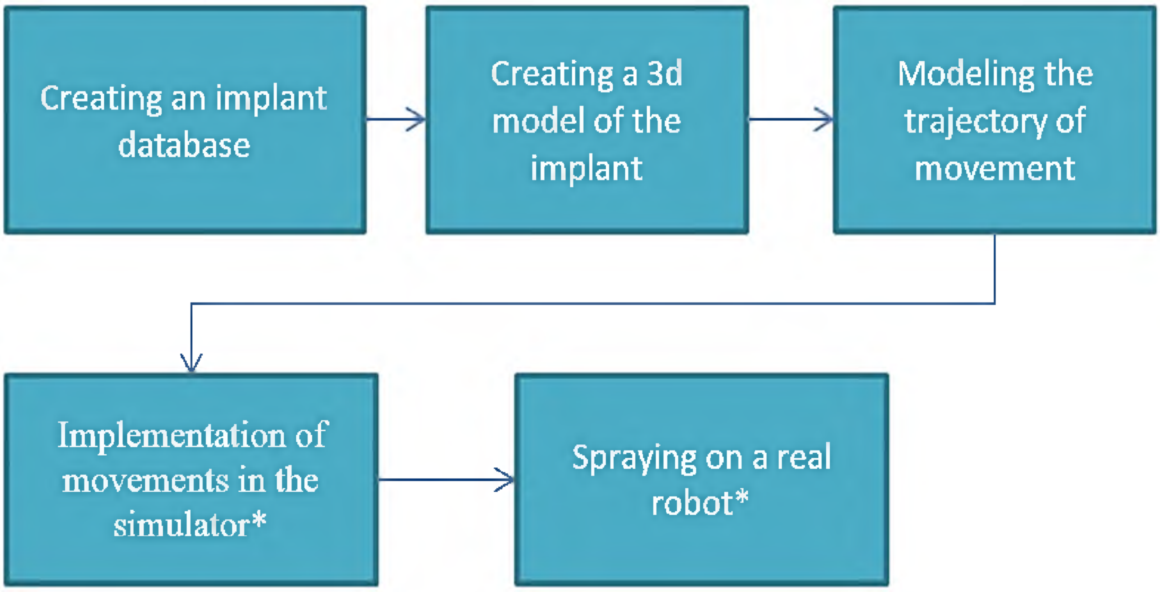

Figure 3. Spray process

*-Robot spraying parameters

Spray spot diameter d=2.5 mm

Robot passing speed v=10 mm/s

Distance to spraying object S=150 mm

Robot travel time t=15 s

Spray process

The endoprosthesis is installed on the arm of the robot and will be sequentially moved by the robot along the trajectory (Fig. 4).

We build a mathematical model of the robot's motion using Hermite polynomials of the third and fourth orders [12-15, 16-21].

Results and its discussion. According to the given models of the third and fourth orders, the trajectories of movement were modeled and the deviations for each model were determined (Table 4).

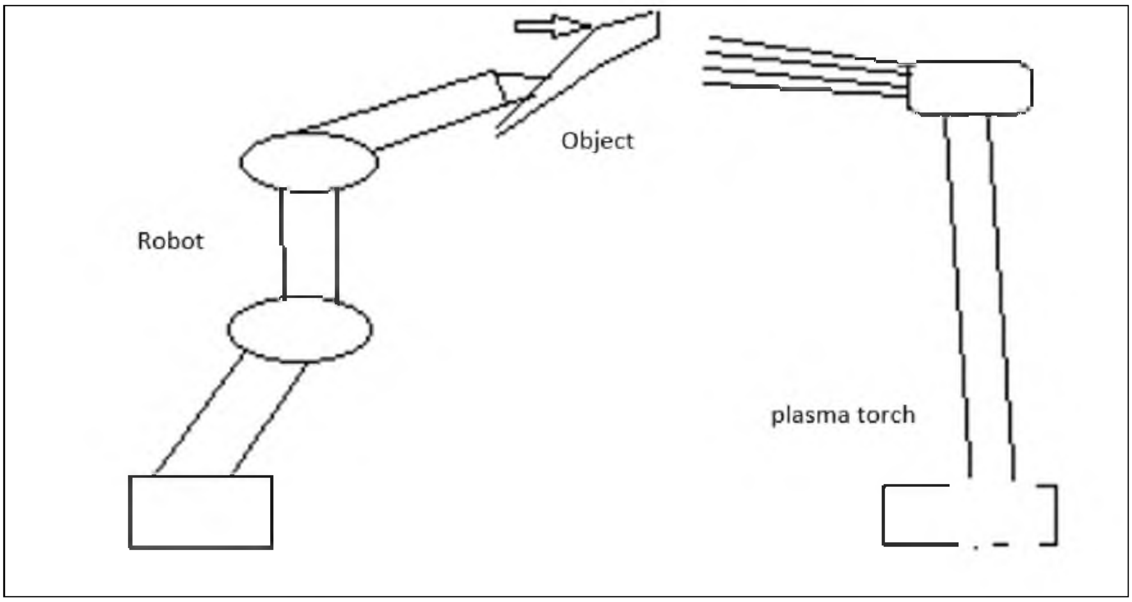

Figure 4. Scheme of spraying the implant

Table 4. Analysis of modeling errors

Class	Modeling of the spraying trajectory			
	Type	Error of 3 orders	Error of 4 orders	Output
1	Hip replacement	0,05	0,04	The approximation error when using the Hermite interpolant is 4-orders of magnitude less
	Lower leg endoprosthesis	0,047	0,038	The approximation error when using the Hermite interpolant is 4-orders of magnitude less
	Shoulder joint endoprosthesis	0,044	0,038	The approximation error when using the Hermite interpolant is 4-orders of magnitude less
2	Vertebral endoprosthesis	0,046	0,039	The approximation error when using the Hermite interpolant is 4-orders of magnitude less
	Cervical endoprosthesis	0,045	0,036	The approximation error when using the Hermite interpolant is 4-orders of magnitude less
	Finger joint replacement	0,047	0,039	The approximation error when using the Hermite interpolant is 4-orders of magnitude less

Stage 4

After building a mathematical model, it is necessary to develop an infological model, an IS architecture.

The proposed infological model of IS is shown in Figure 5:

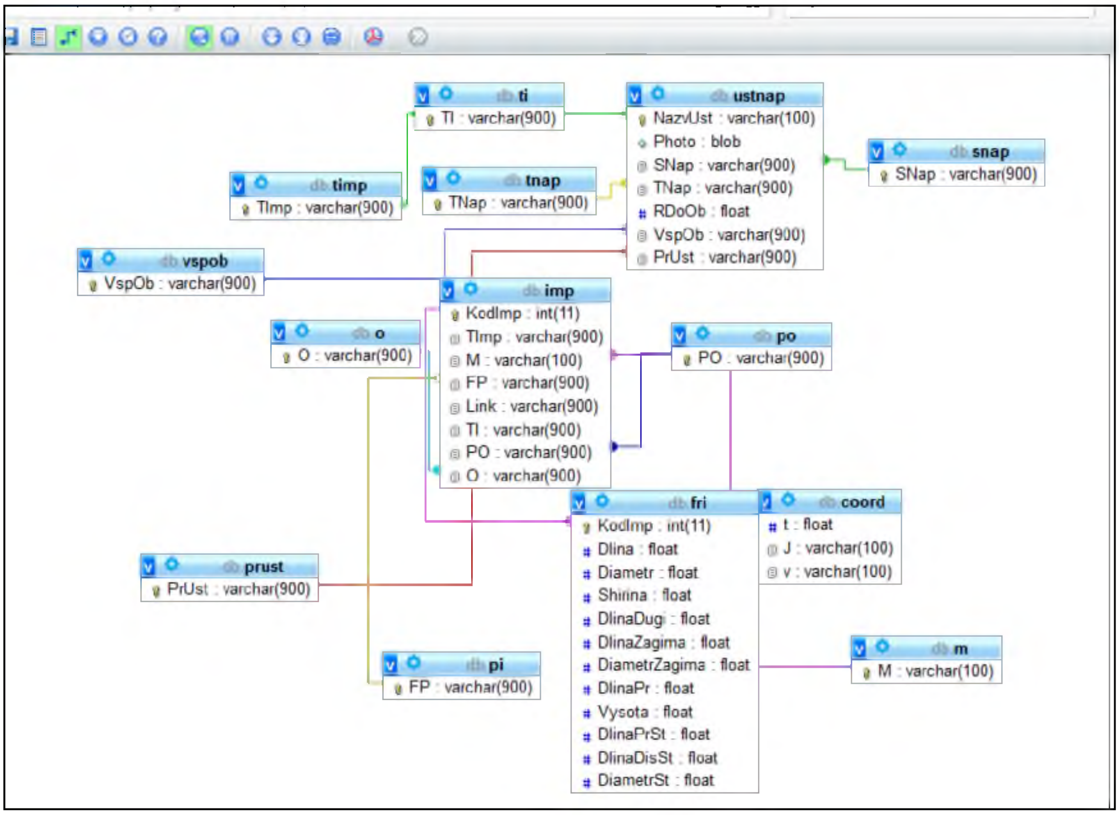

Figure 5. Infological model

The proposed IS structure is shown in Figure 6.

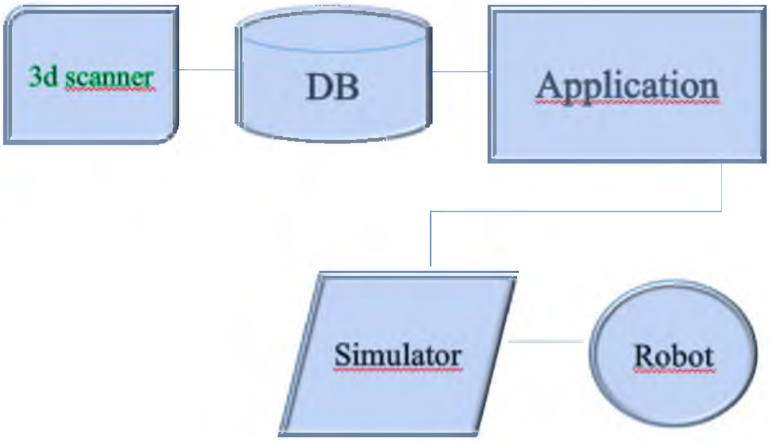

Figure 6. IS structure

Stage 5 – The algorithm for creating a program for a simulator of the movement of a robot for spraying endoprostheses by points is shown in Figure 7:

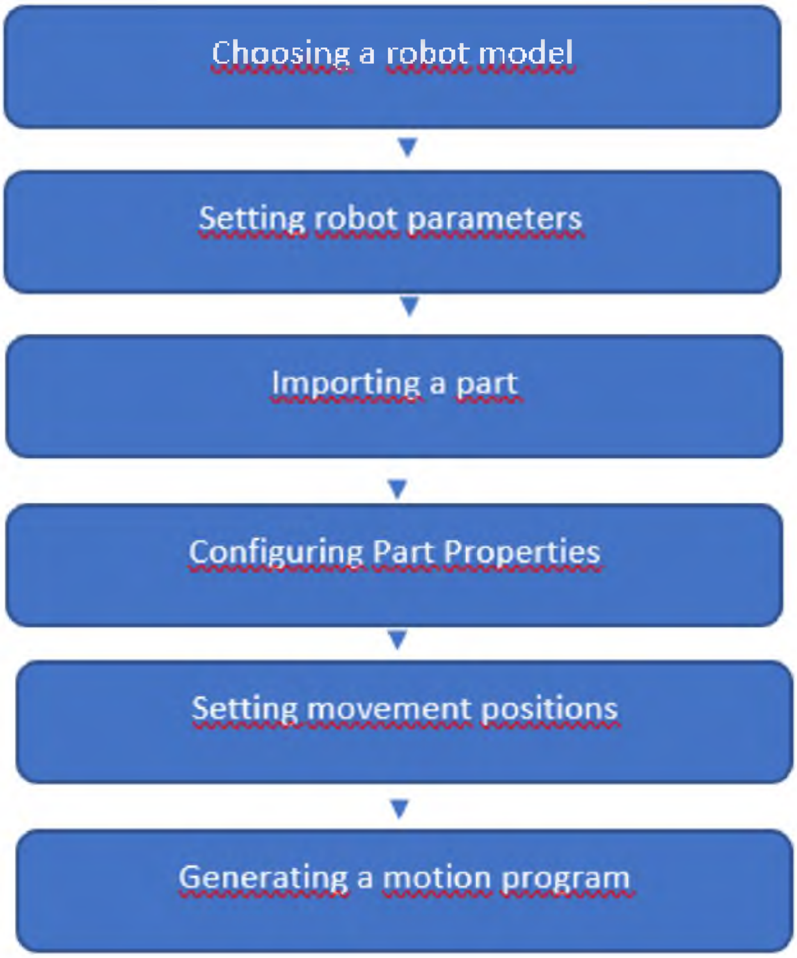

Figure 7. Algorithm for creating a simulation program

According to this algorithm, a robot motion trajectory was constructed for spraying the surface of endoprostheses of six types of selected endoprostheses from the first two classes of endoprostheses.

Conclusion. In this article, a review of the classifications of endoprostheses was carried out, the movement of the robot was modeled according to Hermite models of the third and fourth orders. An algorithm for creating the trajectory of the robot was proposed. A prototype of an information system for modeling trajectories according to a given model was proposed.

Список литературы

1. Иманбаева М.Б., Зуби Ю.Х., Избасканова А.С. Тотальное эндопротезирование тазобедренного сустава с керамика-керамической парой трения в отдаленном периоде наблюдения от 5 до 10 лет. Вестник КазНМУ, №2-2015
2. Джаксыбаев М.Н., Жумагулов М.О. Оперативное лечение тазобедренных и коленных суставов у пациентов страдающих сахарным диабетом, Вестник КазНМУ, № 3-1-2016.

3. Кирпичев И.В. Структура коксартроза в различных возрастных группах у больных, нуждающихся в первичном эндопротезировании тазобедренного сустава. Журнал Современные проблемы науки и образования, Москва, № 3-2015.
4. Завьялов У.С., Квасов Б.И., Мирошниченко В.Л. Методы сплайн-функций. – М., Наука, 1980.
5. Кириченко Н.Ф., Сорока Р.А., Крак Ю.В. «Манипуляционные роботы. Алгоритмическое и программное обеспечение средств управления движением», учебное пособие, Киев КГУ, 1987
6. Интерполяция. 20.08.2020. URL: https://refdb.ru/look/1629442-pall.html
7. Золотых Н.Ю. Matlab в научных исследованиях. Нижегородск, 2004
8. Методы интерполяции в Матлаб. 15.05.2020. URL: http://geum.ru/next/art-295114.php
9. Karymsakova I.B., KrakYu.V., Denissova N.F. Criteria for implants classification for coating implants using plasma spraying by robotic complex // Eurasian Journal of Mathematical and Computer Applications. – 2017. – Volume 5, Issue 3. – P.44-52.
10. Karymsakova I.B, Denissova N.F, Kumargazhanova S.K, Krak Iu. V. Robotic plasma spraying system for implants of complex structure: methods and solutions, International Journal of Computing, 19(2) 2020, 1-2
11. Карымсакова И.Б., Денисова Н.Ф., Крак Ю.В. Усовершенствование методов построения систем создания имплантов с использованием современных производственных решений // Международная научная конференция «Интеллектуальные системы принятия решений и проблемы вычислительного интеллекта (ISDMCI'2017)». 22–26 мая 2017. Материалы международной научной конференции. – Зализный порт. Украина. Херсон: Издательство ПП Вишемирськиий В.С., 2017. – С. 69-70.
12. Karymsakova I.B., KrakYu.V., Denissova N.F. Criteria for implants classification for coating implants using plasma spraying by robotic complex // Eurasian Journal of Mathematical and Computer Applications. – 2017. – Volume 5, Issue 3. – P.44-52.
13. Решение математических задач в системе компьютерной математики в пакете Matlab. 04.11.2022. . URL: https://sites.google.com/site/vpaketematlab/3-realizacia-cislennyh-metodov/03-3-realizacia-splajnov-v-matlab
14. Сплайны. 04.11.2022. . URL:https://ozlib.com/823878/informatika/splayny
15. Эрмитовая многоинтервальная интерполяция MatLab. 04.11.2022. URL: https://radiomaster.ru/cad/matlab/glava17/index36.php
16. Zhu S.L., et al., Effect of porous NiTi alloy on bone formation: A comparative investigation with bulk NiTi alloy for 15 weeks in vivo. Materials Science & Engineering C, 2008. 28(8): p. 1271-1275.
17. Lee B.H., et al., Effect of surface structure on biomechanical properties and ossteointegration. Materials Science & Engineering C, 2008. 28(8): p. 1448-1461
18. Borisov Yu., Kislitsa A., Voynarovich S. "Microplasma wire spraying"// Proceedings of the Int. Thermal Spray Conference and Exposition ITSC 2004 "Thermal Spray Solutions Advances in Technology and Application" Osaka Japan – 2004. – p. 657 – 661.
19. Alontseva D., Borisov Yu., Voinarovych S., Kyslytsia O. Development of technology of microplasma spraying for the application of biocompatible coatings in the manufacture of medical implants Przegląd Elektrotechniczny 7 (2018) p. 94–97
20. Alontseva D. Introduion to Coating Design and Processing. ASM Handbook, Volume 5A, Thermal Spray Technology. R.C. Tucker, Jr., editor, 2013
21. Alontseva D., Krasavin A., Kolesnikova T., Russakova A. Modeling of Processes Taking Place during Powder Coating Treatment by an Electron Beam or a Plasma Jet// Acta Physica Polonica A Vol. 125, No. 6, 2014. – P. 1275-1279.

References

1. Imanbayeva M.B., Zubi U.H., Izbaskanova A.S. Totalnoe endoprotezirovanie tazobedrennogo sustava s keramika-keramicheskoi paroi trenia v otdalennom periode nablydenya ot 5 do 10 let. Vestnik KazNMU, № 2-2015.

2. Dzhaksybayev M.N., Zhumagulov M.O. Opereativnot=e lechenie tazobedrennyh I kolennyh sustavov u pacientov stradayuchih saharnym diabetom, Vestnik KazNMU, № 3-2016.
3. Kirpichov I.V. Structura koksartroza v razlichnyh vozrastnyh gruppah u bolnyh, nuzhdayuchihsya v pervichnom endoprotezirovanii tazobedrennogo sustava. Zhurnal Sovremennye problem nauki I obrazovanya, Moskva, № 3-2015.
4. Zav'yalov U.S., Kvasov B.I., Miroshnichenko V.L. Metody splajn- funkcij. – M., Nauka, 1980.
5. Kirichenko N.F., Soroka R.A., Krak YU.V. «Manipulyacionnye roboty. Algoritmicheskoe i programmnoe obespechenie sredstv upravleniya dvizheniem», uchebnoe posobie, Kiev KGU, 1987
6. Interpolyaciya. 20.08.2020. URL: https://refdb.ru/look/1629442-pall.html
7. Zolotyh N.YU. Matlab v nauchnyh issledovaniyah. Nizhegorodsk, 2004
8. Metody interpolyacii v Matlab. 15.05.2020. URL: http://geum.ru/next/art-295114.php
9. Karymsakova I.B., KrakYu.V., Denissova N.F. Criteria for implants classification for coating implants using plasma spraying by robotic complex // Eurasian Journal of Mathematical and Computer Applications. – 2017. – Volume 5, Issue 3. – P. 44-52.
10. Karymsakova I.B, Denissova N.F, Kumargazhanova S.K, Krak Iu. V. Robotic plasma spraying system for implants of complex structure: methods and solutions, International Journal of Computing, 19(2) 2020, 1-2
11. Karymsakova I.B., Denisova N.F., Krak YU.V. Usovershenstvovanie metodov postroeniya sistem sozdaniya implantov s ispol'zovaniem sovremennyh proizvodstvennyh reshenij // Mezhdunarodnaya nauchnaya konferenciya «Intellektual'nye sistemy prinyatiya reshenij i problemy vychislitel'nogo intellekta (ISDMCI'2017)». 22–26 maya 2017. Materialy mezhdunarodnoj nauchnoj konferencii. – Zaliznyj port. Ukraina. Herson: Izdatel'stvo PPVishemirs'kij V.S., 2017. – S. 69-70.
12. Karymsakova I.B., KrakYu.V., Denissova N.F. Criteria for implants classification for coating implants using plasma spraying by robotic complex // Eurasian Journal of Mathematical and Computer Applications. – 2017. – Volume 5, Issue 3. – P. 44-52.
13. Reshenie matematicheskih zadach v sisteme komp'yuternoj matematiki v pakete Matlab. 04.11.2022. URL: https://sites.google.com/site/vpaketematlab/3-realizacia-cislennyh-metodov/03-3-realizacia-splajnov-v-matlab
14. Splajny. 04.11.2022. URL:https://ozlib.com/823878/informatika/splayny
15. Ermitovaya mnogointerval'naya interpolyaciya MatLab. 04.11.2022. URL: https://radiomaster.ru/cad/matlab/glava17/index36.php
16. Zhu S.L., et al., Effect of porous NiTi alloy on bone formation: A comparative investigation with bulk NiTi alloy for 15 weeks in vivo. Materials Science & Engineering C, 2008. 28(8): – P. 1271-1275.
17. Lee B.H., et al., Effect of surface structure on biomechanical properties and ossteointegration. Materials Science & Engineering C, 2008. 28(8): P. 1448-1461.
18. Borisov Yu., Kislitsa A., Voynarovich S. “Microplasma wire spraying”// Proceedings of the Int. Thermal Spray Conference and Exposition ITSC 2004 “Thermal Spray Solutions Advances in Technology and Application” Osaka Japan – 2004. – P. 657-661.
19. Alontseva D., Borisov Yu., Voinarovych S., Kyslytsia O. Development of technology of microplasma spraying for the application of biocompatible coatings in the manufacture of medical implants Przegląd Elektrotechniczny 7 (2018). – P. 94–97.
20. Alontseva D. Introduion to Coating Design and Processing. ASM Handbook, Volume 5A, Thermal Spray Technology. R.C. Tucker, Jr., editor, 2013
21. Alontseva D., Krasavin A., Kolesnikova T., Russakova A. Modeling of Processes Taking Place during Powder Coating Treatment by an Electron Beam or a Plasma Jet // Acta Physica Polonica A Vol. 125, No. 6, 2014. – P. 1275-1279.