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DESIGN OF THE WORKSPACE AND THE MOVEMENT TRAJECTORY OF AN INDUSTRIAL ROBOT

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Abstract: *Industrial robots are essential for modern production systems, but ensuring their workspace is designed for safe interaction with humans is crucial. The design of the workspace involves organizing and distributing the space to minimize collision risks. Factors such as robot size, activity type, and production stability must be considered. Optimizing the workspace involves motion planning algorithms and simulations to design efficient routes and test different configurations. This optimization leads to increased productivity, improved product quality, and lower costs. Simulations are also used to design safe and effective robotic manufacturing processes.*
Key words: *trajectory, collision, simulation, production and assembly systems, robotic systems).*

1. INTRODUCTION

Industrial robots have become a crucial part of modern production systems. Their ability to automate and streamline production processes brings many benefits to businesses in terms of increased productivity, quality and competitiveness. However, with the expansion of robotic production, more and more emphasis is being placed on production efficiency and safety at work.

One of the critical areas that must be considered in terms of safety is the design of the industrial robot's workspace. Ensuring that the workspace is optimally designed and adapted for safe interaction between the robot and humans is essential.

The design of the workspace of an industrial robot is crucial for the efficient and safe operation of production processes. The industry relies increasingly on robotic production, which brings many benefits, such as increasing productivity and efficiency, reducing errors and optimizing costs. Our article also covers this topic, where the emphasis is on ensuring safety and preventing collision situations within the robot's workspace.

The principle of the correct design of the workspace consists of its organization and distribution concerning the robotic system and the person. The goal is for the space to allow robots to perform tasks efficiently but, at the same time to minimize the risk of accidents or collisions. The complexity of this process lies in the fact that various factors such as the size and characteristics of the robot, the type of activity performed, the time required for the action, and above all, ensuring stable and safe production must be considered.

The design of the workspace is a process that requires detailed analysis and planning in terms of all the risks that may arise when working with robots. One of the main requirements is to minimize the occurrence of collision situations that can cause injuries or material damage. It requires the correct location of the robot and workstations and the implementation of appropriate safety measures.

In the article, we will deal with the analysis of various factors that must be considered when designing an industrial robot's workspace. We will discuss minimizing collisions that can cause injury or property damage. We will also propose solutions and safety measures that will help improve safety when working with robots.

Research in industrial robot workspace design is significant because new challenges and risks are encountered with the increasing use of robots in industrial environments.

Research on this issue is becoming essential because the rapid development in engineering production and industrial robots brings new challenges to the design of the workspace. With the increase in the presence of robots in industrial environments, we have to deal with unknown risks and ensure that robots have sufficient space to operate while not endangering the safety of people.

In the article, we will take a detailed look at this area, go through the process of planning and designing a workspace and point out possible problems that may arise. We will also present various examples and solutions to help with robots. Our work will bring new knowledge and help design an efficient and safe workspace for industrial robots.

2. LITERATURE SURVEY

An industrial robot is an automatic machine capable of performing actions and activities that are performed repeatedly in a normal human work cycle. Industrial robots are designed and built to simplify manufacturing processes, improve accuracy, increase productivity and reduce costs. Industrial robots are programmable in three or more axes, which allows them to work with high flexibility, speed and precision.

The advantages of using industrial robots consist primarily in increasing the efficiency and productivity of industrial processes. Robots produce products with consistent quality; they can work continuously 24/7 without needing breaks. They also reduce the risk of occupational accidents during difficult, dangerous or monotonous activities. Another advantage is that robots can work in demanding and hazardous environmental conditions, where there would be a risk to the health or life of a person.

Despite many advantages, industrial robots also have certain disadvantages. High initial purchase and programming costs are one of the main obstacles for small and medium-sized businesses. Although a robot can be programmed to perform various tasks, its flexibility is still limited compared to a human's.

The workspace of an industrial robot is the space in which the robot can perform its programmed tasks. This space must be optimized so that the robot can function efficiently and, at the same time, does not expose people or property to risks.

Optimizing the operation of an industrial robot is the process of improving its performance and efficiency. This optimization is often achieved through better programming of the robot, adaptation of its speed and accuracy, and advanced technologies for monitoring and control. Optimizing the workspace of an industrial robot involves adjusting its position and orientation so that the robot can perform the required tasks more efficiently and with greater precision. It may also include adapting the surrounding environment to maximize its safety and effectiveness. Optimizing the workspace of an industrial robot is a complex process that requires deep knowledge of the production process and the hardware configuration of the robots. The goal is to optimize the use of robots in the production environment so that they perform tasks efficiently, accurately and safely.

Industrial robots are often deployed in conditions where space is limited. Their workspace needs to be optimized to function effectively and deal with challenges. It is achieved through motion planning algorithms and simulations.

Motion planning is used to design optimized routes for robot manipulations, considering various obstacles in a manufacturing environment. It could include calculating the fastest path between two points or determining the most efficient way to manipulate an object.

Simulations are used to model different scenarios in the environment; they allow testing different configurations of the robot and its routes before actual deployment. It helps predict and fix problems that might lead to accidents or manufacturing defects.

Combining these methods optimizes the industrial robot's workspace and better integrates it into production. The result is increased productivity, improved product quality and lower operating costs.

With an optimized workspace of an industrial robot, higher work efficiency, better production flexibility and faster response time to changes in the product or process are expected. It also reduces the risk of accidents and shortens the time needed to prepare and set up the robot.

This optimization is constantly in the process as technological advances and innovations in the field of robotics bring new possibilities and methods to improve the use and integration of industrial robots into production systems.

Considerable attention is paid to this issue worldwide; for example, in articles [1], [2], the authors deal with the issue of safety at work in the case of collaborative assembly in the automotive industry.

In their article [3], other authors deal with repetitive positioning accuracy during robotic assembly. This article aimed to develop a dependency enabling the determination of the repeatability error value of the robot's positioning at any given point in its workspace without the need to perform time-consuming measurements.

In the article [4], attention is paid to the non-uniformity of the movement speed of the end effector in the robot's working space due to the arm's angular movements.

A systematic review of the literature on designing human-robot collaborative (HRC) workspaces for humans and robots in industrial environments is provided by [5]. The study analyzed 252 articles and identified 65 articles for further analysis. The findings are presented in three categories: Category 1 focuses on specific influencing factors in HRC, and Category 2 includes related recommendations.

3. METHODOLOGY

Figures have to be made in high quality, Simulation creates a computer model (or simulation) of a natural system or situation. It is an abstract modelling of a system or process to gain insight into its work, decisions or outcomes in a particular case. Simulations are used for analysis, study and training, identification of problems and solutions, prediction of results and gathering relevant information.

Simulation is significant in the design of a robotic manufacturing process. Simulation is an excellent help in planning these processes. The goal is to create an efficient and productive process that optimizes the use of resources and minimizes costs. Simulation allows you to experiment with different process aspects before investing time and money.

With the help of simulations, for example, it is possible to decide how many robots will be needed to perform a specific task, how they will work together, or how efficiently they will use space. Furthermore, the robots' movements and interactions with the work environment and other equipment can be simulated to avoid possible collisions or other problems.

The importance of simulation is equally crucial in the design of the workspace of an industrial robot. Simulations can help determine the optimal robot position and reach, maximize the efficiency of robot movement and operation, and prevent potential conflicts with other equipment or workers.

Thus, simulations provide a safe and effective way to test different scenarios and designs without putting the natural system or workers at risk and bring the knowledge and information needed to create robust, efficient and safe robotic manufacturing processes and industrial robot workspaces. Simulation is thus an integral part of planning and development in industrial robotics.

3.1 Optimization of the workspace and movement trajectory

Our goal is to improve the layout of the work area and the movement path of an industrial robot for spot welding.

To realize the simulation of the given system based on its digital model, we had to define the correct kinematics of the 3D CAD model of the industrial robot and spot-welding tongs. The modelled objects are divided into entities without movement (passive) and objects with movement (articulated or prismatic joints), which allow them to move. We refer to moving joints as kinematic mechanisms. In this case, these moving joints in mechanisms are formed by joints. We connected the individual parts hierarchically so that each part is either a parent or a subordinate link to another part or both: we could define a transitional part as a subordinate part to one and a parent to another. If we linked the mechanisms so that no link has more than one parent or more than one child, the mechanism became a kinematic chain. For each connection, we set limits for maximum and minimum movement (movement distance), speed, and acceleration. We classified these mechanisms as either a device or a robot. If it only has cells and links, it is considered a robot; if it has a base frame and a tool frame, it is considered equipment. We assigned a part frame to the robot tool centre point (TCPF), which we initially overlapped with the tool frame, and a reference frame (REFRAME), to which the coordinates of all robot frames except the base frame refer. We named these frames and assigned them six numerical values expressing X-Y-Z position coordinates and Rx-Ry-Rz orientation coordinates.

3.2 Simulations and used software

We used the Tecnomatix software and its "Process simulate" module developed by Siemens for the simulation. This software presents a range of tools and solutions in a wide range of data collection, from production to planning new production systems. It is currently one of the most complex software for simulation and optimization of production processes on the market.

One of the components of this software is a module for the simulation and programming of industrial robots. This module can simulate and program the work of industrial robots, allowing manufacturers to accurately plan and test production processes before applying them in a natural environment. Users can see exactly how the industrial robot will move and perform individual operations in real-time.

This software helps to optimize processes and can control and communicate with various industrial robots, allowing users to simulate and program different types of robots in production in virtual reality. The result is the ability to simulate other systems and uncover potential problems and bottlenecks, leading to cost savings and increased process efficiency.

In addition to helping to eliminate possible errors in the planning of production processes, Tecnomatix also supports the optimization of space and time factors.

Overall, Tecnomatix is a sophisticated and integrated tool for the simulation and optimization of production processes that can significantly contribute to the efficiency and effectiveness of work.

3.3 Spot welding workplace - model

To create the digital model simulation itself, it is necessary to define the correct kinematics of the CAD model of the industrial robot and spot-welding tool. (Fig. 1) The Process Simulate system distinguishes between passive objects and objects with joints that allow them to move; the latter are kinematic and are determined mechanisms. Mechanisms have connections connected by axes that form joints. Links are hierarchically linked to each other such that each link is either a parent link or a child link relative to another link, or both: an intermediate link can be a child link to one link and a parent link to another link. If the links of a mechanism are linked in such a way that no connection has more than one parent or more than one child, the mechanism is a chain. Each joint is either prismatic (linear) or rotary and has limits on maximum and minimum movement (movement distance), maximum speed and acceleration. Each mechanism is either a device or a robot. If it only has cells and connections, it is a device. It is a robot if it also has a base frame and a tool frame.

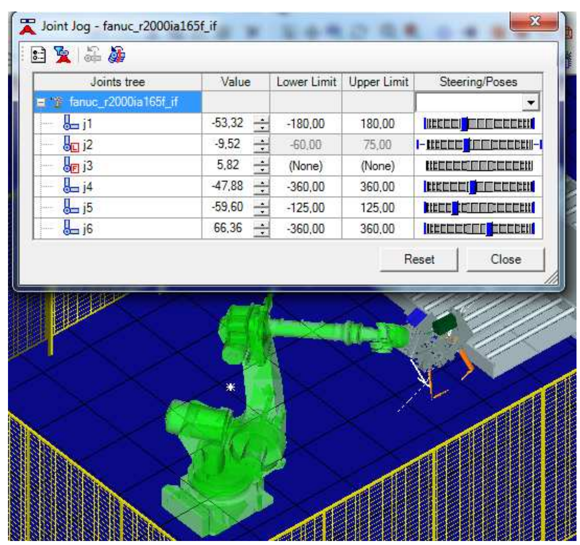

Fig. 1. The 3D model of spot-welding station

The robot also has a centre point tool frame (TCPF) that is initially overlaid 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 labelled with names and have six numerical values expressing X-Y-Z position coordinates and Rx-Ry-Rz orientation coordinates; the Rx coordinate is the rotation around the X axis, the Ry coordinate is the rotation around the new Y axis, and the Rz coordinate is the rotation around the new Z axis.

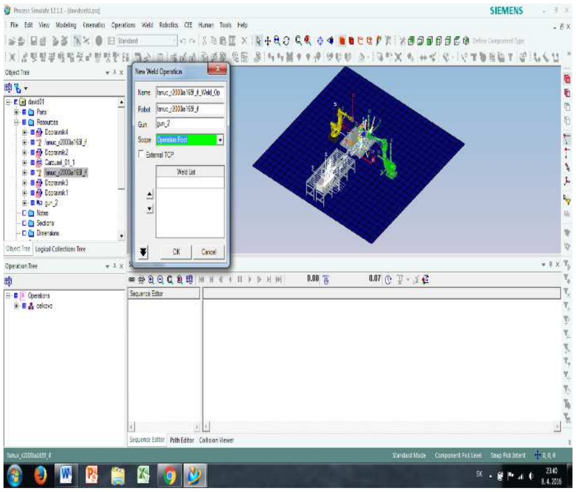

Fig. 2. New welding operation

When the kinematic 3D CAD model of the industrial robot with end-effector is created, we can start creating the simulation. To create the simulation, we will use the "New Weld Operation" function, which includes a design of weld points. (Fig. 2). We will create auxiliary points to navigate the industrial robot to the desired location. All technological and auxiliary points must be determined to create the correct trajectory and simulation. Technological points represent specific places where the technological process - building welding - is carried out. (Fig. 3)

The technological unit – the tool (welding tool) is connected to the robotic arm. Auxiliary points are used to precisely navigate the movement of the robot arm during the entire technological cycle. The auxiliary points must be determined in such a way as to prevent a collision between the robot arm or between the tool and the environment. It is essential because the robot is programmed to automatically choose the shortest route when starting the process from the "Home" position to the location of the first welding point or when passing between individual welding points.

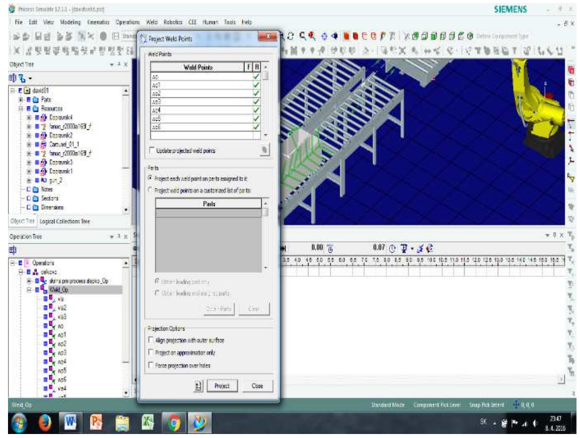

Fig. 3. Weld points

The next step is focusing on technological and auxiliary points, which were created to guide the welding scoring tools attached to the arm of the industrial robot. (Fig. 4) To prevent the industrial robot from colliding with the welding tongs and other objects nearby, We have to set the correct orientation of the points in the coordinate system with the x, y, and z axes. The direction and angle of approach of the industrial robot's tool (welding tools) to a predefined point, such as a technological or auxiliary access point, must be set (Fig. 5).

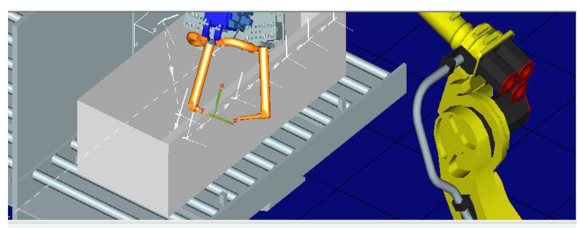

Fig. 4. Point definition

After we have created the path trajectory of an industrial robot with an end effector, the orientation of technological and auxiliary points set, and the collision states removed, we can create a simulation.

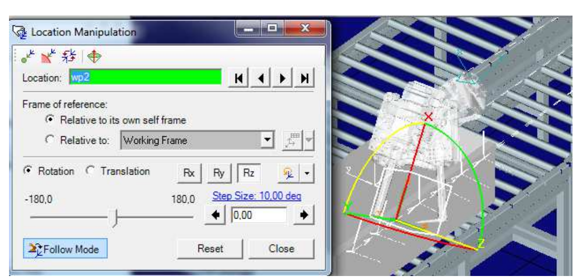

Fig. 5. Point orientation

In the provided section, we can simulate a technological process using various speed parameters for the movement of an industrial robot. This allows us to observe variations in the temporal character of the technological process and potential collisions. Prior to initiating the simulation, it is required of us to arrange the individual operations according to the time sequence in the "Operation Tree". When crafting a simulation that comprises multiple operations, we can form groups and subgroups which will encompass individual operations (Fig. 6).

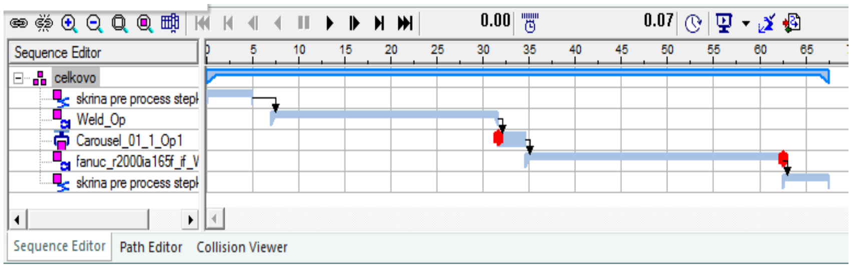

Fig. 6. Operation tree

4. RESULTS

In Fig. 7, the time course of the load measured on the industrial robot's joints can be observed by us. We can also read the current range of motion of individual joints and the proposed trajectory from the total range of motion of specific joints.

The digital model proposed by us was required to be tested concerning the reach of the industrial robot's arm and the arrangement of the production system's components. It ensured that a collision was averted between the individual elements of the production system and the industrial robot equipped with the end effector by us.

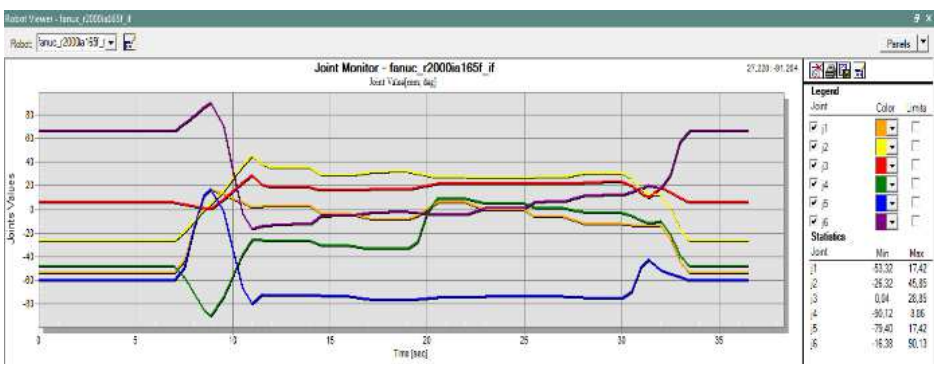

Fig. 7. Joints load

Apart from the load characteristics on each joint, we are also enabled to identify the utmost speed of movement for a particular joint, as represented in Fig. 8. Being equipped with this information affords us the capacity to refine and reapply the process simulation, as a result introducing genuine information into actual production.

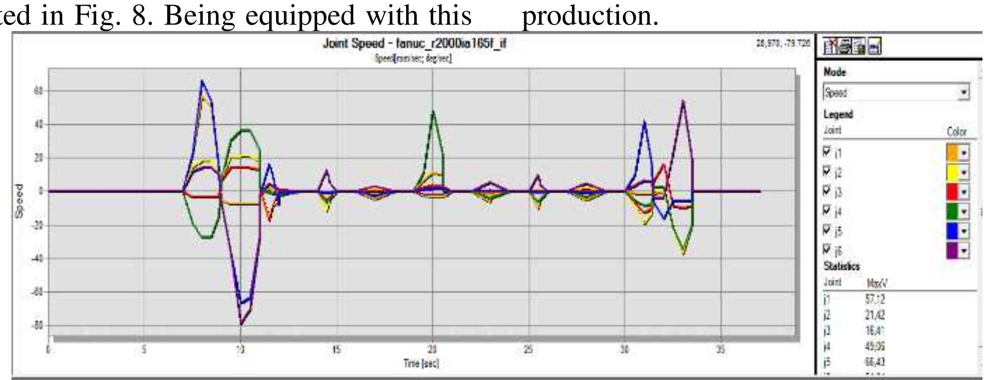

Fig. 8. Joint speed

Our approach involved verifying the industrial robot's arms reaches and developing its optimal trajectory in the mentioned robotic workstation case. The robotic mechanisms and systems' kinematic and dynamic attributes were examined through simulation. The motion of a mechanism or system was regulated by sequencing the time, as per our plan. The resulting dynamic simulation we produced included details about the individual components' movement speed and the industrial robot's trajectory, the operation duration, collision states, and the job layout. As implemented in our technological operation, the total trajectory time interval length is derived from the accumulation of individual lengths of the industrial robot's movements' time intervals. The operational and inter-operational process movement speed was observed to dictate the time interval. Care was taken to ensure that the industrial robot's record of success didn't compromise the technological operation's accuracy and quality. We also considered factors including movement inertia, impacts, and structural strength. To some degree, the layout configuration of the production system's singular parts dictated the industrial robot's optimal trajectory identification. The data input precision and the CAD models' geometrical accuracy influenced the reliability of acquired information by our assessment.

5. CONCLUSION

Based on our research, we designed and implemented optimization of the workspace and motion trajectory for an industrial robot in a spot-welding application. The results showed that rigorous planning and modelling could significantly contribute to industrial robots' more efficient and safer operation.

Using Siemens' Tecnomatix software, we extensively simulated and tested our model to ensure it was working correctly. Comparing our approach with other existing methods, we found that our model was accurate in replicating real-world conditions and effectively avoided collisions, reducing the risk of equipment damage or worker injury.

In addition, research has revealed that careful determination of technology points and auxiliary points is crucial for adequately guiding an industrial robot. It was also necessary to check the robot's joints' load and speed to ensure optimal operation.

As part of the Digital Factory notion in line with the Industry 4.0 strategy, we have started more frequently creating and integrating simulations of multiple processes in production, logistics, and other industrial sectors. Simulating the CAD model of the industrial robot and the welding tongs' kinematic diagram properly led us to consider simulation results as viable data, similar to those achieved during the production process but devoid of considerable financial investment.

As for future research directions, we recommend continuing to test and refine the model under real-world conditions and further testing with different types of robots and industrial applications. This work could also be extended by research into optimizing other aspects of robotic operations, such as energy efficiency or adaptability to changes in the work environment.

In conclusion, this research represents an important step towards more efficient and safer use of industrial robots, with the potential to significantly contribute to the advancement of industrial automation.

The results of this study have broad implications and open many possibilities for future research and applications in practice, which will allow further development and improvement of robotics-based technologies.

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PROIECTAREA SPAȚIULUI DE LUCRU ȘI A TRAIECTORIEI DE MIȘCARE A UNUI ROBOT INDUSTRIAL

Rezumat: Roboții industriali sunt esențiali pentru sistemele moderne de producție, dar este crucial să se asigure că spațiul lor de lucru este proiectat pentru interacțiunea sigură cu oamenii. Proiectarea spațiului de lucru implică organizarea și distribuirea spațiului pentru a minimiza riscurile de coliziune. Trebuie luați în considerare factori precum dimensiunea robotului, tipul de activitate și stabilitatea producției. Optimizarea spațiului de lucru implică algoritmi de planificare a mișcării și simulări pentru a proiecta rute eficiente și a testa diferite configurații. Această optimizare duce la creșterea productivității, la îmbunătățirea calității produselor și la costuri mai mici. Simulările sunt, de asemenea, folosite pentru a proiecta procese de fabricație robotizate sigure și eficiente.

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