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Analysis of Robotic Joints` Motion for Dental Handling Operations Using RoboDK Simulator

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Abstract **– Industrial automation and robotics are currently a strong field of engineering that is continuously developing and bringing with it significant technological advances. As information technology advances, so too do the processes using elements of this industry, helping to increase both productivity and efficiency. In the creation of robotic environments, simulation tools are used in the design phase through which all the necessary tasks, layouts can be created in detail while minimizing time and financial resources. Currently, the robotic simulator tools market is expanding, which brings with it the solution of several application decisions. The decision-making focuses on determining the appropriate simulator with a wide range of capabilities for simulating handling operations in the process of different types of manufacturing. This paper focuses on the study, analysis and testing of a robotic simulator that could be implemented in the context of dental manufacturing, which has several specificities associated with it. RoboDK software was reviewed as part of the study. After creating a model corresponding to a real workplace, analysis plots of the movements of the robot's joints and gripper during manipulation operations were created.**

Keywords **– Dental production, automation, RoboDK, manipulator, simulation.**

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1. Introduction

Within the enterprise as a work-organization system, the sum of manipulation processes forms a subsystem with characteristic features and peculiarities, which, however, has all the characteristics characterizing the work-organization system [1]. Manipulation processes, the existence of which is due to the necessity of bridging the time and space mismatch of production and consumption operations, differ from production processes in that they usually do not change the utility value of objects. In comparison with other work processes, it can be concluded that manual and physically demanding work still predominates in manipulative processes, according to the ratio of the expenditure of live and objectified work [2], [3]. Work processes in the field of material handling are fundamentally different not only from the basic production processes, but different specificities are also manifested in individual processes within the material handling itself.

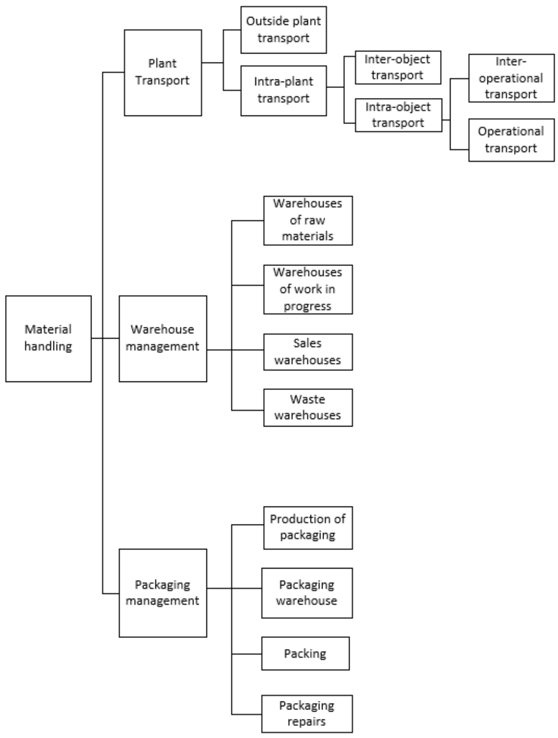

Figure 1. Classification of handling processes [4]

These specifics mainly consist in:

- Irregularities in work operations (time point of view)
- Non-stationary workplaces (spatial aspect)
- Loose division of labor
- The frequent occurrence of sudden works, caused mainly by contractors
- The diversity of manipulation operations, etc.

Figure 1 presents a classification of handling processes. The current technical and organizational level of handling systems imposes, in addition to requirements in the field of work organization (division of work, collective forms of work, increasing qualifications), extraordinary demands on the human side of work (impact of the working environment, physical exertion of work, etc.) [5]. New equipment components in handling processes have special requirements for increasing qualifications, especially in connection with service. The nature and particularities of material handling require extraordinary skills from managers, especially at low levels of management, focusing on division of labor, collective forms of work and operative management.

The scope and nature of handling activities in individual industries and types of production are different. Manipulation activity as a secondary one is based on the primary activity, on production and on its characteristic features. The scope and content of handling operations will therefore be influenced by such factors as the division of labour, cooperation, specialization, etc., whether it will be piece, serial or mass production, the nature of the processed raw material, etc. Currently, handling robots are used to solve handling tasks in production processes. The implementation of these devices significantly increases work productivity, product quality, and the qualification level of the company.

In Figure 2 a robotics classification scheme is shown. The scheme contains the main criteria for selecting a robot with the aim of implementing it in production or a company. Robots are classified according to geometry, drive, application area, control method, type of intelligence, and type of movement. When choosing a robot, it is necessary to focus on the type of manipulation operation and movement that the robot is to perform, the required repeatability and the geometry of the robot. Nowadays, there are many types of robots to perform various complex and simple functions [7].

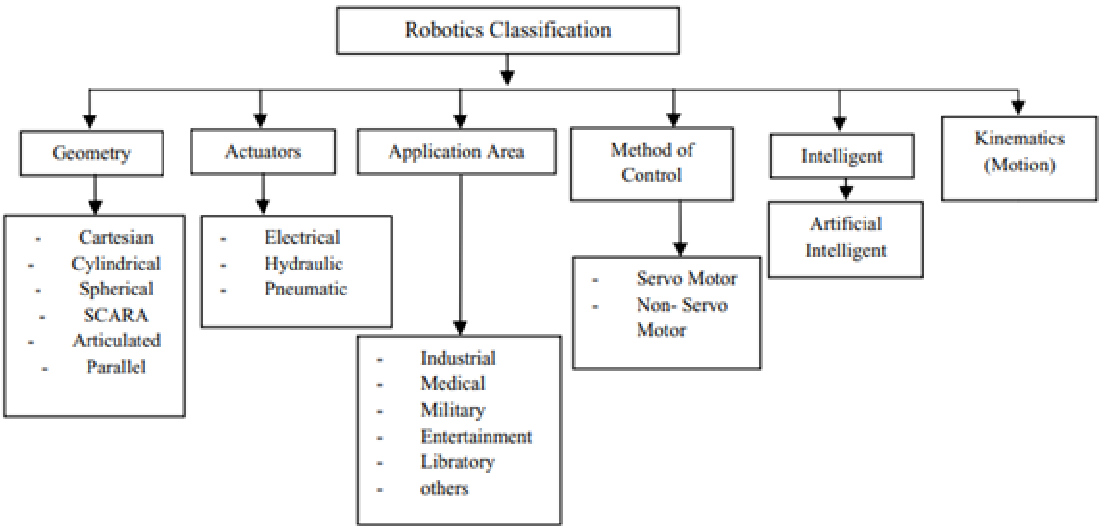

Figure 2. Robotics classification [6]

Manipulators are designed to perform functions such as moving parts, assembling and installing them [8]. Industrial robots are classified according to purpose. From this aspect, stationary or mobile robots can be distinguished. Mobile industrial robots in the field of logistics are also known by the abbreviation:

- AGV (Automated Guided Vehicle)
- AMR (Autonomous Mobile Robot)

Articulated industrial robots` mechanism is similar to the anatomy of the human hand.

The increased number of joints allows the robot to perform various movements in the workspace. Due to the similarities in terms of mechanical construction with the human hand, they are also known as manipulative hand or robotic hand [9]. Linear industrial robots are used in the field of handling, processing, and assembly of parts or materials. They can be identified based on specific linear movements. Cylindrical industrial robots are characterized by specific rotary movements. Parallel industrial robots or delta are robots located in a parallel plane, which consists of three arms assembled in a common base.

This type of robot is most often integrated and used in packaging applications in the pharmaceutical, electronic or food industries due to their precise movements [10], [11].

Figure 3. Robot manipulators [6]

2. Methodology

The issue of implementing a robot manipulator in the manufacturing process is to properly build the trajectory and identify the processes that need to be automated. The method for solving this problem is to analyse a simulator of handling operations in the dental implant manufacturing process. A RoboDK software was analysed. RoboDK is a powerful yet accessible software solution for simulating any industrial robot and developing control programs for various robotic systems. RoboDK enables you to maximize the performance of your robot. This software provides the capability to create control programs in an offline mode, outside the production environment. RoboDK allows you to program robots using a personal computer, eliminating production downtime associated with on-site programming. A workspace and functions for use are shown in Figure 4.

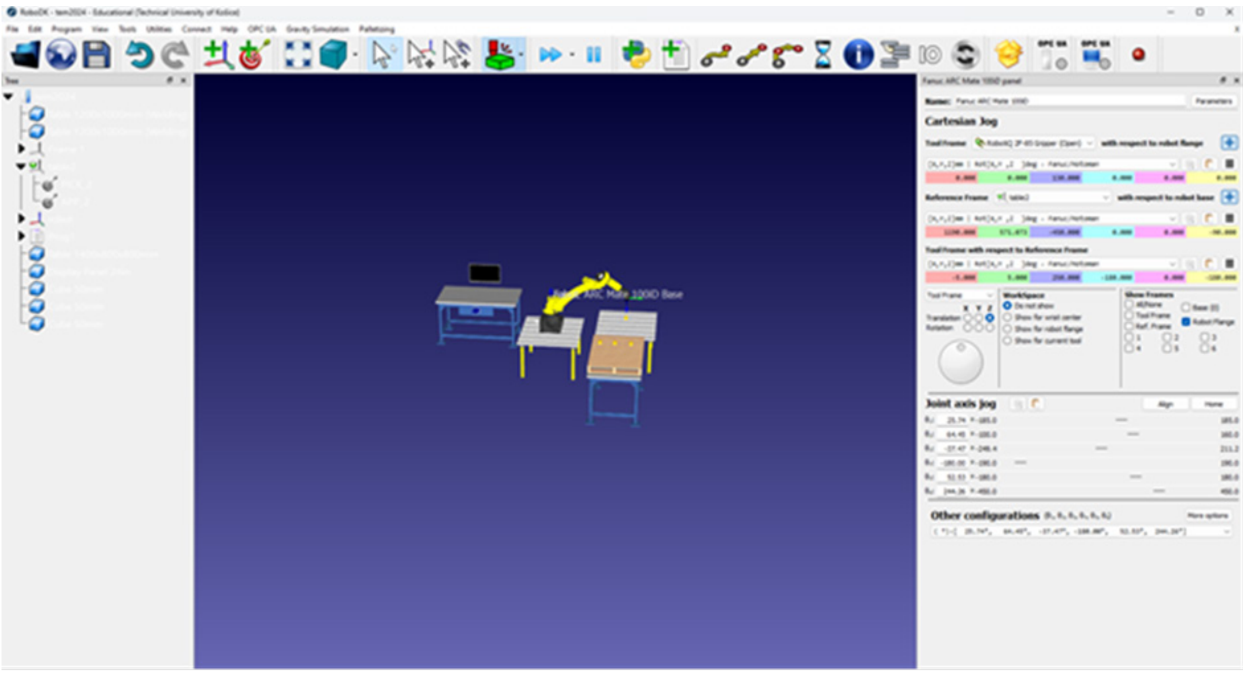

Figure 4. RoboDK software workspace

The software also allows full positioning of the robot's joints, shoulders, and gripper depending on the user's needs and the robot's technical capabilities. These positioning settings are shown in Figure 5.

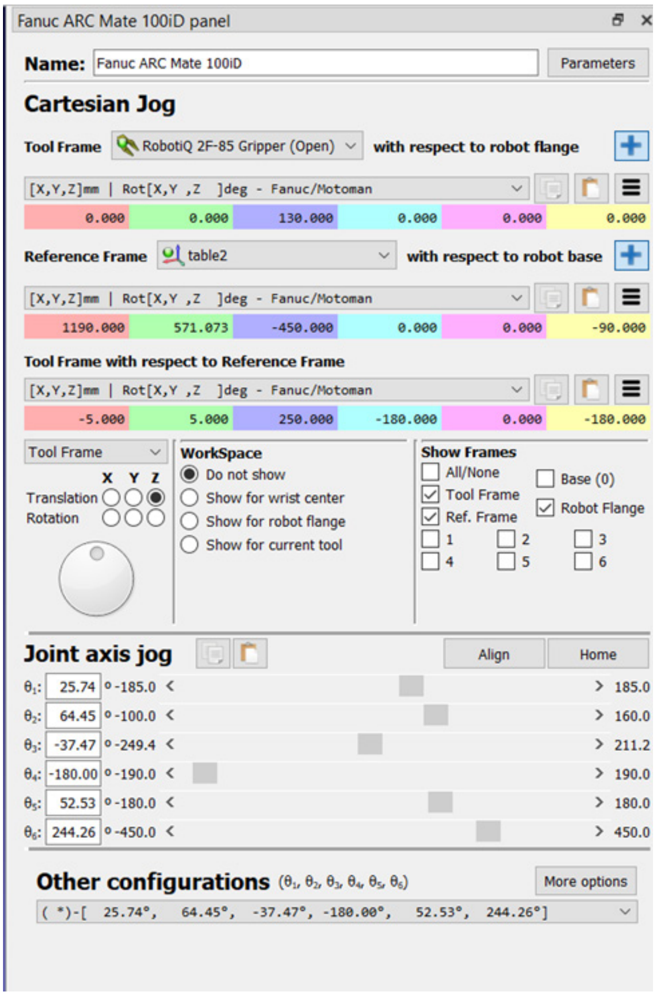

Figure 5. Robot`s and gripper`s positioning settings

After analyzing the production process, a model of the workplace was created in the above software. Robot was chosen to create the workstation model from library – Fanuc ARC Mate 100iD. The Fanuc ARC Mate 100iD robot is a 6-axis robot arm, it offers a 12 kg payload and 1441 mm of reach. The repeatability of the Fanuc ARC Mate 100iD robot is 0.08 mm and the robot weight is approximately 250 kg. Common applications of the Fanuc ARC Mate 100iD include additive manufacturing, dispensing, remote TCP, welding, and handling operations. The workplace was modelled according to the example of real production, which contains worktables, pallets for storing parts computer for data managing and is shown in Figure 6.

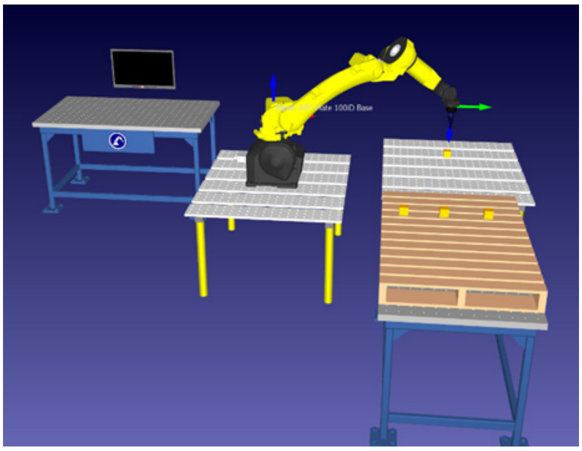

Figure 6. Created model of robotic workplace

3. Results

The process of creating a simulation of robotic manipulation operations involves proper trajectory planning. The trajectory contains several selected points along which the robot moves to form movements to perform handling operations. Trajectory planning is shown in Figure 7. An example of trajectory points is shown in this screenshot, for example: PICK_2 and APP_2.

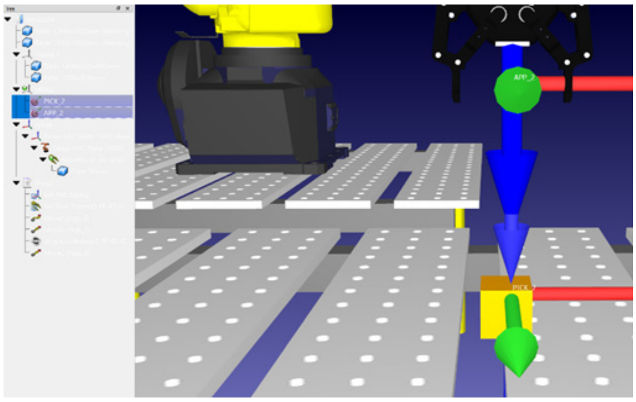

Figure 7. Determining the trajectory of manipulative robot's operations

The manipulation program is created using motion trajectory points and gripper kinematics instructions. Trajectory definition consists of changing the robot's location and the gripper's position and fixing this position using the function adds a new target for the selected robot. On each defined point it is possible to specify the necessary instruction, for example: open gripper, close gripper, wait command with the specified time, and to specify the number of repetitions of a particular operation.

The gripper kinematics in this program is already defined by software. While creating the program code, it is necessary to specify the position of the gripper fingers in open or closed position.

Program code is created by defining the motion type and trajectory point. Common code is created by combining subprograms. This program provides code in the Python programming language, as well as analyses of the trajectories of the robot's joints, the limits of their motion amplitude, and the dependence of their rotation with respect to time. Analyses of tool position over the time are shown in Figure 8.

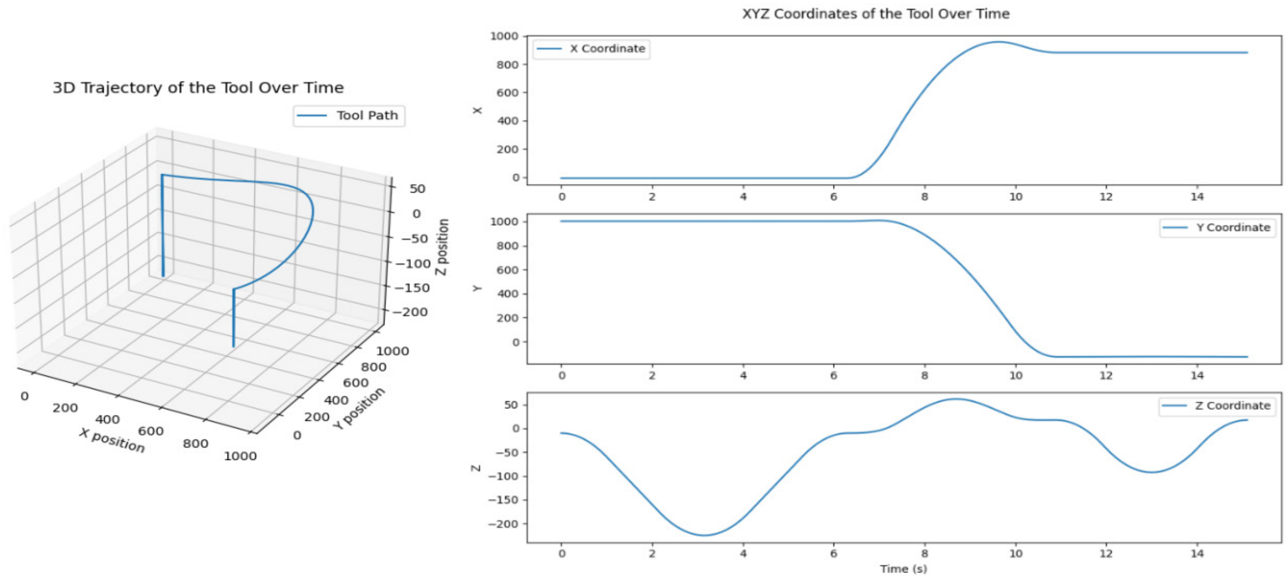

Figure 8. Analyses of tool position over the time

These graphs illustrate how the position of the gripper changes over time while executing the instructions of a given manipulation program. The first graph shows two types of motion: linear and interpolated. The difference between these two types of motion lies in axis movement. Motion along a single axis is linear, while motion across two or more axes is interpolated. These graphs are needed to control the clarity of manipulation that is so important for these operations in manufacturing processes. In a process like dental implant production, precision, and accuracy of movements and operations are important.

In addition to analyzing the gripper motion, analysis of the robot's joint motion as a function of time and the range of possible motion amplitude is also available. Most classic robotic arms have six joints that have rotation type of moving. These graphs will help to find out in what position the robot's joints are and whether the trajectory points set by the programmer do not exceed the possibility of their movement. A fundamental problem in trajectory generation is not knowing the range of possibility of motion of the robot. Graphs of the range of amplitude of the robot's joints and their rotation as a function of time are shown in Figure 9.

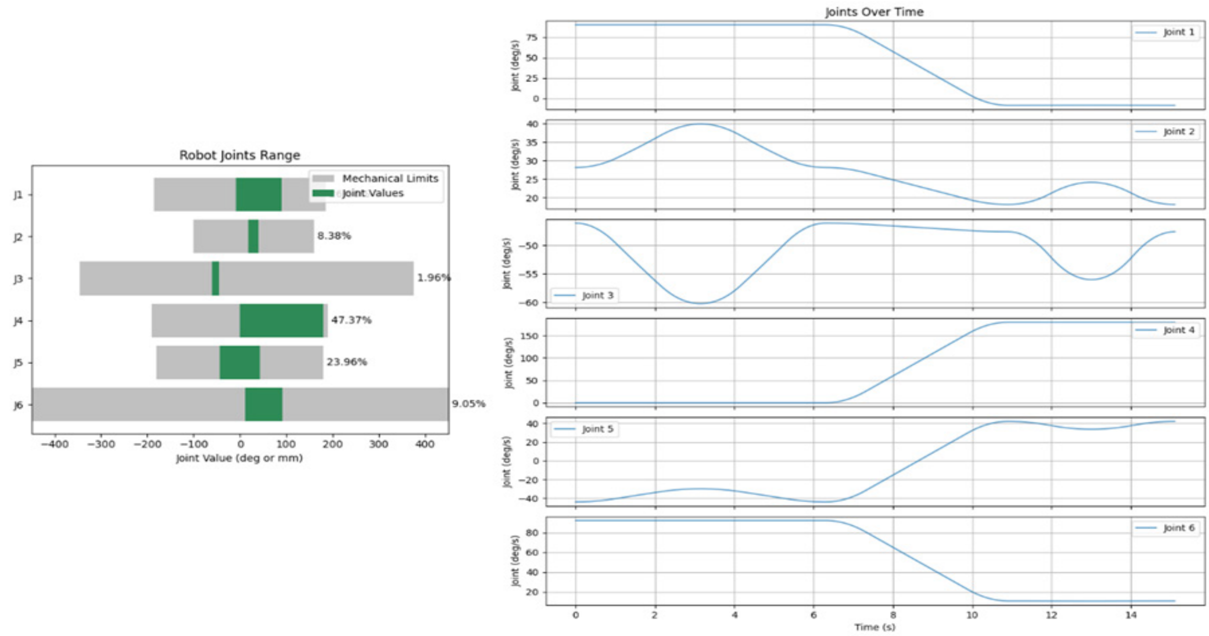

Figure 9. Graphs of robot joints range and joints over time

Using these graphs, it is easy to find out how many percent of the possible range of amplitude is taken up by performing movements of a defined trajectory. Each robot has its own limits of movement amplitude and this function is useful for exploring the possibilities, as well as for adding new points to the trajectory. These graphs aid in identifying the types of motions, amplitudes of possible movements, as well as their trajectories for the correct positioning of the robot on the production line and assignment of manipulative operations to be performed.

4. Conclusion

In conclusion, the analysis of the use of the RoboDK simulator for handling operations in the dental implant manufacturing process emphasizes its importance as a transformative tool in modern manufacturing. With its advanced programming capabilities, RoboDK allows professionals to carefully plan and execute transportable operations with precision and efficiency. By simulating different scenarios and optimizing robotic movements, RoboDK facilitates the seamless integration of robotic technology into dental implant manufacturing practices. In addition, the user-friendly interface allows engineers to tailor robotic manipulation to the specific needs of production lines while minimizing risk. As dental manufacturing continues to embrace technological innovation, RoboDK is an asset that promises to revolutionize dental implant manufacturing operations and raise processing standards in the dental industry. Furthermore, this software provides an extensive library for selecting robotic manipulators, object types, and environments. The capability of graphical analysis allows for visually determining motion boundaries, their types, and gripper positions depending on the simulation timeline. These types of analyses are crucial for implementing robots into production, mitigating risks, costs, and production process downtime. The integration of robots into manufacturing enables companies to enhance quality characteristics and obtain certifications for production quality improvement, as automation is an integral part of continuous improvement in the dental implant manufacturing process.

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