Geometric parameters identification of the didactic robot ROMIK

1 The aim of the exercise

The aim of this exercise is to become familiar with the kinematic structure of the didactic robot named ROMIK and the identification of its geometric parameters.

2 Basis theory

2.1 ROMIK robot characteristic

The didactic robot ROMIK is a small manipulator driven by the stepped motors. The main device of the electronic controller is a MC68332 microcontroller. The PC and the robot controller are connected together as a standard master–slave connection using asynchronous serial interface (19200, 8N1). The whole system allows to set the joint position and read the temporary motors position (m_i). The variables value of the motors position are presented as integers counted from a certain starting position and noticed the step number of the motors. The starting position of every motor is automatically set at the start up (synchronise procedure). In this robot's configuration, named **synchronise configuration**, every position counter of the motors is set at the 5000 value. Every shut down of the motors resets the counters value and the synchronise procedure is necessary.
Thanks to directly driven axes in joint 1 and 2, the limit switch is reached in the particular angular position $\{\theta_{Si} = q_{Si}|\ i = 1, 2\}$ which corresponds with the particular motors position m_{S1}, m_{S2}. However, the indirect drive in the joint 3 (relative to link 1, not link 2) causes that the limit switch in this joint is reached when the angle $\theta_{S3} = q_{S3} - q_{S2}$, so there is more than one value in the angles q_2, q_3 as well as in matching motors positions m_2, m_3.
Similar, in joints 4 and 5 the drive is indirect and it is also related to the link 1, and is provided by the differential drive. The change in angle q_4 is proportional to sum of the changes in the motors position $m_4 + m_5$, and the changes in angle q_5 to its difference $m_5 - m_4$. The fact causes, similar as in joint 3, that the limit switches are reached in many configurations of the

angles q_3, q_4, q_4.

2.2 Kinematic structure for joint coordinates θ_i

The diagram of the didactic robot ROMIK is presented in the pict. 1. At the end of every link the corresponding coordinate system is attached. The axes X_1 and X_2, from the basis coordinate system, determine the robot planar surface. Axes Z_1, Z_2, Z_3, Z_4 are perpendicular to the planar surface.

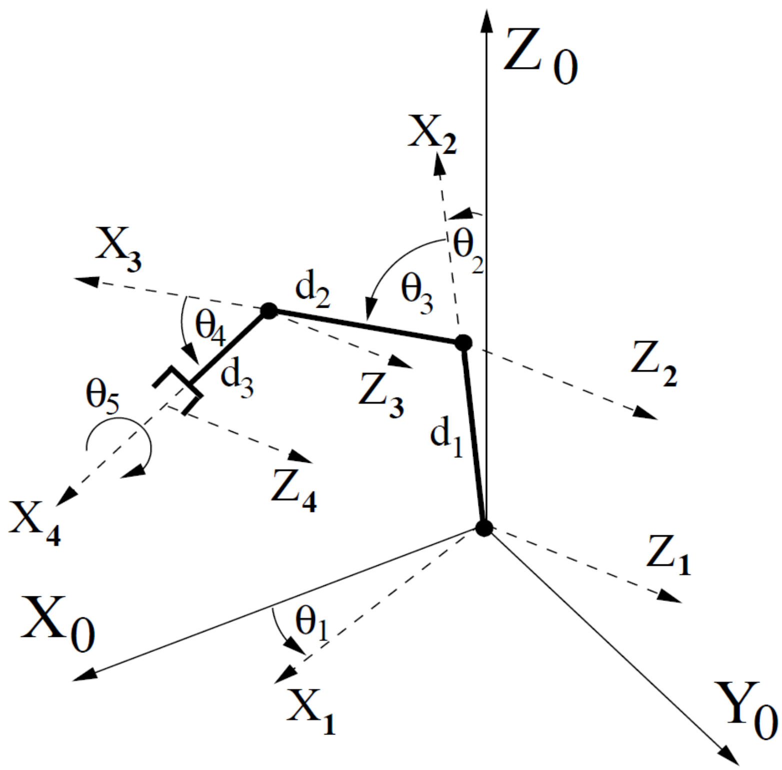

Figure 1: The didactic robot ROMIK kinematic structure for standard joint coordinates

Joint coordinates:

- θ_1 – rotate angle of the base column [°],
- θ_2 – angle between the arm and the vertical (axis Z_0) [°],

- θ_3 – angle between the forearm and the arm [°],
- θ_4 – angle between the end–effector and the forearm [°],
- θ_5 – rotate angle of the end–effector [°],
- θ_6 – end–effector spacing [mm].

The task–space coordinates:

- x, y, z – cartesian coordinates of the end–effector in a basis system $X_0Y_0Z_0$ [mm],
- β – angle between end–effector's axis and the horizontal plain [°],
- ϕ – rotate angle of end–effector [°],
- s – end–effector spacing [mm].

2.3 Denavit–Hartenberg notation for θ_i

Forward kinematics model for ROMIK robot is obtained by using Denavit–Hartenberg notation. The Denavit–Hartenberg transformation between local coordinate systems corresponding with every pair of links

$$\begin{aligned}
0-1 &: A_1(\theta_1) = Rot(z,\theta_1)\cdot Rot(x,-90^\circ),\\
1-2 &: A_2(\theta_2) = Rot(z,\theta_2-90^\circ)\cdot Trans(x,d_1),\\
2-3 &: A_3(\theta_3) = Rot(z,\theta_3)\cdot Trans(x,d_2),\\
3-4 &: A_4(\theta_4) = Rot(z,\theta_4)\cdot Trans(x,d_3),
\end{aligned}$$

where d_i are the geometric parameters of the robot

- d_1 – length of the arm [mm],
- d_2 – length of the forearm [mm],
- d_3 – length of the end–effector [mm].

2.4 Kinematic structure for modified joint coordinates q_i

Due to driving construction of the robot, the following modifications are convenient

- q_1 – rotate angle of the base column [°],
- q_2 – angle between the arm and the vertical (axis Y_1) [°],
- q_3 – angle between the forearm and the vertical (axis Y_1) [°],
- q_4 – angle between the end–effector and the vertical (axis Y_1) [°],
- q_5 – rotate angle of the end–effector [°],
- q_6 – end-effector spacing [mm].

The diagram of the didactic robot ROMIK with modified joint coordinates is presented in pict. 2.
Task–space coordinates are the same as for standard joint coordinates.

2.5 Denavit–Hartenberg notation for q_i

The Denavit–Hartenberg transformation for modified coordinates correspond to local coordinate systems in pict. 2 is then

$$
\begin{aligned}
0-1 &: A_1 = Rot(z, q_1) \cdot Rot(x, -90°),\\
1-2 &: A_2 = Rot(z, q_2 - 90°) \cdot Trans(x, d_1),\\
2-3 &: A_3 = Rot(z, q_3 - q_2) \cdot Trans(x, d_2),\\
3-4 &: A_4 = Rot(z, q_4 - q_3) \cdot Trans(x, d_3).
\end{aligned}
$$

It can be noticed that relations between the standard joint coordinates θ_i and the modified coordinates q_i are

$$
\begin{aligned}
q_1 &= \theta_1,\\
q_2 &= \theta_2,\\
q_3 &= \theta_2 + \theta_3,\\
q_4 &= \theta_2 + \theta_3 + \theta_4,\\
q_5 &= \theta_5,\\
q_6 &= \theta_6.
\end{aligned}
$$

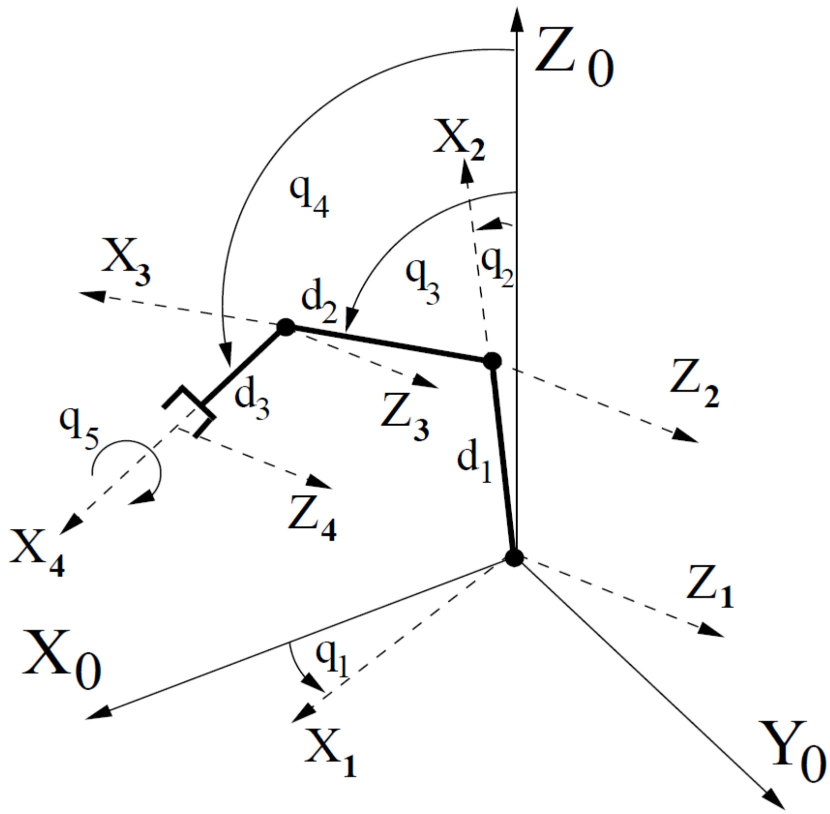

Figure 2: The didactic robot ROMIK kinematic structure for modified joint coordinates

3 Exercise description

3.1 Workplace manual

The workplace is composed of robot ROMIK and PC connected together via serial interface (ttyS1 – COM2). The PC program `ident` can be started from the console in the `Linux` operating system.
The robot ROMIK should be placed at the table edge, in that way that the side with power switch is parallel to the edge.
Before the program starts, the robot power should be turned on and the synchronise procedure will end (all motors will stop). After starting the `ident` application the synchronise procedure starts again, and the following

menu will appear on the screen:

```
Identyfikacja parametrow geometrycznych robota ROMIK
```
Geometric parameters identification of the robot ROMIK

```
Synchronizacja zakonczona.
```
Synchronisation done.

```
Przestrzen napedowa:
m1= 5000 m2= 5000 m3= 5000
m4= 5000 m5= 5000 m6= 5000
```
Motors state–space:

```
Przestrzen konfiguracyjna:
q1= 89.08 q2= -31.37 q3= 86.64
q4= 16.09 q5=   0.00 q6=  0.00
```
Joint state–space:

```
Przestrzen zadaniowa:
x=  1.94 y= 120.08 z= 263.92
b= 16.09 f=   0.00 s=   0.00
```
Task–space:

```
I. Ustawienie pozycji we wspolrzednych wewnetrznych
```
I. Setting of the joint coordinates position
```
X. Odczytanie pozycji we wspolrzednych zewnetrznych
```
X. Reading of the task-space coordinates position
```
Q. Koniec
```
Q.Quit

Command `I` allows to set the robot configuration in q_i coordinates (empty line leave the particular value unchanged). At the end of input the motion starts. Command `X` outputs the robots position in three coordinates systems:

- $\{m_i\}$ – motors state–space (motors position in pulses),
- $\{q_i\}$ – joint state–space,
- $\{x, y, z, \beta, \phi, s\}$ – task–space.

Command `Q` ends the `ident` application and turns off the motors.

3.2 Preliminary exercise preparation

1. Using Denavit–Hartenberg transformation (see sect. 2.3) to calculate forward kinematics

$$(\theta_1, \ldots, \theta_6) \to (x, y, z, \beta, \phi, s) \tag{1}$$

   or

$$(q_1, \ldots, q_6) \to (x, y, z, \beta, \phi, s). \tag{2}$$

2. Think how to choose the robot's configuration which allows to determine robot's geometric parameters d_1, d_2 and d_3.

3.3 Task to do

Using the `ident` application performs few robot configuration changes and defines the position of the basis coordinate system. Define the limits of each joint coordinates θ_i (or q_i). To identify the robot's geometric parameters d_i begin with setting the certain robot's configuration. Next, for this configuration read the task–space coordinates value from the application. Basing on this data and previously defined forward kinematic, compute the geometric parameters d_i.