REACHABILITY PLANNING OF INDUSTRIAL ROBOT IN CONCEPT OF DIGITAL FACTORY

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Abstract: *One of the factors that influence the production and assembly systems based on robotic cooperation is the reachability of the required locations as well as the design of the robotic arm paths without the need for initial testing at a real workplace, which could lead to damage of some parts in the workplace. The resulting robot paths must be collision-free, they cannot correlate with other elements of the automated workplace, they should also follow the set production cycle. The trajectory time described by the industrial robot end effector influences the overall production cycle time. For this reason, it is necessary to create a trajectory which represents the shortest path described by the industrial robot. The design of the end effector path of an industrial robot must in general meet many criteria, either in terms of tact or safety. By simulating multiple path trajectory variants in the digital environment, it is possible to select the ideal trajectory of motion of the industrial robot depending on the layout of individual elements of the production or assembly system and the elimination of collisions. When designing a robotic workstation, the main parameters of the industrial robot are range and load capacity. By implementing CAD data and customer requirements into the digital environment of the selected software, we can verify the data and choose the most appropriate solution. The main benefits of industrial robot application and the use of available software to efficiently design a robotic system include benefits such as shorter production times and associated higher productivity, labor cost savings and wage costs reduction, robots are used in other applications after the end of the production cycle of the original product, thereby achieving savings in investment costs.*

Keywords: TECNOMATIX, PROCESS SIMULATE, DIGITAL FACTORY, INDUSTRIAL ROBOT, WELD POINT,

1. Introduction

Nowadays, efforts are being made to shorten the cycle of products, to increase the usability of production systems and to reduce the complexity of products, requiring changes in the technical preparation of production as well as in the production process. The number of newly-developed and upgraded products in the industry is large and will be further enhanced by the improvement of technical solutions. A partial solution is the application of industrial robots to manufacturing or assembly systems.

Industrial robots are used in various industries such as welding, pressing, machining, painting, painting, etc. Pressure to increase quality, productivity and cost reduction opens space for industrial robots, including machine handling and material handling. Industrial robots can move with high precision repeatability and trajectory of handling moves compared to conventional solutions, making cycle times shorter. The advantage is that the robot is not a dedicated device, for example, on machine operation, e. g. within the cycle time can do other additional operations in addition to the primary operation.

The main technical advantages of the industrial robot are undoubtedly the stability of the process and hence the achievement of high quality requirements for the final product, as well as the flexible production process change and the rapid incorporation of the technical change of the product. The major economic benefits include shortening production times and bringing together higher productivity, labor cost savings and lower wage costs, the ability to use robots in other applications after the end of the production cycle of the original product, and thereby achieve savings in investment costs. When designing a robotic workstation, the main parameters are the industrial robot, its range and load capacity.

Optimization of a robotic workstation can be analyzed from multiple angles, regardless of the area. Optimization can occur in:

- production,
- communication,
- management,
- logistics,
- ATC.

Optimizing these and other areas is geared to the main goal of increasing efficiency, saving costs, increasing productivity. Maintaining the right to maintain high quality and production stability is a matter of course. The possibility and scope of optimization of the robotic workplace is given by sufficient flexibility, which is achieved using appropriate technologies at the very design of the workplace. Availability visualization is done in a 3D software environment where it is possible to determine the cycle time, the reachability of the industrial robot and at the same time to verify the functionality of the proposed workplace. With the increasing demands on the efficiency of production, its reliability and the quickest putting into operation are an important part of the design of the production and assembly lines, becomes a computer simulation.

Computer simulation enables virtual verification of plans and assembly lines before the start of production, helping to mitigate risks, whether cost or real-estate safety. It is a comprehensive tool that can verify the feasibility of the assembly process by controlling the reachability and eliminating possible collisions. This process is performed by simulating the whole assembly procedures of the product and the required tools and their interaction. Using computer simulation, it is possible to design the most optimal way of these processes and to incorporate all the necessary means necessary for the planned production process. The main advantages of computer simulations include the possibility of early detection of errors in the design and optimization phase of production, the possibility of making analyzes of the feasibility of a given solution or examining ergonomics of manual works.

2. Literature analysis

The effectiveness of robotization lies in the rapid integration of robots into production processes and, above all, in their economic and social benefits. Under economic benefits, we mean increasing labor productivity, stability and improving production quality, improving production management, and saving resources. In addition to the benefits that can be quantified to save production costs, the introduction of robots generates many secondary effects that only assist in deployment, such as lowering the technical preparation of production, reducing the need for operative production planning, and shortening production lead times.

2.1 Robotized workplaces

Robotic applications for Smart Manufacturing, whose definition and ideas constitute the current development trend in robotic systems, define new requirements for the technical level of in-use equipment. Innovating current solutions puts emphasis on the development of fully integrated and interoperable manufacturing systems that can respond in real time to conditions and requirements changing in real time. An integral part of the successful development of the Smart Manufacturing Application vision is industrial robots that provide the user with a high level of functionality, flexibility and mobility. Their ability to collaborate safely in direct interaction with humans or other industrial robots, on the other hand, provide simple parameterization and definition of the tasks performed, which will allow the rapid and seamless integration of new devices into existing infrastructure within the production process. [4]

The geometry description aims at defining the movement of the end effector of the industrial robot over time and excluding force effects, determining its path, velocity and acceleration. The operation of the industrial robot consists in adjusting the discrete positions of the working head or in the continuous motion of the working head after a generally defined spatial trajectory, whereby the orientation of the working head is also controlled. Thus, the working head is a functional part which, depending on the nature of the desired activity, determines the use of the motion robot movement system. Due to the kinematic scheme of industrial robots and the scope of their workspace, emphasis is placed on the trajectory itself to eliminate the risk of interaction with the robot peripherals, and therefore emphasis is placed on workplace layout and ease of accessibility. [4]

*2.2 Simulation soft*ware

Simulation software allows simulation of all activities from product design, assembly techniques, production planning, operational management, manufacturing of parts, inspection, assembly, packaging through to dispatch, in order to reduce material and energy consumption, increase productivity, reduce inventory, shorten the interim development and production times, increase time and power utilization of production facilities, and increase product quality. The potential of using simulation software is high. To select the software, you need to have a clear idea of the usability and suitability of the selected software, and it is necessary to correctly define the criteria and the objective of the project.

Issues and errors detected during simulation:

• large transport points,

• small storage capacity,

• Insufficient storage capacity,

• excess or shortage of workers,

• poor layout of workplaces,

• downtime.

• high caries,

• Insufficient maintenance,

• Unusable workplaces during breaks,

• Verification of functionality, reliability and performance,

• poorly planned progress of individual operations in the project.

There are models that are built for single use only (eg when analyzing processes to confirm the correctness of our hypotheses). Next are the models whose use is repeated. These are, therefore, simulation models of production and logistics systems that are still available to the user. Such models are used, for example, to verify the availability of system capacities, production plans, and the number of workers depending on the plan. An important part of the reuse of the model is its updating. The user not only changes the production plan but needs to constantly update the basic process data in the simulation model (e.g. machine failure, cycle times, sorting times). Today's simulation software can communicate with different databases or spreadsheet editors. Therefore, process data can be maintained in MS Excel spreadsheets or automatically downloaded from the enterprise information system. This greatly reduces the simulation model user's expertise. Although the construction of the model is performed by an expert, it can also be used by a scheduler in the production, and may not be able to control the programming language. [3]

2.3 Tecnomatix Process Simulate

Process Simulate is one of the major modules for simulating manufacturing processes that helps minimize startup costs and change the production program. It enables the virtual verification of plans and assembly lines before the start of production, thus helping to mitigate risks, whether cost-related or in real-life safety. It is a comprehensive tool that can verify the feasibility of the production or assembly process and eliminate possible collisions. This process is carried out by simulating the entire assembly or production procedures of the product and the required tools and their interaction. Its task is to design the most optimal solution of the processes and to involve all the necessary means necessary for the planning of the production process. This module is fully integrated with the Teamcenter platform, allowing engineers and designers to reuse data that has been used in past designs and re-process, validate, edit, and use in the future. This archiving enables easy return to data, facilitates and accelerates the design of production systems and links. It also simplifies the simulation of human processes, mechanical processes, tools, devices and robots. Process Simulation creates complex and realistic views of the look and course of production through relatively detailed and credible simulations. [1, 2]

Process Simulation is the solution to minimize the risk of manufacturing change or the rise of new production lines. It will allow you to verify practically plans from the concept to the start of production to help mitigate these risks. The ability to use 3D data of products and resources, facilitates virtual verification, optimization and introduction of complex manufacturing processes, resulting in faster startups and higher production quality. Tecnomatix - Process Simulation can verify the feasibility of the assembly process by verifying availability and collisions. This is done by simulating the complete order of assembly of the product and its working tools. Tools such as cutting, measuring, and collision detection allow detailed control and optimization of production and assembly scenarios.

The main features include activities such as 2D and 3D view, 3D simulation, static and dynamic collision detection, 3D measurement, assembly planning, line design and workspace, filtering and displaying products and production information. There are advantages [2]:

• Reduce the risk of changing the production system,

• shortening planning time for new production systems,

• Reduce change costs with early error detection,

• Analysis of ergonomic processes,

• selecting the best option, by deducting several production alternatives [2]

When using the Tecnomatix - Process Simulate software correctly, the given robot simulation can be used as off-line programming and PLC code generation. The off-line industrial robot programming method offers several benefits, shortening the time of deployment of the robot, detecting collisions and detecting unrealizable and dangerous situations. The actual working range of the robot is known before the physical realization, which allows the selection of a suitable industrial robot. In addition to the advantages when introducing a new workstation, it is advisable to apply the off - line programming method to the process of changing the workplace, during which the delays occur during reprogramming of the robot during operation. [2, 5]

3. The example of Tecnomatix Process Simulate application

At first, we need to define what kind of research question we are going to solve by simulation.

Research question:

What are the limitations of the new proposed production system, and how can the production system be put into practice realistically and to what extent?

In the following example, we will introduce a digital model that defines a manufacturing system focused on spot welding process. A key element is the creation of a trajectory of an industrial robot with an end effector. This model is designed by Tecnomatix Process Simulate from SIEMENS.

To create the simulation of the digital model itself, it is necessary to define the correct kinematics of the CAD model of the industrial robot and scoring welding pliers.

The Process Simulate system distinguishes between passive items and those having joints enabling them to move; the latter are kinematic and are designated mechanisms. Mechanisms have links connected by axes to constitute joints. Links are hierarchically related to each other such that every link is either a parent link or a child link relative to another link, or both: an intermediate link may be a child link to one link and a parent link to another link. If the links of a mechanism are connected such that no link has more than one parent or more than one child, the mechanism is a chain. Every joint is either prismatic (linear) or rotational, and has limits of maximum and minimum movement (distance of travel), and maximum speed and acceleration. Every mechanism is either a device or a robot. If it has only links and joints, it is a device. If in addition it has a base frame and a tool frame, it is a robot. A robot also has a tool center-point frame (TCPF) which initially is superimposed on the tool frame, and a reference frame (REFRAME) to which the coordinates of all robot frames except the base frame are referenced. These frames are identified by names and have six numerical values expressing the X-Y-Z coordinates of position and the Rx-Ry-Rz coordinates of orientation; the Rx coordinate is a rotation around the X axis, the Ry coordinate is a rotation around the new Y axis, and the Rz coordinate is a rotation around the new Z axis. [6]

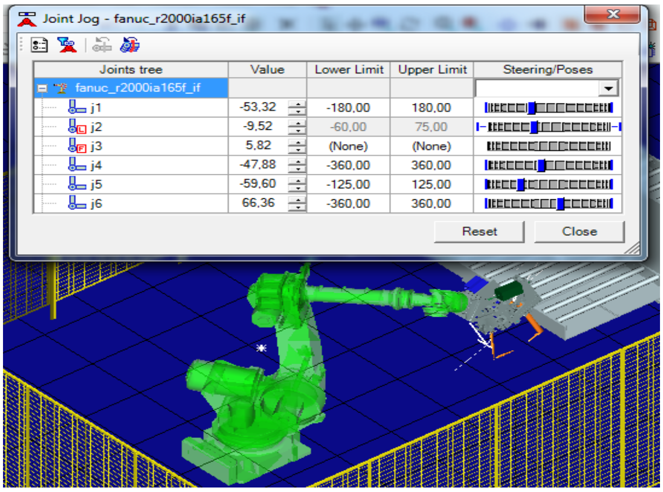

Fig. 1 Value of joint

When we have a CAD model of an end-effector industrial robot and a kinematics created, simulation can be created. In this example, New Weld Operation is used, which involves designing welded points. Subsequently, auxiliary points are created to guide the industrial robot with the welding point ticks to the desired location. To create the right trajectory and simulation, it is necessary to identify the technological points and points. Technological points are specific places where the technological process takes place. In this case, it is spot welding. The welding point pliers are attached to the industrial robot arm. The auxiliary points serve to accurately guide the welding scoring pliers on the industrial robot arm to the point of the first welded point, through the intersections between the welded points and to leave the space after the welding operation is completed. These help points are important to correctly determine that no collision occurs because the robot automatically selects the shortest path when starting a process with the Home position to the point of the first welded point or when passing between the welded points.

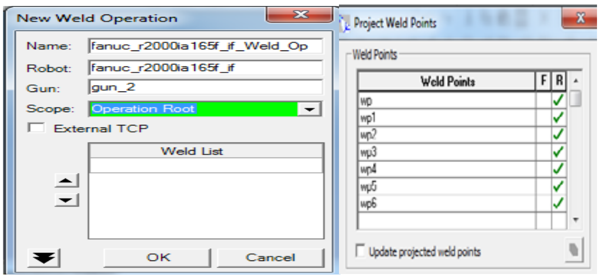

Fig.2 Project Weld Points

The next step for guiding welding scoring pliers mounted on the arm of the industrial robot is the orientation of the created technological and auxiliary points. It is necessary to set correct points orientation in the coordinate system with axes x, y, z to avoid collisions of the industrial robot with welding pliers with other objects in the vicinity. It sets the direction and angle of access of the industrial robot's tool (welding point pliers) to a predefined point, such as a technological or auxiliary access point.

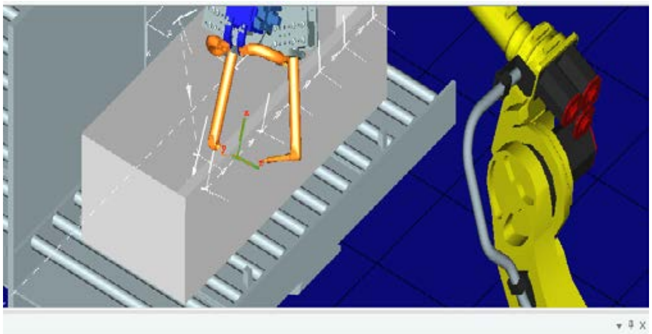

Fig.3 Trajectory of motion weld gun

After creating the trajectory of the industrial robot path with the end effector, adjusting the orientation of the technological and auxiliary points, and removing the collision states, it can create a simulation.

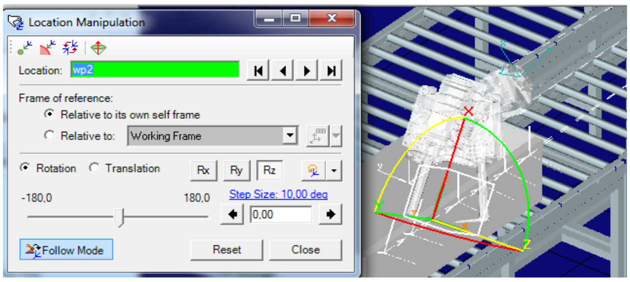

Fig.4 Location and orientation weld gun

In this part, it is possible to simulate a technological process with different speed parameters of the movement of an industrial robot where it is possible to observe the change of the time character of the technological process and eventually the collision. Before running the simulation, it is necessary to sort the operations in the Operation Tree according to the time sequence. In the case of creating a simulation consisting of multiple operations, it is possible to create groups and subgroups that will include individual operations.

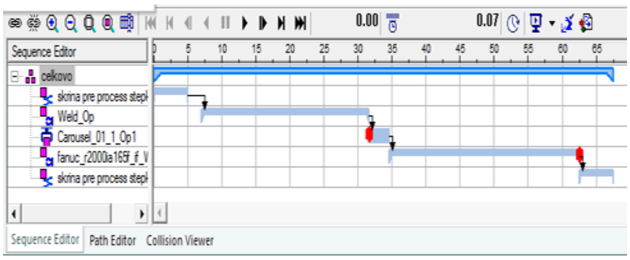

Fig.6 Sequence Editor

4. Results and discussion

The proposed digital model must be tested in terms of the reachability of the industrial robot and the distribution of the individual components of the production system. This prevented the collision between the parts of the production system and the industrial robot with the end effector resp. to remove collisions.

In addition to the interaction of the components of the production system, the load characteristics of each joint were verified. In Fig. 7 Joint value, it is possible to see the measured values in terms of time. Among other things, it is possible to read the actual movement range of individual joints at the proposed trajectory from the overall motion range of individual joints.

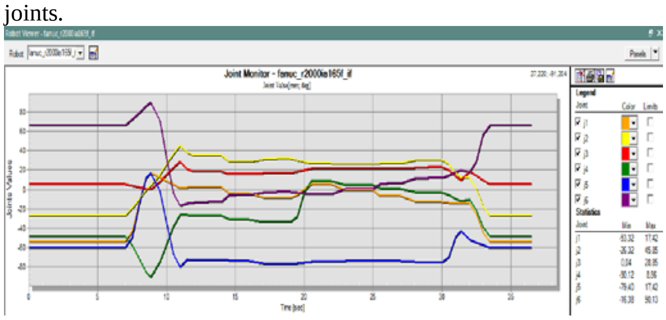

Fig.7 Joint Value

In addition to the load characteristics of the joints, it is possible to read out the greatest speed of movement of individual joints. Thanks to it, it is then possible to retroactively refine the simulation of the process to provide realistic information for implementation into real production.

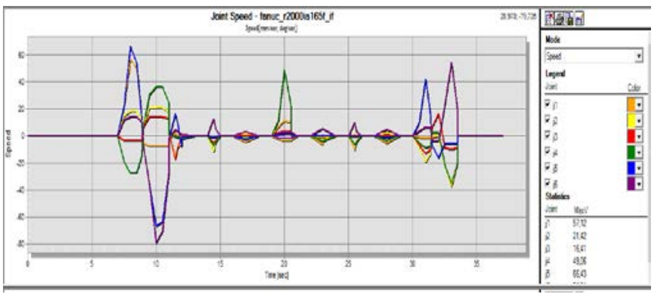

Fig. 8 Joint Speed

This is an option to show the complexity or simplicity of the path when designing larger ranges of joints means consuming more time and energy to perform the operation

5. Conclusion

With an increasing number of industrial robot installations, processes related to automated application design and the use of CAx systems that target different levels of their development are at the forefront. Software solutions allow you to create simulations across the range of tasks from simple object availability testing within the robot workspace to virtual plant simulation including process, production, logistics, product, and more.

The result of the example used is to verify the reachability of the industrial robot while creating the optimal trajectory of the industrial robot. Using simulation, you can test the kinematic and dynamic properties of mechanisms and systems. Movement of a mechanism or system is controlled by a time sequence. The output is a dynamic simulation that carries information about the movement speeds of individual parts and the trajectory of the industrial robot, the length of the technological operation, the collisions and the layout of the workplace. The total length of the trajectory time interval is the sum of the individual lengths of the time intervals of the industrial robot movements from which the technological operation is composed. The time interval is affected by the speed of movement of the operational and inter-operation processes. The speed of movement of the industrial robot must not affect the accuracy and quality of the technological operation. Consideration must also be given to factors such as inertia, movement, strength or structural strength. An important element is the dispositional distribution of the individual components of the production system, which to a certain extent affects the finding of the optimal trajectory of the industrial robot. The accuracy of the input data and the geometric accuracy of the CAD models influence the credibility of the information obtained.

The creation and more frequent introduction of simulations of various processes in manufacturing, logistics or other industries is an integral part of the Digital Factory concept, which falls under the Industry 4.0 strategy. Simulation facilitates decision making when designing new and optimizing existing production systems. Assuming the correct creation of the kinematic CAD model of the industrial robot and the welding pliers, the obtained simulation data can be considered as data obtained in a real production process, but without significant financial investment.

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