

PAPER • OPEN ACCESS

Information-measuring system to improve the quality of motion control robot manipulators

To cite this article: K I Goryanina *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **680** 012008

View the [article online](#) for updates and enhancements.

Information-measuring system to improve the quality of motion control robot manipulators

K I Goryanina¹, O I Katin¹, M A Vernezi¹, D Yu Donskoy¹, L A Tregubenko¹ and N X Chiem²

¹Laboratory of local automation and embedded systems Don State Technical University, Gagarin Square 1, Rostov-on-Don 344000, Russia Federation

²Le Quy Don Technical University, Hanoi, Vietnam

E-mail: gorianina.k@yandex.ru

Abstract. The use of robotic systems consisting of mechanical manipulators and control systems is now widely used not only in industrial production, but also in medicine, sorting and even in everyday life and services. In recent years, the market of service robotics has been actively developing. Successful implementation of automation systems depends on solving complex scientific and technical problems primarily in the following areas: machine vision, sensor networks, navigation systems. Of particular importance is the task of increasing the accuracy of manipulation. The article proposes a variant of the formation of information-measuring system of the robot manipulator based on MEMS sensors. And also recommendations on the choice of sensors of the sensor system to control the manipulation system of the robot are given.

1. Introduction

Currently, industrial manipulation robots (MR) are used in various fields of industry to perform a wide range of technological tasks.

They are a complex electromechanical object, which has a number of features. First, MR distinguished by a complex kinematic structure that contains many independent or interconnected links. Secondly, the change in the position of the latter in space affects the physical forces acting on the manipulator. Thirdly, there is a need for synchronous control of a large number of engines.

The interaction of modern robots with the real environment, in addition to hard-coded actions, should be built with the elements of adaptation, i.e. taking into account information about the state and position of working bodies and technological equipment, the state of the environment and objects in the working area. This information, the volume and nature of which are determined by the purpose of the robot, the features of the environment of its functioning and the process, provides information and measurement system, structurally included in the control device of the robot.

It is the organs of "senses" of the robot and largely determines its functionality, operational efficiency and reliability, the complexity of the tasks, as well as the safety of the staff robot, Which has the ability to "feel", it is easier to perform complex actions, to adapt when performing a wide range of tasks. This increases the degree of versatility of the robot, which ultimately, despite the increase in the intrinsic value of the robot, leads to a decrease in the cost of production and maintenance during operation.



The main requirement for industrial manipulators is the accuracy of positioning and moving along a given trajectory. In this regard, the design of the robot control system should take into account the factors that affect the quality of motion: 1) features of the kinematic scheme, 2) changes in dynamic characteristics.

Thus, the task of improving positioning accuracy is associated with the need for accurate and/or mutually synchronized manipulations by several manipulators. Potentially, this problem can be solved by increasing the sensor equipment of the manipulators and on this basis – the optimization of controlled movements of the robot manipulators.

One of the fundamental problems, the solution of which depends on the success in the creation of adaptive robots, is the use of modern types of sensors, which allow to obtain a large amount of local information about the problem environment in a short time, and the integration of this information into the control system of the robot manipulator.

Thus, the global goal of the work is to improve the quality of motion control of robot manipulators by: development of MIMO model, automatic control system and placement on the manipulators of the array of sensors of the local sensor system.

In the article for a better understanding of the movement of the manipulator will be considered direct and inverse problems of kinematics, as well as the developed system array of sensors of local information.

2. Mathematical description of the kinematic scheme

The characteristics of control systems for complex mechatronic objects, such as manipulation robots, are significantly influenced by their kinematic and dynamic parameters. As a result, it is necessary to give their detailed mathematical description, convenient for use in the implementation of control system.

In the solution of the specified task it is possible to allocate two interconnected directions. The first is to create an accurate kinematic model of the manipulator, allowing to uniquely determine its spatial configuration, which in turn will make it possible to describe the laws of movement of the working body. The second direction is to describe the dynamic characteristics and relationships that exist in the manipulator, which will describe its behavior when moving along a given path.

To plan the trajectory of the manipulator and determine its position in space, it is necessary to solve two main classes of problems in the form of direct and inverse kinematics problems [1].

The solution of the direct problem is used to convert information about the position of the manipulator from its own coordinate system to the working (absolute), which is required to determine the coordinates of the working body of the manipulator.

The solution of the inverse problem is designed to calculate the required spatial configuration of the manipulator by the position of the working body, and is the main problem in planning the trajectory of its movement.

The solution of these problems requires a description of the overall characteristics of the manipulator in a form convenient for their analysis and writing coordinate transformation equations. Of the existing approaches, the main ones are their expression in the form of a system of linear or matrix equations [2, 3].

The method of homogeneous transformations is the most effective for performing numerical transformations. As applied to the description of manipulation robots, the Denavit-Hartenberg parameters (DH-parameters) has become widespread. It allows you to record the kinematics of the manipulator by a set of matrices of spatial transformations of dimension 4x4, expressing the relative position of the CS of individual units. In this case, the kinematic scheme of the manipulator is described by an equation of the form:

$$T = \prod_{i=1}^n A_i \quad (1)$$

where:

T - the matrix position of the working body,

A_i - I-junction transformation matrices,

n - number of joints in operation.

2.1 Equation of the direct problem of kinematics

The solution of the direct kinematics problem requires the transformation of the set of coordinates describing the position of the manipulator in its own coordinate system into the coordinates of the working coordinate system.

$$(q_1, q_2, \dots, q_n) \rightarrow (x_1, x_2, \dots, x_n),$$

where:

q_1, q_2, \dots, q_n - coordinates in their own coordinate system (attached);

x_1, x_2, \dots, x_n - coordinates in absolute coordinate system (absolute).

When using a six-axis manipulator operating in a rotational coordinate system, and applying the previously selected working coordinate system, using the expression (1), we obtain:

$$T = {}^0 A_1 A_2 A_3 A_4 A_5 A_6 = \begin{bmatrix} n & s & a & p \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad (2)$$

where:

n, s, a - vectors 3x1 orientation of the working body;

p - vector 3x1 position of the working body in the base coordinate system.

The individual transformation matrices will take the form:

$$\begin{aligned} {}^0 A_1 &= \begin{bmatrix} \cos \theta_1 & 0 & -\sin \theta_1 & 0 \\ \sin \theta_1 & 0 & \cos \theta_1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, {}^1 A_2 = \begin{bmatrix} \cos \theta_2 & -\sin \theta_2 & 0 & \alpha_2 \cos \theta_2 \\ \sin \theta_2 & \cos \theta_2 & 0 & \alpha_2 \sin \theta_2 \\ 0 & 0 & 1 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \\ {}^2 A_3 &= \begin{bmatrix} \cos \theta_3 & 0 & \sin \theta_3 & -\alpha_3 \cos \theta_3 \\ \sin \theta_3 & 0 & -\cos \theta_3 & \alpha_3 \sin \theta_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, {}^3 A_4 = \begin{bmatrix} \cos \theta_4 & 0 & -\sin \theta_4 & 0 \\ \sin \theta_4 & 0 & \cos \theta_4 & 0 \\ 0 & -1 & 0 & d_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \\ {}^4 A_5 &= \begin{bmatrix} \cos \theta_5 & 0 & \sin \theta_5 & 0 \\ \sin \theta_5 & 0 & -\cos \theta_5 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, {}^5 A_6 = \begin{bmatrix} \cos \theta_6 & -\sin \theta_6 & 0 & 0 \\ \sin \theta_6 & \cos \theta_6 & 0 & 0 \\ 0 & 0 & 1 & d_6 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \end{aligned} \quad (3)$$

where:

$\theta_i, d_i, a_i, \alpha_i$ - DX-parameters (figure 1):

θ_i - the attached angle by which you want to rotate an axis x_{i-1} around an axis z_{i-1} so that it is aligned with the axis x_i ;

d_i - the distance between the intersection of the axis z_{i-1} with the axis x_i and the origin of the $(i-1)^{\text{th}}$ and coordinate system;

a_i - linear offset (shortest distance between axes z_{i-1} and z_i);

α_i - angular offset – the angle by which you want to rotate an axis z_{i+1} around an axis x_i so that it is aligned with the axis z_i .

The parameter values d_i, a_i, α_i are determined by the orientation of the absolute coordinate system and the selection of the reference point.

The values θ_i in this case correspond to the attached coordinates of the manipulator and describe the position of the manipulator in its own coordinate system.

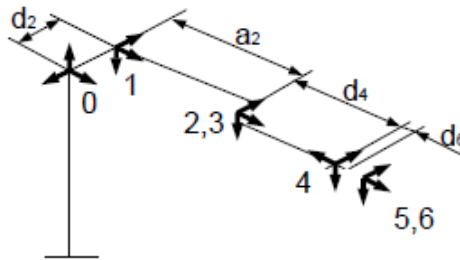


Figure 1. Manipulator DH parameters ratio

2.2 Equations of inverse kinematics problem

In contrast to the direct kinematics problem, the inverse one has much more approaches to its solution, of which the main ones are the methods of inverse transformations and biquaternions [4, 5].

Let's consider the main features of each method.

The inverse transformation method consists in determining the values of the individual attached coordinates based on the existing transformation matrices (3). As a result, ready-made analytical expressions can be obtained.

Solution of kinematics by means of biquaternions is carried out by kinematic configuration using dual quaternion and compute the values of joined coordinates by the unit quaternion transformations. This method makes it possible to describe the kinematic configuration of the manipulator in a more compact form compared to the matrices (3), but requires the implementation of more complex computational algorithms compared to the method of inverse transformations.

Based on the need to implement an algorithm for solving the inverse kinematics problem in the control system of the manipulation robot, which has limited computational capabilities, it is necessary to choose an approach with the possibility of optimizing the calculations.

2.3 Manipulator dynamic structure

When moving the manipulator there are changes in its spatial configuration, which in turn leads to a change in the forces acting on its individual elements. To account for these changes is required to describe the dynamic characteristics of the MR and their relationship with the kinematic structure of the manipulator.

The task of describing the dynamic characteristics of the MR can be divided into the following stages:

- 1) determination of the moments acting on separate links;
- 2) description of the set of links between the individual links;
- 3) presentation of dynamic characteristics in a convenient form for further analysis.

In the process of motion, the forces acting on the manipulation robot create two main types of moments: 1) gravitational moments, 2) centrifugal and Coriolis moments.

Gravitational moments are determined by the influence of gravity on the links of the manipulator. They act independently of the speed and are an expression of the potential energy of the manipulator.

Centrifugal and Coriolis moments occur when the manipulator moves in space. Since there are kinematic connections between individual links, the forces acting on them are determined not only by their own speeds, but also by the speeds of other links.

Generalized moments of dynamic interaction arise as a result of changes in the position of the links in their accelerated motion relative to each other.

The General equation of dynamics of the manipulator [6-8] can be written as:

$$\tau(t) = D(q(t))\ddot{q}(t) + h(q(t), \dot{q}(t)) + c(q(t)), \quad (4)$$

$\tau(t)$ - vector $n \times 1$ of generalized moments in manipulator joints;

$q(t)$ - vector $n \times 1$ of adjoint variables of the manipulator;

$\dot{q}(t)$ - vector $n \times 1$ of generalized velocities;

$\ddot{q}(t)$ - vector $n \times 1$ of generalized accelerations;

D - matrix $n \times n$ of inertia (kinetic energy) of manipulator;

h - vector $n \times 1$ of Coriolis and centrifugal moments;

c - vector $n \times 1$ of gravitational moments;

n - number of joints in MR.

Gravitational moments are determined by the effect of gravity on the individual links of the manipulator. They depend on the mass, position and orientation of the manipulator in space. Each element of the vector of gravitational moments c_i can be expressed as:

$$c_i = \sum_{j=1}^i F_{gJ} r_{ij}, \quad (5)$$

where:

F_{gJ} - gravity acting on a link j ;

r_{ij} - distance vector between the centers of gravity links i and j .

Thus, to determine the gravitational component of the moment, it is necessary to describe the kinematic structure of the manipulator and determine the positions of the centers of gravity of individual units.

3. Information-measuring system

The manipulator can be considered as an analogue of the human hand. Its design largely determines the capabilities of the robot. These capabilities are much lower than the capabilities of the human hand, which has 27 degrees of mobility or, if you do not take into account the movement of the fingers, 12 degrees of mobility. The number of degrees of mobility of the manipulator is limited and usually does not exceed 7.

In existing manipulators, as a rule, only the sense of orientation (or rather – the relative relative position of the manipulator elements relative to each other) and, sometimes – a sense of force/weight due to the control of the torque forces (usually – the magnitude of the current drives the manipulator).

All this naturally (and significantly) limits the sensitive capabilities of existing robotic manipulators and makes their use in everyday life and special areas limited.

The main function of the information-measuring system are feedback devices designed for active control in the process of the parameters of the state of the robot and process equipment, as well as the parameters of the environment and objects in the working area.

In General feedback devices include systems:

1) control of parameters of the robot state (positions and speeds of movement of working bodies and elements of mechanisms, efforts in elements, emergency blocking, diagnostics and forecasting of a resource of work);

2) perception and analysis of information about the external environment (tactile, visual, location, etc.);

3) ensuring safety (registration of the spatial position of the robot and its individual parts, the location of personnel and equipment in the work area). Primary information these systems receive from feedback sensors, or sensitive elements, which are the most important components of feedback devices.

Internal state sensors are used to generate signals in the feedback circuits by the position and speed of the manipulator links, by force and torque.

External state sensors are designed to measure parameters in the far and near zones and for tactile measurements. These sensors are divided into contact and non-contact. The contact sensors measure when an object is in contact with a touch, slip, or torsion process. The principle of operation of contactless sensors is based on the determination of changes in the acoustic or electromagnetic fields of interaction with the object.

To ensure the absolute orientation of the manipulator fingers in the gravitational field of the Earth and measure the angle of rotation of the manipulator relative to a fixed coordinate system associated with its base, MEMS accelerometers and gyroscopes are installed on each finger of the manipulator.

Also, to determine the mutual orientation of the fingers of the manipulator, it is advisable to use magnetic sensors consisting of a sensing element and an electromagnet. The use of such sensors is important when visual inspection is difficult or impossible.

To determine the surface temperature, low-inertia film sensors are installed, which are installed on the inner surface of the phalanx of the fingers or palm.

When working with small and fragile objects, the proximity and touch sensor is of great importance. Sensors due to their simplicity can be placed in several places on the inner surface of the hand of the manipulator and used in the capture and fixation of various objects.

Research is conducted on an anthropomorphic manipulator manufactured by Android technology. The module with the manipulator movement system is equipped with a metal anthropomorphic grip with five structural links, a vision system and specialized software. It is designed to practice manipulative actions with various objects. Open architecture allows you to make changes to existing SOFTWARE or create new ones for specific tasks, testing your own developments on a robotic system. The anthropomorphic manipulator module is shown in figure 2.

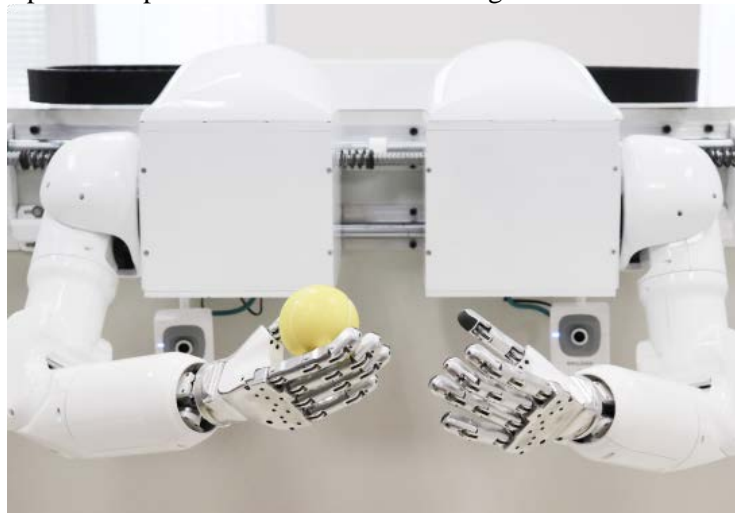


Figure 2. Manipulator system module

Most of the above sensors exist in the form of MEMS-integrated circuits with output to digital bus type I2C and / or SPI, providing easy docking with modern interfaces of computing devices. Certain types of sensors (primarily tactile) will require the development of their own control circuits. The greatest difficulty lies in the processing and coordination of information received from this heterogeneous array of sensors, its analysis, and the development of control actions.

4. Conclusion

The proposed principles of hardware architecture allow us to develop a control system for manipulative robots that meets the requirements of modern industry. By integrating heterogeneous array of sensors automatic control system of a manipulator must be moved without colliding with the surrounding objects; the retention of objects with a single force; the determination of the temperature of the object clamped in the manipulator or object that it approaches the manipulator; determining the color of the object, which is approaching the manipulator.

The proposed new concept will improve the quality and accuracy of movement of manipulators when performing a wide range of technological tasks.

References

- [1] Lebedev P.A. 1967 *Kinematics of spatial mechanisms* p 280
- [2] R. S. Hartenberg and J. Denavit, *A kinematic notation for lower pair mechanisms based on matrices* Journal of Applied Mechanics, vol. 77, pp 215–221
- [3] D'Souza A., Vijayakumar S., Schaal S. 2001 *Learning inverse kinematics*. Proceedings. 2001 IEEE/RSJ International Conference on / IEEE. Vol. 1. pp 298–303
- [4] Tolani D., Goswami A., Badler N. I. 2000 *Real-time inverse kinematics techniques for anthropomorphic limbs*. Graphical models. Vol. 62, no. 5. pp 353–388
- [5] I. L. Kantor, A. S. Solodovnikov. 1973 *Hypercomplex numbers*. p 144.
- [6] Tertychny-Dauri V. 2012 *Dynamics of robotic systems*. p 128
- [7] Avagimov A. G. 1989 *About special terms and conditions single-loop spatial mechanisms with several degrees of freedom* pp. 11-18
- [8] Kolovsky M. Z., Sloushch A. V. *Fundamentals of industrial robot dynamics* p 240