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ROBOTIC PLASMA SPRAYING SYSTEM FOR IMPLANTS OF COMPLEX STRUCTURE: 3D MODEL AND MOTION PLANNING

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Abstract: The problem of a robotic system creating for plasma spraying of biocompatible coatings on complex shaped implants based on a Fanuc LR Mate 200 id manipulation robot and modeling spraying trajectories using a virtual simulator Roboguide V6.40 is considered. Parametric classification of implants is carried out whenever possible by plasma spraying using robotic devices. The main procedures for implants preparation for spraying were investigated. The 3D UNIVERSE scanner is used for scanning the implant and building its spatial model, the 3D model of the implant is being developed in Geomagic Design X. To build the manipulator program movements taking into account the speed of movement, it is proposed to use fourth order splines, which is built in the Matlab tools with finding of the optimal close spline to the original values. As the example of Cox femoral joint implant, a simulation of robot motion is performed using a virtual simulator Roboguide V6.40 with the possibility of transferring the program to a real Fanuc LR Mate 200 id robot.

1. INTRODUCTION

For production of implants methods of a gas-thermal spraying for drawing porous and active coverings from powders of metals and ceramics [1-3] on orthopedic and dental implants are used [2-4]. It is shown that implants with biocompatible covering [5, 6] have the porous structure formed by particles of titanium powder (Ti) with a surface that has the hardest contact with again formed bone cages. In comparison with a traditional wire spraying this method allows reducing losses of the evaporated material when drawing coverings on small-sized products thanks to small (1 … 5 mm) spraying spot size [2, 6]. In recent years the method and the equipment of a microplasma spraying (MPN) of a biomedical Ti-covering with the use of wire was developed. For spraying Ti-coverings, microplasma spraying MPN-004 created at Paton Institute of Electrical Welding of Ukraine was installed and adapted for spraying coverings from pro-reducing dies or powders [7, 8]. The microplasma spraying is a type of a gas-thermal spraying where the electric arc lights up between the cathode and the anode with the environment of argon which is used as plasma-forming and protective gas. Particles of powder or a wire come to a plasma stream move, heat up and get on a surface, creating a covering. Spraying process is carried out with an atmospheric pressure and demands observance of the set distance to the processed surface, the fixed speed of movement along a surface and perpendicularity of a stream to a surface, therefore the plasmatron is fixed on the robot or the detail moves in taking of the robot on the set trajectory with observance above the listed conditions [9]. The microplasma spraying differs in a laminar stream and a small spot of spraying, with a low power up to 4 KW that gives advantages when processing small details and receiving satisfactory plasma spraying on porous coverings [9]. Robotic equipment is widely applied to a spraying of the implants using different plasma spraying [10-12].

Use of 3D printers for these purposes is the perspective way of the Ti implants creation. Advantages of the given approach to receiving implants include the possibility of creating an implant for individual patient and the fact that the titanium implant allows providing the correct load dispatch on all volume of an implant [13]. 3D technologies allow printing implants on a 3D-printer to the special biconvex form helping construction to be closer to an adjacent bone [14, 15].

Let us note also that computer modeling methods for the implementation of implants and robotics at the research projects have a lot of influence on scientific investigation and learning [16-18].

2. A PROBLEM STATEMENT

The main technical characteristics of the developed technologies, difference of their consumer properties from the existing analogs are as follows:

– use of technology of microplasma spraying allows creating one in a uniform fabrication cycle - and the multilayer strengthened surface layers on surfaces of details of any (even very difficult) forms which provide durability and hardness, by 2-3 times increase wear resistance, protect a surface from corrosion and give it properties of biocompatibility;

– use of methods of mathematical computer simulation of robots and environment [17, 18] allows creating medical implants with the predicted properties and structure;

– use of new control algorithms, CNC machines, and the industrial robot will allow us to carry out implants processing with a high quality, efficient performance and to organize wasteless production.

The purpose of this investigation is modeling of trajectories for developing robotic systems of plasma spraying on implants of the complex geometrical-topological structure.

The object of the research is implants which are used for complete or partial replacement of the injured human organs. The problem of an implant survival at the modern level of development is solved by means of covering implants with biocompatible material.

The solution to the following problems is planned in this article:

1. Using the parametrical method, to develop the system of classification of implants and to produce materials, to classify implants by the geometrical-topological sizes of components and to select implants in compliance with necessary conditions for the subsequent plasma spraying.

2. To select an implant for implementation of process of spraying. By means of the 3D SCAN 3D UNIVERSE scanner and the Geomagic Design X program to develop a 3D model of the selected implant.

3. To select the main process steps of implant spraying by means of robotic installations.

4. To select an optimum spline for creation of an interpolation polynomial with the set coordinates and speeds. Raise an order of the used spline and simulate a solution to this task in the environment of Matlab.

5. On the example of the selected implant to construct simulation of the robot motion by means of the virtual Roboguide V6.40 simulator.

The main advantage of the proposed approach is the possibility of its implementation on real technical equipment that was created at D. Serikbayev East Kazakhstan State Technical University.

The article consists of the following sections: classification of implants where the system of implants classification is developed in compliance with the required conditions for the subsequent plasma spraying; creation of an implant 3D model where the main methods of an implant 3D model creation are described and an optimal method for the spraying process is defined; the set-up of spraying process where the main process steps of an implant spraying with definition of file data exchange are selected; creation of spraying trajectories where the mathematical method of spraying trajectory modeling by means of splines and implementation modeling in the environment of Matlab for further data transfer of the received trajectory in the simulator is described; presenting the technology of plasma spraying where the microplasma spraying and the main characteristics used in the course of spraying are described; and simulation of motions of the robot where the program in the virtual simulator with possible transfer of robot trajectories to the program on the real robot is described.

3. A PARAMETRICAL METHOD OF THE IMPLANTS COMPLEX GEOMETRICAL-TOPOLOGICAL STRUCTURE CLASSIFICATION

Implants – a class of medical products used for implantation in an organism: in the form of prostheses and as the identifier. Implants are rather complicative surfaces to be obtained and processed, required the exact equipment, in particular robotic complexes.

Implants are selected for each person separately therefore, the physical sizes of implants are parametrical functions that allow making an implant by adjustment of parameters under the specific sizes.

The conducted researches [19] resulted in analyzing the types of implants by such criteria as:

their physical geometrical sizes, application, firm vendors, materials of production, manufacturing techniques. Implants are used for replacement (strengthening, gain) of the damaged bone and skeletal elements of a person and which can be made with the use of industrial manipulator robots. It is possible to refer implants to the main types: implant of a coxofemoral joint; implants of a knee joint; endoprosthesis of a shoulder joint; implant of an elbow joint; implant of an ankle joint; implant of cervical diaphyseal; implant of a beam wrist joint; interphalangeal joint of fingers of a brush; wrist joint of fingers of a brush; vertebral implant. Production of other types of implants, in particular, tooth implants, cochlear implants, implants of a retina, heart valves, etc. demands development of specialized technical complexes, in particular, with the use of 3D printers.

As developing of a robotic complex on the basis of the Fanuc LR Mate 200 id manipulator robot is the purpose of the given research, considering restrictions of a work space of this robot, we select the following extreme values of the physical sizes of implants which can be made on this complex (Table 1):

Table 1. Limits of the physical dimensions of the implants

№	Physical parameter	Limits (mm)
1	Length	>15,0
2	Diameter	>5,0
3	Width	>5,0
4	Arc length	>10,0
5	Clamp length	>10,0
6	Clamping diameter	>10,0
7	Rectangle length	>10,0
8	Height	>10,0
9	Proximal stalk length	>10,0
10	The length of the distal stem	>10,0
11	Stem diameter	>10,0

Let us note that high-quality coating application by the manipulator robot requires also execution of certain conditions of feasibility of such operations, in particular, restrictions which are given in Table 2 need to satisfy:

Table 2. Spraying limitations

№	Parameter	Minimum value (mm)	Maximum value (mm)
1	Distance to implant	145,0	155,0
2	Spraying diameter	10,0	25,0
3	Coating thickness	0,05	1,0

Thus, using the proposed method for classifying implants according to geometrical-topological dimensions, a set of implants suitable for subsequent plasma spraying was obtained. Based on a robotic complex with the use of the Fanuc LR Mate 200 id robot it is possible to make the following implants: coxofemoral, knee, shoulder, elbow, talocrural and beam wrist joints and also interphalangeal and wrist joints of fingers of a brush.

As a result of the conducted research, in MS SQL Server Management Studio 2012 the database was developed for accounting the existing and possible implants of different vendors, classification of implants as application and material of production, classification of implants by the geometrical-topological sizes of components, classification of the software at creation of 3D models of implants for machines with the numerical control (CNC), accounting of the physical sizes of implants, updating, record of elements, adding of new fields, file data exchange with Matlab.

4. 3D MODEL OF IMPLANTS

Let us note that there are following main methods of creation of a 3D model of an object: 3D scanning; creation of model in an automated design engineering system (CAD) of SolidWorks; photogrammetry. For creation of a 3D model of a human bone we will use the 3D SCAN 3D UNIVERSE scanner which recovers the corresponding sizes. In the subsequent stage the 3D model of an implant (Fig. 1) of these sizes is developed in the Geomagic Design X program.

The scan 3D UNIVERSE scanner is end-to-end solution to the hardware and the software for creation of 3D documentation of any objects and processing of measurement results, for example, for 3D-printing. The ability to integrate the scanner with the high-quality software of Geomagic of the return engineering, allows us to carry out automatic data processing in the CAD parametrical model and to exercise control of dimensional accuracy of preparation [20, 21].

Figure 1 – 3d model of a hip joint implant

5. ALGHORITHM OF THE SPRAYING PROCESS

Spraying of implant by means of a robotic complex is difficult process. It can be divided into five stages conditionally:

1. Creation of the implants database;
2. Creation of an implant 3D model;
3. Mathematical modeling of spraying trajectory;
4. Simulation of motions of the robot;
5. Spraying on the real machine (Fig. 2).

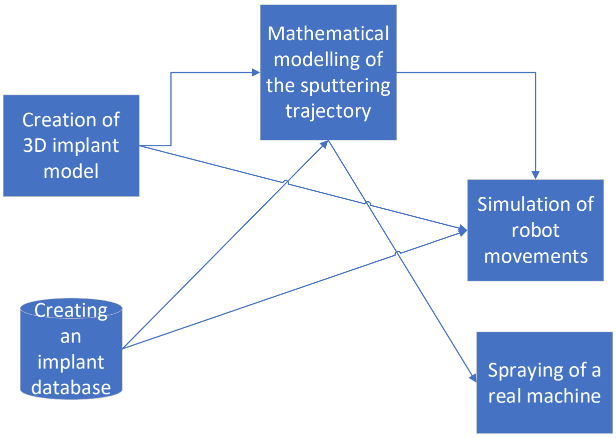

Figure 2 – Scheme of the stages of robotic system creation

Normal functioning of a system requires implementation of file data exchange. In the created system file, data exchange is carried out as follows: in the Geomagic Design X program, 3D model of the implant is created and the parameters of the given 3D model are transferred to the Matlab environment and the MS SQL Server Management Studio 2012 implant database.

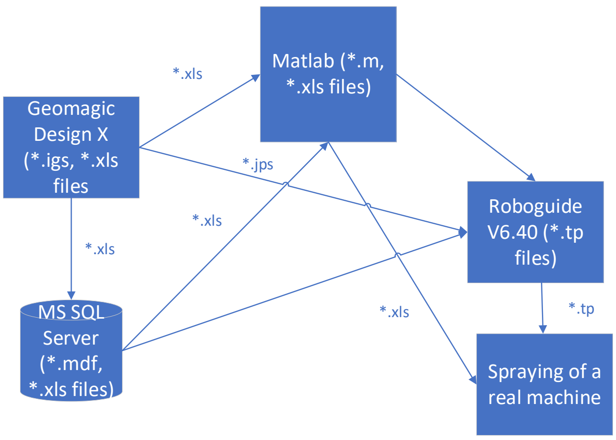

Figure 3 – Scheme of the transfer from the virtual simulator to the real robot

In the environment of Matlab the trajectory on the set coordinates, speeds and time is under construction, the intermediate values of coordinates received in the environment of Matlab are transmitted to the virtual simulator and the database of implants, the created implant 3D model in the Geomagic Design X program in the *.igs format is transferred to the virtual Roboguide V6.40 simulator, the simulation program can be transferred from the virtual simulator to the real robot (Fig. 3).

6. TRAJECTORIES PLANNING

For drawing up mathematical model of the motion we will use the following assumptions. Let at the stage of planning of motion trajectory some final sequence of points – values of the generalized coordinates be received. It is required to construct on this sequence dependence, continuous on time, which in discrete time points coincides with given values. In other words – it is necessary to construct an interpolation polynomial which in certain known time points will coincide with values in knots. For a solution of the problem of effective drawing a biocompatible covering, it is necessary to demand that the first derivative of this interpolation polynomial in knots of a grid coincided with given values, and the second derivatives of a polynomial were continuous. It is connected with dynamic characteristics of manipulation robots which are used for creation of laws of the movement [18]. The control system of the industrial Fanuc LR Mate 200 id robot allows us to read out and set values of the generalized coordinates and speed of the movement of the robot on each generalized coordinate. In terms of creation of a spline it means that passing through the set knots and with assigned speed in these knots is required [22, 23].

Let us note that a spline of the third order

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

for i- that generalized coordinate which meets passing conditions through knots and in these knots meets $t_1, t_2, \ldots, t_n$ conditions:

$$\begin{gathered} q_i(t) = \theta_i; \quad q_i(t_{i+1}) = \theta_{i+1}; \\ \dot{q}_i(t_i) = v_i; \quad \dot{q}_i(t_{i+1}) = v_{i+1}, i = \overline{1, n-1}, \end{gathered} \tag{2}$$

where $\theta_1, \theta_2, \ldots, \theta_n$ - given values of the interpolated function in these knots, i.e., $\theta(t_i) = \theta_i$ and $v(t_i) = v_i$ - assigned speeds i - that generalized coordinate in these knots – is called the Hermit spline. Unknown coefficients of a spline are calculated by one of the three methods of linear algebra, most often – pro-race method [22, 23].

However, the Hermit cubic spline does not meet the requirements of continuity of the second derivative in grid knots. For satisfactory conditions of continuity of the second derivatives in knots of a grid it is suggested to raise an order of a spline and to construct interpolation function in the form of a spline of the fourth order.

Mathematical statement of a problem involves creation of function of the fourth order which meets continuity conditions on an interval together with the first and second derivatives, passing through the set knots with assigned speed, i.e., meeting conditions:

$$\begin{gathered} q_i(t_{i+1}) = \theta_{i+1}, \ \dot{q}_i(t_{i+1}) = v_{i+1}, \\ q_i(t_{i+1}) = q_{i+1}(t_{i+1}), \quad \dot{q}_i(t_{i+1}) = \dot{q}_{i+1}(t_{i+1}), \\ \ddot{q}_i(t_{i+1}) = \ddot{q}_{i+1}(t_{i+1}). \end{gathered} \tag{3}$$

Let us add a condition on the ends of an interval t_1 and t_n: $q_1(t_1) = \theta_1$, $q_{n-1}(t_n) = \theta_n$.

Then we will look for a spline in the form of a polynomial [22]:

$$q_i(t) = \sum_{l=0}^{4} a_i^{(l)} (t_{i+1} - t)^l, \quad i = \overline{1, n-1}. \tag{4}$$

Thus, $5(n-1)$ for determination of coefficients $a_i^{(l)}$ we have conditions $5n-8$, other three conditions can be set depending on a specific objective. In particular, from conditions of continuity of a spline, we will receive that $a_i^{(0)} = \theta_{i+1}$, and $a_i^{(1)} = -v_{i+1}$ at the same time v_n can be known, or is not present.

Taking into account these values we will receive the system of the equations which connect coefficients $a_{i+1}^{(2)}, a_{i+1}^{(3)}, a_{i+1}^{(4)}$ with the known values $\theta_{i+1}, \theta_{i+2}, v_{i+1}, v_{i+2}$ and coefficient $a_i^{(2)}$ from the previous interval:

$$\begin{pmatrix} h_{i+1}^2 & h_{i+1}^3 & h_{i+1}^4 \\ 2h_{i+1} & 3h_{i+1}^2 & 4h_{i+1}^3 \\ 1 & 3h_{i+1} & 6h_{i+1}^2 \end{pmatrix} \begin{pmatrix} a_{i+1}^{(2)} \\ a_{i+1}^{(3)} \\ a_{i+1}^{(4)} \end{pmatrix} = \\ = \begin{pmatrix} v_{i+2}h_{i+1} + \theta_{i+1} - \theta_{i+2} \\ v_{i+2} - v_{i+1} \\ a_i^{(2)} \end{pmatrix}, \tag{5}$$

where $h_{i+1} = t_{i+2} - t_{i+1}$

Let us note that the determinant of a system (5) equals $h_{i+1}^6 \neq 0$ and, therefore, the decision always exists. Unknown coefficients of a spline are on the following recurrence relations:

$$\begin{gathered} a_{i+1}^{(2)} = a_i^{(2)} + \frac{3(v_{i+2} - v_{i+1})}{h_{i+1}} + \frac{6(\theta_{i+1} - \theta_{i+2})}{h_{i+1}^2}, \\ a_{i+1}^{(3)} = -\frac{2}{h_{i+1}} a_i^{(2)} + \frac{5(v_{i+2} - v_{i+1})}{h_{i+1}^2} - \\ - \frac{8(v_{i+2}h_{i+1} + \theta_{i+1} - \theta_{i+2})}{h_{i+1}^3}, \\ a_{i+1}^{(4)} = \frac{1}{h_{i+1}^2} a_i^{(2)} - \frac{2(v_{i+2} - v_{i+1})}{h_{i+1}^3} + \\ + \frac{3(v_{i+2}h_{i+1} + \theta_{i+1} - \theta_{i+2})}{h_{i+1}^4}. \end{gathered}$$

Given recurrence relations give the chance to express $a_{n-1}^{(2)}, a_{n-1}^{(3)}, a_{n-1}^{(4)}$ through $a_1^{(2)}$, namely:

$$\begin{gathered} a_{n-1}^{(2)} = a_1^{(2)} + S(n), \\ a_{n-1}^{(3)} = -\frac{2}{h_{n-1}} a_1^{(2)} - \frac{2}{h_{n-1}} S(n) + \\ + \frac{3v_n + v_{n-1}}{h_{n-1}^2} + \frac{4(\theta_{n-1} - \theta_n)}{h_{n-1}^3}, \\ a_{n-1}^{(4)} = \frac{1}{h_{n-1}^2} a_1^{(2)} + \frac{1}{h_{n-1}^2} S(n) - \\ - \frac{v_{n-1} + 2v_n}{h_{n-1}^3} + \frac{3(\theta_n - \theta_{n-1})}{h_{n-1}^4}, \end{gathered}$$

where $S(n) = 3\sum_{k=3}^{n} (\frac{v_k + v_{k-1}}{h_{k-1}} + \frac{2(\theta_{k-1} - \theta_k)}{h_{k-1}^2})$.

As it was noted above the value can be set or defined from the following conditions: speeds on both ends of an interval and acceleration on one of them are set; speed or acceleration on one of the ends and a condition of smoothness of the movement on all interval are set; speed or acceleration on one of the ends and an energy minimum condition are set.

For each of the given regional conditions there is the only spline of the fourth order.

For creation of a spline of the fourth order (4) we will seize the Matlab environment opportunities where there are built-in functions for creation of splines and also functions for finding coefficients of a polynomial [24, 25].

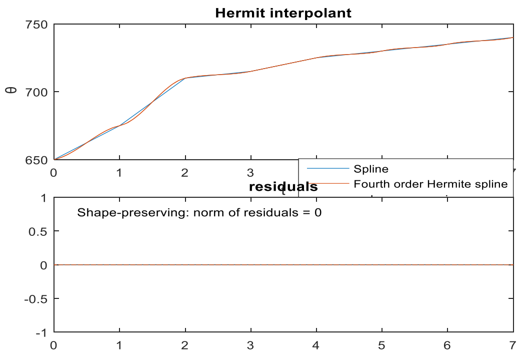

Figure 4 – Interpolation using the splines of the third and fourth order

Substituting model test data of time, value for each of the generalized coordinates and their speed, we received the following results for creation of a cubic spline (in Fig. 4 the schedule is drawn in blue color) and a spline of the fourth order (in Fig. 4 the schedule is drawn in red color) for the first generalized coordinate of the industrial robot, on abscissa axis – knots of this trajectory, on ordinate axis – value of the generalized coordinate in these knots. Below in the same Fig. 4 the schedule of errors of approach is induced. Similar splines were received for other five generalized coordinates of the robot.

As it is seen in Fig. 6, when using these splines the requirement of function smoothness is fulfilled, the passing condition on the set trajectory with assigned speeds is respectively satisfied. For splines, the norm of an error of approach has to be very small as both the cubic spline, and a spline of the fourth order, are interpolation splines and their values coincide in interpolation knots with preset values [22, 23].

For all six coordinates an approach error is zero that is the proof of creation of a spline optimum close to reference values. On the constructed splines and on values of mistakes we choose optimum approach from six schedules. In this case optimum approximate spline is the first spline which is closest to reference values and the error of approach is equal to zero.

7. REALIZATION OF THE PLASMA SPRAYING TECHNOLOGY

Production of implants consists of a fabrication stage of the implant and a stage of its surface processing. And processing of a surface is the important stage defining biological tolerance (tolerance) of implants.

Cobalt chrome, titanium implants are produced by method of casting, milling and turning, powder metallurgy, hot stamping, electrochemical processing and stamping with the subsequent milling.

Technological process of a plasma spraying generally consists of preliminary cleaning of a surface, activation processing and directly coating application by movement of a product along a plasmatron or on the contrary.

Figure 5 – Picture of the real hip joint implant

The microplasma spraying is a type of a gas-thermal spraying at which particles of powder or wire come to a plasma stream, move in it, heat up in it and hit against a substrate, creating a covering.

To carry out an experiment of spraying, the implant of a coxofemoral joint (Fig. 5) was selected.

The implant is fixed in capture of the manipulator robot which should move and rotate an implant for an optimum spraying on a surface. High-quality coating application requires execution of the following conditions:

1) the plasmatron evaporates a laminar plasma stream metal powder, it is at distance about 150 mm from an object at an angle 90°.

2) diameter of a spraying should be – 10-25 mm (we will note that the more porous there surface is, the better the implant gets accustomed in a human body, according to the conclusions of specialists,), coating thickness of 0,05...1,0 mm.

3) inconsequential losses of powder of metal at a spraying should make 10-15%.

4) the used material – VT6 titanium.

For modeling of trajectories from the database of implants in MS SQL Server Management Studio coordinates, time and motion speed are transferred to the Matlab environment where the spline of the fourth order is under construction. For creation of the program motion of the Fanuc LR Mate 200 id manipulator robot, the received 3D model of an implant is loaded into the virtual Roboguide V6.40 simulator.

Let us note that the FANUC ROBOGUIDE application is run by modeling and simulation of motions of the manipulator robot, working out commands for specific preparation that, in turn, provides considerable saving of time during creation of new settings of the movement. To reduce time for three-dimensional modeling, models of details can be imported from the PC in the type of data of CAD. The big library of the software for simulation allows users to select and change details and the sizes.

On the spline of the fourth order constructed in the environment of Matlab intermediate coordinates which then are loaded into the virtual Roboguide V6.40 simulator are calculated.

The FANUC ROBOGUIDE application carries out simulation of both motions of the robot, and commands for specific scope of application and provides considerable saving of time during creation of new settings of the movement [26-28]. To guarantee the minimum influence on production, modules can be developed, tested and reversed independently. To reduce time for three-dimensional modeling, models of details can be imported from the PC in the type of data of a CAD. The big library of the software for simulation allows users to select and change details and the sizes. Work with the intuitive and clear and extremely simple ROBOGUIDE application in use requires the minimum training. It is also available with specialized work benches to specific scopes of application.

In Fig. 6 the Fanuc LR Mate 200 id robot in which the implant of a coxofemoral joint is fixed is represented.

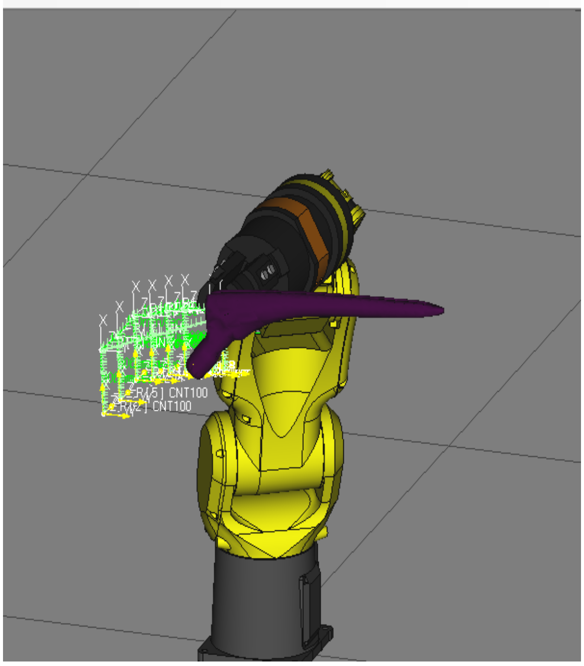

Figure 6 – Modeling trajectories for Fanuc LR Mate 200 id robot

For modeling a trajectory of the motion for spraying in the virtual simulator the targets (coordinates on which there should pass a robot, the speed with which there passes a robot) are set, and by on them the movement program of the manipulator robot is generated. Robot trajectories of the program on the simulator are given in Fig. 6.

The experiments on the creation of spatial models of implants and modeling of the trajectories of spraying by the proposed methods and their transfer to a real robotic system showed their ability to solve real problems.

8. CONCLUSIONS

As a result of a parametrical method of classification, the system of implants classification of application and production materials was developed, implants are classified by the geometrical-topological sizes of components and eight types of implants were selected in compliance with the necessary conditions for the subsequent plasma spraying.

Five main process steps of spraying of an implant by means of robotic installations were selected.

For implementation of spraying process, the implant of a coxofemoral joint was selected. With the help the 3D SCAN 3D UNIVERSE scanner and the Geomagic Design X programs the 3D model of an implant of a coxofemoral joint was developed.

For creation of an interpolation polynomial with the set coordinates and speeds the spline of the fourth order which provides the continuity of the second derivative trajectory was used. The solution to this task with a spline of the fourth order in the environment of Matlab is simulated.

On the example of an implant of a coxofemoral joint simulation of the robot motion by means of the virtual Roboguide V6.40 simulator was constructed. Test examples showed feasibility and efficiency of the offered approach.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

[1] A. Vardelle, C. Moreau, N. J. Themelis, C. Chazelas, “Perspective on plasma spray technology,” *Plasma Chem. Plasma Process*, vol. 35, pp. 491–509, 2015.

[2] B. Fotovvati, N. Namdari, A. Dehghanghaddiko-laei, “On coating techniques for surface protection: A review,” *Journal of Manufacturing and Materials Processing*, vol. 3, issue 1, pp. 1-22, 2019.

[3] J. Cizek, J. Matejicek, “Medicine meets thermal spray technology: A review of

patents," *Journal of Thermal Spray Technology*, vol. 27, issue 8, pp. 1251-1279, 2018.

[4] L. Pawlowski, *The Science and Engineering of Thermal Spray Coating*, 2th Edition, Wiley, 2008, 656 p.

[5] R.B. Heimann, "Thermal spraying of biomaterials," *Surface and Coatings Technology*, vol. 201, issue 5, pp. 2012-2019, 2006.

[6] B.-H.Lee, C. Lee, D.-G. Kim, K.C. K. H. Lee, Y. DoKim, "Effect of surface structure on biomechanical properties and ossteointegration," *Materials Science & Engineering C*, vol. 28, issue 8, pp. 1448-1461, 2008.

[7] Yu. Borisov, A. Kislitsa, and, S. Voynarovich, "Microplasma wire spraying," *Proceedings of the International Thermal Spray Conference and Exposition ITSC 2004 "Thermal Spray Solutions Advances in Technology and Application*, Osaka Japan, May 10-12, 2004, pp. 657-661.

[8] D. Alontseva, Yu. Borisov, S. Voinarovych, O. Kyslytsia, "Development of technology of microplasma spraying for the application of biocompatible coatings in the manufacture of medical implants," *Przegląd Elektrotechniczny,* vol. 7, pp. 94-97, 2018.

[9] J. R.C. Tucker, *Introduction to Coating Design and Processing,* ASM Handbook, Volume 5A, Thermal Spray Technology, 2013, pp.76-88.

[10] MSH Techno. [Online]. Available at: http://www.msht.ru/catalog/998/

[11] Vacuum systems and pumps. [Online]. Available at: http://inlinecom.ru/ionnoplazmen-noe-napylenie/

[12] Thin film spraying technology. [Online]. Available at: http://www.russianelectronics.ru/developer-r/review/2195/doc/49951/

[13] P. Honigmann, N. Sharma, B. Okolo, U. Popp, B. Msallem and F. M. Thieringer, "Patient-specific surgical implants made of 3D printed PEEK: Material, technology, and scope of surgical application," BioMed Research International, vol. 2018, Article ID 4520636, pp. 1-8, https://doi.org/10.1155/2018/4520636.

[14] Spinal health. [Online]. Available at: https://spinet.ru/news/?id=2112

[15] R. Bosco, J. v.-D. Beuken, S. Leeuwenburgh, J. Jansen. "Surface engineering for bone implants: a trend from passive to active surfaces," *Coatings*, no. 2, pp. 95-119, 2012.

[16] Y. Kondratenko, G. Khademi, V. Azimi, D. Ebeigbe, M. Abdelhady, S.A. Fakoorian, T. Barto, A. Roshanineshat, I. Atamanyuk, D. Simon, "Robotics and prosthetics at Cleveland state university: Modern information, communication, and modeling technologies," *Communications in Computer and Information Science*, vol. 783, pp. 133-155, 2017.

[17] T. Sobh, R. Mihali, A. Sachenko, "Fully autonomous web based virtual robot prototyping and manufacturing," *Proceedings of the 5th Biannual World Automation Congress, WAC 2002, ISORA 2002, ISIAC 2002 and ISOMA 2002*, Orlando, USA, June 9-13, 2002, vol.14, pp. 441-446.

[18] Yu. V. Krak, "Coordination approach to the organization of motion of manipulation robots," *Journal of Automation and Information Sciences*, vol. 29, issue 2, pp. 22-29, 1997.

[19] I.B. Karymsakova, Yu.V. Krak, N.F. Denissova, "Criteria for implants classification for coating implants using plasma spraying by robotic complex," *Eurasian Journal of Mathematical and Computer Applications*, vol. 5, issue 3, pp.44-52, 2017.

[20] 3D Today. [Online]. Available at: https://3dtoday.ru/blogs/top3dshop/3d-scanning-technology/

[21] Universal 3D scaner Scan3D UNIVERSE. [Online]. Available at: http://on-v.com.ua/novosti/texnologii-i-nauka/universalnyj-3d-skaner-scan3d-universe/

[22] U.S. Zavyalov, B.I. Kvasov, V.L. Miroshnichenko, Methods of Spline-Function, Moscow, Nauka, 1980, 352 p. (in Russian).

[23] Yu.V. Krak, A.V. Barmak, E.M. Baraban, "Usage of NURBS-approximation for construction of spatial model of human face," *Journal of Automation and Information Sciences*, vol. 43, issue 2, pp. 71-81, 2011.

[24] C.B. Moler, *Numerical Computing with MATLAB*. [Online]. Available at: www.mathworks.com/moler

[25] Matlab & Toolboxes. [Online]. Available at: http://matlab.exponenta.ru/spline/book1/6.php

[26] W. Schollenberger, *Roboguide V6.40 Manual*. Copyright OOO Fanuc Robotics Russia, 94 p. (in Russian)

[27] Roboguide. [Online]. Available at: https://www.fanuc.eu/ru/roboguide

[28] Yu.A. Bahmutskii, O.V. Gromyko, "Modelling and programming of robotized complex in Fanuc Roboguide package," *Theoretical and Applied Mechanics*, Minsk, no. 28, pp. 244-247, 2013. (in Russian).

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