Solution of Forward Kinematics of Redundant Parallel Robot for Predictive Control

K. Belda, M. Valášek, J. Böhm*

belda@utia.cas.cz

CTU, Faculty of Mechanical Engineering,
Department of Mechanics, Division of Mechanics of Bodies.
* Institute of Information Theory and Automation, AS CR,
Deparment of Adaptive Systems
Pod vodárenskou věží 4, 182 08 Praha 8.

The most topical industrial robots and manipulators do not cope with increasing requirements on speed and accuracy. Therefore, the new approaches to their construction are being found. Parallel robots, especially redundantly actuated, seem to be one of the promising ways to solve these requirements. And, moreover, they have several advantages over traditional serial robots.

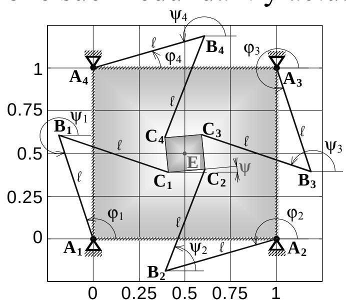
The main is the following:

- All or almost all drives are located on the basic frame and truss construction of the robot leads to higher stiffness than in serial types. It is advantageous for accurate machining and positioning.

On the other hand the parallel robots have one constrain:

- That is given in more possibility of arms collision. But this can be solved if this constraint would be taken into account at the planning of desired trajectory. However, this disadvantage does not markedly keep down movement of the robot.

As an example, let us consider one such redundantly actuated planar parallel robot.



It consists of the basic frame, which at the same time encloses workspace of the robot, four independent drives, movable platform and eight arms, which connect the movable platform with the basic frame. The arms are parallely situated.

From the mechanical point of view, this robot has one drive and one pair of arms redundant, because generally the number of degrees of freedom of body in a plane is only three. Accordingly, for control of the robot and for its mechanical determination, only three pairs of appropriate arms are necessary. But in this case, the singular position in the workspace will appear. Therefore the redundant drive is used in order to overcome the problem. And, moreover, it improves stiffness and rotation speed of movable platform and gives the possibility to comply with the other additional control requirements.

The aim of this work is investigation of the direct kinematics for real-time control of redundant parallel structure of the robot at using of the specially planned trajectory.

Firstly the work focuses on the trajectory planning. It provides that the planned trajectory has the first derivation continuous and smooth and at the same time the second derivation is also continuous and segmentally smooth. And the following part briefs the solution of the direct kinematics.

The coordinates appearing in the branch of robots and manipulators may be divided into drive coordinates $\mathbf{q}_1$, operational $\mathbf{x}$ and other ancillary coordinates $\mathbf{q}_2$. All these coordinates are either independent (their number equals number of degrees of freedom) or dependent. Between them there are relations generally expressed by system of nonlinear equations: $f(\mathbf{x}, \mathbf{q}_1, \mathbf{q}_2) = \mathbf{0}$.

The direct kinematics solves problem of recomputing the drive coordinates $\mathbf{q}_1$ on operational, in our case, independent coordinates $\mathbf{x}$. In comparison with the classical robots, where it is not difficult, the direct kinematics of the parallel robots especially redundantly actuated is not simple task. Then, we find the function $\mathbf{x} = f(\mathbf{q}_1)$, which unfortunately is not analytically solved.

We have several possibilities, how to solve this. Either we can use classical numerical solution or engineering solution in the form of control task.

Numerical solution is based on Newton's method, which is applied on nonlinear relation between operational and drive coordinates. By this, the systems of linear algebraic equations are obtained, which can be already solved relative to the required operational coordinates. The Newton's method is not bad, but it is slower. It is caused by its iteration character of the algorithm.

The latter approach for determination of the operational coordinates uses properties of differential kinematics. It includes computation of the jacobian of the system, which expresses the linear dependence of the derivatives of the both drive and operational coordinates. By numerical integration the operational coordinates can be obtained. This work shows the solution using the differential kinematic approach and discusses the problems, which appear at the design of such way.

Presented approaches to the direct kinematics (Newton's method and differential kinematics) are suitable for simulation and mainly for real time using. They were successfully tested and differential kinematics was implemented to the real time control tracking.

References:

[1] SCIAVICCO, L. – SICILIANO, B.: *Modeling and Control of Robot Manipulators* McGraw-Hill, 1996.

[2] STEJSKAL, V. – VALÁŠEK, M.: *Kinematics and Dynamics of Machinery* Marcel Dekker Inc. 1996.

[3] BELDA, K.: *Graphical Environment for Simulation of the Control of Planar Redundant Parallel Robot* VŠCHT Praha, 2000, pp. 38–42.

[4] VALÁŠEK, M.: *Dynamic Time Parametrization of Manipulator Trajectories* ÚTIA AV ČR, 1987, pp. 155 – 174.

This research has been supported by CTU grant No.300104412, GAČR grant No.101/990729.