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MANIPULATOR TRAJECTORY AND WORKSPACE IN THE MATLAB AND MSC ADAMS ENVIRONMENTS

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Abstract: *The contribution is dedicated to computer modelling and its application in the design of mechanical systems with a focus on manipulator and robot models. This article discusses the use of Matlab/Simulink and MSC Adams/View programs in the design and subsequent analysis of a robot model. Attention is given to direct and inverse kinematics. We provide an example of solving inverse and direct kinematics, as well as an example of using the Adams program in the design and simulation of a mobile robot.*

Keywords: Direct kinematics, inverse kinematics, simulation, trajectory, workspace.

1. Introduction

The first steps in robotics were robots with a fixed platform for manipulation tasks (Fig. 1a). The mechanisms of industrial robots and manipulators consist of bodies that form various types of kinematic chains. This has been addressed by numerous authors (Siciliano and Khatib, 2008; Murray et al., 1994; Khalil and Dombre, 2002). In most cases, these mechanisms represent open or mixed kinematic chains. Two bodies of a kinematic chain interconnected so that their mutual mobility is limited form a kinematic pair (Fig. 1a–c). Depending on the type of kinematic constraint in the kinematic pair, kinematic chains are composed of translational or rotational kinematic pairs. When designing mechanisms such as industrial robots, reliable calculation of the relevant kinematic quantities is necessary. These quantities then allow further scaling of individual parts of the mechanism. To achieve this goal, we use simulation models and computer modelling (Swevers et al., 2007).

In the first part of the paper, we delve into the theory of simple open kinematic chains, which are utilised in the construction of various manipulators and robots. We describe the method of determining angular quantities of an open kinematic chain with two links by solving inverse kinematics. The trajectory of the end effector is determined by a fifth-degree polynomial. Subsequently, the angular quantities are determined by solving inverse kinematics. The direct kinematic task is used to determine the workspace. Workspaces are provided for various angular constraints at the manipulator's joints.

In the second part, MSC Adams-View software is used for the design and optimization of the trajectory of a two-link robotic arm (Frankovský et al., 2012, Delyová et al., 2014). Simulation software like MSC Adams is an excellent tool for dynamic analysis of various complex interconnected mechanical systems, being fast and very efficient (Vavro et al., 2017). It allows for evaluating the results in graphical form (Tedeschi et al., 2017). In the final section of the paper, we assess the results of the kinematic analysis.

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2. Direct and inverse analysis

This part of the paper demonstrates the solution to the direct and inverse kinematic tasks. The model of a two-link robotic arm is used. This two-link manipulator can be found, for example, in Scara manipulators shown in Fig. 1b). The manipulator workspace is also illustrated. The inverse kinematics task is to determine the angular coordinates of the actuators given the coordinates of the end effector position. Eqs, (1) and (2) are used. The solved Scara model belongs, in terms of kinematics, to simpler models and we can solve it analytically. The solution will be based on the scheme of the two-link robotic arm in Fig. 2a–c and Eqs. (1) and (2).

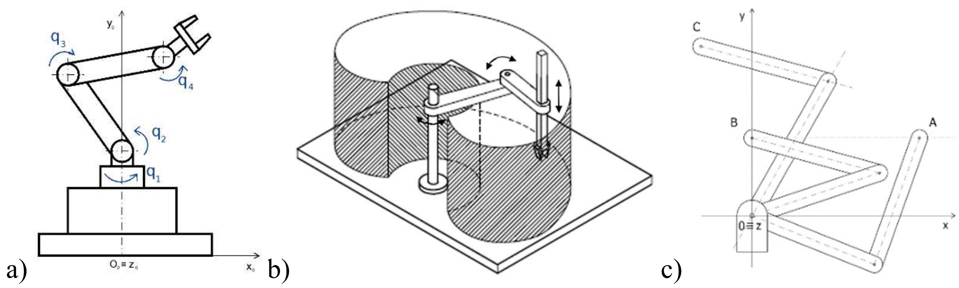

Fig. 1: a) Model of the 4R manipulator, b) Scara manipulator with workspace, c) two link manipulator.

The manipulator consists of arms with lengths L_1 = 0.22 [m] and L_2 = 0.19 [m], fixed to a solid base. This could be a stand or the arms could be on a mobile chassis, if it were a service robot. A manipulator with a fixed base and two arms has 2 degrees of freedom. We will investigate the motion of the two arms of the manipulator in the plane in Fig. 2a–b.

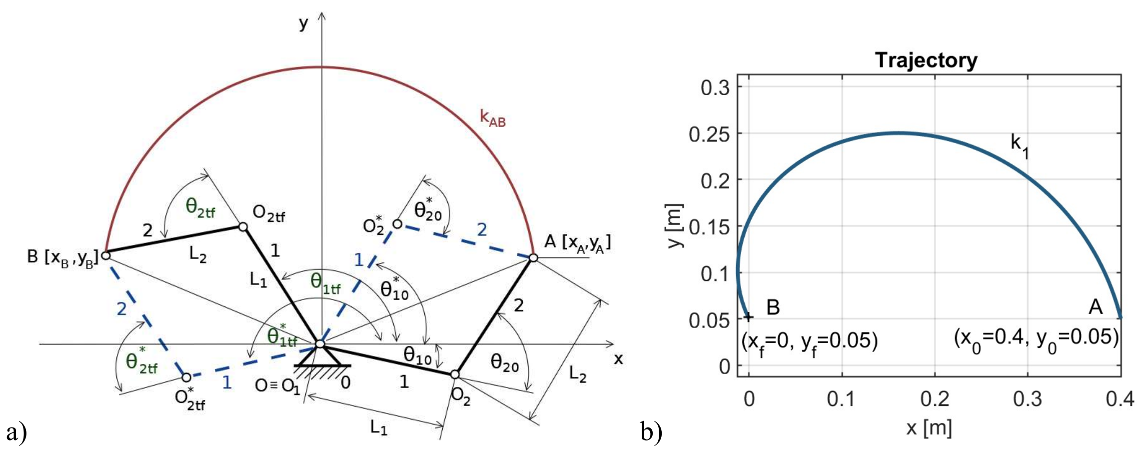

Fig. 2: Model of the two arm manipulator with angles θ_{1t0}, θ_{2t0}, θ_{1tf}, θ_{2tf} and with trajectory k_{AB}.

The rotation angle in individual kinematic pairs is denoted by angles θ_1, θ_2 according to Fig. 2a. Each link is assigned a coordinate system 0_i, x_i, y_i, z_i, and each joint is assigned a generalized coordinate q_i, which is defined along the axis of rotation (Fig. 2a). Generalized coordinates determine the instantaneous position of the body. We denote them as q_1, q_2 (Fig. 2a). It holds for generalized coordinates $q_1 = \theta_1$, $q_2 = \theta_2$. We assume that the drives are located in rotational kinematic pairs.

To determine the angles, we will use the Eqs. (1) and (2) provided below. There is typically more than one solution, as seen in Fig. 2a. We will address the task during the movement of the end effector of the second arm, between the individual points A, B, C, D, E according to Fig. 3a–c. The conversion of coordinates x_A, y_A using generalized coordinates θ_1, θ_2 stems from the geometry shown in Fig. 1a:

$$x_A = L_1 \cdot cos(\theta_1) + L_2 \cdot cos(\theta_1 + \theta_2) \quad (1)$$

$$y_A = L_1 \cdot sin(\theta_1) + L_2 \cdot sin(\theta_1 + \theta_2) \quad (2)$$

With the known position of x_A and y_A , the solution for the two unknown angles θ_1 and θ_2 is determined by solving the two equations (1) and (2). This involves solving the inverse kinematics problem.

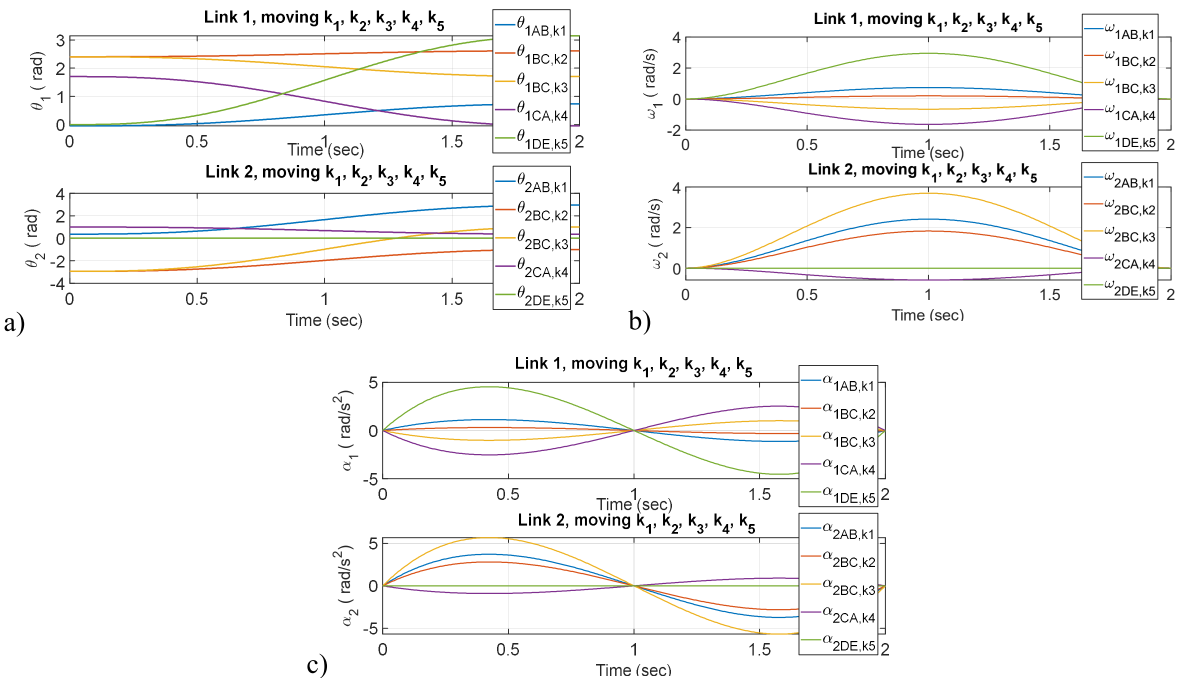

Fig. 3: The progression of angular quantities during individual movements along curves k_1 to k_5.

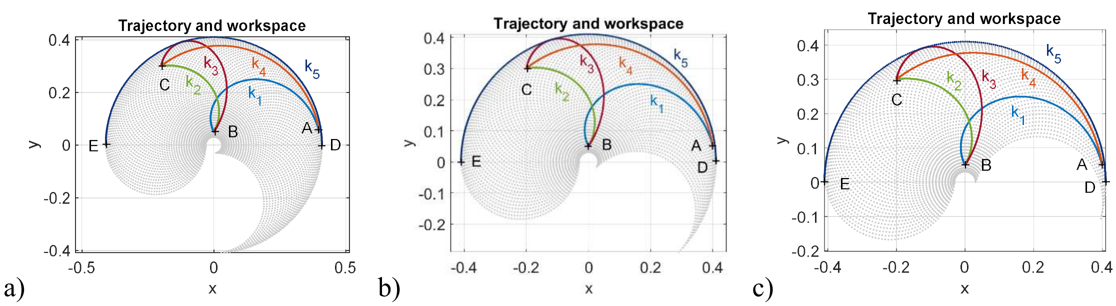

Fig. 4: The diagram of the trajectories k_1, k_2, k_3, k_4, k_5 and the workspace.

3. Simulation using MSC Adams

The improvement in computing technology has led to the development of computer methods in the field of complex spatial mechanical systems. MSC Adams employs an object-oriented programming environment with animated simulation. It simulates complex mechanical systems with multiple degrees of freedom. Models are defined directly by the geometry of individual bodies and their kinematic constraints, driving forces, and motion generators. We present a simulation of a robot in MSC Adams.

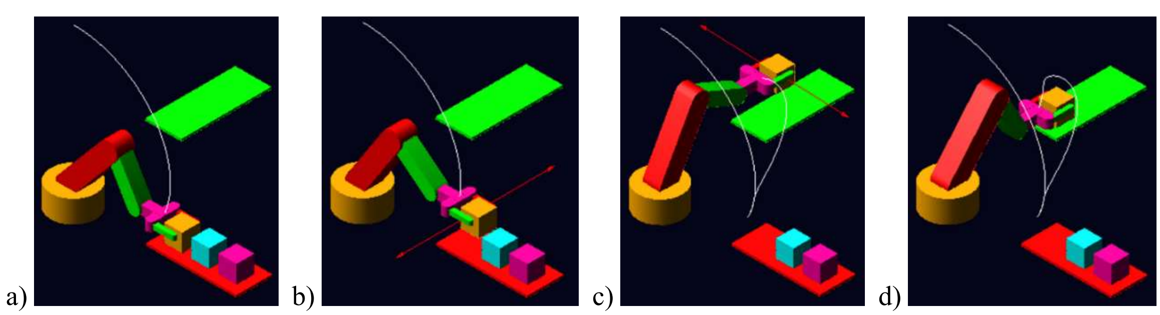

Fig. 5: Time plots of trajectories.

Computer modelling of prototypes is a highly convenient tool for creating, processing, editing, and presenting simulation results in the form of graphs. Graphs of output variables allow for viewing real-time values of measured quantities during the simulation itself (Fig. 6a-d). With multibody modelling software, there's no need to solve mathematically described motion with equations of motion. We only utilize information about the geometric parameters of the designed model. An example of a manipulator model is shown in Fig. 6a-d, illustrating various views of the manipulator simulation model in the MSC Adams View program during multibody modelling with depicted end-point trajectories.

The progression of angular rotation and angular velocity determined by simulation in the program is processed by the Postprocessor, and the graphs are shown in Fig. 6.

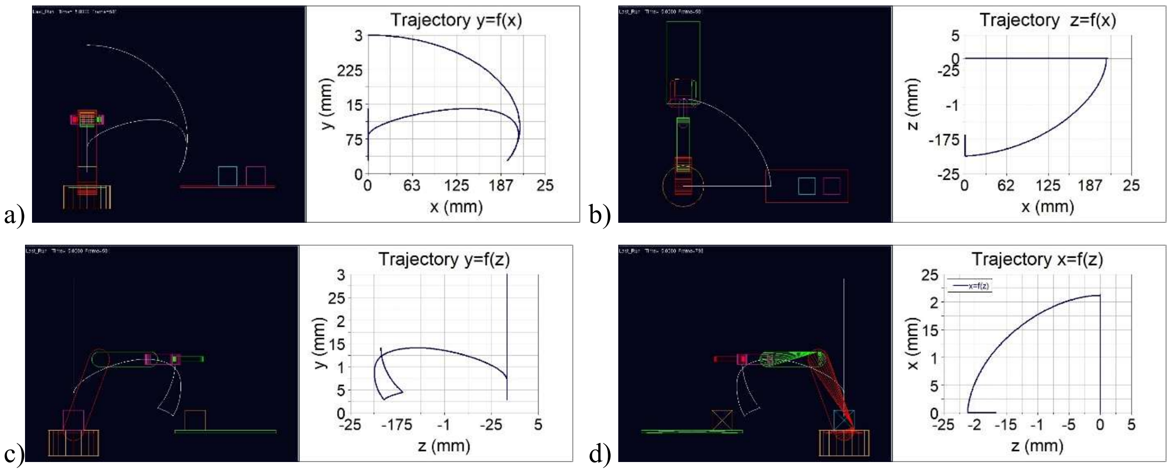

Fig. 6: Relations of kinematic quantities of member 1 of the bound system.

4. Conclusion

The article presented the kinematic analysis of a two-link manipulator using simulation in Matlab and MSC Adams/View. The direct and inverse tasks are solved in Matlab. The results are depicted in the form of time diagrams of the investigated variables. The trajectories of motion and workspace are shown. MSC Adams provides tools for virtual prototyping, model visualization, and easier evaluation of the obtained results. It allows simulating the motion of multibody mechanical systems, making it a suitable aid for teaching and practice. The contribution of this work is mainly didactic, particularly in the field of applied mechanics and mechatronics, presenting the possibility of computer simulation.

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