

WORKSPACE CHARACTERISATION FOR A WELDING INDUSTRIAL ROBOT

KARAKTERISTIKE RADNOG PROSTORA KOD INDUSTRIJSKOG ROBOTA ZA ZAVARIVANJE

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Sažetak: Industrijski roboti su dio proizvodnog sustava i važno je smjestiti ih u sustav prema njihovim zahtjevima, potrebama i ponašanju. Podaci dobiveni iz tehničkih podataka o robotima s obzirom na radni prostor (njegove dimenzije i oblik) nisu dovoljne za projektiranje proizvodnog sustava. Nedostaje informacija o pokretljivosti. Da bi se predočilo ponašanje robota u radnom prostoru, uvodi se pojam anizotropije brzine robota i definira se kao normalizirana duljina najkratčeg vektora brzine elipsoidnih osi koje se mogu konstruirati u centralnoj točki alata za bilo koji položaj robota. Zatim se izvodi grafička reprezentacija 3D radnog prostora koja uključuje i anizotropiju brzine te se daje primjer projektiranja proizvodnog sustava sa robotom za zavarivanje. U ovom primjeru predstavljene su i obrađene prednosti grafičke reprezentacije radnog prostora sa uključenom anizotropijom brzina.

Abstract: Industrial robots are part of production systems and it is important to place them into the system according to requirements and their properties and behaviour. The information, obtained from the technical sheets of robots, about workspace (its dimensions and shape) is insufficient for designing the production system. The information about mobility is missing. To represent the behaviour of the robot in the workspace, velocity anisotropy of the robot is introduced and defined as the normalised length of the shortest velocity ellipsoid axes which can be constructed in the tool centre point for any position of robot. A graphical representation of the 3D workspace with included velocity anisotropy is then performed and an example for a design of a robotised welding production system is given. In this example the benefits of the graphical representation of the workspace with included velocity anisotropy are presented and discussed.

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1. INTRODUCTION

Robots are used in variety of industrial applications. The use of robots is dictated from the market requirements and the competitiveness between producers in different branches. The majority of industrial robots are used in the motor vehicles industry, followed by the production of automotive parts. And most of them are used for welding operations. The introduction of robotised welding systems is important particularly when the technological and quality requirements on the product are higher than it can be done with conventional or manual welding methods. The robotisation of production systems is not important just for the humanisation of the working process but also for increasing the quality and the continuity of products in particular welding and the decreasing of production costs. The welding robot is almost an indispensable part of the production chain where pretentious structures are welded. This is possible because of the wide selection of industrial robots in the world's market. Especially for welding operations new robotic structures, welding equipment and peripheral devices are designed. The peripheral devices increase the applicability of welding robots for different welding technologies. But only the use of high quality robots and equipment cannot guarantee top-level quality of the products if the technological set-up of the robotised technological system is not optimal. The design of robotised technological systems is therefore very important for high quality realization of the technological processes and because of this, high quality products [1].

The aim of the present paper is to show the development and the 3D representation of the velocity anisotropy of the industrial robot in the workspace.

The development is shown on the example of a real industrial robot which is specially designed for spot and MAG (Metal Arc Gas) welding applications. The graphic representation of the 3D workspace with included velocity anisotropy field is generated with an auxiliary software package on the basis of Autocad Mechanical Desktop. The graphical presentation enables the visualization of the velocity anisotropy in a three dimensional space and it is specially designed for the use with production system design software.

The presented approach can be also used for creating 3D maps for families of industrial robots which differ in dimensions or even in the structure. These maps can be integrated into CAD programs for designing robotised production systems and for off-line programming purposes of industrial robots and simulations.

2. TRAJECTORIES IN THE WORKSPACE

The TCP trajectories of industrial robots can be divided into two main groups:

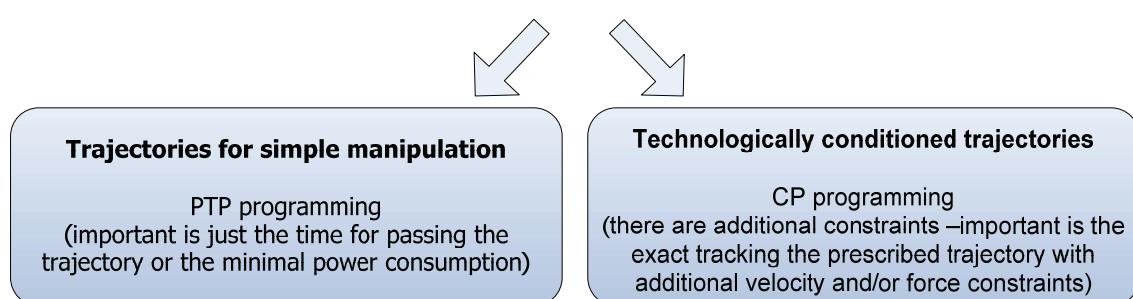


Fig. 1. Trajectories for simple manipulation / technologically conditioned trajectories
(PTP – point to point, CP continuous path)

In this work we are interested in technologically conditioned trajectories, where not just the correct passing through is important, but also the velocity profile on it, Fig. 1.

The parameter for determining the velocity anisotropy in each point in the robot's workspace depends on the momentary robot's position in the space. To overcome the difficulties which result from the description of the position and the orientation of the TCP [2-5] and because the transmission of kinematic and kinetic quantities from the actuators to the TCP depends in general on the first three "positional" degrees of freedom, the wrist degrees of freedom which are responsible for the orientation of the TCP are not taken into consideration.

3. MANIPULABILITY OF THE MECHANISM

In all positions in the workspace the robot has not got equal mobility. The transmission of motions, from each actuator to the TCP, will not guarantee equal velocities of the TCP in all points in the space, Fig. 2. The TCP point on the robot is identical with the point in the workspace. For each point in the workspace we can find a position of the robot mechanism and to this position the corresponding manipulability.

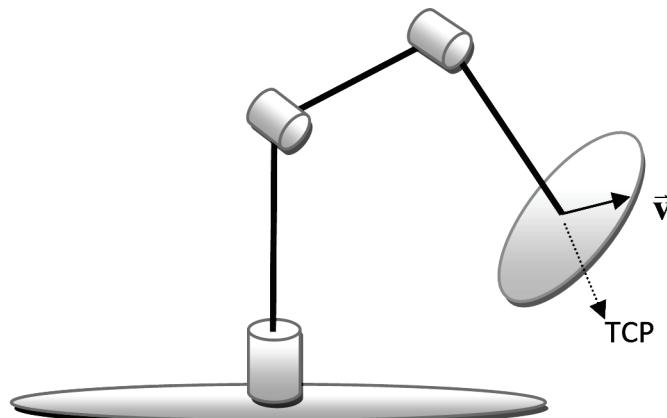


Fig. 2. Manipulability and the velocity anisotropy

The velocities which the robot's TCP can produce in an arbitrary point of the workspace are different not just from point to point in the workspace, but also differ in different directions in a point. So the velocity is anisotropic in robot's workspace. This can be clearly represented with a velocity ellipsoid [6-8]. The velocity ellipsoid in the workspace of the robot can be constructed in the TCP as the result of transformation of velocity hyper-sphere from configuration space into an ellipsoid in the task space, Fig. 3.

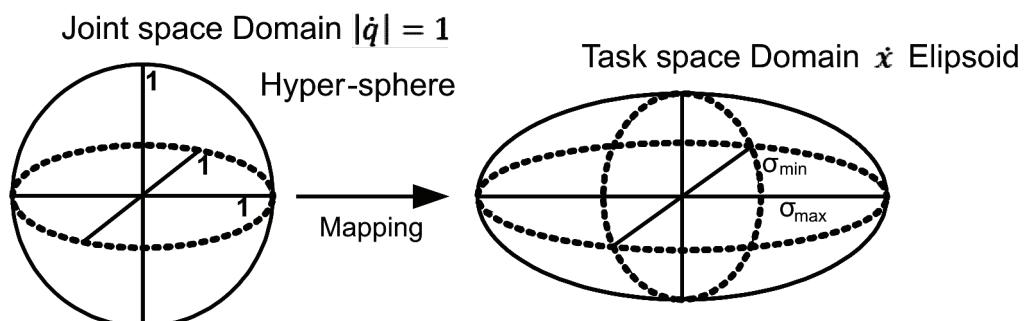


Fig. 3. Hyper-sphere / Velocity ellipsoid

The lengths of the axes of the ellipsoid are proportional to the singular values of J . Singular values of the Jacobian matrix are calculated for each robot position numerically. Singular values of matrix J , if the matrix is regular, corresponds with the eigenvalues of the matrix [9-10] with

$$\sigma_i = \sqrt{\lambda_i}, \quad i = 1, 2, \dots, m. \quad (1)$$

The number of non-zero singular values σ_i of the matrix defines the range of the Jacobian matrix. If just one singular value is zero, the Jacobian matrix is singular and the mechanism is in a singular position. The product of singular values defines the volume of the velocity ellipsoid and through this the manipulability index of the serial mechanism.

$$M = \sigma_1 \sigma_2 \dots \sigma_m. \quad (2)$$

The relation between the minimal and the maximal singular value is the condition number

$$K = \frac{\sigma_{\min}}{\sigma_{\max}} \quad (3)$$

it is a normalized quantity which defines the roundness of the velocity ellipsoid. The ellipsoid is close to a sphere when K is near to 1 and flat, when K is near to zero. If $K=0$, the Jacobian matrix is singular, and if $K=1$ it is far from a singular position, the mechanism is in a velocity isotropic position.

4. CALCULATION OF THE MANIPULABILITY FOR INDUSTRIAL ROBOT

Among many other criteria we decided to use the condition number (3) for quantifying the mechanism manipulability [11]. For calculation of this parameter we need the robot's kinematic structure and its geometrical data. From the structure and the geometrical data the Jacobian matrix can be calculated in symbolic form. The eigenvalues are then calculated numerically. If the matrix is regular, the eigenvalues represent the lengths of all three axes of the velocity ellipsoid and therefore our parameter of velocity anisotropy is given according to (3).

5. EXAMPLE OF THE OTC AX-V4 INDUSTRIAL ROBOT

The robot AX-V4 is one from the new generation of OTC robots specially designed for MAG arc welding purposes. The speciality of this robot structure is a hollow arm, which is used to carry through the required installations and so enables better flexibility for welding because no wires and pipes are installed outside the robot structure. The payload of the robot is 4 kg and in Fig. 4 two layouts of the workspace are given. Both are from the data sheets of the robot.

With the introduced procedure for developing the workspace with included parameter of velocity anisotropy we get Fig. 5, where isometric projection of the workspace is given. Additional to this isometric projection two cross sections in the x-y and x-z direction through the robots base coordinate origin are shown in Fig. 6 and Fig. 7.

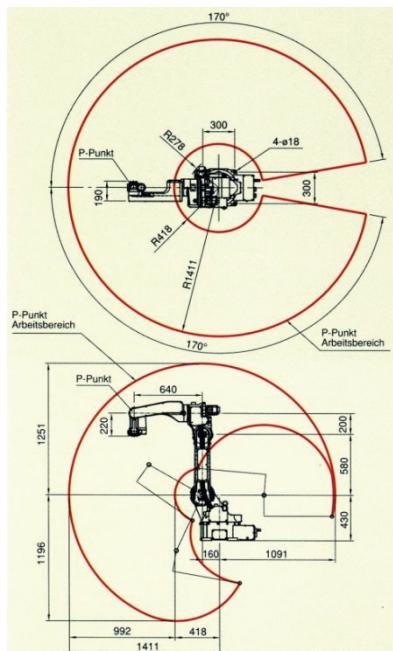


Fig. 4. Layouts of the workspace

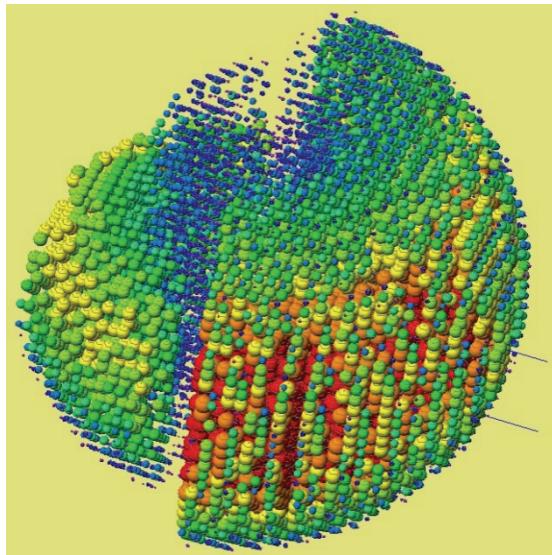


Fig. 5. Isometric projection of the workspace

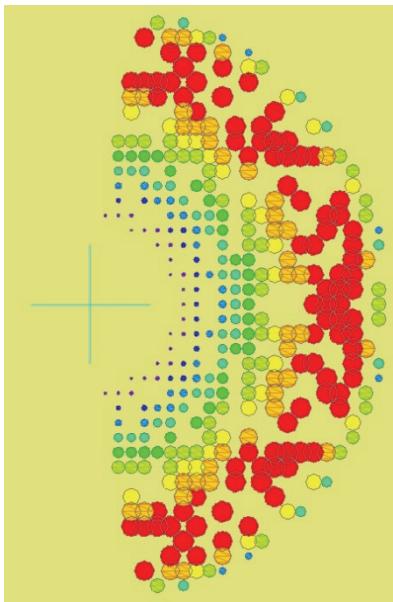


Fig. 6. X-Y cross section of the workspace

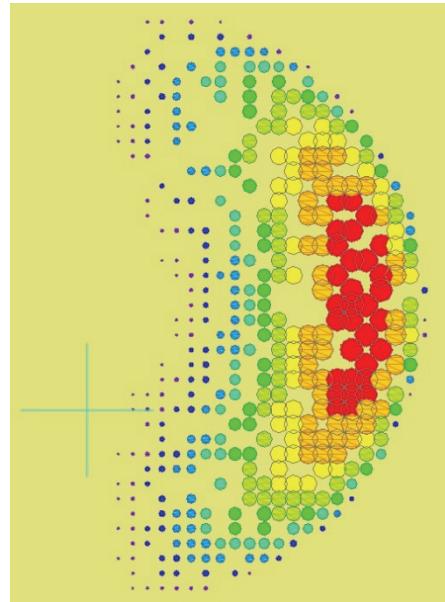


Fig. 7. X-Z cross section of the workspace

6. DISCUSSION AND CONCLUSION

The graphical presentation of velocity anisotropy in Fig. 5-7 is very useful for designing robotic systems for welding operations. Two shown layouts (Fig. 6 and Fig. 7) can be perfectly used for embedding the welded part into the workspace when the welds are positioned on the edges of the parts. In fig. 8a the welded part is set into the workspace perpendicularly to the robot. The robot can move parallel to the part. The area of high manipulability is too small

according to the dimensions of the part and the robot cannot completely cover it with sufficiently high manipulability. If we rotate the robot's axes for 90°, Fig. 8b, so that the robot is parallel to the welded part, then the workspace area of higher manipulability covers the welded part much better and we can expect better quality of welding on it.

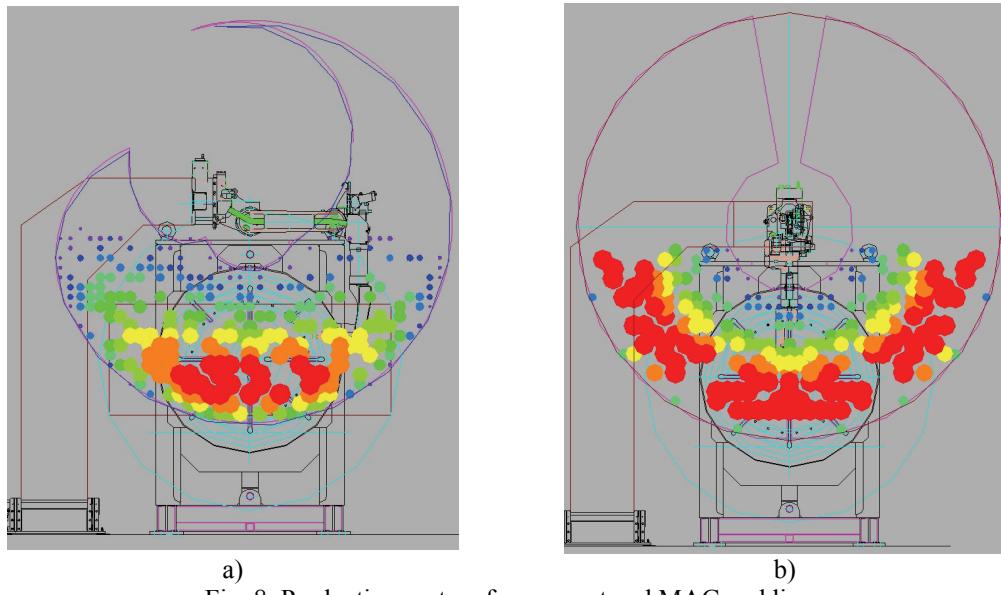


Fig. 8. Production system for arc spot and MAG welding

In the present paper a procedure for analyzing and 3D representation of robot's workspace is given. Additionally a parameter for velocity anisotropy in each point of the workspace is introduced. The velocity anisotropy is defined with the condition number.

To show the benefits of the presented procedure a realized robotised production system for MAG welding is presented in fig. 8a and b. In given figures it is clearly shown that the correct positioning of the work piece can guarantee better covering of all welding operations on the part (fig. 8b). The benefit of the introduced graphical representation of the anisotropy is the recognition of difficulties with welding in the edges of the part during the design of the robotic system. The position of the robot could be displaced before the production system is finished and put into work.

From the designer's point of view the visualization of the velocity anisotropy is an important and useful tool, because it gives the possibility of over-viewing the robot's behaviour in the production system in the phase of designing and virtual simulations before the system is really produced.

The introduced tool helps the designer of production systems with additional data, which are not available from the producer's data sheets. With the given tool it becomes possible to avoid difficulties which appear when the robot is not properly positioned into the production system.

Today it is impossible to think about design without software tools which do not support 3D representation. The presentation of the velocity anisotropy of the robot's workspace is in 3D with the possibility of making arbitrary cross sections through it to get better insight into the behaviour of the velocity anisotropy inside the workspace.

7. REFERENCES

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