A Method for Determining the Trajectory Characteristics of Industrial Robot

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Abstract: The paper presents a synthesis of the main characteristics of industrial robots and proposes an original method for determining the trajectory characteristics of the robots. The sensing system is described including the electronic block diagram. The application software used to determine the trajectory characteristics is presented.

Keywords: Trajectory, sensing system, position determining.

1. INTRODUCTION

The industrial robots are more and more important in industrial manufacturing processes. Car industry, mechanics, electronics are domains where industrial robots are largely used.

The manufacturers and the users of industrial robots tried to classify and standardize the robots and also to establish a basic terminology of the domain, in order to determine the characteristics and the main performances of a robot.

An actual pursuit is to setup some methods for evaluating the robots, in order to normalize and certify their performances. The normalization of the performance criteria, the precise definition of the characteristics and their quantification are important measures to be taken in order to facilitate the client-supplier relations.

In this paper, a synthesis of the main characteristics of industrial robots is presented, and an original method for determining the trajectory characteristics of the robots is proposed.

2. THE MAIN CHARACTERISTICS OF INDUSTRIAL ROBOTS

Some definitions are important in order to define the characteristics according to AFNOR (French Asociation for Normalization) and ISO (International Organization for Standardization):

- *position* - the position of the mechanical interface of the robot, defined by (x, y, z) coordinates and (λ, ρ, θ) angles in the working space;
- *commanded position* - the position commanded by the program;
- *the actual position* - the position reached by the robot as response to the commanded position;
- *axis system* - three axis systems are used (Fig. 1): the axis system of the working space (x_1, y_1, z_1), the axis system of the robot base (x_2, y_2, z_2), also known as primary axis, and the axis system of the mechanical interface of the robot (x_3, y_3, z_3), also known as secondary axis.

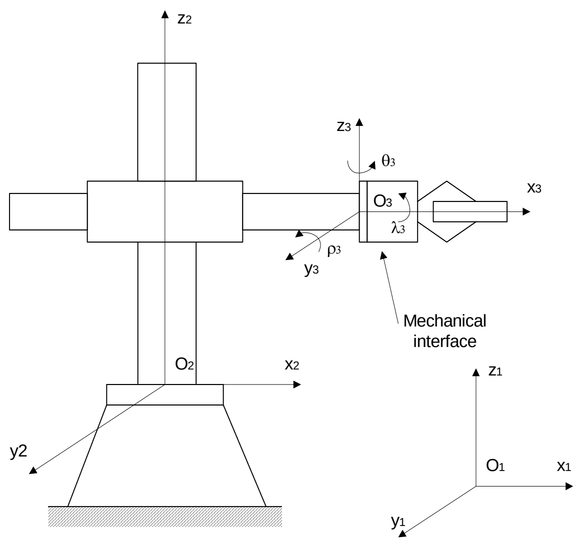

Fig. 1. The axis systems of a robot.

Two main categories of industrial robots are known according to the tasks accomplished by the robots. In the first category are included the robots used to position an object or a tool in its working space, as in the case of point welding, assembling, manipulating, inserting electronic components, etc. In the second category are included the robots used to move an object or a tool in a programmed and continuous way, as in the case of continuous welding, trimming up of parts, etc. So, the main characteristics used to evaluate the performances of the industrial robots are the following, e.g. Avram M. et al. (2004):

- general characteristics;
- position characteristics;
- trajectory and speed characteristics;
- static compliance characteristics.

2.1 General characteristics

The main general characteristics are the following:

- *nominal load* - the maximum load the robot can manipulate keeping its performances (stiffness of the structure, acceptable vibrations, performances of motors, etc.); the nominal load may be stated in terms of mass, torque, inertia torque or force; the nominal load value must be stated within the axis system of the mechanical interface of the robot;

- *working space or the working volume* - the space where there is no limitation for the movement of the secondary axis of the robot, except for the limitations imposed by the joints of robot; the external surface of the working volume is delimitated by the extreme movements of the origin of the secondary axis;

- *working speed* - the real moving speed depends on: the moving direction, the robot configuration, the actuated load, the position of the stop points in the working space, the response time of the command system, etc.; in the case of complex trajectories, the duration of a working cycle cannot be calculated and it will be determined by simulation or experimental;

- *resolution* - the smallest distance or the smallest angle that can be effectuated by the robot axis.

2.2 Position characteristics

The main position characteristics are the following:

- *local positioning accuracy* - the difference between the commanded position and the position achieved by the robot (Fig. 2); two parameters can be determined:

  - *translation accuracy Δa* (Fig. 2, a) - the difference between the commanded position «O» and the weight center «C» of the assemblage of points reached after more movements on the same trajectory;

  - *angular positioning accuracy $\Delta\varphi$* (Fig. 2, b) - the difference between the commanded angle and the average of the angles reached by the robot;

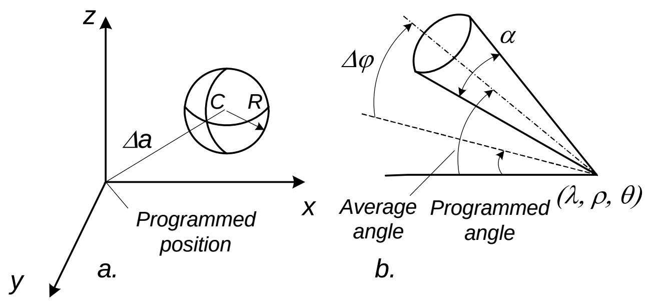

Fig. 2. The local positioning accuracy and the repeatability.

- *repeatability* - in the case of reaching the programmed position «O» after "n" movements using the same trajectory, the repeatability is given by the radius "R" of the sphere with the center in the weight center «C» of the assemblage of points reached after "n" movements (Fig. 2, a), respectively the angle "α" of the cone from Fig. 2, b;

- *multidirectional positioning accuracy* - in the case of reaching the programmed position «O» using different trajectories (Fig. 3), with "i" movements along trajectory 1, "j" movements along trajectory 2, and "k" movements along trajectory 3, where $i+j+k=n$, the multidirectional positioning accuracy is given by the maximum distance between the weight centers of the assemblages of points reached after "i", "j" and "k" movements;

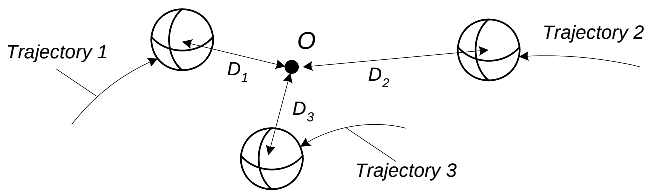

Fig. 3. The multidirectional positioning accuracy.

- *stabilization time*: from the moment when the "reached position" signal is given (t = 0, Fig. 4), the movement continues; the stabilization time (t_{s1} or t_{s2}) corresponds to the moment when the distance to the "reached position" becomes smaller than a specified limit;

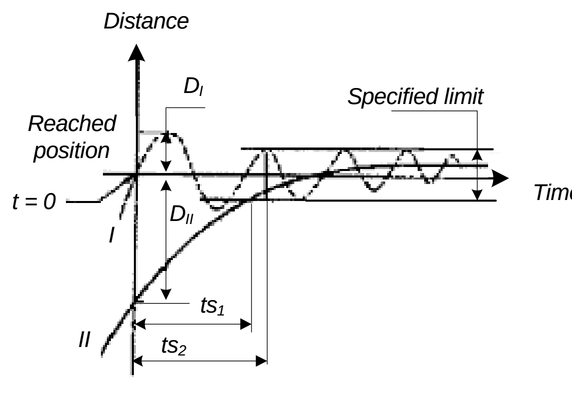

Fig. 4. The stabilization time.

- *override* - the maximum distance to the "reached position" in the stabilization phase (D_I or D_{II});

- *deviation from the "reached position"* - the slow variation form the "reached position" in a specified time interval.

2.3 Trajectory and speed characteristics

For the applications where the movement of the mechanical interface of the robot must describe an imposed trajectory, the following characteristics are defined:

- *accuracy of the trajectory* - the distance d_{ti} between the commanded trajectory and the actual trajectory of the mechanical interface of the robot (Fig. 5);

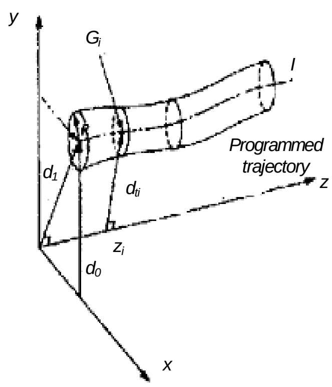

Fig. 5. The accuracy of the trajectory.

- *repeatability of the trajectory* - for "*n*" repeated movements of the robot, the "*n*" trajectories can be included in a tube whose axis is the geometrical locus of the instantaneous weight centers G_i; *the repeatability of the trajectory* is given by the radius "*R*" of this tube (Fig. 5);

- *joining error of two perpendicular trajectories* - the positive deviations *D* (overtake) and the negative deviations *A* (joining) of the actual trajectory from the commanded trajectory when the commanded trajectory is a square (Fig. 6);

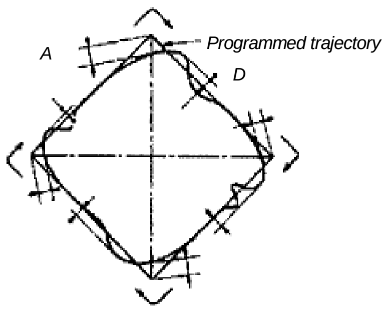

Fig. 6. The joining error.

- *speed accuracy* - the difference between the commanded speed and the actual average speed of the mechanical interface (*EV* in Fig. 7);

- *speed repeatability* - the variation range of the speed when the movement is repeated "*n*" times (*RV* in Fig. 7);

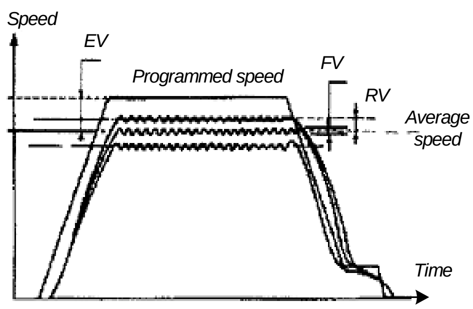

Fig. 7. Speed accuracy and repeatability.

- *speed variation* - the maximum difference between a constant commanded speed and the instantaneous speeds along the trajectory (*FV* in Fig. 7).

2.4 Static compliance characteristics

The compliance indicates the level of elasticity of a mechanical system and is defined as the ratio between the deflection and the applied force. In the case of an industrial robot, the static compliance is given by the ratio between the deflection of the mechanical interface and the unit of applied force, measured against the axis of the robot base.

3. METHOD FOR DETERMINING THE TRAJECTORY CHARACTERISTICS

The trajectory characteristics can be estimated by complex computations, taking into account all the parameters that produce errors (gaps, measuring errors of the sensors, deflection errors, etc.), e.g. Chen, N.X. et al. (2005), La Hera, P.X.M. (2011) and Madhavan, S.K. et al. (1991). This paper deals with an original method for direct determ ining the trajectory characteristics of the robots.

3.1 General concepts

The sensing system for determining the trajectory characteristics of a robot works on the following principles, e.g. Bucsan C. (1999):

- the sensing system is not placed on the robot, but in its working space, considered to be a parallelepipedic room with known sizes, as shown in Fig. 8;

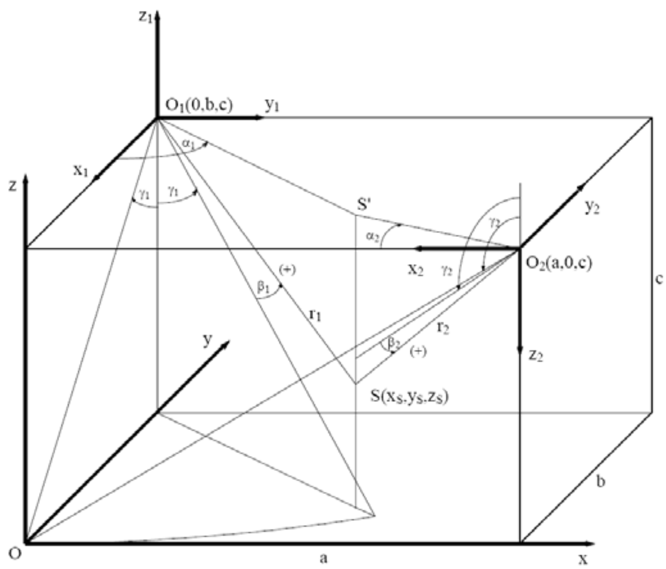

Fig. 8. The general arrangement of the sensing system.

- the sensing system consists of two sensors for space-direction finding, which are placed in the fixed points O_1 and O_2 , that are the origins of the normal coordinates of the sensors; this two sensors automatically follow, in a permanent and simultaneous way, a IR point source S fastened onto the final effector of the robot; the space position finding of the source is carried out by computing the coordinates of the intersection point of the two directions pointed by the sensors, against the Oxyz normal coordinates of the working space;

- the data produced by the two sensors are picked-up by means of a multifunction I/O data acquisition (DAQ) board connected to a PC, and they are processed according to an adequate software; this way, the real trajectory of the final effector is permanently known and it can be compared with the programmed trajectory.

3.2 The Space-Direction Finding Sensor

The principal component of the sensing system is the space-direction finding sensor - SDFS, whose configuration is shown in Fig. 9.

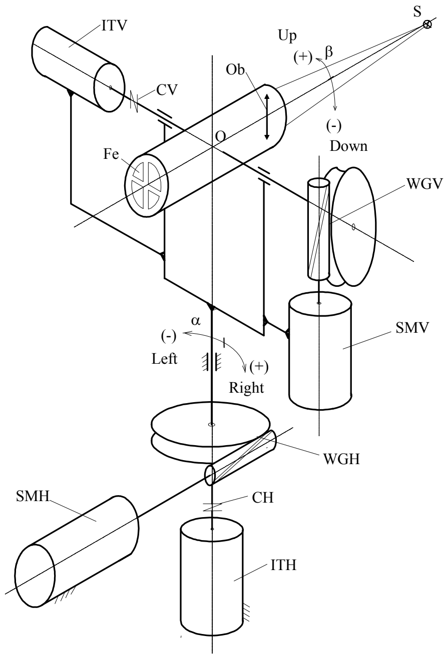

Fig. 9. The space-direction finding sensor configuration.

The sensor is provided with an electro-optical viewing device consisting of the objective Ob and the quadrate IR photosensor Fe.

When the axis of the viewing device coincides with the direction of the point source S, the four signals produced by the photoconductive zones are equal and at this moment, if the direction of the axis is known, the direction OS is also known.

The viewing device movement in order to follow the moving point source S is produced by the stepping motors SMH and SMV by means of the worm-gears WGH and WGV.

The measurement of the rotation angle α in the horizontal plane, against the vertical axis, is carried out by the rotational incremental transducer ITH; the measurement of the rotation angle β in the vertical plane, against the horizontal axis, is carried out by the rotational incremental transducer ITV.

The worm-gears are provided with backlash-influence eliminating devices; the incremental transducers are directly connected to the rotating shafts by means of the special couplings CH and CV, in order to minimize the measuring errors.

The electrical signals produced by the four photoconductive zones of the photosensor give information on the sign of the deviation, and the stepping motors are commanded in order to minimize this deviation. When the four signals are equal, meaning that the viewing device axis coincides with the direction of the source S, the contents of the incremental transducers counters are transferred into the memory of the PC and the values of the angles α and β are computed.

If the point source S is moving, the sensor permanently follows it and gives information on its direction against the origin O (the intersection point between the vertical axis and the horizontal axis).

3.3 The sensing system

Fig. 10 shows a view of the sensing system.

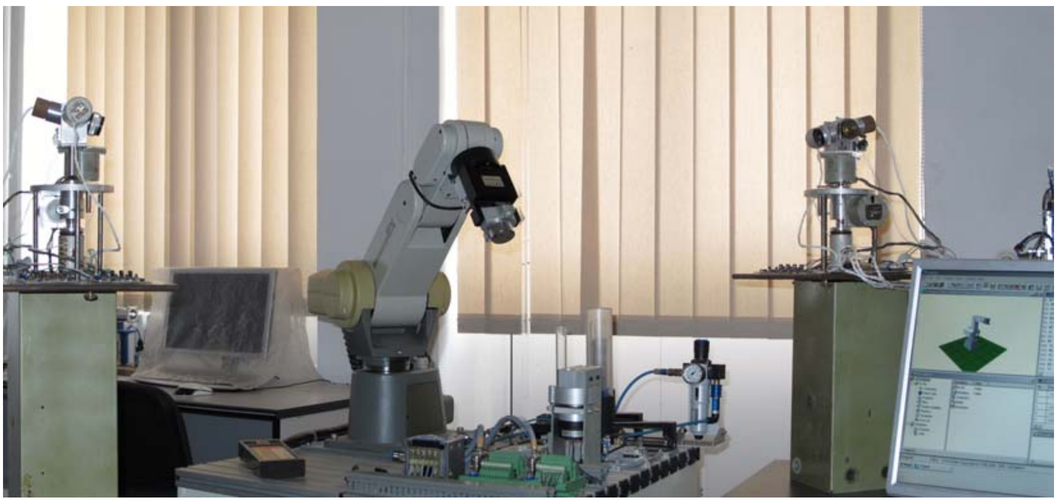

Fig. 10. A view of the sensing system.

The block diagram of the sensing system is shown in Fig. 11.

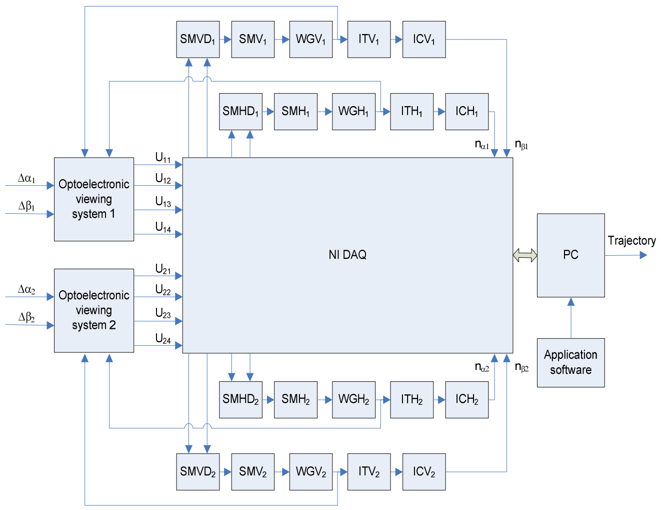

Fig. 11. The space-direction finding sensor configuration.

For every space-direction finding sensor, the stepping motors drivers, $SMHD_i$ and $SMVD_i$ receive from the DAQ board two signals: one for the direction of rotation and the other for stepping, until the signals U_{ij} produced by the four photoconductive zones of the photosensor and which are applied to four analogic input lines of the DAQ board, become equal. In the meantime, the incremental transducers produce impulse sequences which are applied to the input lines of the impulse counters ICH_i and ICV_i. These circuits detect the direction of rotation and count up or down, as needed, so as the number of the counted impulses is proportional with the angular movement, measured from a zero position mechanically established. The two values $n_{\alpha i}$ and $n_{\beta i}$ are picked-up by the acquisition system in the moment the signals U_{ij} become equal, and the direction is computed and given by the pair of angles (α_i,β_i).

3.4 The Space-Position Determining

For the actual position of the point source S fastened onto the final effector of the robot, the two sensors give the pairs (α_1,β_1) and (α_2,β_2) which define the directions O_1S and O_2S (Fig. 8).

The space-position of the source $S(x_S,y_S,z_S)$ against the Oxyz normal coordinates is determined by computing the coordinates of the intersection points of the two directions. The initial conditions are the following:

- the working space of the robot is a parallelepiped with sizes a, b, c;
- the two sensors are placed in the points $O_1(0,b,c)$ and $O_2(a,0,c)$ respectively;
- on every system-start the point source S is brought in the origin O(0,0,0,), so that the directions O_1O and O_2O become the origins for measuring the angles (α_1,β_1) and (α_2,β_2).

Finally, we get the coordinates of the point source S as a function of the pairs of angles (α_1,β_1) and (α_2,β_2) given by the two space-direction finding sensors, as following:

$$\begin{cases} x_s = \dfrac{b\cos(\gamma_2+\beta_2)}{\Delta}\sin(\gamma_1+\beta_1)\sin\alpha_1 \\ y_s = -\dfrac{b\cos(\gamma_2+\beta_2)}{\Delta}\sin(\gamma_1+\beta_1)\cos\alpha_1 + b \\ z_s = -\dfrac{b\cos(\gamma_2+\beta_2)}{\Delta}\cos(\gamma_1+\beta_1) + c \end{cases} \tag{1}$$

with:

$$\Delta = \begin{vmatrix} \sin(\gamma_1+\beta_1)\cos\alpha_1 & \sin(\gamma_2+\beta_2)\sin\alpha_2 \\ \cos(\gamma_1+\beta_1) & \cos(\gamma_2+\beta_2) \end{vmatrix} \tag{2}$$

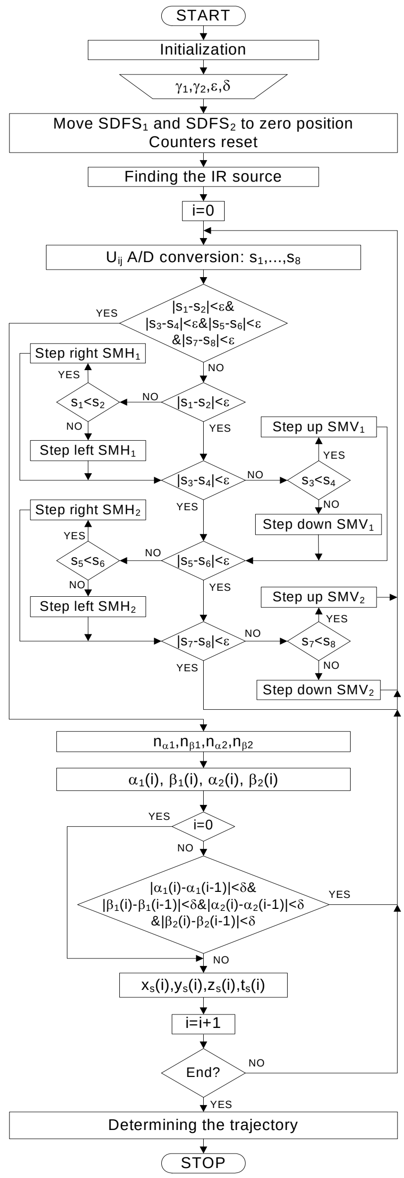

Fig. 12. The application software block diagram.

3.5 The application software

The application software carries out the following tasks:

- moving the space-direction finding sensors $SDFS_1$ and $SDFS_2$ to the zero position;
- commanding the space-direction finding sensors in order to follow continuously and simultaneously the IR point source;
- determining the space position of the point source at every time t_s;
- determining the trajectory of the point source using the least-squares approximating method.

The block diagram of the application software is shown in Fig. 12.

4. CONCLUSIONS

1. The research results show that the sensing system can be used as an automatic system for following the trajectory of the final effector of a robot, or the trajectory of an autonomous robot, in order to determine the deviations from the programmed trajectory.

2. The sensing system as described shows an important advantage in not being placed on the robot, that making possible the resolving of the direct cinematic problem, so it can be used to check the positioning accuracy of the industrial robots.

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