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Sensing of Intelligent Robots Based on Applications of Tactile Slip Displacement Sensors

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Abstract: This paper discusses the design of modern tactile and slip displacement sensors for information-control systems of intelligent and adaptive robots. It provides information on three approaches for using slip displacement signals (for correction of claiming force, for identification of manipulated object mass and for correction of robot control algorithm). The study presents the analysis of different methods for slip displacement signals detection, as well as new sensors schemes, mathematical models and correction methods. Special attention is paid to investigations of sensors developed by authors with the capacity, magnetic sensitive elements and with automatic adjustment of clamping force. The proposed structure of multi-functional computerized information-control system for intelligent robot is presented. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: Tactile sensor, Slip displacement sensor, Model, Adaptive gripper, Intelligent robot, Control system.

1. Introduction

Updated intelligent robots pose high dynamic characteristics and effectively function under determinate conditions. The robot control problem is more complex in the uncertain environment, as robots are deficient of flexibility. Supplying robots with effective sensor systems provides essential extension of their functional and technological feasibility. For example, robot may often encounter a problem of gripping and holding i^{th} object in the process of manipulations with the required clamping force P_i^r excluding its deformation or mechanical injury, $i = 1...n$.

To successfully solve the current tasks the robot should possess the capability to recognize the objects by means of their own sensory systems. Besides, in some cases the main parameter due to which robot can distinguish objects of the same geometric form is their mass $m_i, (i = 1...n)$. The robot sensor system should identify the mass m_i of each i^{th} manipulated object in order to identify a class (set) an object refers to. The sensor system should develop required clamping force P_i^r corresponding to mass value m_i, as $P_i^r = f(m_i)$. Such current data may be used when the robot functions in dynamic or random environments. For example, there may be a situation when the robot should identify for any type of objects their unknown parameters and location in robot's working zone. The visual sensor system may not always be utilized, in particular, in poor vision conditions. Furthermore, in such cases when the robot manipulates with an object of variable mass $m_i(t)$, its sensor system should provide the appropriate change of a clamping force value $P_i^r(t) = f[m_i(t)]$ for gripper fingers. This information can be also used for the robot control algorithm correction, since a mass of the robot's arm last component and its summary inertia moment vary.

One of the modern approaches to solve the identification problem concerning the mass m_i of grasped objects and producing the required clamping force P_i^r is in the development of tactile sensor systems based on object slippage registration while slipping between the gripper fingers. Some sensor systems based on the slip displacement sensors were considered in [1-2], but the random robot environment very often requires the development of new robot sensors and sensor systems for increasing speed of operations, the growth of positioning accuracy or the desired path-following precision [3].

2. Registration of Slip Displacement Signals in Intelligent Robotics

2.1. Analysis of the Main Data Acquisition Methods for Detection of Slip Displacement Signals

Thus, the task of the slippage signals registration between robot fingers for manipulated objects stands in connection with [3]:

a) The necessity of the required force creation being adequate to the object mass value;
b) The recognition of objects;
c) The necessity of robot gripper's trajectory and control algorithm correction.

As usual, the slippage signals detection in robotic systems is accomplished either in the trial motion or in the regime of continuous lifting of the robot arm.

The idea of a trial motion regime comprises the process of the iterative increase in the compressive force value if the slippage signal is being detected.

The choice of the method of slip displacement data acquisition depends on robot's purpose, the salient features of its functioning medium, the requirements of its speed of response and performance in terms of an error probability.

Let's consider the main methods of slip displacement data acquisition, in particular [3–9]:

The method of vibration detection. This method is based on a principle of the vibration detection in the sensing element when the object is slipping. To implement the method mentioned such sensing elements may be adopted: a sapphire needle interacting with the crystal receiver or a rod with a steel ball, connected with the electromagnetic vibrator.

*The method of pressure re-distribution detection***.** The method relies on the detection of a distribution change in pressure between gripper fingers at the object slippage and is based on the physiological sensibility function of man's skin. The pressure transducers serve as nerves and are surrounded by elastic substance as in human body.

The method of rolling motion detection. The method is characterized by transducing the object displacements in the vertical direction at slipping to the rolling motion of a sensitive element. A slip displacement signal is detected at rolling of a cylinder roller with elastic covering and a large friction coefficient. The roller's rolling motions may be converted to an electric signal by means of photoelectric or magnetic transducers, containing a permanent magnet on a movable roller, and in case of a magnetic head being placed on a slippage sensor.

The method of impact-sliding vibrations detection. A core of the method implies the detection of liquid impact-sliding vibrations when the object is slipping. An acrylic disk with cylinder holes is used in the slip displacement sensor, realizing the method under consideration. A rubber gasket made in the form of a membrane protects one end of the disk, and a pressure gauge is installed on another end. The hole is filled with water in the way that its pressure exceeds slightly the atmospheric pressure. While the motion of the object is in contact with a membrane the impact-sliding vibrations are appearing and, therefore, inducing impulse changes in water pressure imposed by a static pressure.

The method of acceleration detection. This method is based on the measurement of accelerations of the sensitive element motion by the absolute acceleration signal separation. The slip displacement sensor comprising two accelerometers can be used in this case. One of the accelerometers senses the absolute acceleration in the gripper, another responds to the acceleration of the sensitive plate springing when the detail is slipping. The sensor is attached to the computer identifying the slip displacement signal by comparing the output signals of both accelerometers.

*The method of the interference pattern changes detection***.** This method involves the conversion of the intensity changes reflected from the moving surface of the interference pattern. The intensity variation of the interference pattern is converted to a numerical code, the auto-correlation function is computed and it achievs its the peak at the slip displacement disappearance.

The method of the configuration changes detection in the sensitive elements. The essence of the method incorporates the measurement of the varying parameters when the elastic sensitive element configuration changes. The sensitive elements made of conductive rubber afford coating of the object surface protruding above the gripper before the trial motion. When the object is displacing from the gripper the configuration changes, the electrical resistance of such sensitive elements changes accordingly confirming the existence of slippage.

The method of data acquisition by means of the photoelastic effect. An instance representing this method may be illustrated by a transducer, in which under the applied effort the deformation of sensitive leather produces the appearance of voltage in the photoelastic system. The object slippage results in the change of the sensitive leather deformation being registered by the electronic visual system. The photosensitive transducer is a device for the transformation of interference patterns into the form of a numerical signal. The obtained image is of binary character, each pixel gives a bit of information. The binary representation of each pixel enables to reduce the time of processing.

The method of data acquisition based on the friction detection. The method involved ensures the detection of the moment when the friction between the gripper fingers and the object to be grasped goes over from friction of rest to dynamic friction.

The method of fixing the sensitive elements on the object. The method is based on fixing the sensitive elements on the surface of the manipulated objects before the trial motions with the subsequent monitoring of their displacement relative to the gripper at slipping.

The method based on recording oscillatory circuit parameters. The method bases on a change in the oscillatory circuit inductance while the object slippage. The inductive slip sensor with a mobile core, stationary excitation winding and solenoid winding being one of the oscillatory circuit branches implements the method. The core may move due to the solenoid winding. The reduction of the solenoid winding voltage is leading to the process of lowering, the core is lowering under its own weight from the gripper center onto the object to be grasped. The oscillatory circuit induces the forced oscillations with the frequency coinciding with the frequency of excitation in the excitation winding.

The method of video signal detection. The basis of this method constitutes a change in detection and ranging of patterns or video pictures as an indication of the object slippage. The slip displacement detection is accomplished by means of the location sensors or visual sensors based on a laser source that has either a separated and reflecting beam, or a vision with a non-coherent beam of light conductors for picture lighting and a coherent beam for image transmission.

Analysis of last publication on tactile and slip displacement sensors shows [3, 8, 9] that researchers develop a lot of new solutions using well-known and new design methods.

2.2. Modification of the Slip Sensors

The choice of a slip displacement detection method involves the multicriterion approach taking into account the complexity of implementation, the bounds of functional capabilities, mass values and overall dimensions, reliability and cost.

In this paper, the authors consider a few instances of updating the measurement systems. To suit requirements of increasing the noise immunity of the vibration measurement method a modified method has been developed. The modified method is founded on the measurement of the sensitive element angular deviation occurring at the object slippage (Fig. 1). The mathematical models of such slip displacement sensors (SDS) with a measurement of changeable capacity are presented in [10–14].

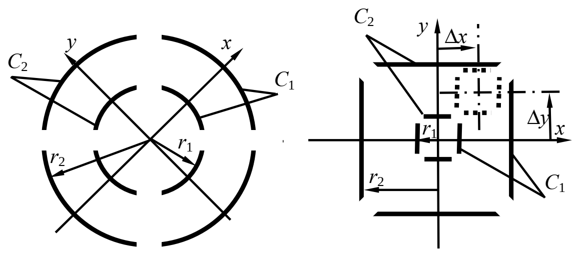


Fig. 1. Different models of slip displacement sensor based on measurement of changeable capacity C_1,C_2: a) cylinder model; b) rectangular model.

The second method serves as a basis for developing the distributed slip sensors of the matrix type. This paper discusses a two-dimensional tactile SDS, that has a form of a round piezooptic beamconductive plate. Another modification of the matrix type slip sensor is a sensitized module constructed in the thin conducting film in the form of 12 contactors joined in a measurement circuit.

The need for rigid gripper orientation before a trial motion has been causing the development of the slip sensor based on a cylinder roller with a load which has two degrees of freedom.

The sensitive element of new developed by authors [3] sensor has the form of a ball with light-reflecting sections disposed in a staggered order thus providing the slippage detection by the photo-method. The ball is arranged in the sensor's space through the spring-loaded slides, each slide is connected with the surface of the gripper's space by an elastic element made of conductive rubber.

The ball motion is secured by friction-wheels and is measured with the aid of incremental transducers in another modification of the slip sensor with the ball acting as a sensitive element. The ball contacts with the object through the hole. In this case the ball is located in the space of compressed air dispensed through the hole.

At the moment, a lot of engineering solutions for slip displacement sensors designing are based on the application of sensitive electroconductive rubber [5, 8].

3. Advances in Development of Self-Clamping Grippers of Intelligent Robots

3.1. New Trends in Designing Multi-Sensor Grippers with Slip Displacement Signal Detection

The slip displacement signals, responsible for creation of the required compressive force adequate to the object mass, provide the conditions for the correction of the gripper trajectory-planning algorithm, which identifies an object mass as a variable parameter [15]. The object mass identification is carried out in response to the final value of the compressive force, recorded at the slippage signal disappearance. It is of extreme importance to employ the slip sensors with uprated response when the object mass changes in the functioning process.

In those cases, when the main task of the sensing system is the compression of the object without its deformation or damage, it is expedient in future research to project the advanced grippers of a self-clamping design (Fig. 2), excluding the gripper drive for the compressive force growth (at slipping) up to the required value.

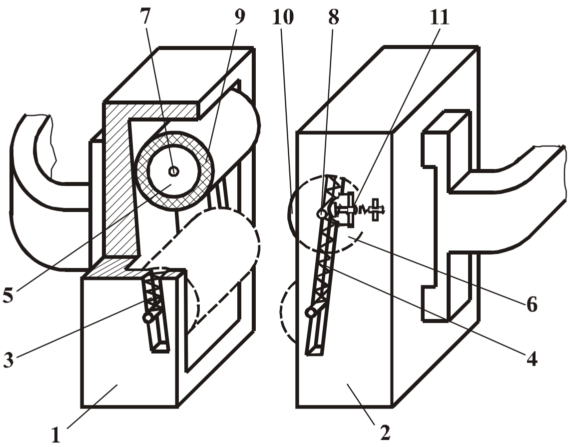
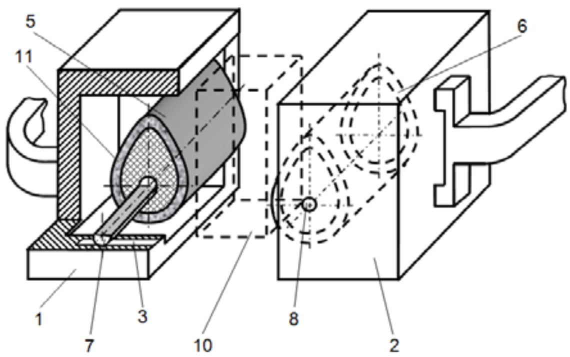


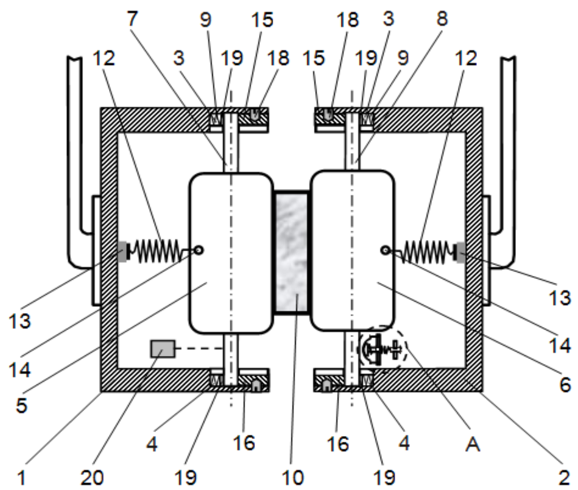
Fig. 2. Self-clamping gripper of intelligent robot: 1, 2 - finger; 3, 4 - directing groove; 5, 6 - roller; 7, 8 – roller axle; 9, 10 - elastic; 11 - contact sensor.

In such a gripper (Fig. 2), the rollers have two degrees of freedom and during object's slippage they have compound behavior (rotation and translation motions). This gripper (Fig. 2) has adaptive property since the object self-clamping is being accomplished with a force adequate to the object mass up to the moment of the slippage disappearance [7, 16].

Another engineering solution [17] for designing self-clamping gripper is presented in Fig. 3, where cams are used as clamping elements. On the left finger (Fig. 3) of robot gripper made two partial horizontal cross-sections through the bottom of the guide groove and through the middle axis of cam roller. The surface of each cam roller, which is in direct contact with the object of manipulation (Fig. 3) covered by elastic rough material, such as rubber. Adaptive gripper of intelligent robot is equipped with the first sensor of compressive force (Fig. 3), which records the movement of the cam rolling element with increasing compressive force of adaptive gripper fingers. First clamping force sensor can be made, for example, as potentiometric, inductive or capacitive.



a) Front view



b) Top view

Fig. 3. Self-clamping gripper of intelligent robot with cam rollers:
1, 2 - finger; 3, 4 - directing groove; 5, 6 – cam's roller; 7, 8 – cam's roller axis; 9 – cylinder return spring,which is connected with cam's roller axis; 10 – manipulated object; 11 - elastic rough material; 12 - cylinder return spring, which is connected with surface of cam's roller; 13 - fixator; 14 - hinged connection; 15, 16 – pad of blocking fixator; 17 – a hole in the pad of blocking fixator; 18 – screw; 19 – segmental fixator; 20 – first sensor; A – second tactile sensor of clamping force.

When compressed fingers (1, 2), axis gripper (7, 8) go deep into the appropriate slots (3, 4) until compression (Fig. 3) of cylindrical springs (9), which is achieved with the creation of minimum (pre-set) value of compressive force F_{min} by fingers of the gripper. As with the at least one cam's roller axle interacts with a second sensor of compressive force (Fig. 3, 4), the electroconductive contacts are closed, which is a command signal for vertical motion of adaptive gripper, in particular, for lifting an object (10) by intelligent robot. The output of the first sensor of clamping force is formed by compressive force signal value that corresponds to the established compressive force between fingers of gripper and corresponds to the mass of the manipulated object.

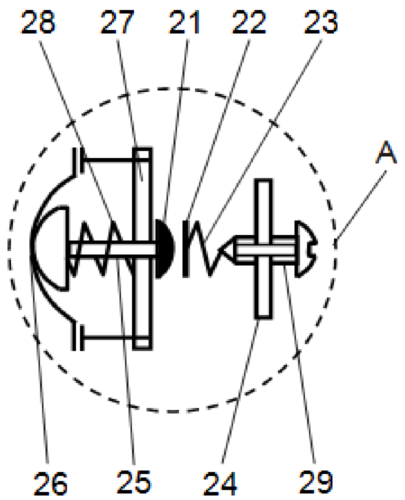


Fig. 4. Second tactile sensor of self-clamping gripper of intelligent robot: 21, 22 – electroconductive contact; 23, 28 – cylindric spring; 24, 27 – bar, which fixed on the finger; 25 – rod; 26 – elastic cover; 29 – adjusting screw.

The process of reqired clamping force creating, according to unknown mass of manipulated object, illustrated by Fig. 5, where:

- Fig. 5(a) presents the position of adaptive gripper with manipulation object and position of cam's rollers in situation, when intelligent robot creates the minimum value of clamping force F_{min}, where h_1 is a distance between gripper fingers and base surface;

- Fig. 5(b) presents the positions of cam's rollers and adaptive gripper with manipulation object in situation, when intelligent robot creates the required value of clamping force F_{req}, where h_2 is a distance between gripper fingers and base surface (30) and $\Delta_1 = (h_2 - h_1)$ is a value of vertical displacement of robot gripper during process of required clamping force creating;

- Fig. 5(c) presents the position of adaptive gripper in situation when intelligent robot moves the manipulation object in vertical direction, where $\Delta_2 = (h_3 - h_2)$ is a value of vertical displacement for the manipulation object.

3.2. Main Requirements for Data Acquisition in Real Time

Frequently the handling operations require a compressive force being exerted through the intermediary of the robot's sensing system in the continuous hoisting operation. This regime shows a simultaneous increase in the compressive force while the continuous hoisting operation and lifting of the gripper in the vertical direction accompanied by the slip displacement signal measurement. When the slippage signal disappears the compressive force does not increase and, therefore, the operations with the object are accomplished according to the robot's functioning algorithm. To realize the trial motion regime and the continuous hoisting operation being controlled in real time, the stringent requirements to the parameters should be met [3], in particular:

a) the response time between the moment of slippage emergence and the moment when the gripper fingers begin to increase the compressive force;

b) the time of the sliding process including the moments between the emergence of sliding and its disappearance;

c) the minimal object displacement detected by the slip signal.

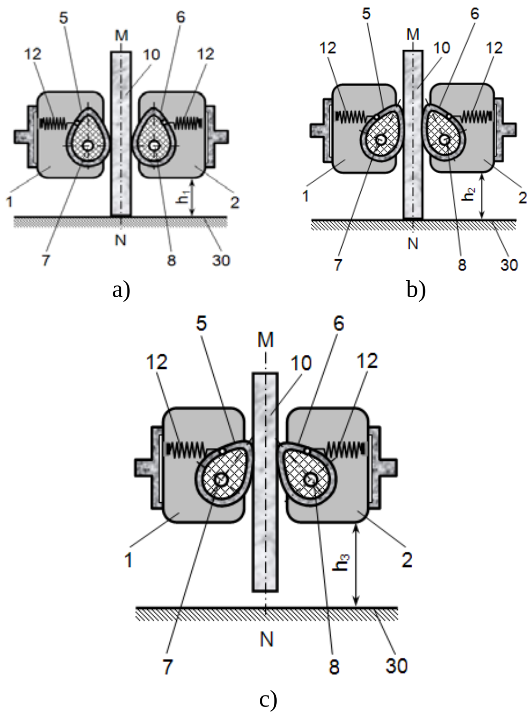


Fig. 5. The sequence of self-clamping gripper's positions during creating minimal (a) and required (b) values of clamping force and during vertical lifting (c) of manipulated object: 30 - base surface.

The problem of raising the sensors response in measuring the slip displacement signals is tackled by improving their configuration and using the measuring circuit designs with high resolving power.

4. Analysis of Mathematical Models for SDS with Sensitive Components "Constant Magnet-Hall Sensor"

4.1. Mathematic Model of SDS with Magnetic Sensitive Element

This study presents a number of sensors for data acquisition in real time [7, 11, 13, 18]. Let's consider structure and mathematical model of the developed by the authors SDS with magnetic sensitive element which can detect the bar's angular deviation appearing at the object slippage (Fig. 6). Mathematic model $U = f(\alpha)$ can be used to determine the sensitivity of the SDS and the minimal possible amplitudes of robots trial motions.

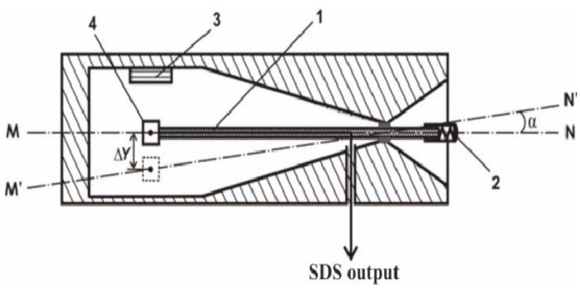


Fig. 6. SDS with magnetic sensitive element: 1 – bar; 2 - head; 3 - constant magnet; 4 – Hall sensor.

To construct mathematical models, consider the magnetic system comprising a prismatic magnet with dimensions $c \times d \times l$, which is set to ferromagnetic plane with infinite permeability $\mu = \infty$ (Fig. 7), where: c - width, d - length, and l - height of magnet, $(d >> l)$. The point $P(X_P, Y_P)$ is the observation point, which is located on the vertical axis and can change its position relative to the horizontal axis Ox or vertical axis Oy. Hall sensor with a linear static characteristic is located at the observation point P.

Let's form the mathematic model for the determination of the magnetic induction B and the output voltage $U_{out}(P)$ of the Hall sensor in relation to an arbitrary position of the observation point P under the surface of the magnet. The value of magnetic induction (outside the magnet volume) is $\overline{B} = \mu_0 \overline{H}$, where μ_0 is a magnetic constant and $\overline{H}$ is a vector of magnetic field strength.

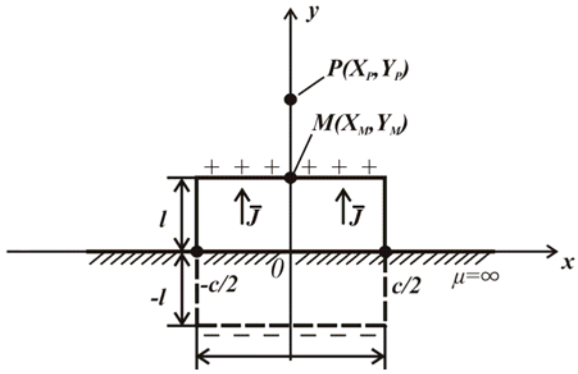


Fig. 7. Model of magnetic sensitive element.

In the middle of the magnet - the value of magnetic induction is determined by the dependence $\overline{B} = \mu_0(\overline{J} + \overline{H})$, where J is a magnetization value. $J = J_0 + \chi H$, where χ is a magnetic susceptibility and J_0 is a residual magnetization value.

The constant magnet can be represented [19–21] as a simulation model of the surface magnetic charges that are evenly distributed across the magnet pole faces with the surface density J_T.

Thus, a y-component of the magnetic field strength H_y of magnetic charges can be calculated as:

$$H_y = -\frac{J_T}{2\pi}\left[\begin{pmatrix} arctg\dfrac{X_P + c/2}{l - Y_p} - \\ -arctg\dfrac{X_P - c/2}{l - Y_p} \end{pmatrix} - \\ -\begin{pmatrix} arctg\dfrac{X_P + c/2}{-l - Y_p} - \\ -arctg\dfrac{X_P - c/2}{-l - Y_p} \end{pmatrix}\right] \quad (1)$$

and y-component of magnetic induction B_y can be presented as:

$$B_y = -\frac{J_T \mu_0}{2\pi}\left[\begin{pmatrix} arctg\dfrac{X_P + c/2}{l - Y_p} - \\ -arctg\dfrac{X_P - c/2}{l - Y_p} \end{pmatrix} - \\ -\begin{pmatrix} arctg\dfrac{X_P + c/2}{-l - Y_p} - \\ -arctg\dfrac{X_P - c/2}{-l - Y_p} \end{pmatrix}\right] \quad (2)$$

To determine the parameter J_T, it is necessary to measure the induction of the center of pole faces $B_y\big|_{x=0,y=l+}$. Value $(y=l+)$ indicates that the measurement of B_{mes} is conducted outside the volume of magnet. The value of magnetic induction at a point with the same coordinates on the inside of the pole faces can be considered equal to the value of induction from the outside pole faces, by virtue of the continuity of the magnetic flux and lines of magnetic induction, namely:

$$B_y\big|_{x=0,y=l+} = B_y\big|_{x=0,y=l-} \tag{3}$$

So, we can write:

$$B_y\Big|_{\substack{x=0\\y=l+}} = B_{mes} = \mu_0 J_T + \mu_0 H_y\Big|_{\substack{x=0\\y=l-}}, \tag{4}$$

where B_{mes} is the value of magnetic induction measured at the geometric center of the top pole faces of the prismatic magnet.

On the basis of (1) we obtain:

$$\begin{aligned} B_{mes} &= \mu_0 J_T \times \\ &\times\left[1-\lim_{Y_P\to l-}\frac{2}{2\pi}\left(\begin{aligned}&arctg\frac{c/2}{l-Y_p}+\\&+arctg\frac{c/2}{l+Y_p}\end{aligned}\right)\right]= \\ &=\mu_0 J_T\left(\frac{1}{2}+\frac{1}{\pi}arctg\frac{c}{4l}\right), \end{aligned} \tag{5}$$

$$J_T = \frac{2\pi B_{mes}}{\mu_0\left(\pi + 2arctg\dfrac{c}{4l}\right)} \tag{6}$$

For *y*-component of magnetic induction $B_y(P)$ at the observation point P the following expression was obtained:

$$\begin{aligned} B_y(P) &= -\frac{B_{mes}}{\left(\pi+2arctg\dfrac{c}{4l}\right)}\times \\ &\times\left[\left(\begin{aligned}&arctg\frac{X_P+c/2}{l-Y_p}-\\&-arctg\frac{X_P-c/2}{l-Y_p}\end{aligned}\right)-\right. \\ &\left.-\left(\begin{aligned}&arctg\frac{X_P+c/2}{-l-Y_p}-\\&-arctg\frac{X_P-c/2}{-l-Y_p}\end{aligned}\right)\right] \end{aligned} \tag{7}$$

4.2. Modeling Results for Magnetic SDS

For the analysis of the existing mathematic model (7), let's calculate the value of magnetic induction [3] on the surface of the magnet (Barium Ferrite) with parameters of c = 0.02 m, d = 0.08 m, l = 0.014 m and a value of magnetic induction $B_{mes} = 40$ mT (value measured at the geometric center of the upper limit of the magnet).

The simulation results for magnetic induction are represented as $B_y = f_i(X_P), i = 1,2,3$ above the magnet for different values of the height Y_P of the observation point $P(X_P, Y_P)$, where indicated: f_1 - for $B_y\Big|_{\substack{x\in[-20;20]mm\\y=l+1mm}}$, f_2 - for $B_y\Big|_{\substack{x\in[-20;20]mm\\y=l+5mm}}$ and f_3 – for $B_y\Big|_{\substack{x\in[-20;20]mm\\y=l+20mm}}$.

As can be seen from the Fig. 8, magnetic induction $B_y = f_1(X_P)$ above the surface of the magnet is practically constant for the coordinate $X_P \in [-5;5]$ mm, which is half of the corresponding size of magnet. If the distance from the observation point P and magnet increasing ($f_2(X_P), f_3(X_P)$ in Fig. 8), curve shape changes become more gentle, with a pronounced peak above the geometric center of the top pole faces of the prismatic magnet (at the point $X_P = 0$). For the Hall sensor (Fig. 8) in the general case the dependence of output voltage $U_{out}(P)$ on the magnitude of the magnetic induction B_y is defined as:

$$U_{out}(P) = U_C + kB_y(P), \tag{8}$$

where k is the correction factor, that depends on the type of Hall sensor and U_C is constant component of the Hall sensor output voltage.

For Hall sensors with linear dependence of the output signal U_{out} from the magnetic induction B_y occurs as $k = const$ and $k = f\{B_y(P)\}$ for nonlinear dependence. For Hall sensor SS490 (Honeywell) with linear dependence (8) the values of parameters are: $U_C = 2.5V$ and $k = 0.032$ (from static characteristic of Hall sensor).

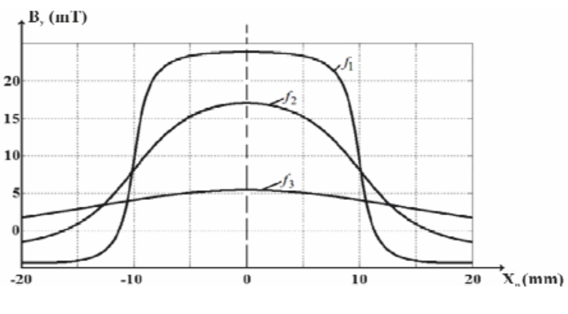


Fig. 8. Simulation results for $B_y(P)$ based on the mathematical model (7).

Authors present the mathematical model of the Hall sensor output voltage $U_{out}(Y_P)$ at its vertical displacement above the geometric center of the top pole faces of magnet ($X_P = 0$):

$$U_{out}(Y_P) = 2,5 + 7,4 \cdot 10^{-3} \times \times \left(arctg \frac{0,01}{0,014 - Y_P} + + arctg \frac{0,01}{0,014 + Y_P} \right) \quad (9)$$

The comparative results for dependences $U_{out}(Y_p)$, $U_E(Y_p)$ and $U_R(Y_p)$ are presented in Fig. 9, where $U_{out}(Y_p)$ was calculated using mathematic model (9), $U_E(Y_p)$ are the experimental results according to [22] and $U_R(Y_p)$ is nonlinear regressive model according to [23]. Comparative analysis (Fig. 9) of developed mathematical model $U_{out}(Y_p)$ and experimental results $U_E(Y_p)$ confirms the correctness and adequacy of the synthesized models (1), (7) - (9).

5. Computerized System for Intelligent Robot's Control Based on Tactile and Slip Displacement Sensors

In many cases, it is very important and necessary to fix the fingers of robot gripper in desired position on the manipulated object. The current position can be shifted according to desired position during slip displacement process for manipulated object. Authors developed (Fig. 10) the computerized information-control system, which allows (in automatic mode) fixing the fingers in desired (determinate) position on the manipulated object after identification of value of object mass (by intelligent robot) based on signals of tactile and slip displacement sensors.

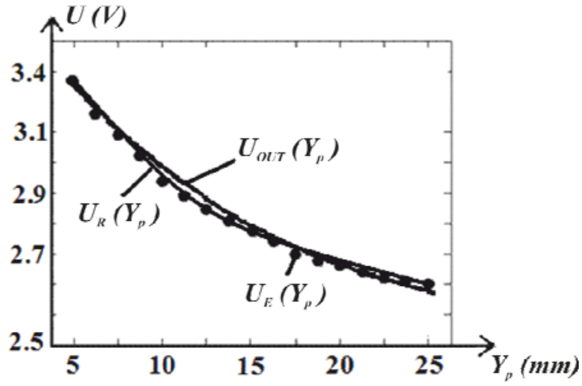


Fig. 9. Modeling and experimental results.

The structure and main components of the developed computerized information-control system of intelligent robot as multi-sensor system [14, 24-25] are represented in Fig. 10, where components are marked as: 1- tactile sensor; 2 - slip displacement sensor; 3,18 – amplifier; 4, 5, 6 - element OR; 7, 8 – block of delay; 9, 10 - RS-triggers; 11, 12 - threshold element; 13 – integrator; 14 –register; 15 - digital-analog converter; 16 - reference voltage source; 17 - voltage divider; 19 – a drive of fingers; 20, 21, 22 – adders; 23 - NOT element; 24 - computer control unit; 25, 26, 27, 28, 29, 30, 31 - control switch.

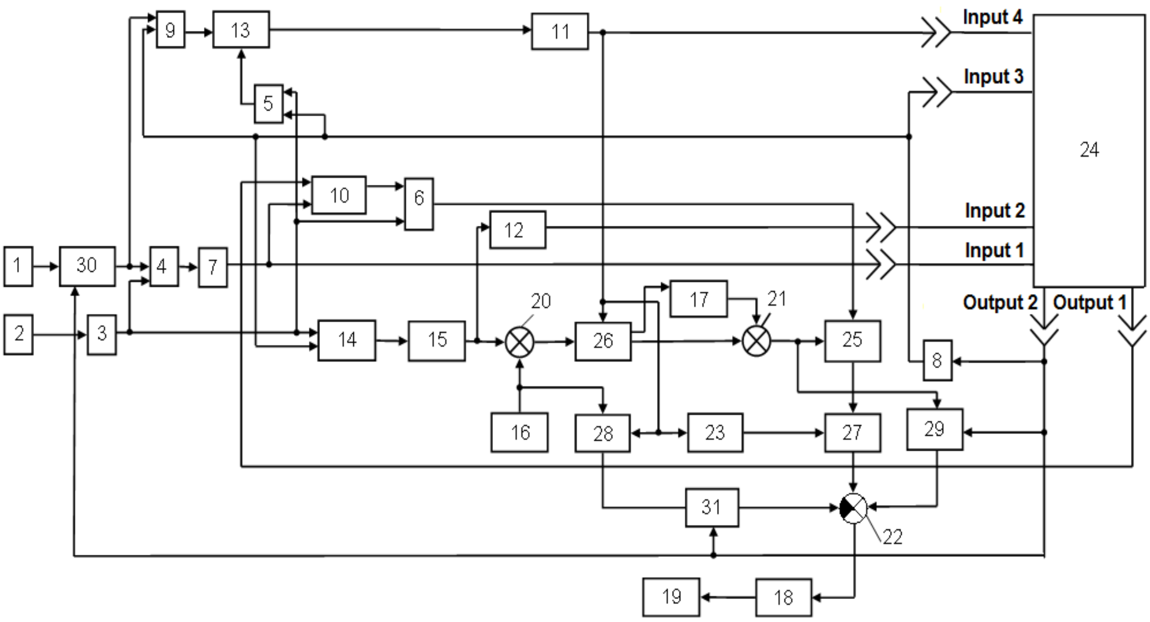


Fig. 10. The structure of computerized information-control system of intelligent robot.

As a tactile sensor (Fig. 10) it is possible to use any sensor [14], which is fixed in one of the gripper fingers of intelligent robot and can form a single discrete output signal corresponding to the presence (logic "1") or not (logic "0") contact of manipulated object with robot fingers. The output of slip displacement sensor should be in the form of logic "1" (if displacement is appeared) or logic "0" (if displacement is absent) [25].

The computer control unit (Fig. 10) can be realized based on the digital components [26], in particular, very perspective is such realization on the FPGA microprocessor base with possibility for reconfiguration [27, 28]. In this case, the multi-functional peculiarities of computerized information-control system may be expanded for various types of intelligent robots with different planned missions in different work environments.

6. Conclusions

The methods of the slip displacement signal detection considered in the present paper furnish an explanation of the main detection principles and allow robot sensing systems obtain wide capabilities. Authors developed wide variety of SDS schemes and mathematical models with capacitative, magnetic and light-reflecting sensitive elements with improved characteristics (accuracy, time response, sensitivity). The results of the research are applicable in the automatic adjustment of clamping force of robot's gripper and correction of robot motion algorithms in real time. The methods introduced by authors may be also used in random functioning conditions, in settling the problems of the automatic assembly, sorting, patterns and images recognition in the working zones of robots. Proposed sensors, their models and structure of computerized information system can be used for synthesis of intelligent robot control systems [3, 29–31] with new features and for solving orientation and control tasks during intelligent robot contacts with obstacles.

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