COLLABORATIVE ROBOTS(COBOTS)-SYSTEMATIZATION AND KINEMATICS

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Abstract. The robotic arms of the human arm type, so-called collaborative robots or cobots, have been improved, optimized and diversified greatly in recent years. However, most of them are still equipped with mechanical grippers with pliers-like jaws. The paper presents the significant variants of collaborative robots now on the market, highlighting specific independent movements. It is shown and exemplified that solving direct and inverse kinematic analysis of these robots can be done with the method of homogeneous operators. It is recommended to equip these robots with anthropomorphic finger grips in order to obtain a maximum efficiency of their use.

Key words: Robotic arm, Human arm, Collaborative robot, Direct kinematics, Inverse kinematics.

1. INTRODUCTION

After the advent of industrial robots in technological processes, for a long time, as it happens nowadays to a large extent, industrial robots have been and are equipped for parts transfer operations, with mechanical grippers with jaws (see Fig. 5b). Robotic arms similar to the human arm were also developed and perfected, which became compact, precise and reliable. Thus, in the robotic technological processes, the classic industrial robots got to be replaced, as increasingly obvious trend, with robotic arms equipped with anthropomorphic grippers, fixed or mounted on mobile platforms, to the more complex shape of humanoid robots. In this way, it is possible to replace human operators with these variants of humanoid arms or robots.

2. TYPES OF COLLABORATIVE ROBOTIC ARMS

The industrial robot, respectively, the robotic arm had from the beginning as a model the human arm, with the mention that the initial variants of industrial robots had large dimensions, and some disproportions compared to the human

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arm. Anatomically and cinematically the human arm represented in Fig. 1, is characterized by several elements and seven independent movements (in *xyz* coordinate axis): three rotations in the shoulder (ω_1; ω_2; ω_3) one rotation in the elbow(ω_4), one rotation around the forearm (ω_5) and two rotations at the wrist level (ω_6; ω_7).

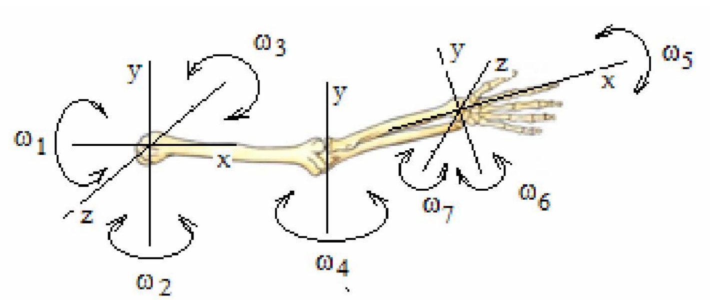
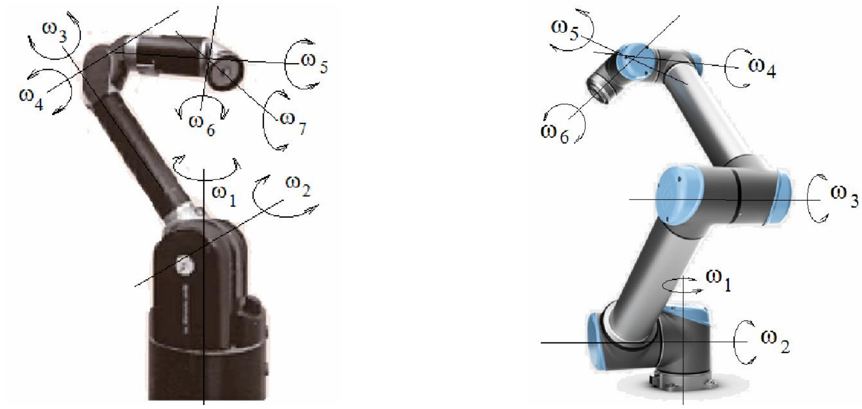


Fig. 1 – Anatomically and cinematically the human arm.

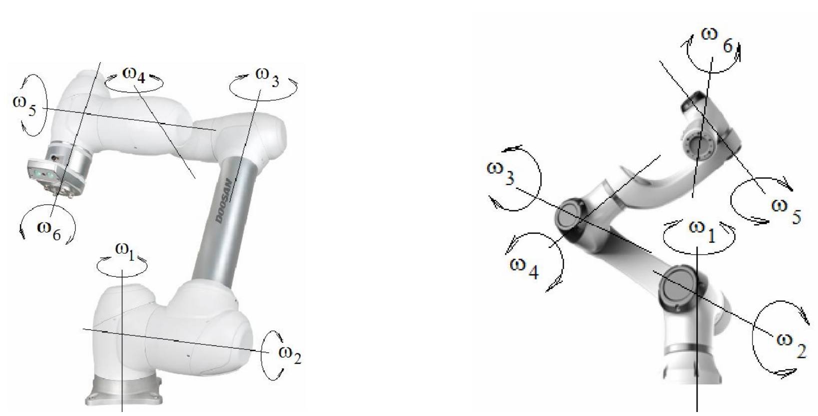
As we have already mentioned, the first variants of industrial robots only tried to copy the structure and kinematics of the human hand, direction in which they were partially successful. But in the last 10–15 years, robotic arm structures have appeared that are much more similar to the human arm and with comparable performance. Some of these variants will be presented(for each variant the independent movements are highlighted: $\omega_1,...,\omega_7$, corresponding to the number of degrees of freedom, an original contribution of this paper, useful for the easier understanding of the operation of these robots). The Barrett Arm (Fig. 2a) has been made since the early 2000s and is particularly accurate. The main features of this robotic arm are: height 42 cm, length 72 cm, width 34 cm, weight 27 kg, high speed and very good accuracy [1] . Fig. 2b shows the Universal Robot UR 10 robotic arm. Its main features are: it safely works alongside employees or separately, it automates tasks up to 22 lbs. (10 kg), its reach radius is up to 51.2 in. (1300 mm), 360-Degree rotation on each wrist joint, 6-axis capability; 0.1 mm repeatability, lightweight and mountable at only 24.3 lbs., easily programmed to switch tasks [2].



a) b)

Fig. 2 – Collaborative robots: WAM Barrett robotic arm (a); Universal Robot UR 10 robotic arm (b).

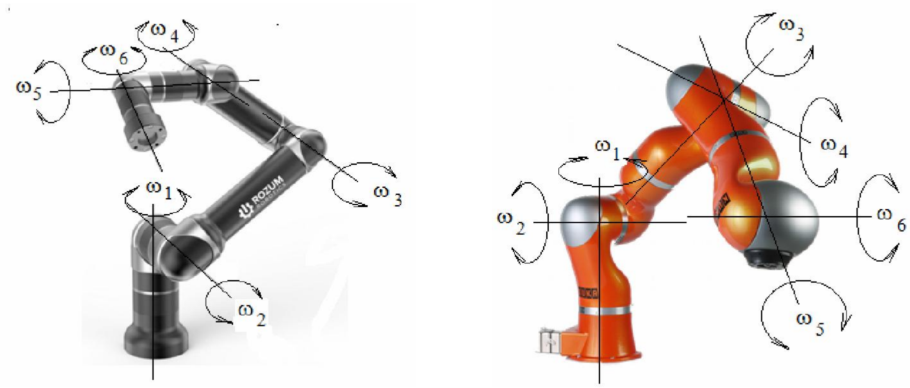
Doosan M 1013 Robotic Arm (Fig. 3a) is characterized by: Degrees of freedom: 6, payload: 10 kg, reach: 1300 mm, tool speed: 1 m / s, repeatability: ± 0.1 mm, operating temperature: 5–45° C, weight: 33 kg, installation position: floor, ceiling, walls, protection rating: IP54, I / O, ports: configured with 6 I / Os, power supply: 24V / Max. 3A, joint movement (range / speed): J1 , J2 : ± 360 ° / 120 ° / s, J3: ± 160 ° / 180 ° / s, J4, J5, J6: ± 360 ° / 225 ° / s [3] . Fig. 3b shows the robotic arm type Elfin which has the following features: control mode: continuous path control, drive mode: electric, application loading, pick and place, condition: new, CE certification, trademark: Han′s Robot [4].



a) b)

Fig. 3 – Collaborative robots: Doosan M 1013 Robotic Arm (a); Elfin Robotic Arm (b).

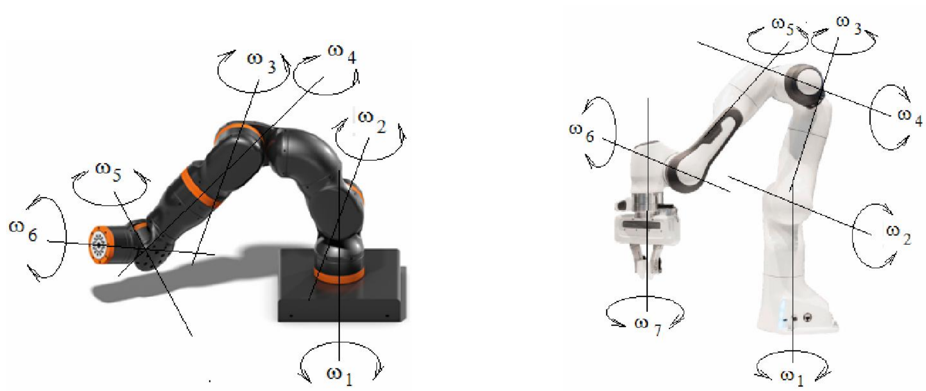
Another variant of robotic arm of this type is ROZUM Robotics (Fig. 4a) characterized by: ultra lightweight and mobile (8 kg weight), strong and dexterous (3 kg payload, 700 mm reach), precise (+/– 0.1 mm repeatability), and fast (30 rpm / 2 m / sec) [5]. KUKA robotic arm (Fig. 4b), made after a long period of improvement and optimization of KUKA classic robots, in which we can also remark the great difference between the traditional industrial robots and articulated robotic arms of the last generation, is characterized by: 7 -DOF robotic arm, adaptation algorithms, the robot is equipped with torque sensors allowing us to perform torque control and by extension impedance control allowing for compliant interaction and motion-adaptation [6].



a) b)

Fig. 4 – Collaborative robots: ROZUM robotic arm (a); KUKA robotic arm (b).

The Rebel Arm 1–2 robotic arm (Fig. 5a) is characterized by: 6 DOF, with integrated control system and motor, outer chassis consists entirely of polymers and is therefore cost-effective and light, articulated arm enables applications involving human-machine collaboration, lightweight, internal cables, joints are suitable for service robotics applications, brushless DC motors instead of stepper motors [7] . The Panda robotic arm (Fig. 5b) is characterized by : easy-to-program robotic arm designed for small businesses, able to move in seven axes and designed with a smart sense of "touch," the Panda can help conduct science experiments, build circuit boards or pretest equipment (two Panda arms can even work together to build a third) [8].



a) b)

Fig. 5 – Collaborative robots: Rabel robotic arm (a); Panda robotic arm (b).

All types of robotic arms presented are part of the so-called class of collaborative robots designed to interact friendly and very efficiently with the human operator.

In most cases these robotic arms used individually or in pairs, have been equipped and are still equipped, as already mentioned, on a large scale with grippers with jaws, pliers, or sporadically with finger grippers (3, 4 or 5 fingers) articulated. This situation is explained by the still low-performance and affordable variants of anthropomorphic finger grippers.

It is time for this situation to be overcome and to move widely to the endowment of robotic arms of the collaborative type with anthropomorphic grippers with five articulated fingers.

3. SOLVING THE DIRECT KINEMATIC PROBLEM WITH THE METHOD OF HOMOGENEOUS OPERATORS

A problem of particular importance for robotic arms of the human arm type is the solution of direct kinematics. The following is a brief example of solving direct kinematics for a robot of this type, for which the method of homogeneous operators is applied [9], [10]. This method application involves the use of homogeneous operators of rotation, translation, and rotation-translation compound operators, respectively, for translation-rotation. In Fig. 6a, we shown the form of the homogeneous elementary translation operator of the reference system

$O_m x_m y_m z_m$ to the reference system $O_n x_n y_n z_n$, by the axis $x_m = x_n$:

$$A_{mn} = T_{mn}^{x} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ d_{nm} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{1}$$

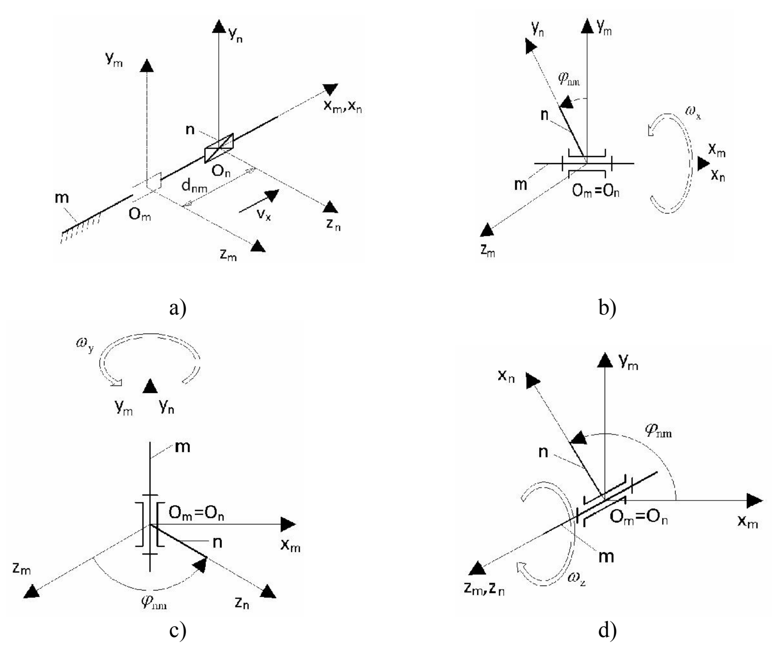


Fig. 6 – Appropriate kinematic schemes for homogeneous elementary operators: Translation (a); Rotation by x axis (b); Rotation by y axis (c); Rotation by z axis (d).

In the same form, the matrix of elementary homogeneous rotation operators by x-axis, y-axis and z-axis, according to Fig. 6b, c and d, are:

$$A_{mn} = R^{x}_{mn} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & C_{nm} & -S_{nm} \\ 0 & 0 & S_{nm} & C_{nm} \end{bmatrix}; \; A_{mn} = R^{y}_{mn} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C_{nm} & 0 & S_{nm} \\ 0 & 0 & 1 & 0 \\ 0 & -S_{nm} & 0 & C_{nm} \end{bmatrix};$$

$$A_{mn} = R^{z}_{mn} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C_{nm} & -S_{nm} & 0 \\ 0 & S_{nm} & C_{nm} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (1)$$

In these matrices, $S_{nm} = \sin \varphi_{nm}$ and $C_{nm} = \cos \varphi_{nm}$ are sines respectively cosines of rotation angles. Rotation is around the respective axes, from the reference system *m,* to the reference system *n*. If we use two elementary homogeneous rotation and translation operators, respectively, translation and rotation ones, we can obtain compound homogeneous operators corresponding to matrices resulted by multiplying the matrices corresponding to homogeneous elementary operators. Compounds operators ease, to some extent, the kinematic calculation, by reducing the number of operations of multiplication of the matrices corresponding to rotations around axes in kinematic couplings and translations between the two axes of two successive couplings. Lower, we exemplify the direct kinematic problem solving for the kinematic structure with 6 axes (0,1,2,3,4,5) analyzed and represented in Fig. 7.

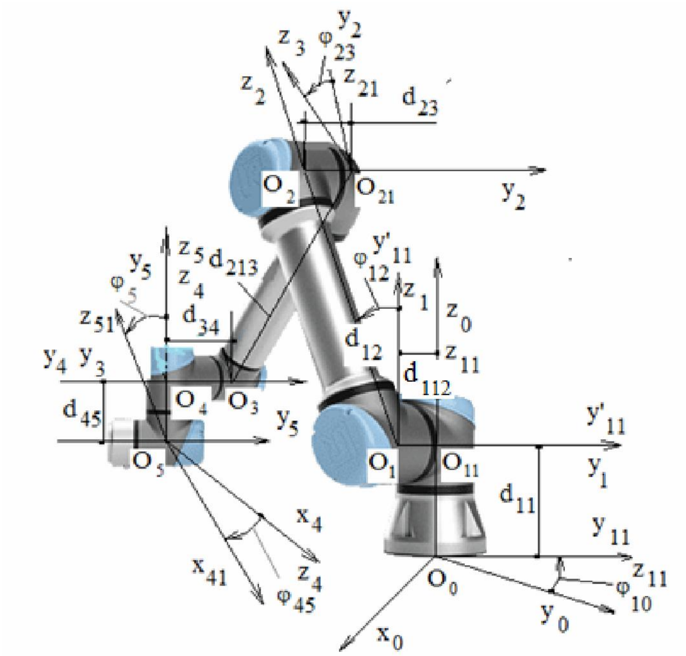


Fig. 7 – The necessary notations for solving the direct kinematics with the method of homogeneous operators.

For to obtain the reference system coordinates $O_5x_5y_5z_5$ reported to the reference system $O_0x_0y_0z_0$ (the direct kinematics problem) we write matrix forms of the rotation or translation operators, of successive passage from the reference system *m* to the reference system *n*: m= 0,1,2,3,4,5; n=0,1,...,5. The matrix of the reference system coordinates $O_5x_5y_5z_5$, as compared to the reference system $O_0x_0y_0z_0$ is product of the transfer matrices above matrix, under the form:

$$A_{05} = A_{01'}A_{1'1}A_{12'}A_{2'2}A_{23'}A_{3'3}A_{34'}A_{4'4}A_{45} \tag{2}$$

The kinematic analysis presented may be extrapolated to any other structure of the robotic arm type human arm.

4. INVERSE KINEMATICS

With the inverse kinematics, the rotation of the pivot joints for a position of the characteristic point M can be obtained.

If we know the elements of the A_{OM} matrix (M-final characteristic point of the robot):

$$A_{OM} = T_{mn}^{x} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{bmatrix}; \tag{3}$$

for inverse kinematics, the following equation is used:

$$A_{01}\, A_{12}\, A_{23}\, A_{34}\, A_{45}\, A_{5M} = A_{0M} \tag{4}$$

With inverse operators, $A_{01}^{-1}, A_{12}^{-1}, A_{23}^{-1},...,$ a system is obtained and then its solutions, depending on the matrices: $A_{01}, A_{12}, A_{23},..., A_{5M}$.

5. CONCLUSIONS

Based on what is presented in this paper, the following conclusions can be drawn:

- human arm type robotic arms, also called collaborative robots or cobots if their shapes are more complex, greatly improved and diversified in recent times, even one of the big companies brought to market industrial robots and such structures;
- the direct kinematic problem and the inverse kinematics problem are solved relatively simply with the method of homogeneous operators;
- the maximum efficiency of collaborative robotic arms use can be achieved by equipping them with anthropomorphic grippers, still difficult to access because of high costs, and a sometimes unnecessary complexity.

Acknowledgements.

Received on October 14, 2020

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