Solution of the Problem of Estimating the Geometric-kinematic Parameters of a Manipulation System

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***Abstract*— The estimation of the geometric and kinematic characteristics of the manipulation system is considered in this paper. The presented assessments technique is aimed at the determination of additional quantitative characteristics of the manipulation system according to the existing parameters in the technical passport of the device. The analysis is made on the example of a typical production task of moving parts, which is performed by the manipulation system. Based on the requirements for the functioning of the manipulation system and the working area, the requirements for evaluation the characteristics of selected system are suggested. The Matlab environment using the Robotics Toolbox is used for research.**

Key words*— *manipulation system; estimation of efficiency of operation; Matlab RoboticToolbox; maneuverability; agility; coefficient of service; working area; model

I. Introduction

Currently, the use of manipulation systems (MS) is actual for the automation of technological processes and industries, which allows the complex mechanization and automation of almost all technological operations in production. The manipulation systems have been particularly active introduced to the enterprises of the machine-building industry, in particular, for the tasks of moving, positioning, stacking of technological equipment, etc. [1, 2].

The manipulation system is a complex system consisting of several links, which are controlled by means of executive mechanisms (servos, hydraulic mechanisms, pneumatic drives, etc.) [3].

At the moment the market of manipulation systems offers a large number of implementations with different technical characteristics [4]. As a result, at the initial stage of the organization of production, there is a task of choosing the required parameters of the MS, which will provide the necessary functionality and will correspond to the applied technological scheme of production [5].

Consequently, the task of developing a methodology for determining, specifying and investigating additional characteristics and parameters of the MS with the purpose of their further use in the selection and determination of the possibilities of its effective application in production is becomes relevant. [6].

II. Problem Statement

We define the problem of choosing the manipulation system as follows. There is a conveyor belt along which shape measuring 50mm x 35mm x 18mm arrives from the packing department. In order for the manipulation system could grasp the object in the same place there is a narrowing at the end of the conveyor belt, which is intended for line up the packaged forms. The task of the manipulation system is to move the manipulation object to the next conveying level for subsequent packaging. The point at which the manipulation object is to be placed is located at a height of 280 mm above the plane of the conveyor belt, the base of the manipulation system is located at a height of 90 mm above the conveyor belt and at the distance of 100 mm from the point of grasping and the transfer point. The transfer point can vary, but it always has a removal of 100 mm and the height of 90 mm from the base of the manipulation system. The Fig. 1 schematically shows the structure of the task

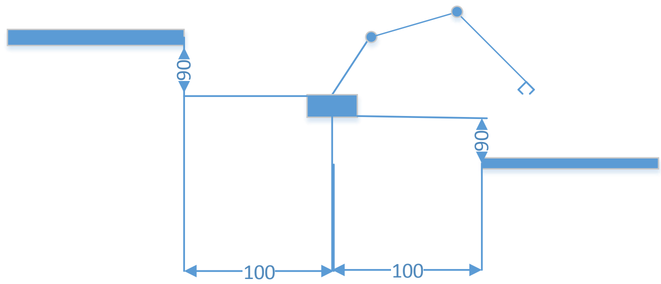

Fig.1. General scheme of the technological process

Thus, base on the typical production task it can be seen that the boom outlet of the manipulation system should be at least 220mm. Since, the manipulation object is always at a certain point of space on the conveyor belt and in a certain position, the maneuverability coefficient can be equal to 0. The form of the service area is spherical (hemisphere), since the object transfer point can vary. The service factor in the working area should be KC>0.65, since the transmission point can vary, and the grasping angles may vary with transmission point too [7–8].

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III. DESCRIPTION OF THE METHODOLOGY FOR ASSESSING THE PARAMETERS OF THE MANIPULATION SYSTEM

In order to determine the assessments technique of the manipulation system, a four-link manipulation system Kuka KS 6-2 firm «KUKA Roboter» (Germany) was chosen, the structural diagram of which is presented in the Fig. 2.

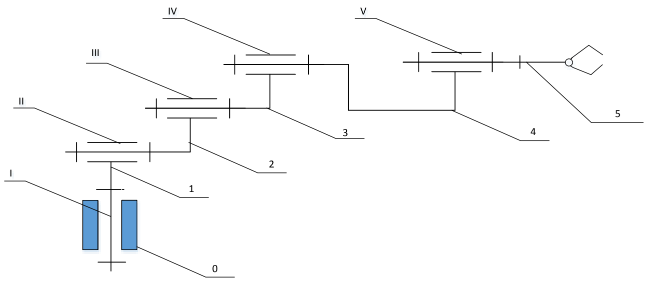

Fig.2. Structural diagram of MS

The basic mechanism of this MS consists of a fixed link 0 and movable links 1-5. The structural scheme of the mechanism of this MS corresponds to a spherical coordinate system. At the end of link 5 is fixed gripping device or grasper. It's designed to capture and hold the manipulation object while the MS is operating. The links of the main linkage mechanism of the MS form among themselves five one-degree of freedom kinematic pairs (all rotational).

Important characteristics of any MS are mobility and agility. Agility of the manipulation system depends on the mobility of the manipulator. These characteristics are important for industries, where the layout of the production node assumes the appearance of objects in the area of the manipulation system [9].

The number of degrees of freedom for a stationary grip for the MS is equal 0. Consequently, at a given point of the working area in a given direction, the grasper can only approach with one single position of the links, which meets the requirements.

Another important parameter for evaluating the functionality of the manipulation system is the service area determined by the locus of points coinciding with the position of the grasper center within which it is possible to perform a given operation, characterized by a grasper position, with respect to the manipulation object. [10–11].

To create the MS model requires information about technical characteristics of the MS such as link lengths, limiting the rotation angles, classes of kinematic pairs, etc. Based on the above characteristics, the MS model was built in Matlab Robotics Toolbox [12]. As a result, a visualized MS model was obtained. This model can be used in the future to build a working area, determine service angles, kinematics simulations, etc.

For constructing the service area, it is proposed to use an approach based on the maximum and minimum angles of the manipulator, since the manipulator under consideration has the one-degree of freedom rotational pairs [13–14].

In the MS under consideration the actuating mechanisms with an angle of rotation of 180º are used. And its articulations are defined in such a way that at zero angles its orientation looks, as it is shown in the Fig. 3.

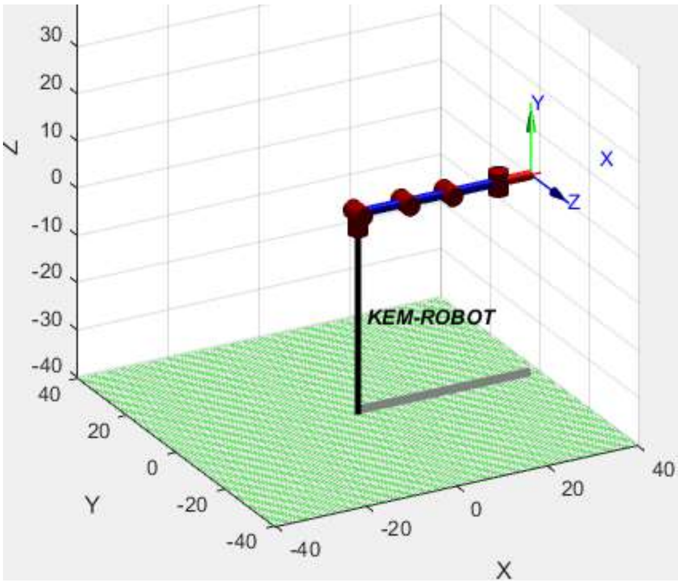

Fig.3. The manipulator orientation with zero angles of rotation

To build the manipulation system model, the Denavit-Hartenberg method was used [12]. The configuration of this MS in the Matlab is presented in the Fig. 4.

j	theta	d	a	alpha	offset
1	q1	12.8	0	-1.571	0
2	q2	0	-15	0	1.571
3	q3	0	-12.2	0	0
4	q4	0	0	1.571	-1.571
5	q5	0	0	0	0

```
grav =    0  base = 1  0  0  0   tool =  1  0  0  0
          0         0  1  0  0           0  1  0  0
       9.81         0  0  1  0           0  0  1  0
                    0  0  0  1           0  0  0  1
```

Fig.4. The configuration of MS

Fig. 3 shows that the radius of the service area will be determined by the length of the kinematic pairs from the I kinematic pair to the grasper. To construct a service area should identify several points that will be defined by grasper, such way so that the extreme grasp point of MS is maximally removed from the I kinematic pair. [15]. For the MS under consideration, these parameters are summarized in Table 1.

TABLE I.

№ point	Angle I	Angle II	Angle III	Angle IV	Angle V
1	0	0	0	0	0
2	90	0	0	0	0
3	180	0	0	0	0
4	90	180	0	0	0
5	0	180	0	0	0

Thus, the service area of the manipulating system has been obtained in the form of a hemisphere with a radius of 382 mm (Fig. 5). Based on the results of the construction of the working area, you can determine the workplace of the manipulation system in production [16].

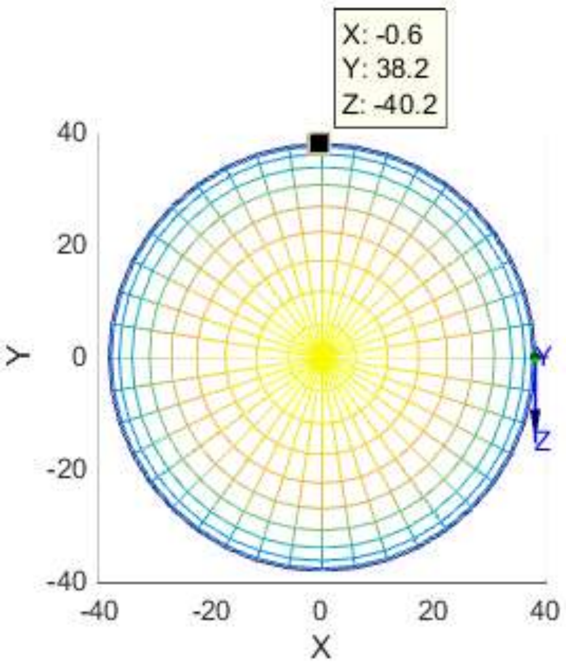

Fig.5. The projection of the service area on the XY plane

An essential parameter of the MS assessment is the coefficient of service (CS), which allows estimating the geometric quality of the MS, its ability to perform various operations [17]. The definition of the service coefficient is a laborious task. It consists in calculating the surface area cut out on a ball centered at a given point and with a radius equal to the length of the last link of the manipulator's working area, obtained from the original manipulator by dropping the last link [18–19]. In analytical form, the formula for calculating the service coefficient is shown below:

$$K_c = \alpha / 4\pi,$$

where α – spatial solid angle, which is the set of all admissible directions.

Determine the service coefficient for the manipulation system under consideration. To do this, let's analyze the structure of the considered manipulator on the plane (Fig. 6).

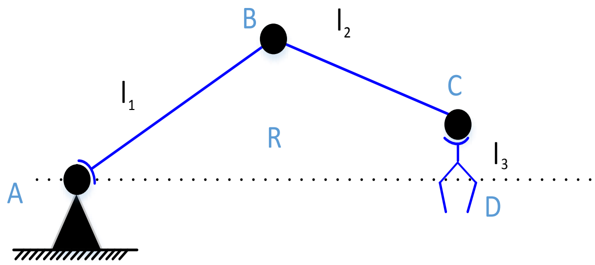

Fig.6. The structure of the manipulator on the plane

In this configuration of MS, the link AC does not make a full turn, ie in the flat four-links manipulator the link AC is rocker. Therefore, the problem of determining the service area, in which the coefficient of service K is equal to 1, is reduced to determining the length of the rack R of the crank-rocker mechanism according to the condition of the existence of the crank. For the system under consideration, the minimum radius of the service area is Rmin = 8.2 cm, and the maximum radius is Rmax = 27.8 cm. Hence, the allowable area of the location of the point D on the reference plane is located between the circles with the radiuses Rmax and Rmin with the center at point A (Fig. 7).

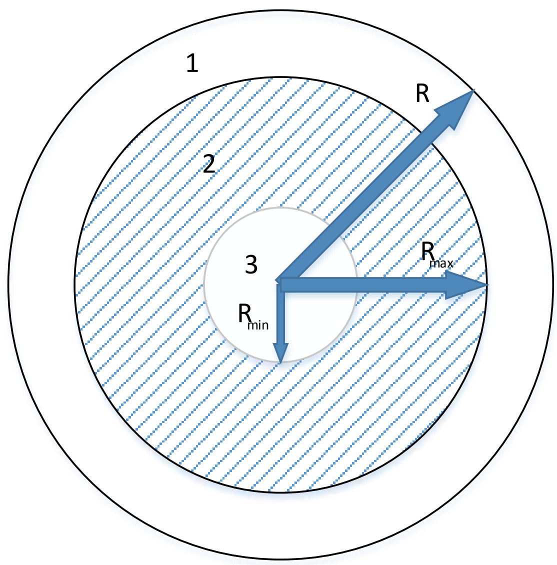

Fig.7. The MS zones

For zones 1, 2, 3 the service coefficients K are equal to 0.25, 1 and 0 respectively.

Thus, the service coefficients for the three working areas of the manipulation system were obtained. From the above, it can be seen that the working area is divided into three more zones, where the manipulation system performs its work with different degrees of service.

As a result of the MS assessment, the scheme of which is shown in the Fig. 2, were received the following characteristics (Table II):

TABLE II.

Characteristics	**Working area**	**Radius of action**	**Agility**	**CS**
Required	Hemisphere	More then 220 mm	0	>0.65
Estimated	Hemisphere	382 mm (278 mm with CS=1)	0	0.25/1/0

Table II shows that the manipulation system Kuka KS 6-2 firm «KUKA Roboter» (Germany) satisfies the functional requirements of the considered industry task. Based on the obtained results, it can be seen that the manipulation system has a working area of 382 mm, which meets the requirements. The CS in this zone is less than required, but this is not critical, because the CS in zone 2 (where the radius of action is 278 mm and satisfies the requirements too) is equal to 1. As a result, this manipulation system can effectively operate in zone 2.

CONCLUSION

Thus, as a result of the work the estimation of functionality of the performance of the industry task by manipulation system was carried out. This estimation reflects only the geometric and kinematic components without taking into account the dynamic characteristics of the system. Using this approach in conjunction with the assessment of dynamic characteristics will allow a more detailed analysis the functionality of the MS. However, this example is shows that, using only the technical parameters of the MS (passport parameters), it is possible to make a preliminary assessment of the functionality of the MS for solving the industry task without calculating the dynamic characteristics

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