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The modeling of an anthropomorphic robot arm

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Abstract. This paper considers the anthropomorphic manipulator kinematics modeling problem. The considered anthropomorphic robot SAR-400 manipulator with five-fingered gripper has twelve degrees of freedom. In the paper the robot SAR-400 arm kinematic model and the simulation results are presented.

1 Introduction

From a mechanical point of view, like a human arm, the anthropomorphic robot arm is a kinematically redundant object [1]. Usually the anthropomorphic robot arm has seven degrees of freedom (DOF) from the shoulder to the wrist [1]. Kinematic redundancy leads to the abilities for robot manipulator to perform the end effector translation to a given position by an infinite number of trajectories. Such redundant manipulators have increased maneuverability and allow the manipulators to avoid falling into singular states and also can be effectively used in complex space-limiting areas [1–4].

There are two approaches are generally used for trajectory formation of such kinematically redundant manipulators. The one approach is based on finding the pseudo-inverse Jacobi matrix and it can be used to determine the DOF velocities [5]. Thus, the required generalized coordinates increments can be determined by obtained velocities. The movements determining problem in redundant degrees of freedom allows manipulator to eliminate singular states, to avoid obstacles, and so on. Also, along with the requirement to move the end effector to an assigned position, additional goals can be reached. There are a number of other approaches, including those based on the fuzzy logic use to solve the inverse kinematics problem [6, 7], but the gradient method is the most commonly used method for avoiding the constraints of mechanical joints when forming manipulator trajectory [1–4].

In this paper we consider the problem of anthropomorphic robot arm modeling. As a real research object, the left anthropomorphic robot SAR-400 [8] arm is considered. The robot arm modeling emulates human-like motions from the kinematics point of view. The paper is organized as follows. Section II describes the basic structure and features of the anthropomorphic robot SAR-400. The robot arm kinematics description is given in section III. Section IV illustrates forward and inverse kinematics modelling results of SAR-400 arm. Finally, section V summarizes the results and conclusions.

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2 The anthropomorphic robot SAR-400

The robot SAR-400 [8] is a torso manipulator, which has an anthropomorphic structure and consists of a base frame, a body mounted on it, on which are mounted two anthropomorphic manipulators with five-fingered grippers, a head unit with a computer stereo vision system (fig.1). This figure shows: 1 – head unit; 2 – compartment of stereo video cameras; 3 – rotary mechanism of the head unit; 4 – torso unit; 5,6,7,8 – rotational kinematic pairs of the manipulator; 9 – five-fingered gripper; 10 – rack for SAR-400. Each robot arm is a multi-link manipulator with 12 degrees of freedom. The values of robot SAR-400 parameters are listed in the table 1.

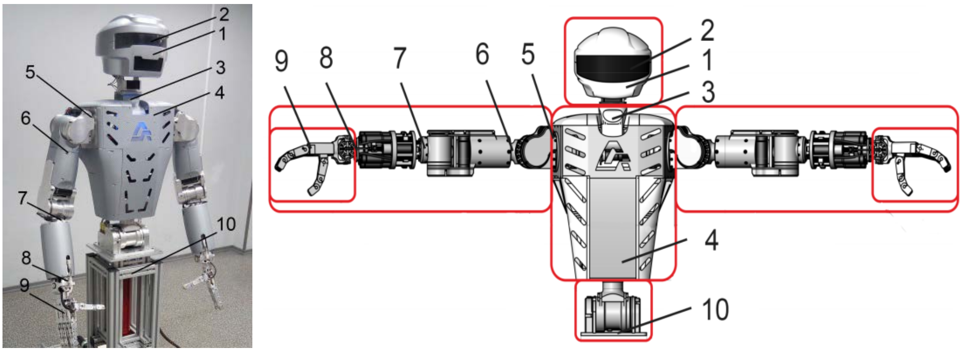


Fig. 1. The robot SAR-400

Table 1. The anthropomorphic robot SAR-400 parameters.

Parameters	Robotic arm of SAR-400
Total number of DOF Number of Robot arm DOF	31 12
Weight	70.0 kg (with hand 1.2 kg)
Height	825 mm
Arm joint type	Revolute
Robot arm length	Shoulder to wrist (290 mm) Elbow to wrist (280 mm)
Rotational speed of joint drives Rotation speed of gripper drives	170 deg/s 110 deg/s
Accuracy of fixing the position of the joints	12 bit (4 096 pulses per rotation)

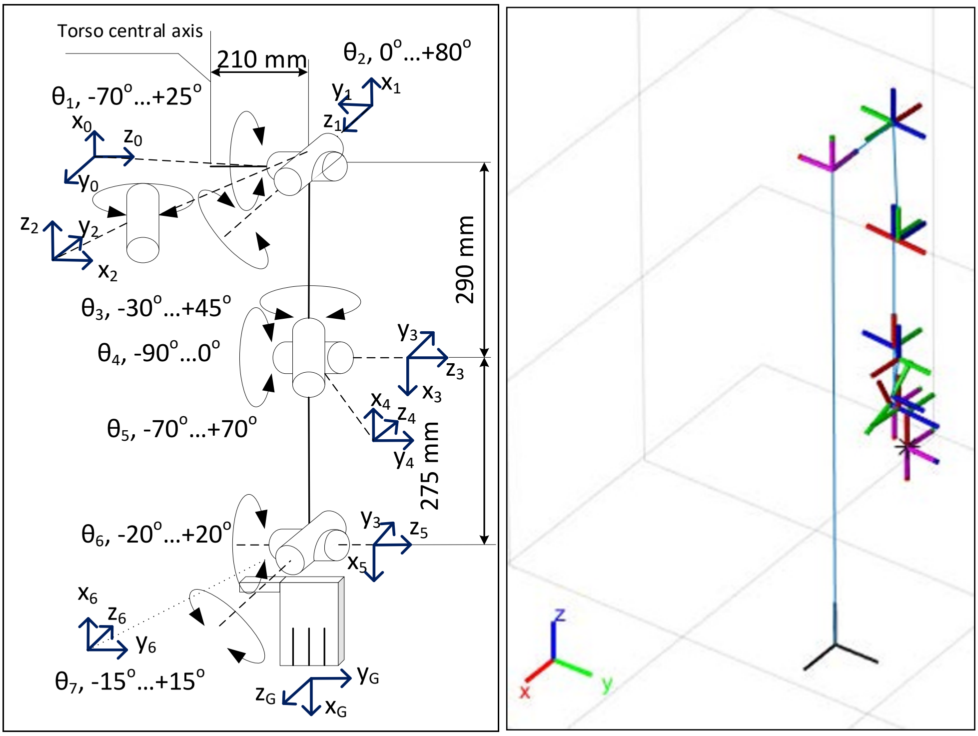
3 The kinematics model of robot SAR-400 arm

The Fig. 2-a shows the coordinate systems and connection lines of the 12-DOF robot arm using the Denavite-Hartenberg convention that allows the construction of the forward kinematics function by composing the coordinate transformations into one homogeneous transformation matrix.

The coordinate transformation description from (i–1)-th to i-th frames is given by the homogeneous transformation matrix [3, 4]

$$A_i(\theta_i) = \begin{pmatrix} C\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & a_i C\theta_i \\ S\theta_i & C\alpha_i C\theta_i & -S\alpha_i C\theta_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} n_{xi} & o_{xi} & a_{xi} & p_{xi} \\ n_{yi} & o_{yi} & a_{yi} & p_{yi} \\ n_{zi} & o_{zi} & a_{zi} & p_{zi} \\ 0 & 0 & 0 & 1 \end{pmatrix}.$$

where $C\varphi_i$ and $S\varphi_i$ are $\cos(\varphi_i)$ and $\sin(\varphi_i)$, respectively.



a) b)

Fig. 2. Coordinate systems of robotic arm.

As far as it known [4] there are some situations when the Denavite-Hartenberg method do not allows us to construct joint frames effectively enough. For instance, this situation may appear when there is a necessity of describing hierarchical rigid body constructions by Denavite-Hartenberg method. In these cases, the resolution may be implemented by using auxiliary fixed frames that also can be described by Denavite-Hartenberg parameters. This ability is used into Matlab software in Robotics System Toolbox [9].

By using Matlab notation of Denavit-Hartenberg parameters the joint frames are formed by presented in Table 2 parameters. Here the index finger tip is chosen as an end-effector and is defined as a fixed joint. The little finger is omitted since it is synchronized to the ring finger. The Fig. 2-b shows the initial robot state defined into Matlab environment.

Since having defined a frame for each joint, the coordinate transformation describes the position and orientation of the end-effector with respect to the base frame is given by [3]

$$T = \prod_i A_i(\theta_i) = \begin{pmatrix} \vec{n} & \vec{o} & \vec{a} & \vec{p} \\ 0 & 0 & 0 & 1 \end{pmatrix},\ i \in \{1-7,\ 10\}$$

where θ_i is the joint variable, $\vec{n}$, $\vec{o}$ and $\vec{a}$ are the unit vectors of the attached to the end-effector frame, and $\vec{p}$ is the position vector of the origin of this frame with respect to the origin of the reference frame (fig. 2).

Table 2. Denavit-Hartenberg parameters of the robotic arm.

joint name	***joint type***	a_i, **mm**	α_i	d_i, **mm**	θ_i	**range**
shoulder_pan_joint	fixed	0	90°	1205	–90°	
shoulder_roll_joint	revolute	0	–5°	210	$\theta_1 + 90^{\circ}$	–70°.. 25°
shoulder_lift_joint	revolute	0	–90°	0	$\theta_2 + 0$	0.. 80°
upper_arm_roll_joint	revolute	0	–90°	0	$\theta_3 - 90^{\circ}$	–30°.. 45°
elbow_flex_joint	revolute	–12	90°	–290	$\theta_4 + 90^{\circ}$	–90°.. 0
forearm_roll_joint	revolute	–12	90°	0	$\theta_5 - 180^{\circ}$	–70°.. 70°
wrist_flex_joint	revolute	0	90°	–275	$\theta_6 - 180^{\circ}$	–15°.. 15°
wrist_twist_joint	revolute	0	90°	0	$\theta_7 + 90^{\circ}$	–20°.. 20°
thumb_rool_joint	revolute	25	–90°	–34	$\theta_8 - 90^{\circ}$	–100°.. 0
thumb_flex_joint	revolute	20	–90°	–84	θ_9	–5°.. 135°
fingers_joint	fixed	150	180°	0	+180°	–155°.. 5°
index_finger_joint	revolute	0	0	34	θ_{10}	–155°.. 5°
index_finger_tip_joint	fixed	90	0	0	0	
ring_finger_joint	revolute	0	0	–11	θ_{11}	–155°.. 5°
middle_finger_joint	revolute	0	0	12	θ_{12}	–180°.. 5°

4 Modelling of forward and inverse kinematics

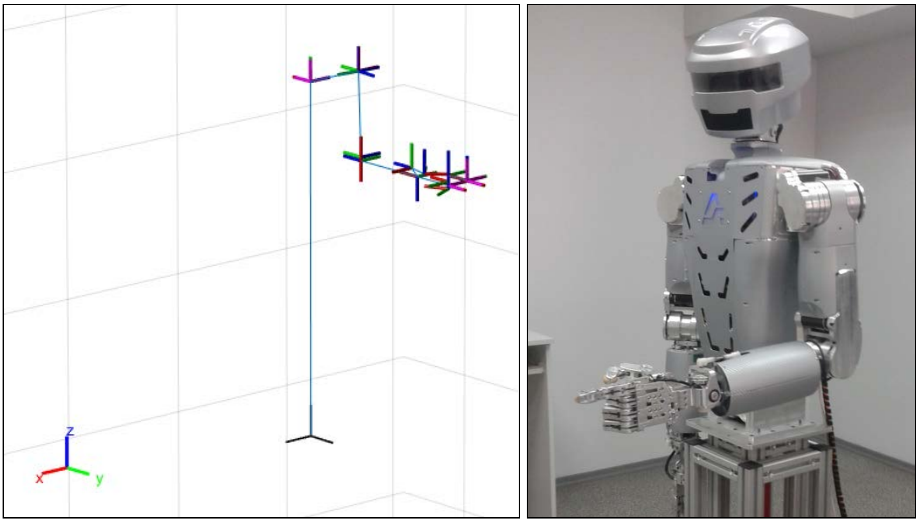
Let us first discus the forward kinematics solution. To emphasize the end-effector position let $\theta_8 = 0^o$, $\theta_9 = 135^o$, $\theta_{11} = -155^o$, $\theta_{12} = -180^o$. Then to check the given kinematics model let the joint variable are $\theta_3 = 5^o$, $\theta_4 = -90^o$ and the rest one variables that define position of end-effector are zeros. Finally, T matrix is

$$T = \begin{pmatrix} 0 & -1 & 0 & -0.21 \\ 1 & 0 & 0 & 0.52 \\ 0 & 0 & 1 & 0.93 \\ 0 & 0 & 0 & 1 \end{pmatrix}.$$

The view of [$\vec{n}$ $\vec{o}$ $\vec{a}$] block coincide to chosen base axes, fig 3-a. The fig 3-b shows the robot SAR-400 position implementation. The robot control was implemented programmatically by using Matlab environment and the robot TCP/IP control protocol notation.

The inverse kinematics solution can be demonstrated by finding the appropriate the joint variables θ_i, $i \in \{1-7,\ 10\}$ to reach manipulator point $[-0.25 \quad 0.55 \quad 1.3]^T$, marked as big green dot in Fig. 4-a.

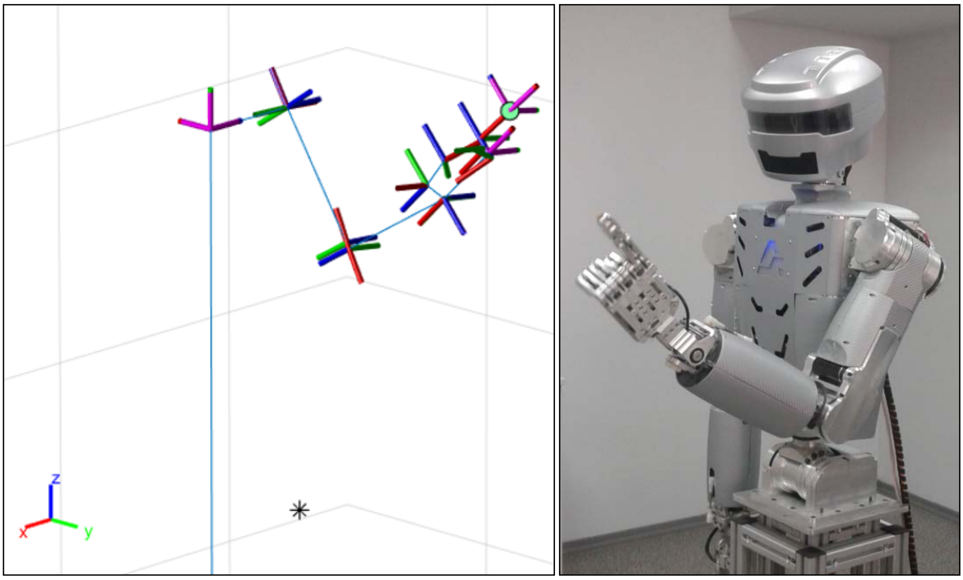
The inverse kinematics solution was given by using of the Matlab implementation of Broyden-Fletcher-Goldfarb-Shanno (BFGS) gradient projection algorithm. The found solution is $\theta_1 = -34^o$, $\theta_2 = 0^o$, $\theta_3 = 8.2^o$, $\theta_4 = -88^o$, $\theta_5 = 3.75^o$, $\theta_6 = -15^o$, $\theta_7 = -0.2^o$, $\theta_{10} = 5^o$.



a) b)

Fig. 3. Robotic arm pointed toward the base axes.

The implemented inverse kinematics solution is shown in Fig.4-b.



a) b)

Fig. 4. Inverse kinematics solution illustration.

5 Conclusions

The paper presents the forward and inverse kinematics solutions for the robot SAR-400 anthropomorphic arm. The kinematics model was built by using Denavit-Hartenberg method and implemented into Matlab environment. The given modeling results shows the success of declared paper tasks. The complete robot SAR-400 kinematics model building and solution of the dynamics problems are the issues of the future work.

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