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THE CONCEPT OF FORCE-MOMENT SENSING OF MULTI-POSITION MECHATRONIC MODULES OF INTELLIGENT ROBOTS

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THE CONCEPT OF FORCE-MOMENT SENSING OF MULTI-POSITION MECHATRONIC MODULES OF INTELLIGENT ROBOTS

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***Abstract**: The concept of force-moment sensing of multiposition mechatronic modules (MMM) of intelligent robots and robotic systems is considered. In modern intelligent mechatronic modules, the use of force-torque sensing is focused on expanding their functionality in the automation of various technological operations. In the developed intelligent multi-position mechatronic module of motion, its control loop includes a force-torque system (FTS) designed to measure the components of the main vector of forces and moments acting on the gripper or tool of the mechatronic module and form a logical or continuous control action on the actuator in projections on the associated him a coordinate system. The structure of the system of force-torque sensing of intelligent mechatronic modules is proposed, including a database and knowledge, a pre-processing unit, a force-torque sensor, a processor and a control system. A classification is made according to the principle of measuring the components of the main load vector by the sensing method and by the control object.*

***Keywords.** Multi-position mechatronic module, break-torque sensor, database and knowledge, control system, robot, gripper.*

INTRODUCTION. In modern robotics and mechatronics, the application of sensing systems is of great importance. The issues of adaptive and intelligent control of robots built on the basis of multi-position mechatronic modules is not possible without the use of various sensing systems, in particular, force-moment sensing systems. The article is devoted to the issues of force-moment sensing of multi-position mechatronic modules of intelligent robots, classification of the principles of constructing FTS robots based on mechatronic devices [1,2]. The structural diagram of the developed mechatronic module with force-torque sensing and the principle of its functioning are presented.

Research methodology

The following works [1, 2, 5, 7, 9, 10] are devoted to the issues of force-moment sensing, which summarize the main aspects of the construction and application of FTS in intelligent robots and robotic systems. In modern intelligent mechatronic modules, the use of force-torque sensing is focused on expanding their functionality in the automation of various technological operations. In the developed intelligent multi-position mechatronic module of motion, its control loop includes a force-moment sensing system (SSO) designed to measure the components of the main vector of forces and moments acting on the gripper or manipulator tool and form a logical or continuous control action on the actuator in projections onto the associated coordinate system [2,3,4]. The structure of the system of force-torque sensing of intelligent mechatronic modules is proposed, including a database and knowledge, a pre-processing unit, a force-torque sensor, a processor and a control system (Fig. 1).

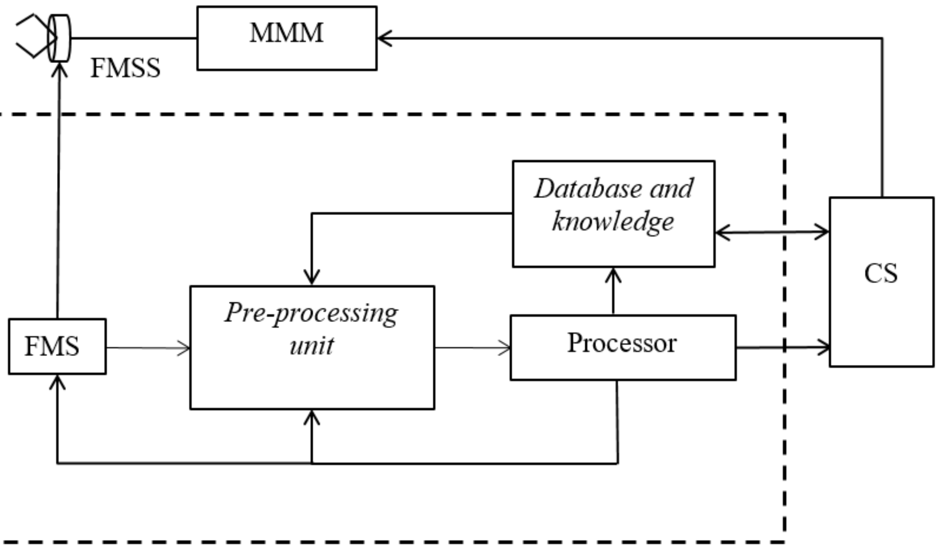

Fig 1. Structure of FMSS intelligent mechatronic modules.

Unlike other sensor devices, the computational means of the FMSS are usually local and are implemented on the basis of controllers and computers.

A classification graph of the FMSS of intelligent mechatronic modules has been developed, which is shown in Fig. 2.

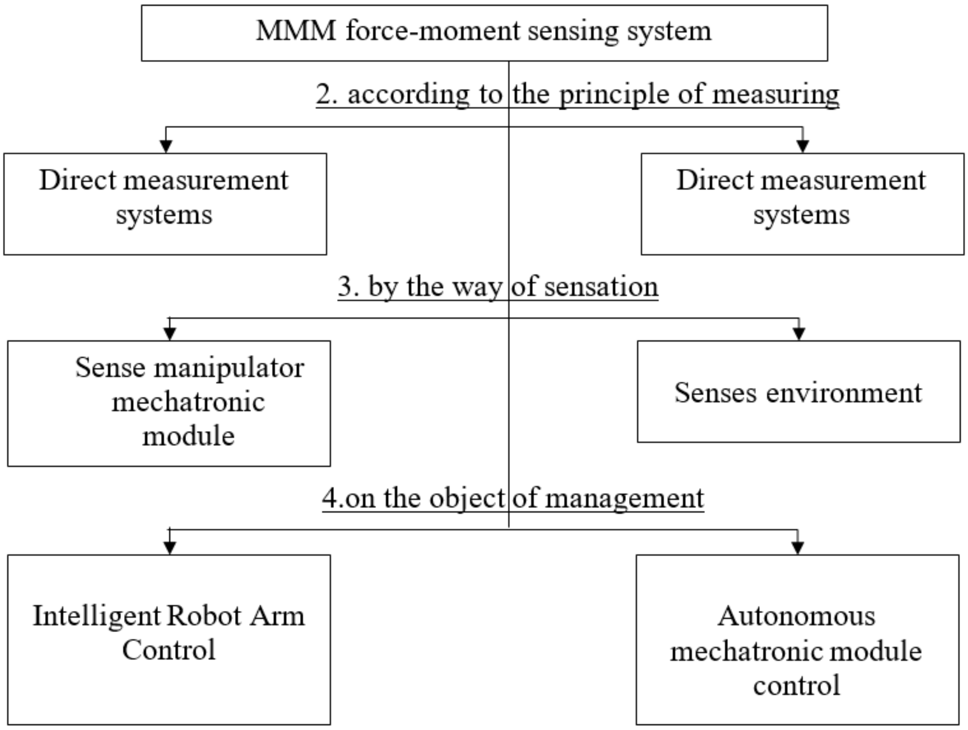

Fig 2. Classification graph of FMSS MMM.

There are five typical options for constructing the FMSS (Table 1). The first version of the construction of the FMSS assumes control of the manipulator using the FMS installed on it. Let's consider these options in more detail [3,4,5].

Table 1.

Options for building SFMSS robots based on mechatronic modules

Option number	Measuring principle	Place of installation of FMS	Controlled mechanism
1	Straight	On the mechatronic module	Mechatronic module
2	»	Same	Standalone module
3	»	Outside the mechatronic module	Mechatronic module
4	»	Same	Standalone module
5	Indirect	—	Mechatronic module

In the general case, the determination of the reaction between an object in the robot's gripper and a certain surface (during abrasive processing) or two objects (during assembly) is possible in several ways. Most often, the method of direct measurement with the "sensing" of the working environment (in this case, the object is installed on a platform equipped with sensors) or the "sensing" of the gripping device of the robot (jaws or wrist), as well as the method of indirect measurement, when information about the forces acting on the modules robot, receive through the tracking system [6,7,8].

Analysis and results

The structural diagram of the developed multi-position mechatronic module with force-torque sensing is shown in Fig. 3.

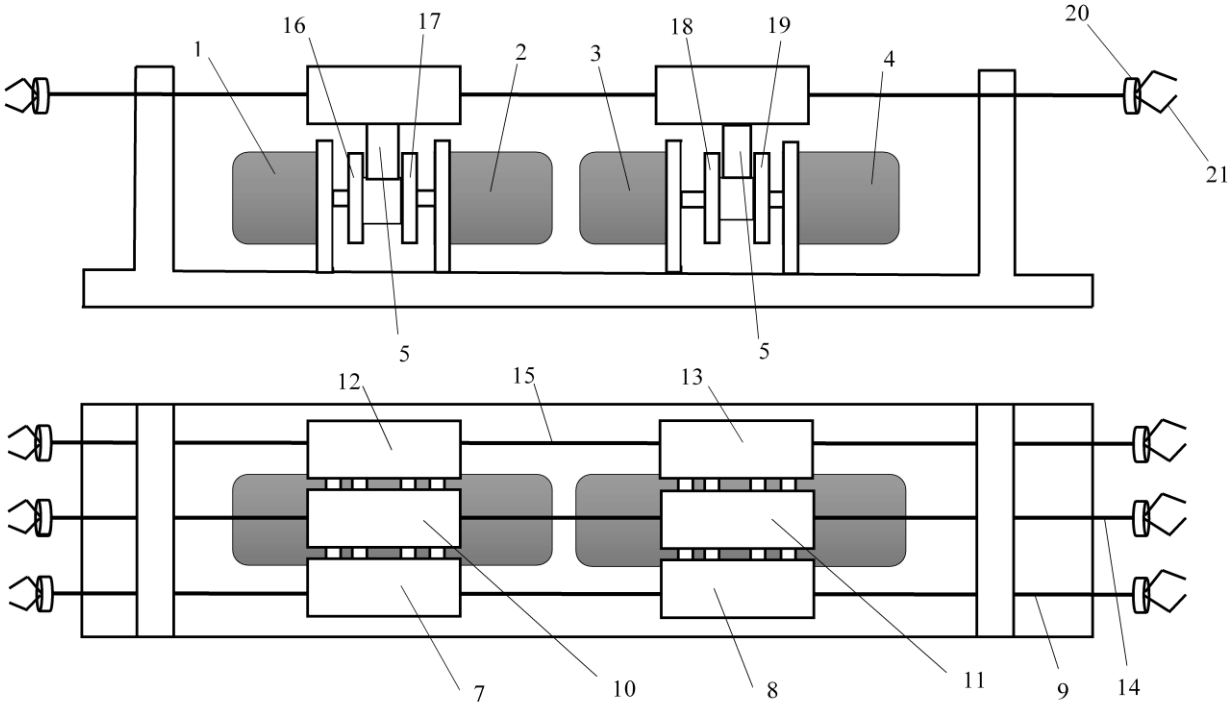

Fig 3. Structural diagram of the developed multi-position mechatronic module with force-moment sensing.

The mechatronic module includes four armored type power electromagnets 1, 2, 3 and 4 of the same type, anchors 16, 17, 18, 19 of which form two moving parts. Three pairs of electromagnetic couplings 7, 8, 10, 12, 11, 13 are rigidly mounted to the moving parts using strips 5, 6, covering two flexible rods 14, 15 made in the form of a closed loop (not shown in the drawing) and one rigid rod 9. By setting various control laws to the electromagnetic clutches 7, 8, 10, 12, 13, it is possible to obtain independent laws of motion of the rods 9, 14, 15, namely, translational step movements. The force-torque sensor 20 is installed in front of the gripper 21 [9,10,11,12].

When the output rod of the mechatronic module (Fig. 4) is in contact with the medium, the force transducer can measure three components of force and three components of moment in relation to the frame attached to it.

As shown in fig. 4., the sensor is used as a wrist connector between the outer arm of the mechatronic module and the limit switch.

The connection is made using a suitable number of tensile elements that are subject to deformation by force and moment. Strain gauges are glued to each element, which provide deformation measurement. The elements

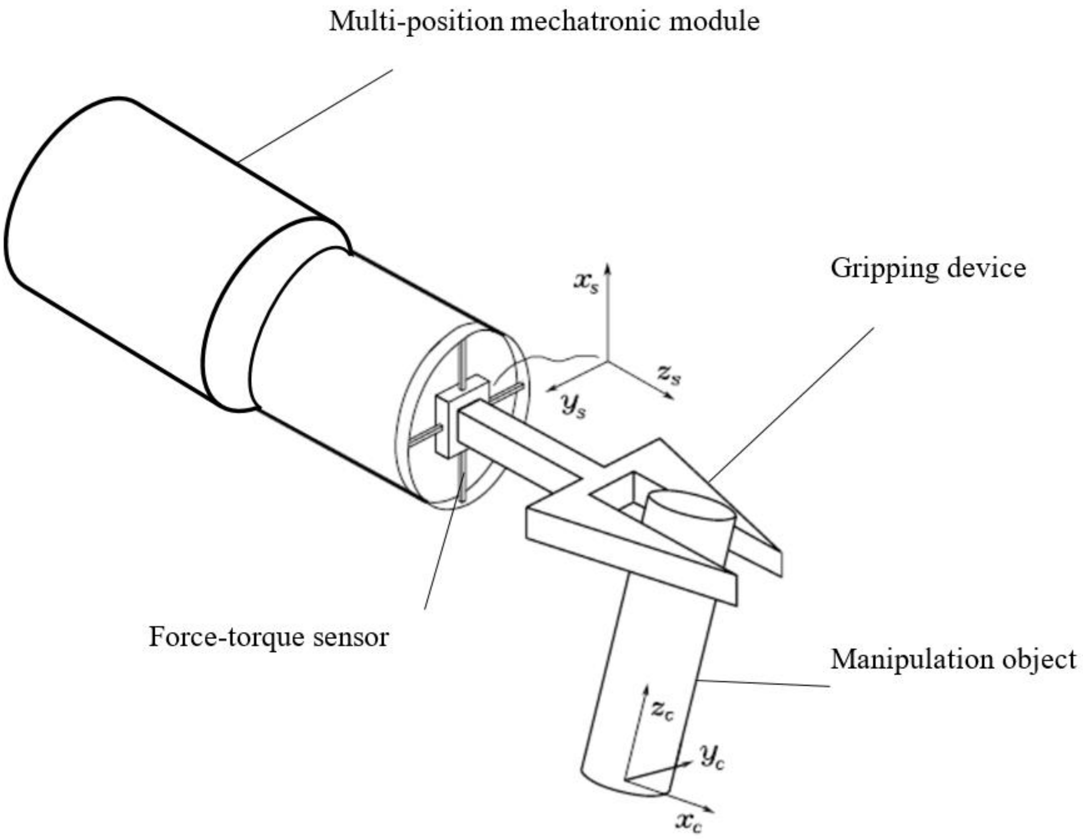

Fig. 4. Using a force- torque sensor on the external link of the mechatronic module.

must be located so that at least one element is noticeably deformed under any possible orientation of forces and moments.

In addition, a single force component with respect to the frame attached to the transducer should cause the least possible amount of deformation in order to obtain good structural separation of the force components. Since complete decoupling cannot be achieved, the number of significant deformations to restore the six components of the force and moment vector is greater than six.

The force sensor is the sensor of the mechatronic module, in which the sliding elements are located as in the Maltese cross; this is shown schematically in Fig. 6. The elements connecting the outer link with the end reflector are four rods in the form of a rectangular parallelepiped [12,13]. Glued on opposite sides of each rod is a pair of strain gauges that make up the two arms of the Wheatstone bridge; only eight bridges and therefore the ability to measure eight deformations. The matrix linking the strain measurements to the force components expressed in the s frame attached to the gauge is called the gauge calibration matrix.

Let w_i, for $i = 1, \ldots, 8$, denote the outputs of eight bridges that measure the deformations caused by forces applied to the rods in accordance with the direction indicated in Fig. 6.

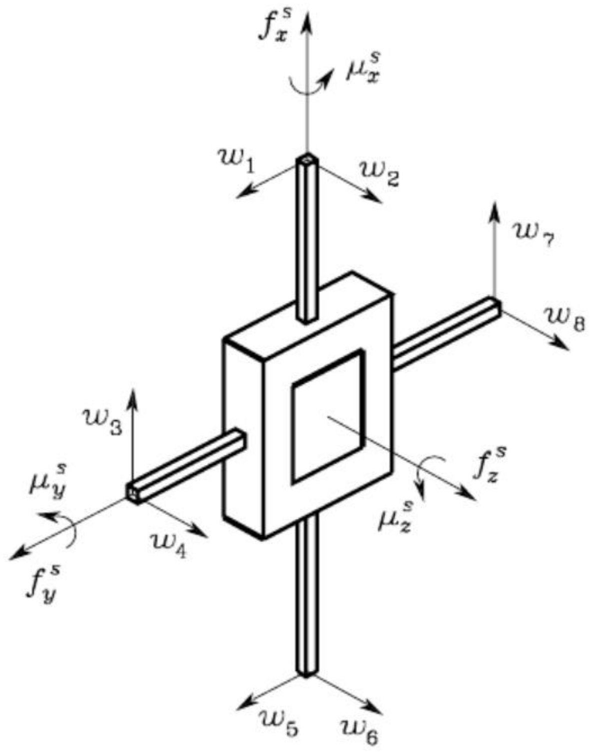

Fig. 6. Schematic representation of a Maltese cross force sensor.

Then the calibration matrix is given by the transformation

$$\begin{bmatrix} f_x^s \\ f_y^s \\ f_z^s \\ \mu_x^s \\ \mu_y^s \\ \mu_z^s \end{bmatrix} = \begin{bmatrix} 0 & 0 & c_{13} & 0 & 0 & 0 & 0 & c_{17} & 0 \\ c_{21} & 0 & 0 & 0 & c_{25} & 0 & 0 & 0 \\ 0 & c_{32} & 0 & c_{34} & 0 & c_{35} & 0 & c_{38} \\ 0 & 0 & 0 & c_{44} & 0 & 0 & 0 & c_{48} \\ 0 & c_{52} & 0 & 0 & 0 & c_{56} & 0 & 0 \\ c_{61} & 0 & c_{63} & 0 & c_{65} & 0 & c_{67} & 0 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \\ w_5 \\ w_6 \\ w_7 \\ w_8 \end{bmatrix}$$

The force measurement through the calibration matrix is assigned to the appropriate signal processing circuitry in the sensor [13,14].

Typical sensors have a diameter of about 10 cm and a height of about 5 cm, with a measuring range of 50 to 500 N for forces and 5 to 70 N m for torque, and a resolution of about 0.1% of the measuring range. maximum effort and 0.05% of maximum torque, respectively; the sampling frequency at the output of the processing circuit is about 1 kHz.

It is worth noting that force transducer measurements cannot be directly used in a force / motion control algorithm, as they describe equivalent forces acting on the transducers, which are different from the forces applied to the end arm of the module (Figure 4). Therefore, it is necessary to convert these forces from the sensor frame s to the frame constraint system c; taking into account the transformations in, we have that we need to know the position r_{cs}^c of the origin of the coordinate frame s relative to the frame c, as well as the orientation R_s^c of the frame s relative to the frame c. Both of these quantities are expressed in the c coordinate system, and, therefore, they are constant only if the finite modulus is stationary after reaching the contact [15,16,17].

CONCLUSION. The concept of construction of multi-position mechatronic modules of linear motion with force-moment sensing is proposed; it is designed to measure the components of the vector of forces and moments acting on the gripper or tool of the manipulator and to form a logical control action on the actuator. The structure of the system of force-moment sensing of intelligent mechatronic modules has been developed, including a database and knowledge, a preprocessing unit, a processor and a control system; modern FMSSs are classified according to the main holidays. The structural diagram of the developed multi-position mechatronic module with force-torque sensing, as well as options for their construction are presented.

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