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SUGGESTIONS FOR TEACHING

for the performance of practical work
in the discipline "Sensor and Detection Technology"
for students of the field of study

11.03.02 Infocommunication Technologies and Communication Systems
"Intelligent Data Processing in Infocommunication Systems and Networks"

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1 Practical Work No 1. Measurement with strain gauges

The purpose of the work: to master the method of measurement with strain gauges, to study their design and main characteristics, to study the principle of their operation.

1.1 Progress of work

1.1.1 To study the principle of operation and the main characteristics of strain gauge sensors using subsection 1.2.

1.1.2 Study the structure of the laboratory stand, draw up its functional scheme.

1.1.3 To study the characteristics of the strain gauge models installed on the laboratory bench, and the procedure for their use.

1.1.4 Take measurements using a strain gauge pressure sensor. Based on the measurement results, draw up a table of the dependence of the sensor output signal value on the measured pressure value.

1.1.5 Take measurements with a strain gauge force sensor. Based on the results of the measurements, make a table of the dependence of the output signal of the sensor on the applied force.

1.1.6 Take measurements with a strain gauge – accelerometer. Based on the measurement results, make a table of the dependence of the value of the sensor's output signal on the acceleration value.

1.1.7 Plot the dependencies obtained from items 1.1.4–1.1.6.

1.1.8 Answer control questions.

1.2 Brief theoretical information

A strain gauge transducer (strain gauge) is a parametric resistive transducer that converts the deformation of a solid body caused by the mechanical stress applied to it into an electrical signal. A resistive strain gauge is a base with a sensing element fixed on it. The principle of measuring deformations with a strain gauge transducer is that the active resistance of the strain gauge changes during deformation. The effect of changing the resistivity of a metal conductor under the influence of all-round compression (hydrostatic pressure) was discovered in 1856 by Lord Kelvin and in 1881 by O. D. Khvolson. In its modern form, a strain gauge transducer is structurally a strain gauge, the sensing element of which is made of strain sensitive material (wire, foil, etc.), fixed with a binder (glue, cement) on the part under study. To connect the sensitive element to the electrical circuit, the strain gauge has

Output conductors. Some strain gauge designs have a substrate located between the sensing element and the examined part for ease of installation, as well as a protective element located on top of the sensing element. Despite the general sympathy for strain gauges, pneumatic and hydraulic load cells are still used in some areas of human activity. For example, pneumatic load cells are still used in places where internal safety and hygiene are very important, while hydraulic load cells are a lifesaver in remote locations where there is no access to an uninterruptible power supply, as they do not need it at all.

A strain gauge load cell is a flexible body that undergoes linear deformation under the influence of an acting force. Sensitive elements, the so-called strain gauges, are glued to suitable places in the body.

A strain gauge is a resistive element whose electrical resistance changes its value due to mechanical deformation (tension or compression). The acting force thus contributes to the change in electrical resistance. Four strain gauges are usually placed on the sensor, which are included in the bridge system so that the change in resistance can be more easily determined. Sensors with metal strain gauges operate according to the described principle. There are also other principles and types of sensors, such as sensors with semiconductor strain gauges. Semiconductor strain gauges are made of silicon, so their sensitivity is significantly higher than that of metal strain gauges. However, they are very dependent on temperature and are therefore only used in special cases.

A piezoelectric force sensor works on a different principle. It uses a piezoelectric phenomenon, i.e. the occurrence of voltage in a crystal under mechanical effort. With the help of a piezoelectric sensor, dynamic forces are measured, but it is not suitable for measuring static forces. There are other types of sensors, for example, vibration, hydraulic, electrodynamic, magnetoelastic, etc., but none of them is used as widely as sensors with metal strain gauges. Other sensors are suitable only for specialized tasks, or they are very expensive. In comparison, force sensors with metal strain gauges are universal: they are suitable for measuring both static and dynamic forces.

Parameters of strain gauge load cells. Shape of the sensor.

For the use of strain gauges in specific cases, the type of sensor is very important, that is, its shape and mounting capabilities. Parameters such as accuracy, overload, etc., depend on the shape of the sensor and the material from which it is made. Therefore, there are different types of sensors, but they are usually modifications of several basic types, such as membrane, flexible, column, etc.

Measurement range.

The main parameter of a strain gauge is its measuring range, which can be increased by up to 30%... 50 %. A higher overload of the sensor, even if only for a short time, will almost always lead to damage to the sensor. Such a sensor can no longer be repaired, as the structure of the material is disturbed. This must always be borne in mind when using sensors in environments where run-out and vibrations are possible.

Sensor sensitivity.

An important parameter, especially from the point of view of processing the output sign, is the sensitivity of the sensor. It is measured in units of millivolts/volts, and its values are most often in the range of 1 to 3. For example, if the sensitivity of the sensor is 2 mV/V and the sensor is powered by a constant voltage of 10 V, then the output signal of the sensor at full load will have

$2 \cdot 10 = 20 \text{ mV}$. This is a relatively low value, so the signal

is usually amplified and only then goes to the measuring instrument or analog card in a PC or PLC.

Other parameters.

Other important parameters are input resistance (from the point of view of signal processing), isolation resistance (from the point of view of safety), degree of protection (from the point of view of working conditions), etc.

Load cell design. A load cell consists of:

- elastic element – a body that takes a load; it is made mainly of alloyed carbon steels pre-heat-treated, to obtain stable characteristics. Structurally, it can be made in the form of a rod, a ring, bodies of rotation, a console. Structures in the form of a rod (or several rods) have become widespread;

- strain gauge – a foil or wire resistor glued to an elastic element (rod), which changes its resistance in proportion to the deformation of the elastic element, which, in turn, is proportional to the load;

- sensor housing – designed to protect the elastic element and strain gauge from mechanical damage and environmental influences. It has a different IP (Ingress Protection Rating) design in accordance with the international standard IEC 60529 (DIN 40050, GOST 14254–96);

- Hermetic entry (cable connector) – designed to connect the strain gauge to a secondary device (weighing indicator, electronic amplifier, ADC) using a cable. Connection options are possible according to the 6- and 4-wire scheme. Strain gauges are equipped with cables of various lengths, there are designs with the possibility of replacing the cable.

For the correct functioning of the scales, it is important to observe the nature of the load application. The force vector acting on the sensor must be strictly in the direction of the sensor axis (elastic element of the load cell, rod, ring). To exclude the lateral influence of the load, self-adjusting

flowing (self-centering) structures. The surface of the supports of such strain gauges has a spherical convex shape.

The principle of operation of a strain gauge is based on measuring the change in the resistance of strain gauges glued to an elastic body, which, under the influence of force (weight of the load), deforms and deforms the strain gauges placed on it.

1.3 Contents of the report

The report on the completion of laboratory work is drawn up on a computer in a text editor. The report must contain:

- the purpose of the work;
- a description of the progress of the work item by point with an indication of the result of the implementation of the item;
- Conclusion.

Control questions

- 1 List the main types of strain gauges.
- 2 Explain the structure and principle of operation of a strain gauge pressure sensor.
- 3 Explain the structure and working principle of a strain gauge force transducer.
- 4 Explain the structure and principle of operation of the strain gauge sensor-accelerometer.
- 5 What types of output can strain gauges have?

2 Practical Work № 2. Study of Photovoltaic Angle-Code Converter

The purpose of the work: to study the principle of operation, structure, and main characteristics of the angle-code photoelectric converter.

2.1 Progress

2.1.1 To study the principle of operation and the main characteristics of photovoltaic angular-code converters (absolute encoders) using subsection 2.2.

2.1.2 Study the structure of the laboratory stand, draw up its functional scheme.

2.1.3 To study the characteristics of the encoder models installed on the laboratory bench.

2.1.4 Study the design of the encoder using a disassembled laboratory sample of the sensor. Draw up a sketch drawing and functional diagram of the sensor.

2.1.5 Perform measurements using an absolute encoder. Obtain waveforms on the output connectors of the encoder.

2.1.6 Answer control questions.

2.2 Brief theoretical information

The advantage of an absolute encoder is that it is not subject to interference. In cases where the signal from the disc cannot be fully read by the encoder, for example, if the shaft rotates too fast, the exact angle of rotation will be recorded when the rotational speed decreases. But even with a rapid rotation of the shaft, it is possible to register the position, although with less accuracy. For this purpose, only the information coming from the higher bits is taken into account, i.e. the distorted (due to the high rotational speed) information coming from the lower bits is simply ignored. The absolute encoder is resistant to vibrations and other types of interference, since there is no error as a result of counting "false" impulses resulting from, for example, vibration.

For a clearer understanding of the principle of operation of absolute encoders, in particular, the basis for the need to use special methods of signal coding in the construction of absolute encoders, it would be appropriate to recall some of the basics of digital technology, including the types/methods of number/signal coding described below.

Types of digital codes and features of their use in positioning systems.

Binary codes.

The term "binary" in meaning is consisting of two parts, components. Thus, binary codes are codes that consist of only two symbolic states, for example, black or white, light or dark, conductor or insulator. In digital technology, a binary code (BC) is a way of representing data (numbers, words, etc.) in the form of a combination of two signs, which can be designated as 0 and 1. Signs or units of BC are called bits. One of the justifications for the use of BC is the simplicity and reliability of accumulating information in any carrier in the form of a combination of only two of its physical states, for example, in the form of a change or constancy of the light flux when reading from an optical code disk.

Binary code decimal.

Binary-decimal code is a widely used code that can be processed directly by a microprocessor and is the basic code for processing digital signals. Binary-decimal code consists of only 0s and 1s. The largest number that can be expressed by binary code depends on the number of bits used, i.e., the number of bits in the combination expressing the number. For example, to express numerical values from 0 to 7, it is enough to have a 3-bit, i.e., 3-bit code. Binary-decimal code is a multistep code. This means that when you move from one position (value) to another, several

bits at the same time. For example, the number 3 in binary code is 011. The number 4 in binary code is 100. Accordingly, during the transition from 3 to 4, all three bits change their state to the opposite at the same time. Reading such a code leads to the fact that due to the imperfection of the reader, for example, due to inevitable deviations (tolerances) in the production of the code disk, the change in information from each of the tracks separately never occurs simultaneously. As a result, during the transition from one number to another, incorrect information about the position of the shaft is given for a short time (or constantly in the case of stopping the encoder shaft directly at the critical section of the transition!). For example, in the section of the above-mentioned transition from the number 3 to the number 4, the number 7 is very likely to be issued, when, for example, the most significant bit during the transition changed its value a little earlier than the others. Thus, the use of ordinary binary code can most likely lead to a number that is far from the real value, and, as a result, an unpredictable response of the control system or controller to a distorted encoder signal. To avoid this, a so-called one-step code is used, for example, a Gray code.

Gray code.

The Gray code (named after the American physicist Frank Gray) is ideal for mechanical positioning systems, including absolute encoders. The Gray code is preferable to the regular binary code because it has the property of the constancy of the binary combination: a change in the encoded number by one corresponds to a change in the code combination in only one bit. Thus, the Gray code is a so-called one-step code. It is built on the basis of the binary code according to the following rule: the most significant bit remains unchanged, and each subsequent bit is inverted if the previous bit of the original binary code is equal to one.

In the case of using the Gray code, the error in reading the information in the transition region from one number to another will only result in the fact that this transition will be only slightly offset in time, but the output of a completely incorrect angular position value in the transition region is completely excluded. This is especially true for sensors where the carrier/source of information (e.g. about the position of the encoder shaft) is a mechanical element. In the case of an absolute encoder, this is an optical disk with mechanical marks on it, where the minimum geometric errors/offsets of several optical tracks/sectors are not mutually excluded due to offset printing errors during production at the stage of drawing on the optical disk. Figure 2.1 below shows an encoder disc with a pattern (raster) in Greycode format.

The advantage of Grey Code is also its ability to mirror information. For example, by inverting the most significant bit, you can simply change the direction of counting. This function is performed by the so-called "Complement" input. Depending on the potential at this input, the value produced by the encoder will increase or decrease with the same physical direction of rotation of the axis.

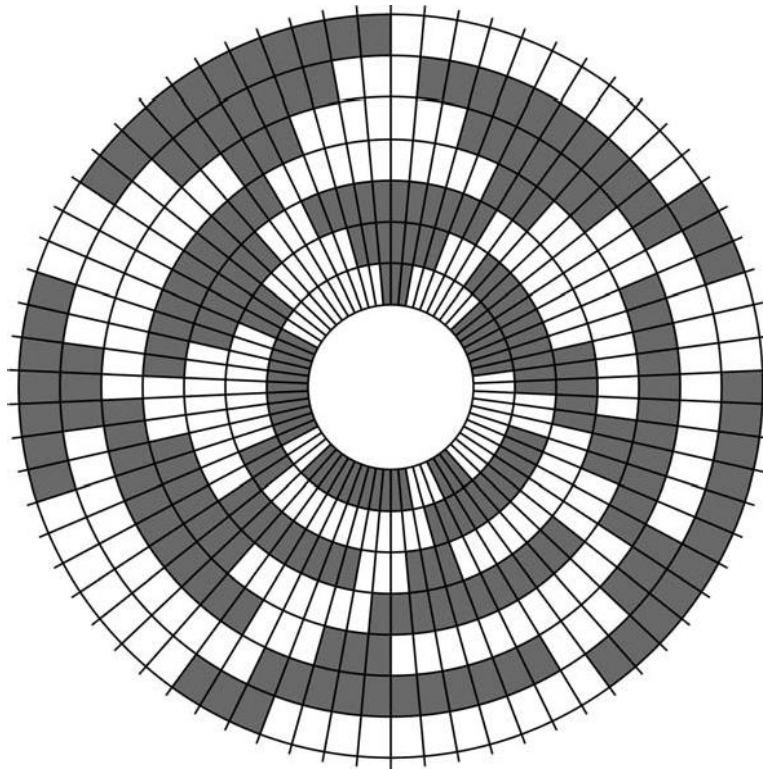


Figure 2.1 – Absolute encoder disk with raster in Gray code

Since the information expressed in the Gray code is purely encoded and does not carry real numerical information, it must first be converted into a standard binary code before further processing. Conversion of the Gray code into a familiar binary code can be done programmatically (in a controller) or using a simple scheme with inverters and XOR logic gates, as shown in Figure 2.2.

Gray-Excess-Code.

The usual one-step Greycode is suitable for resolutions that can be represented as a number raised to the power of 2. In cases where it is necessary to implement other resolutions from a regular greycode, the middle section of the code is cut out and used. In this way, the "one-step" nature of the code is preserved. However, the numerical range does not start from zero, but shifts by a certain value. When processing information, half of the difference between the original and reduced resolution is subtracted from the generated signal. Resolutions such as 360° for angle expression are often implemented by this method. For example, a 9-bit Gray code equal to 512 steps, truncated on both sides by 76 steps, will be 360° .

Optical absolute encoder device.

The Absolute Optical Encoder Measurement System consists of the following main components:

- a swivel shaft mounted on two bearings;
- a code optical disk mounted on a shaft;
- infrared LED (as light source);

They are mainly used to measure the angle of rotation and are used, for example, in antenna systems, eccentric articulating presses, etc.

The resolution of a single-turn encoder is determined/indicated by the number of bits. For example, an encoder with a resolution of 16 bits implies a resolution of 65536 marks per turn.

In turn, to convert the number of marks (steps) in rotation into angular degrees, it is enough to divide 360° by the number of marks, for example: the resolution of 65536 marks (16 bits) corresponds to the resolution: $360/65536 = 0.005^\circ$ (angular degrees) (Figure 2.3).



Figure 2.3 – Single-turn encoder design

Multi-turn encoder.

Linear displacements require the use of a measuring system that registers not only the position of the shaft within one revolution, but also a certain number of revolutions. For example, in linear actuators or in measurement tasks with a gear measuring rod, it is appropriate to use encoders, where, in addition to measuring the angle of rotation within one revolution (by the first stage of the encoder), the number of revolutions is also recorded by an additional kind of gearbox (forming the second stage of the encoder), consisting of several encoded optical disks, thus forming a multi-turn encoder (Multi – Turn). The resolution of a multi-turn encoder, as a rule, is denoted separately as the resolution within one revolution plus the number of revolutions in the format of the number of bits. Thus, the combination of digits in the name of the encoder in the form of, for example, 1216 means the resolution of 12 bits of revolution (4096 revolutions) and 16 bits per revolution (65536 marks per revolution) (Figure 2.4).

Magnetic absolute encoders.

Principle of magnetic measurements.

Magnetic encoders determine the angular position using magnetic field technology. A permanent magnet mounted on the encoder shaft creates a magnetic field that is measured by a sensor that generates a unique absolute position value.

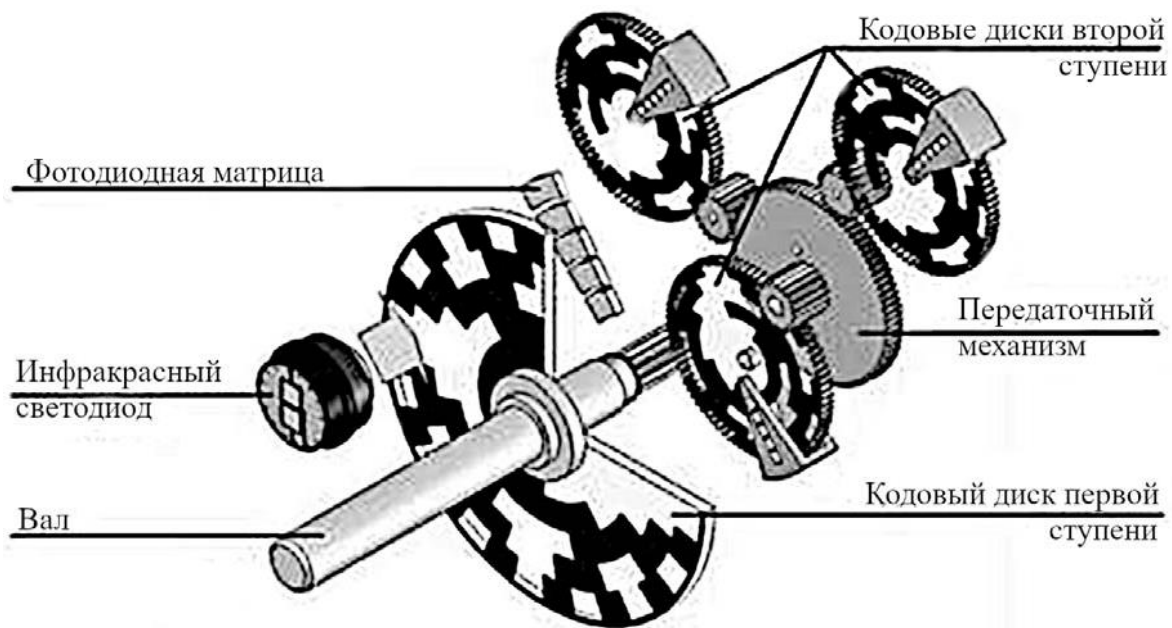


Figure 2.4 – Structure of a multi-turn encoder

Innovative multi-turn technology.

IXARC POSITAL's multi-turn magnetic encoders use innovative technology to track the number of revolutions, even if the rotation occurred when the system was powered off. To accomplish this task, the encoders convert the rotation of the shaft into electrical energy. The technology is based on the Wiegand effect: when a permanent magnet on the encoder shaft is rotated by a certain angle, the magnetic polarity in the Wiegand wire changes dramatically, creating a short-term spike in the voltage in the winding surrounding the wire. This pulse marks the rotation of the shaft and also provides power to the electronic circuit that registers the event. The Wiegand effect occurs under all conditions, even with very slow rotation, and eliminates the need for backup batteries.

Features of magnetic encoders.

Magnetic encoders are reliable, durable, and compact. The battery-free and gear-free design provides mechanical simplicity and lower cost compared to optical encoders. Their compact dimensions allow them to be used in very limited spaces.

2.3 Contents of the report

The report on the completion of laboratory work is drawn up on a computer in a text editor. The report must contain:

- the purpose of the work;
- description of the progress of work point by point;
- Conclusion.

Control questions

- 1 List the main options for the design of absolute encoders.
- 2 Explain the difference between incremental and absolute encoders.
- 3 How is the accuracy of an absolute encoder determined?
- 4 Describe the output signals of the absolute encoder, explain how they can be processed in the information system when measuring the position of such a sensor.

3 Practical Work No 3. Study of Contact Tactile Sensors

The purpose of the work: to master the method of measurement with contact tactile sensors, to study their design and main characteristics, to study the principle of their operation.

3.1 Progress

3.1.1 To study the principle of operation and the main characteristics of tactile contact sensors using subsection 3.2.

3.1.2 Study the structure of the laboratory stand, draw up its functional scheme.

3.1.3 To study the characteristics of the models of contact discrete tactile sensors installed on the laboratory stand.

3.1.4 To study the design of tactile sensors based on a microswitch. To estimate the magnitude of the force leading to the actuation of this type of sensor.

3.1.5 To study the design of a discrete tactile matrix. To evaluate the force required for the actuation of the matrix sensors. To evaluate the accuracy of determining the place of contact impact on the matrix.

3.1.6 Answer control questions.

3.2 Brief theoretical information

A tactile sensor is a device that measures information that results from physical interaction with the environment. Tactile sensors are typically modeled after the biological sensation of skin touch, which is able to detect stimuli resulting from mechanical stimulation, temperature, and pain (although pain perception is not common in artificial tactile sensors). Tactile sensors are used in robotics, computer equipment, and security systems. Tactile sensors are typically used in touchscreen devices on mobile phones and computers.

Tactile sensors can be of different types, including piezoresistive, piezoelectric, optical, capacitive, and elastic sensors.

Haptic sensors appear in everyday life, such as elevator buttons and lamps that dim or brighten when you touch the base. There are also countless other uses of tactile sensors that most people never know about.

Sensors that measure very small changes must have very high sensitivity. Sensors must be designed to have little effect on the measurement results; reducing the size of the sensor often improves this and can lead to other benefits. Tactile sensors can be used to test the performance of all types of applications. For example, these sensors have been used in the production of automobiles (brakes, clutches, door seals, casings), battery lamination, bolted connections, fuel cells, etc.

Tactile imaging, as a medical imaging technique that transforms the sensation of touch into a digital image, is based on tactile sensors. Tactile imaging accurately mimics manual palpation because the probe of the device, with a pressure sensor mounted on its face, acts similarly to human fingers during a clinical examination, deforming soft tissue with a probe and detecting the resulting changes in pressure patterns.

Robots designed to interact with objects that require precision, dexterity, or interaction with unusual objects require a sensory apparatus that is functionally equivalent to human tactile abilities. Tactile sensors have been developed for use with robots. Tactile sensors can complement visual systems by providing additional information when the robot begins to grasp an object. At this time, vision is no longer sufficient, as the mechanical properties of an object cannot be determined by vision alone. To determine weight, texture, stiffness, center of mass, coefficient of friction and thermal conductivity, interaction with the object and some kind of tactile perception are required.

Several classes of tactile sensors are used in different types of robots for tasks involving collision avoidance and manipulation.

Arrays of pressure sensors.

Pressure sensor arrays are large grids of tactile sensors. Tactel is a "tactile element". Each tactel is capable of detecting normal forces. Tactel-based sensors provide a high-resolution "image" of the contact surface. In addition to spatial resolution and force sensitivity, system integration issues such as wiring and signal routing are important. Pressure sensor arrays are available as thin films. They are primarily used as analytical tools used in manufacturing and

R&D processes by engineers and technicians, and have been adapted for use in robots. Examples of such sensors available to users include matrices made of conductive rubber, lead titanate zirconate (PZT), polyvinylidene fluoride (PVDF), PVDF-TrFE, FET, and metal capacitive sensing elements.

Tactile sensors based on optics.

Several kinds of haptic sensors have been developed that take advantage of camera-like technology to produce high-resolution data. A key example is Gelsight technology, pioneered at MIT, which uses a camera behind an opaque gel layer to produce high-resolution haptic feedback. In a Samsung sensor, "translucent through the skin" (STS), a translucent gel is used to obtain a combined tactile and optical image.

Strain gauge sockets are made up of several strain gauges, each of which determines the force in a specific direction. When the information from each strain gauge is combined, the information allows the structure of forces or torques to be determined.

Tactile sensors created biologically.

A variety of biologically inspired designs have been proposed, ranging from simple whisker-like sensors that measure only one point at a time, to more advanced fingertip-like sensors to complete with leather-like sensors, as on the latest iCub. Biologically inspired tactile sensors often include more than one perception strategy. For example, they can detect both the pressure distribution and the pattern of forces that will come from the pressure sensor arrays and strain gauge sockets, providing point-to-point recognition and force detection with human ability.

Advanced versions of biological design tactile sensors include vibration sensing, which has been determined to be important for understanding the interaction between a tactile sensor and objects as the sensor slides over an object. Such interactions are now believed to be important for human use of tools and assessing the texture of an object. One such sensor combines the measurement of force, vibration, and heat transfer.

DIY and outdoor tactile sensors. Recently, a sophisticated tactile sensor with open equipment has been created, allowing enthusiasts and hobbyists to experiment with expensive technology. In addition, with the advent of cheap optical cameras, new sensors have been proposed that can be easily and cheaply created with using a 3D printer.

Tactile touch and contact pressure sensors.

Single tactile touch and pressure sensors are placed on the outer surfaces of the gripper. The matrices of these sensors are installed mainly inside (in the "palm"). Since the contact of the matrices

sensitive elements (SE) with the object of work occurs at many points at once, then it becomes possible to determine the shape of the object, its orientation, as well as the direction of possible slippage. The most significant feature of tactile sensors of the gripper, which distinguishes them from other information devices of the robot, is the presence of direct contact with the object of work. Shock loads arising from the closure of the kinematic circuit of the manipulator, aggressive effects of the external environment, etc. factors have determined the special importance of non-metrological operational requirements. Therefore, along with traditional PEs used in the construction of force measuring devices, microswitches are widely used in tactile systems, as well as materials based on electrically conductive polymers and carbon fibers. New technologies are being developed that make it possible to obtain wear- and heat-resistant strain sensitive materials.

Discrete tactile sensors are the most widespread in industry. They have a relay conversion function and serve to record the fact of contact of the actuator with an object or obstacle. Discrete sensors were the first tactile means and were installed on the inner sides of the fingers of the gripper device in order to determine the presence or absence of an object in the gripping area. Microswitches (in domestic models – MP 5, MP 12) or reed switches (KEM 1, KEM 2) were used as HE sensors.

An example of a matrix with a dimension of 8×8 elements is shown in Figure 3.1, *a*. PE matrices are 64 hemispherical steel membranes with a center-to-center distance of ≈ 2.5 mm. The threshold of actuation is $\sim 0.2 \dots 0.5$ N. All discrete tactile devices have three significant drawbacks: first, a limited service life, second, the impossibility of determining the value of the contact force, and, third, the inaccuracy of the localization of the contact point.

PVF2 films and composite materials with graphite fiber.

The first scheme of an analog "distributed" tactile sensor was the development of the Frenchman J. Clos, who proposed to use electrically conductive silicone rubber as a CE. The transducer consists of two wire plates – electrodes, with a mutually perpendicular arrangement of conductors. The plates are separated by a layer of silicone rubber with a thickness of ~ 200 μm . Contact points at the intersection of conductors form analog CE.

measure proportional to the applied force. Indeed, in the absence of pressure on the sensor, the area of the contact spot is small, its resistance is high and the current through the PE is practically non-existent. With compression, the resistance of the spot decreases and the current increases.

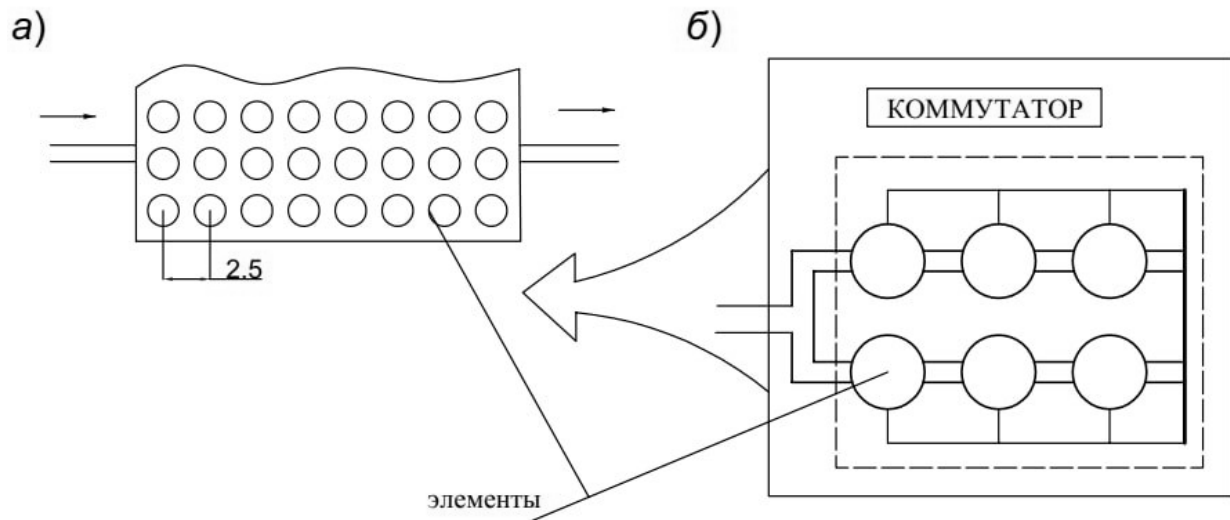


Figure 3.1 – Discrete tactile matrix

The disadvantage of elastomeric designs is the nonlinear conversion function and significant hysteresis. To improve metrological characteristics, preliminary two-way compression of the elastomer with electrode plates is used. This principle was used in the "artificial leather" of C. Batesey, as well as in industrial tactile matrices. The first successful industrial development was the LTS-200 matrix of Lord Corp. (USA) with a dimension of (12×8) , a center-to-center distance of 2.5 mm and a resistance range of 100...5000 Ohm. Metal elements are used as the supporting structure of the matrix. Further development of the idea of elastomeric tactile sensors was the creation of a large integrated circuit of a tactile matrix made using n-MOS technology. The substrate contains a two-dimensional array of cells measuring 1.6×0.9 mm, on top of which a layer of electrically conductive plastic is laid, with a thickness of ≈ 0.5 mm. The core of the system is an in-chip processor that polls local cells, generates a binary code of a tactile image, and selects a tactile contour based on convolution algorithms. The considered sensor with a dimension of 25×25 PE with a size of one cell $\sim 1 \times 1$ mm has a total area of ~ 6.3 cm².

Despite the increasing introduction of elastomeric tactile matrices into industrial robotics, they have a number of drawbacks. First, they have low metrological parameters due to hysteresis and a nonlinear transformation function. Second, an elastomer is not an elastomer

sufficiently reliable and durable material: its service life is limited $\sim (2 \dots 3) \cdot 10^5$ loading cycles.

Perhaps the best material for elastic-sensitive elements of tactile sensors is a fabric made of thin carbon filaments with a diameter of $7 \dots 30 \mu\text{m}$. Along with the high strength and elasticity characteristic of carbon compounds, and, consequently, low hysteresis, carbon fiber fabric has high wear resistance, and the low thickness of the threads allows this material to be used to cover the complex curvilinear surfaces of the manipulator. The intersection resistance between the filaments changes smoothly (this effect is determined by the total properties of the individual fibers that make up the filament), and the intersection conductivity is determined by the number of contacts between the fibers. The noise level is very low (the number of "bad" contacts is averaged among the entire set of them).

The unloaded intersection of two beams with a cross-section of 0.5 mm^2 has a resistance of $2 \text{ k}\Omega$ at an interference level $\phi \sim 5\%$. With a force of 0.01 N , the resistance decreases to $1 \text{ k}\Omega$ and the noise level to 0.5% . The carbon fiber fabric is spun in bundles of graphite and glass filaments or formed in the form of

In the second case, the carbon strands are divided into pieces 2.5 mm long, laid into a mold and compacted to a thickness $\phi \sim 1 \text{ mm}$, (on average, the resistance of such an element with an area of 1 cm^2 is $\sim 200 \text{ Ohm}$). The function of conversion of the tactile matrix is divided into four sections: A – noise area; B – fiber compaction area (this increases the number of paths for current flow); C – fiber curvature area; D – fiber deformation area (in this case, the contact area between them increases).

Carbon fiber sensors are used up to contact pressures of $2 \cdot 10^5 \text{ N/m}^2$, and hysteresis does not exceed 1% .

3.3 Contents of the report

The report on the completion of laboratory work is drawn up on a computer in a text editor. The report must contain:

- the purpose of the work;
- description of the progress of work point by point;
- Conclusion.

Control questions

- 1 List the main types of tactile probes.
- 2 Explain Principle Actions tactile sensor on microswitch.
- 3 Explain the structure of a discrete tactile matrix.
- 4 Explain the structure of the "artificial leather" sensors.

5 Explain the main ways to connect tactile sensors to an information system.

4 Practical Work No 4. Study of Non-Contact Tactile Sensors

The purpose of the work: to study the structure of non-contact inductive, capacitive, magnetic, ultrasonic and optical sensors.

4.1 Progress

4.1.1 To study the principle of operation and the main characteristics of non-contact sensors using subsection 4.2.

4.1.2 Study the structure of the laboratory stand, draw up its functional scheme.

4.1.3 To study the characteristics of the non-contact sensor models installed on the laboratory bench and the procedure for their use.

4.1.4 Take measurements using a non-contact inductive datacutter. Determine the sensing distance of the sensor on objects made of various materials - steel, copper, aluminum.

4.1.5 Take measurements using a non-contact capacitive device. Determine the sensing distance of the sensor on objects made of various materials - steel, copper, aluminum.

4.1.6 Take measurements using a non-contact magnetic device. Determine the sensing distance of the sensor on various objects.

4.1.7 Take measurements using a non-contact inductive datacutter. Determine the sensing distance of the sensor on objects made of various materials - steel, copper, aluminum.

4.1.8 Take measurements using a non-contact inductive coupler. Determine the sensing distance of the sensor on various objects.

4.1.9 Take measurements using a non-contact inductive device. Determine the sensor response distance to an obstacle.

4.1.10 Answer control questions.

4.2 Brief theoretical information

A non-contact sensor, also sensor, is a position switch that actuates without mechanical contact with a moving part (machine). A position switch is a circuit breaker of control circuits, the control mechanism of which is activated when the moving part of the machine reaches a given position.

The absence of mechanical contact between the affected object and the sensing element provides a number of specific properties of the device.

Capacitive non-contact sensors are popular as keypads on household appliances (for example, hobs). Their advantages are uniformity of design, simplicity and cheapness of implementation, ease of sealing.

Pyrometric non-contact motion sensors are widely used in building security systems.

Ultrasonic sensors are most commonly found in parking assistance systems (parking radars) of cars and in area security systems.

In industrial automation, non-contact sensors are widely used:

- as end sensors in the machine tool industry (mainly inductive sensors);
- for registration (counting, positioning, sorting) of objects on conveyors (inductive and optical sensors are used).

For GOST 26430-85 industrial automation, the term "proximity switch" was introduced. Subsequently, GOST R 50030.5.2-99 replaced the term with "non-contact sensor". At present, both terms are used for these products.

Principle of operation.

Capacitive switches are contactless.

The capacitance of an electric capacitor is measured, into the air dielectric of which the recorded object falls. They are used as touchless ("touch") keypads and as liquid level sensors.

Inductive switches are contactless.

The parameters of the inductor are measured, in the field of which the metal object to be recorded falls. The range of registration of a typical industrial sensor is from fractions to units of centimeters. They are characterized by simplicity, cheapness and high stability of parameters. They are widely used as end sensors of machine tools.

Optical switches are non-contact. They work on the principle of blocking the beam of light with an opaque object. The range of typical industrial sensors is from fractions to units of meters. They are widely used on conveyor lines as sensors for the presence of an object, they are also used to control the spatial characteristics of an object (height, length, width, depth, diameter) and to send a signal to the controlled mechanism when a specified threshold is reached. A specific type is laser rangefinders.

Ultrasonic sensors.

They work on the principle of echolocation with ultrasound. A relatively cheap solution allows you to measure the distance to an object. They are widely used in car parking sensors.

Microwave sensors.

They work on the principle of location with microwave radiation "for light" or "for reflection". They have a limited use in security systems as presence or motion sensors.

Magnetically sensitive switches are non-contact.

A simple pair of magnets – reed switches or hall sensors. They are cheap and easy to manufacture. They are widely used in access control and building security systems as door and window opening sensors.

Pyrometric sensors. Register changes in background infrared radiation. Widely used in building security systems as motion sensors.

Inductive non-contact sensors are the most widely represented on the market. They contain a circuit of oscillations that generates an electromagnetic field. They detect any metal part close to them, because induced currents arise on it, which reduces oscillations, this information is read by the sensor.

The main characteristics of the inductive sensor are:

- its use is limited to metal parts;
- relatively low distance – up to 80 mm, the distance varies depending on the type of alloy;
- low price: it costs half the price of an optical sensor;
- durable and resistant to harsh environmental conditions, insensitive to shocks and vibrations, dust, etc.;
- the switching frequency is quite high (several kilohertz), which allows you to control the passage of parts at high speed even when rotating,
- Moving parts do not wear out.

Application of inductive non-contact sensors.

Inductive sensors are used in machine tools, machines for the textile industry, the automotive industry, assembly lines, etc. They are used to detect metal parts in difficult conditions and when it is necessary to inspect fast-moving parts.

Benefits of choosing a capacitive proximity sensor.

The principle of operation of capacitive proximity sensors is similar to that of inductive sensors. The electromagnetic field is generated by a condenser located on the front of the sensor. An approaching object changes the intensity and frequency of vibrations. Unlike inductive sensors, capacitive sensors detect not only metal objects, they are designed for all types of objects and materials of any shape (solid, liquid, viscous, powdery, etc.).

Main characteristics of the capacitive sensor:

- Short sensing distance: less than 60 mm;
- the cost is slightly higher than that of an inductive sensor;
- used for parts of any type and from any materials;
- is able to detect objects through non-metallic partitions;

- sensitive to humidity and dense vapors;
- Widely used for level sensing (e.g., through plastic vials) and for the detection of transparent materials at short range;
- is not subject to mechanical wear, the service life does not depend on the intensity of use;
- suitable for industrial environments (polluted atmosphere);
- High performance.

Application of capacitive non-contact sensors.

Capacitive sensors are used on packaging lines, packaging plants and where the fill level is measured through plastic or glass walls.

Advantages of choosing a magnetic proximity sensor.

Also known as a hall effect sensor, this sensor works on a similar principle to inductive sensors. A magnetic proximity sensor involves a metal glass blade that magnetizes very quickly in the close presence of a magnet and demagnetizes quickly in the absence of a magnet. A magnetic detector operates over a long distance, given its relatively small size. The part to be detected must have a magnet or be magnetized.

The main characteristics of the magnetic sensor are:

- used for magnetized parts or parts with a magnet;
- low price;
- allows you to detect objects through a non-ferromagnetic barrier;
- resistant to vibrations and dirt;
- does not wear out;
- Galvanic isolation can be considered between the object being measured and the circuit.

Advantages of choosing an ultrasonic proximity sensor.

Ultrasonic proximity sensors are based on the emission and reception of high-frequency ultrasonic waves (on the order of 200 kHz). Wave return detects the presence of an object and measures the distance at which it is located (by measuring the time taken by the wave to complete the roundabout). These ultrasonic sensors can be used for direct detection or in a light curtain.

Main features of the ultrasonic sensor:

- detects any objects (powder, metal, solids, liquids, transparent glass, plastic, cardboard, wood, etc.);
- works at a distance of several meters (15 m);
- is insensitive to environmental conditions;
- the response time is limited by the speed of sound propagation in the air;
- relatively high price (from 200 to 1,000 euros);
- sensitive to drafts and temperature (-10 °C to 50 °C);
- does not detect sound absorbers (cotton, foam, etc.).

Application of ultrasonic non-contact sensor.

Rather, this sensor is designed to solve very specific tasks: long-range detection in difficult conditions, detection of transparent or highly reflective objects, etc.

Ultrasonic sensors can be installed, for example, on conveyors to detect bottles or packages. They are also used when it is necessary to determine the level of liquids (vials) or granules (hoppers).

Benefits of choosing an optical proximity sensor.

This sensor is quite widely available on the market. Its operation is based on the optical principle. It detects an object when the light beam is either attenuated or interrupted by an object passing through it. Depending on the object passing through the light beam and the detection distance, various configurations are possible:

- beam interception: the transmitter and receiver are separated from each other;
- reflection: the light beam is reflected from the object and hits the receiver;
- Direct reflection: When light is simply reflected off an object.

Contaminant-sensitive, optical proximity sensors offer important advantages:

- detect any objects (including transparent materials);
- are the most powerful in terms of detection distance: they detect objects up to 200 m away.

Application of optical proximity sensor.

Optical sensors are used to detect parts in the textile industry, robotics, elevators, and general construction. They find applications in material handling and transportation. They are also used for tasks that require the detection of people, vehicles, or animals.

4.3 Contents of the report

The report on the completion of laboratory work is drawn up on a computer in a text editor. The report must contain:

- the purpose of the work;
- description of the progress of work point by point;
- Conclusion.

Control questions

1 Explain the principle of operation and the structure of capacitive non-contact sensors.

2 Explain the principle of operation and structure of inductive proximity sensors.

3 Explain the principle of operation and the structure of magnetic proximity sensors.

4 Explain the principle of operation and structure of ultrasonic non-contact sensors.

5 Explain the principle of operation and structure of optical proximity sensors.

5 Practical Work No 5. Study of Temperature Sensors

The purpose of the work: to study the structure and principle of operation of temperature sensors.

5.1 Progress

5.1.1 To study the principle of operation and the main characteristics of temperature sensors using subsection 5.2.

5.1.2 Study the structure of the laboratory stand, draw up its functional scheme.

5.1.3 To study the characteristics of the temperature sensor models installed on the laboratory bench and the procedure for their use.

5.1.4 Take temperature measurements with a thermocouple. Obtain the dependence of the electromotive force generated by the thermocouple on temperature.

5.1.5 Take measurements using thermal resistance. Get the dependence of the sensor resistance on temperature.

5.1.6 Plot the dependencies obtained from paragraphs 5.1.4–5.1.5.

5.1.7 Answer control questions.

5.2 Brief theoretical information

Thermal-resistive temperature sensors.

Thermal-resistive temperature sensors are based on the principle of changing the electrical resistance (of a semiconductor or conductor) when the temperature changes. They were developed for the first time for oceanographic research. The main element is a thermistor – an element that changes its resistance depending on the ambient temperature.

The undoubted advantages of this type of thermal sensors are long-term stability, high sensitivity, as well as ease of creating interface circuits.

The image shows the 702-101BBB-A00 sensor, the measurement range of which is from -50 °C to +130 °C. This sensor belongs to the group of silicon resistive sensors. Pay attention to its dimensions. This sensor is manufactured by Honeywell International.

Depending on the materials used for the production of thermostatic sensors, the following types of sensors are distinguished.

Resistive temperature detectors (RTDs).

These sensors consist of metal, most often platinum. In principle, any metal changes its resistance when exposed to temperature, but platinum is used because it has long-term stability, strength and reproducibility of characteristics. Tungsten can also be used to measure temperatures above 600 °C. The disadvantage of these sensors is the high cost and non-linearity of characteristics.

Silicon resistive sensors.

The advantages of these sensors are good linearity and high long-term stability. These sensors can also be integrated directly into microstructures.

Thermistors.

These sensors are made of metal-oxide compounds. The sensors measure only absolute temperature. A significant disadvantage of thermistors is the need for their calibration and high nonlinearity, as well as aging, but with all the necessary settings, they can be used for precision measurements.

Semiconductor sensors.

An example is the LM75A semiconductor temperature sensor manufactured by NXP Semiconductors. The measurement range of this sensor is from -55 °C to +150 °C.

Solid-state sensors record changes in the characteristics of the *p-n* junction under the influence of temperature. Any diodes or bipolar transistors can be used as thermal sensors.

The advantages of such sensors are simplicity and low cost, linearity of characteristics, and small error. In addition, these sensors can be formed directly on a silicon substrate. All this makes semiconductor sensors very popular.

Thermoelectric (thermocouples).

Thermoelectric converters (or thermocouples). They operate on the principle of thermoelectric effect, i.e. due to the fact that an electric current will arise in any closed loop (from two dissimilar semiconductors or conductors) if the junctions differ in temperature. For example, one end of the thermocouple (working) is immersed in the medium, and the other (free) is not. Thus, it turns out that thermocouples are relative sensors and the output voltage will depend on the temperature difference between the two parts. And it will almost not depend on their absolute values.

The DTPKH4 thermocouple measures temperatures in the range from -40 °C to +400 °C. It is produced by the Russian company Oven.

The range of temperatures measured with their help – from -200 °C to 2200 °C – directly depends on the materials used in them. For example, thermocouples made of base metals – up to 1100 °C. Thermocouples made of precious metals (platinum group) – from 1100 °C to 1600 °C. If it is necessary to measure temperatures above this, heat-resistant alloys are used (the basis is

tungsten). As a rule, it is used in conjunction with a millivoltmeter, and the free end (structurally led to the head) is removed from the measured medium by means of an extension wire. One of the disadvantages of a thermocouple is a fairly large error. The most common way to use thermocouples is electronic thermometers.

Pyrometers.

Pyrometers are non-contact sensors that register radiation emanating from heated bodies. The main advantage of pyrometers (in contrast to previous temperature sensors) is that there is no need to place the sensor directly in the controlled environment. As a result of such immersion, there is often a distortion of the temperature field under study, not to mention a decrease in the stability of the characteristics of the sensor itself.

There are the following three types of pyrometers. Fluorescent.

When measuring temperature with fluorescent sensors, phosphorus components are applied to the surface of the object whose temperature is to be measured. The object is then exposed to ultraviolet pulsed radiation, which results in a post-radiation fluorescent layer whose properties depend on temperature. This radiation is detected and analyzed.

Interferometric.

Interferometric temperature sensors are based on comparing the properties of two beams – the control beam and the one passed through the medium, the parameters of which change depending on the temperature. The sensitive element of this type of sensor is most often a thin silicon layer, the refractive index of which, and accordingly, the length of the beam path is affected by temperature.

Sensors based on solutions that change color when exposed to temperature.

In this type of pyrometer sensors, cobalt chloride is used, the solution of which has a thermal bond with the object whose temperature needs to be measured. The absorption coefficient of the visible spectrum of a cobalt chloride solution depends on the temperature. As the temperature changes, the amount of light that passes through the solution changes.

Acoustic.

Acoustic thermal sensors are mainly used to measure medium and high temperatures. The acoustic sensor is based on the principle that, depending on the change in temperature, the speed of sound propagation in gases changes. It consists of an emitter and a receiver of acoustic waves (spatially separated). The emitter emits a signal that passes through the medium under study, depending on the temperature, the speed of the signal changes, and the receiver calculates this speed after receiving the signal.

They are used to determine temperatures that cannot be measured by contact methods. They are also used in medicine for non-invasive (without surgical penetration into the patient's body) measurements of depth

temperature, for example, in oncology. The disadvantages of such measurements are that when touched, they can cause physiological responses, which, in turn, leads to a distortion of the measurement of the depth temperature. In addition, reflections can occur at the "sensor - body" interface, which can also cause errors.

Piezoelectric.

In sensors of this type, the main element is a quartz piezoresonator.

As is known, piezoelectric material changes its size when exposed to current (direct piezoelectric effect). A voltage of different signs is alternately transferred to this piezoelectric material, from which it begins to oscillate. This is a piezoresonator. It has been found that the frequency of oscillations of this resonator depends on temperature, and this phenomenon is the basis of the piezoelectric temperature sensor.

5.3 Contents of the report

The report on the completion of laboratory work is drawn up on a computer in a text editor. The report must contain:

- the purpose of the work;
- description of the progress of work point by point;
- Conclusion.

Control questions

- 1 List the main types of temperature sensors.
- 2 Explain how a thermocouple works.
- 3 Explain how thermal resistance works.
- 4 Explain how to connect the thermocouple to the information system.
- 5 Explain how to connect thermal resistance to an information system.

6 Practical Work № 6. Research Location sensors

The purpose of the work is to study the design and principle of operation of ultrasonic and optical location sensors.

6.1 Progress

6.1.1 To study the principle of operation and the main characteristics of location sensors using subsection 6.2.

6.1.2 Study the structure of the laboratory stand, draw up its functional scheme.

6.1.3 To study the characteristics of the locator sensor models installed on the laboratory bench and the procedure for their use.

6.1.4 Measure the distance to the object using an ultrasonic location sensor. Evaluate the accuracy of distance measurement with this type of sensor.

6.1.5 Measure the distance to the object using an optical location sensor. Evaluate the accuracy of distance measurement with this type of sensor.

6.1.6 Answer control questions.

6.2 Brief theoretical information

Location sensing systems are used to measure the coordinates of the product in cases where the use of a computer vision system is impractical or impossible for one reason or another. The installation of locator sensors on the gripper or working tool of an automatic manipulator provides, for example, the ability to accurately track the weld head along the seam trajectory, and also allows you to grip and place products on overhead or belt conveyors. In addition, locator sensing systems are used as safety sensors to prevent collisions of moving parts of the manipulator with objects or people who happen to be in its service area. Location sensing systems with an active or passive method of detecting objects are often called safety sensors in the literature.

To ensure sensitivity, the grippers are equipped with light location transducers, the area of action of which corresponds to the space adjacent to the gripping devices. Along with tactile and photoelectric sensors, ultrasonic devices are used in robots to measure the distance to the grasped objects.

The signals of the location sensors also form the feedback of the control system. Thanks to it, the movement program can simply change at a certain distance to the object, but the speed of approach can also be adjusted, etc. Feedback is used at the second and higher levels of the control system.

In general, the term "location sensor" is understood as a device consisting of a primary transducer that measures some physical parameters of environmental objects by emitting and receiving signals, an amplifier, an analog-to-digital converter, an indicator, as well as, if necessary, a microprocessor, a digital-to-analog converter and a specialized computer for processing and presenting information transmitted to the control system of a robot or robotic technical complex.

The sensors under consideration can be divided into information location sensors for the formation of robot control according to their purpose

and location safety sensors used to protect the actuator from collision with foreign objects.

Information location sensors can also be used to determine the position of an object in space relative to a selected coordinate system.

Location safety sensors are a simplified modification of the information location system operating in relay mode and generating signals about objects of the yes-no type. Rangefinders are also used as safety sensors, signals from which are sent to the threshold device, and the triggering threshold can change during the robot's operation.

Acoustic location sensors have advantages over optical sensors both when operating in a gas environment and in conditions that make it difficult or impossible to use optical means (heavily smoked air, the presence of steam, optical interference from electric welding, etc.). With the help of acoustic sensors, internal defects in products can be detected, their thickness and acoustic characteristics of the material can be measured. Unlike optical sensors, acoustic sensors make it possible to identify the surface material of objects by measuring acoustic parameters. With a sufficiently high accuracy in measuring distances and geometric parameters of objects, they make it possible to obtain an integral assessment of the shape of a surface in a relatively simple program in real time, for example, to measure the angle of inclination of its reflecting section, as well as to classify objects.

One of the most urgent tasks of research work on the creation of acoustic location systems at present is the development of sensors capable of determining the nature (acoustic properties) of a reflecting object at distances of up to 10 m, and sensing devices for transport robots, which are automatically controlled trolleys used to organize flexible production in workshops and warehouses.

Optical location sensors are based on the effects of light interaction with the surface of an object (reflection, absorption, scattering, etc.) and are designed to detect objects in the working area of an adaptive robot and determine such parameters as the coordinates of the object, its geometric dimensions, color, and structure.

Location radiation sensors for measuring distances are divided into two groups:

- 1) devices based on measuring the intensity of a direct radiation beam;
- 2) devices based on measuring the intensity of scattered radiation.

The operation of acoustic location sensors in general is as follows. Probing pulses are formed by the generator and through the switching device go to the radiating transducer.

The ultrasonic pulses emitted by the transducer propagate to the object and, having been reflected from it, go to the receiving transducer (it is possible to use one transducer operating in a combined mode). The received signal is subjected to preliminary analog processing, and then converted into a digital code. After passing through the digital processing unit, the received information is entered into the buffer memory, from which it can be transmitted through the interface unit to the control computer or directly to the actuator at the right time.

To increase information about the object, location sensors with the so-called information field are used, which is a matrix of sensitive elements, similar to those matrices of microsensors that are used as an artificial touch device and are built into the hand or hand grip. The matrix, installed stationary in the working area of the robot, allows you to collect information about the shape and relative location of objects within the sensitivity field.

6.3 Contents of the report

The report on the completion of laboratory work is drawn up on a computer in a text editor. The report must contain:

- the purpose of the work;
- description of the progress of work point by point;
- Conclusion.

Control questions

- 1 List the main types of location sensors.
- 2 Explain the principle of operation of ultrasonic location sensors.
- 3 What is the application scope of ultrasonic location sensors?
- 4 Explain how optical location sensors work.
- 5 What is the application scope of optical location sensors?

7 Practical Work № 7. Research Vision systems

The purpose of the work: to study the structure and principle of operation of the computer vision system that searches for and tracks an object of a given color in the camera's field of view.

7.1 Progress

7.1.1 Develop a virtual three-dimensional environment in the V-REP application. The environment should include a model of a robot with a camera, freely moving

and a set of stationary objects in the form of geometric three-dimensional shapes of different colors, randomly scattered in the field of view of the robot model.

7.1.2 Develop a Python program for obtaining an image from the sensor of the V-REP environment.

7.1.3 Develop a Python program for recognizing an image received from a sensor. The program should solve the problem of searching for an object of a given color in the field of view, determining its coordinates, and highlighting the object in the image returned to the V-REP environment.

7.1.4 Modify the program developed in paragraph 3.1.3 in such a way that it finds an object of a different color. Implement 3-4 options with the location of different objects.

7.1.5 To develop a robot control program according to a given algorithm based on the result of image recognition.

7.1.6 Answer control questions.

7.2 *Brief theoretical information*

Let's consider setting up a virtual environment, integrating with the Python and OpenCV environment for recognizing images from the virtual world.

The architecture of the system used is shown in Figure 7.1.

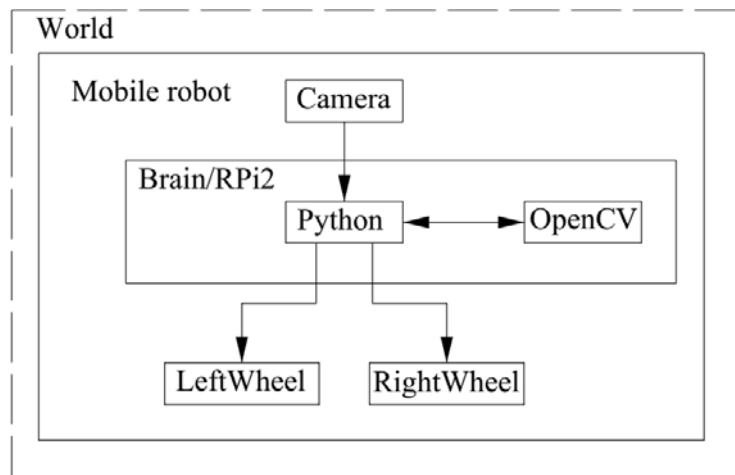


Figure 7.1 – Architecture of the system used

As can be seen from Figure 7.1, the robot control system receives an image, recognizes (via OpenCV) and transmits control commands to the wheels. By replacing the image from the camera with a virtual 3D image, and controlling the wheels with controlling the virtual robot, a stand for working out the algorithm was obtained.

The virtual booth has the architecture shown in Figure 7.2.

In the course of the laboratory work, it is necessary to solve the problem of binding V-REP with an external script in the Python language, which performs image recognition

using OpenCV and displays a marker around the found object.

The architecture of such a system is shown in Figure 7.3.

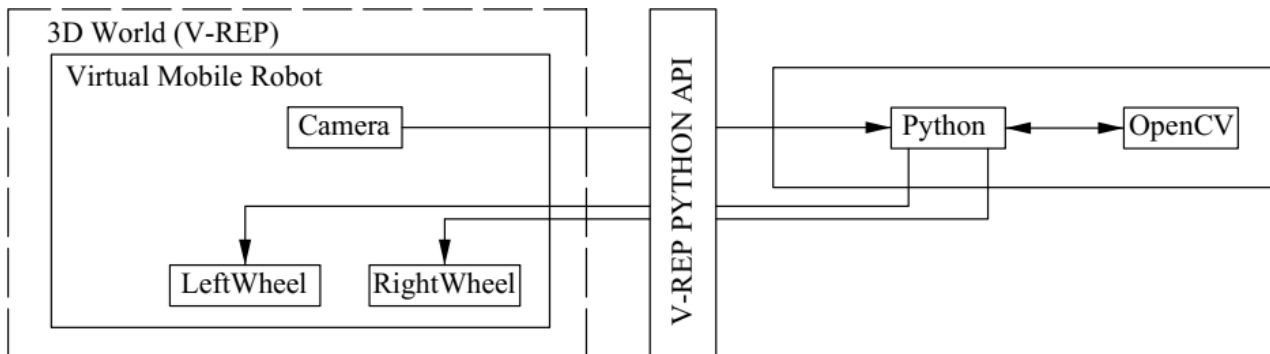


Figure 7.2 – Virtual booth architecture

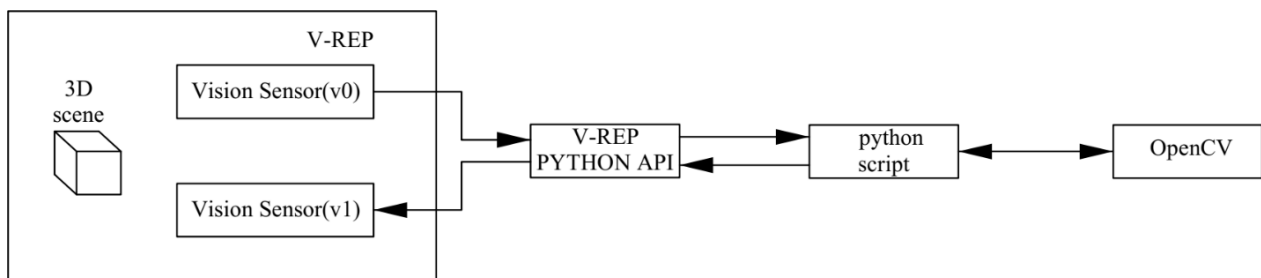


Figure 7.3 – Architecture of the pattern recognition system

In the V-REP application, you need to create a scene.

The scene should contain a camera that scans an area containing various 3D objects. This image should be broadcast to an external Python script that should call OpenCV to recognize and generate a marker, and return the image back to V-REP for inspection.

An example of a scene implementation is shown in

Figure 7.4. A scene contains:

- a movable tripod that rotates;
- A V0 (Vision Sensor) camera is mounted on this tripod;
- A v1 sensor is placed, the data to which is transferred from an external system.

After creating the scene, you can import the V-REP module into the Python environment:

```
import vrep
```

The simplest script that connects to the API looks like this:

```
import vrep
```

```
vrep.simxFinish(-1) # just in case, close all opened connections
clientID = vrep.simxStart('127.0.0.1', 19997, True, True, 5000, 5)
if clientID!=-1:
```

```

print 'Connected to remote API server'
while (vrep.simxGetConnectionId(clientID) != -1):
    print "some work"
else:
    print "Failed to connect to remote API Server"
    vrep.simxFinish(clientID)

```

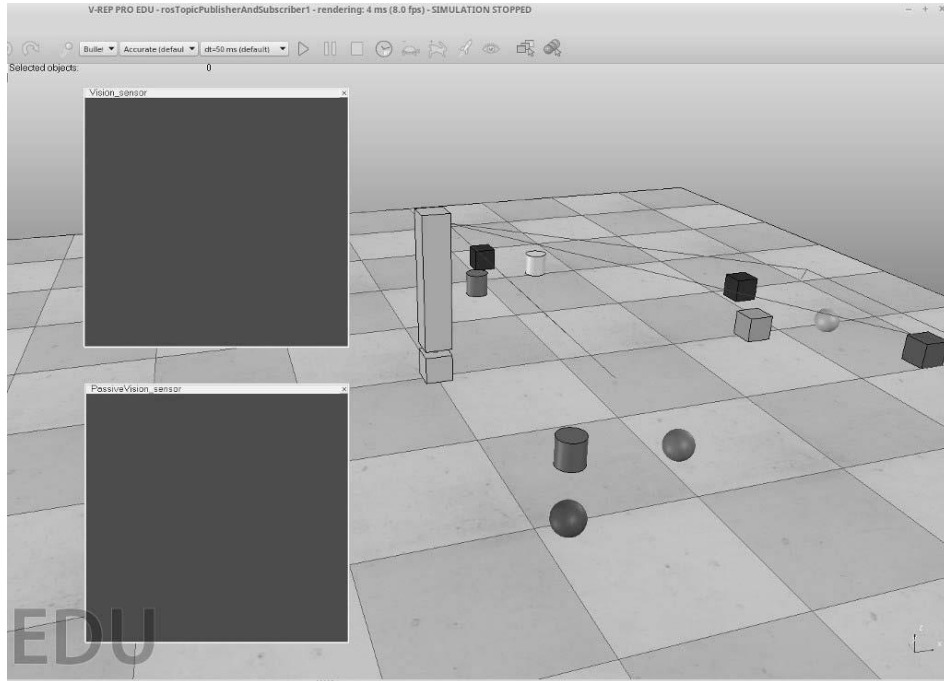


Figure 7.4 – Example of a virtual environment implementation in V-REP

There are two objects on the created scene – v0 and v1. The image is read from the first one, and the result should be written to the second. Therefore, you need to get these objects in the context of a Python script, this is done using the API of the `vrep.simxGetObjectHandle` command:

```

res, v0 = vrep.simxGetObjectHandle(clientID, 'v0', vrep.simx_opmode_oneshot_wait)
res, v1 = vrep.simxGetObjectHandle(clientID, 'v1', vrep.simx_opmode_oneshot_wait)

```

There are two functions for receiving pictures and recordings from the Vision Sensor:

- 1) `vrep.simxGetVisionSensorImage`;
- 2) `vrep.simxSetVisionSensorImage`.

A Python program will look like this:

```

# Image acquisition from sensor v0
err, resolution, image = vrep.simxGetVisionSensorImage(clientID, v0, 0,
vrep.simx_opmode_buffer)
# Image Recording to Sensor V1
vrep.simxSetVisionSensorImage(clientID, v1, image, 0, vrep.simx_opmode_oneshot)

```

After installing the OpenCV module, it becomes possible to import it in the Python environment:

```
import cv2
```

Now you need to implement the simplest recognition function.

In the example, the def function `track_green_object(image)` returns the coordinates of a green object if it is found in the scene.

To mark the found object with a marker, use the basic OpenCV function for drawing a rectangle: `cv2.rectangle`.

Let's consider a fragment of the program, which:

- Gets an image (from v0)
- finds an object (something green);
- Adds a marker (yellow rectangle)
- returns an image (in v1). The fragment looks like this:

```
# get image from vision sensor 'v0'
err, resolution, image = vrep.simxGetVisionSensorImage(clientID, v0, 0,
vrep.simx_opmode_buffer)
if err == vrep.simx_return_ok:
    image_byte_array = array.array('b', image)
    image_buffer = I.frombuffer("RGB", (resolution[0],resolution[1]), image_byte_array,
"raw", "RGB", 0, 1)
    img2 = numpy.asarray(image_buffer)
# try to find something green
    ret = track_green_object(img2)
# overlay rectangle marker if something is found by OpenCV
if ret:
    cv2.rectangle(img2,(ret[0]-15,ret[1]-15), (ret[0]+15,ret[1]+15), (0xff,0xf4,0x0d), 1)
    # return image to sensor 'v1'
    img2 = img2.ravel()
    vrep.simxSetVisionSensorImage(clientID, v1, img2, 0, vrep.simx_opmode_oneshot)
```

7.3 Contents of the report

The report on the completion of laboratory work is drawn up on a computer in a text editor. The report must contain:

- the purpose of the work;
- description of the progress of work point by point;
- listing of a Python program that searches for an object of a given color in the robot's field of view;
- Conclusion.

Control questions

- 1 Explain the structure of the vision system.
- 2 Explain how to encode color in the RGB color space.
- 3 Explain how to encode color in the HSV color space.
- 4 Explain the algorithm for finding an object of a given color used in the considered computer vision system.

8 Practical Work No 8. Study of Distributed Control Systems

The purpose of the work: to study the structure, principle of operation and structure of the distributed control system.

8.1 Progress

8.1.1 Study a laboratory bench that implements a distributed control system. Draw up its functional diagram.

8.1.2 For each controller in the bench, draw up a list of tasks that will be implemented by the corresponding part of the distributed control system.

8.1.3 To study the options for implementing an industrial network between the nodes of the distributed control system under consideration. To analyze the advantages and disadvantages of the system implemented on the laboratory bench.

8.1.4 Develop programs for each controller as part of a distributed control system that implements the list of tasks drawn up in the implementation of paragraph 8.1.2.

8.1.5 To develop a SCADA system project that implements the upper level of the information system, coupled with a distributed control system.

8.1.5 Download the programs developed under paragraph 8.1.4, study the correctness of the distributed control system.

8.1.6 Answer control questions.

8.2 Brief theoretical information

A distributed control system is a process control system that is distinguished by the construction of a distributed I/O system and the decentralization of data processing. The main difference between DCS and a conventional SCADA system is the deep integration of code development tools for the visualization layer and the control level. For example, a change in the

process control algorithm is automatically duplicated in the process display program.

In DCS significant Role play Contours regulation (PID regulators).

The areas of application of DCS are numerous:

- chemistry and petrochemistry;
- oil refining and oil production;
- gas production and processing;
- metallurgy;
- food industry: dairy, sugar, beer;
- power supply, etc. Requirements

for a modern DCS:

- fault tolerance and security;
- ease of development and configuration;
- support for geographically distributed architecture;
- a single configuration database;
- developed human-machine interface;
- transparency is a property of systems that are presented in the form of a single computer system;

– Openness —A system that offers services that require standard syntax and semantics to invoke.

- scalability;
- scaling technologies;
- asynchronous communication technology;
- distribution;
- replication;
- caching.

Scalability can be adversely affected by one major disadvantage of caching and replication. Since we get many copies of a resource, modifying one copy makes it different from the others. Accordingly, caching and replication cause non-repudiation problems.

Concepts of hardware solutions.

Computers are usually divided into two groups: systems that share memory are called multiprocessors, and those that work with their own memory are called multicomputers. The main difference between the two is that multiprocessors have a single address space shared by all processors. In multicomputers, each machine uses its own memory. A typical example of such a system is several personal computers connected to a network. Depending on the type of architecture that connects the network, systems are divided into bus and switched systems. The exclusively multicomputer category is divided into homogeneous

and heterogeneous distributed systems. Homogeneous systems are characterized by a single network connecting computers using a single technology.

Controllers for distributed control systems.

In connection with the sharp reduction in the cost of microprocessor technology with a simultaneous increase in their reliability and characteristics, a decrease in their size and an increase in their functionality, a large number of small-sized controllers and computers of low cost have appeared. The availability of developed network facilities makes it possible to connect these controllers into a single network, and various nodes (controllers, intelligent input-output modules, computers) of this network can be separated from each other over sufficiently long distances.

Such a distributed architecture of the control system has the following advantages:

High reliability of the system. A clear distribution of responsibilities in a distributed system makes it operable even in case of failure or hanging of any node.

Few wiring connections. Controllers are capable of operating in harsh industrial environments, so they are usually installed in the immediate vicinity of the control object.

Easy system expandability. When additional monitoring and control points appear, it is enough to add a new node to the system (controller, intelligent I/O module).

Short modernization time.

Use of computers and controllers of lower power.

Easy to test and debug. Since all elements of the system are active, it is easy to provide self-diagnosis and troubleshooting.

8.3 Contents of the report

The report on the completion of laboratory work is drawn up on a computer in a text editor. The report must contain:

- the purpose of the work;
- description of the progress of work point by point;
- listings or screenshots of programs for controllers as part of a distributed control system;
- Conclusion.

Control questions

- 1 Explain the concept of a "distributed control system".
- 2 List the main types of industrial networks that can be used to connect the components of a distributed control system.
- 3 What is the purpose and scope of the Modbus RTU protocol?
- 4 What is the purpose and scope of the Modbus TCP protocol?

- 5 Explain the implementation of industrial CAN networks.
- 6 Explain the implementation of fieldbus RS-485 networks.
- 7 Explain the features of Industrial Ethernet.

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MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION
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SUGGESTIONS FOR TEACHING

on the organization and conduct of independent work in the
discipline "Sensor and Detection Technology"
for students of the field of study

11.03.02 Infocommunication Technologies and Communication Systems
"Intelligent Data Processing in Infocommunication Systems and Networks"

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INTRODUC

The main task of higher education is to form a creative personality of a specialist capable of self-development, self-education, and innovative activity. The solution of this problem is hardly possible only by transferring knowledge in a ready-made form from a teacher to a student. To solve this problem, the curricula of all specialties include independent work, which makes up a significant part of the student's educational time.

In this regard, the student from a passive consumer of knowledge needs to turn into an active creator of it, able to formulate a problem, analyze ways to solve it, find the optimal result and prove its correctness. The ongoing reform of higher education is essentially associated with the transition of the paradigm of education to the paradigm of education. In this regard, it should be recognized that the independent work of students is not just an important form of the educational process, but should become its basis. This involves focusing on active methods of mastering knowledge, the development of students' creative abilities, the transition from flow to individualized learning, taking into account the needs and capabilities of the individual.

In a broad sense, independent work should be understood as the totality of all independent activities of students both in the classroom and outside it, in contact with the teacher and in his absence.

Independent work *in contact with the teacher* is carried out:

- directly in the process of classroom classes - at lectures, practical and seminar classes, when performing laboratory work;
- outside the schedule – at consultations on educational issues, in the course of creative contacts, during the liquidation of debts, when the student performs educational and creative tasks.

Types of tasks for *extracurricular* independent work can be

To
be:

1. To master knowledge:

- Reading text (textbook, source, additional literature);
- drawing up a text plan;
- graphic representation of the text structure;
- taking notes of the text;
- work with dictionaries and reference books;
- work with regulatory documents;
- educational and research work;
- Usage Audio and video recordings, computer technology, the Internet, etc.

2. To consolidate and systematize knowledge:

- work with the lecture notes (text processing);
- Repeated Work over Educational Material (textbook, primary source, additional literature, audio and video recordings);
- drawing up a plan and theses of the answer;
- compilation of tables for systematization of educational material;
- study of regulatory materials;
- answers to control questions;
- analytical processing of the text (annotation, review, abstracting, synopsis, analysis, etc.);
- preparation of reports for presentation at a seminar, conference;
- preparation of essays, reports;
- compilation of a bibliography;
- testing, etc.

3. For the formation of skills:

- solving problems and exercises according to the model;

- solving variant problems and exercises;
- Solution situational production (professional)

tasks;

- preparation for business games;
- Design and modeling of different types and components

professional activity;

- preparation of term papers and diploma papers (projects);
- experimental work;
- reflexive analysis of professional skills, using audio and video

equipment, etc.

The boundaries between these types of work are quite blurred, and the types of independent work themselves intersect.

1 GENERAL CHARACTERISTICS OF THE STUDENT'S INDEPENDENT WORK IN THE STUDY OF THE DISCIPLINE

The purpose of the student's independent work in the study of the discipline "Sensor and Detector Technologies" is the formation of students' personal qualities, as well as a set of professional competencies of a future bachelor in accordance with the requirements of the Federal State Educational Standards of Higher Education in the field of training.

Tasks of independent work:

- study of the principles of functioning of the main types of robotic sensors;
- obtaining skills in connecting and processing results from robotic sensors.

The work program of the discipline "Robot Sensor Systems" defines the following types of independent work:

- preparation for practical work;
- independent study of literature.

The purpose of the type of independent work "*Preparation for practical work*" in the discipline "Sensor Systems of Robots" is to consolidate the theoretical material in the specialty by students and develop skills for independent professional and research activities in the field of robotic and intelligent systems.

The tasks of the type of independent work "*Preparation for practical work*" in the discipline are due to the need for the student to obtain knowledge, skills, and abilities in accordance with the requirements of the Federal State Educational Standards of Higher Education in the direction of training 11.03.02, on the basis of which the results of training in the discipline (module) are formed, correlated with the planned results of the development of the educational program.

Code, formulation of competence	Indicator code, wording	Planned learning outcomes in the discipline (module), characterizing the stages of the formation of competencies, indicators
OPK-4. Able to understand the principles of modern information technologies and use them to solve problems of professional activity	ID-1 OPK-4 uses information and communication technologies when searching for the necessary information.	Understands the general principles of the functioning of hardware, software and software and hardware of microprocessor technology;
	ID-2 OPK-4 designs a solution to a specific project task, choosing the best way to solve it, based on the current legal norms and available resources and restrictions.	understands technologies for the development and debugging of robotic sensors, including the use of cross-platform programming.
	ID-3 OPK-4 understands modern interactive software systems and basic methods of processing experimental data, including the use of standard software, general and special-purpose software packages.	Works with programmable logic controllers. Carries out software and hardware configuration of robotic sensors.
	ID-4 OPK-4 uses the capabilities of computer technology and software to solve problems of control and algorithmization of information processing processes.	Creates flowcharts of algorithms for the functioning of the developed software products.
	ID-5 OPK-4 is proficient in methods of computer modeling of physical processes in the transmission of information, engineering and computer graphics techniques.	Evaluates the computational complexity of the software products being developed

The purpose of the type of independent work "*Independent study of literature*" in the discipline "Sensor and Detector Technologies" is to expand and consolidate the knowledge acquired by the student in traditional forms of classes and to develop skills for independent work with literature and sources.

The tasks of the type of independent work "*Independent study of literature*" in the discipline "Sensor and Detector Technologies" are due to the need for the student to obtain knowledge, skills, and abilities in accordance with the requirements of the Federal State Educational Standards of Higher Education in the direction of training 11.03.02, on the basis of which the results of learning in the discipline (module) are formed, correlated with the planned results of the development of the educational program.

2 SCHEDULE OF INDEPENDENT WORK

At the first stage, it is necessary to familiarize yourself with the work program of the discipline, which considers the content of the topics of the lecture course, the relationship of lecture topics with laboratory classes, topics and types of independent work. For each type of independent work, certain forms of reporting are provided.

The content of the discipline (module), structured by topics (sections) with an indication of the number of hours and types of classes

№	Section (topic) of the discipline and summary	Emerging competencies, indicators	Full-time				Current Forms control Academic Performance
			Contact work of students with the teacher / of them in the form of practical training, hours			Independent work, hours	
			Lectures	Practical exercises	Laboratory work		
1	Topic 1. Sensory systems in the living world. Development of sensory systems in nature. Human sense organs.	OPK-4				10	Interview

2	Topic 2. Sensory systems that determine geometric and other parameters of the external environment. Rangefinders and locators. Sensor systems that determine position in space. Special sensor systems. Sensor support for building models of the environment, control, navigation and traffic safety. Practical Work No 1. Measurement with strain gauges Practical Work No 2. Study of the Photoelectric Angle-Code Converter Practical Work No 3. Study of Contact Tactile Sensors Practical Work No 4. Study of non-contact tactile Sensors Practical Work No 5. Study of Temperature Sensors Practical Work No 6. Study of Location Sensors	OPK-4			28	40	Interview, practical tasks
3	Topic 3. Computer vision systems. Purpose and composition of computer vision systems. Sensors and equipment for video image processing. Binocular and multi-view systems of technical Vision. Algorithms of Computer Vision Systems. Examples of Computer Vision Systems Application. Practical Work No 7. Study of Computer Vision Systems	OPK-4			6	20	Interview, practical tasks
4	Topic 4. Systems of force-torque sensing of robots. Problems of force-torque sensing. Methods and means of force sensing. Force sensing of robot control systems.	OPK-4				20	Interview
5	Topic 5. Multi-sensor systems. Features of the use and processing of sensory information in multisensory systems. Integration of sensory systems. Practical Work No 8. Study of Distributed Control Systems	OPK-4			6	14	Interview, practical tasks
	TOTAL		-	-	40	104	

3	Topic 3. Computer vision systems. Purpose and composition of computer vision systems. Sensors and processing equipment video images. Binocular and multi-angle systems of technical vision. Algorithms of computer vision systems. Examples of application of systems technical vision.	PP-7	8	-	8.00/ 8.00	10	Interview, defense laboratory work
4	Topic 4. Systems of force-torque sensing of robots. Tasks of force-torque sensing. Methods and Means of force sensing. Force sensing of robot control systems.	PP-7	8	-	8.00/ 8.00	10	Interview, defense laboratory work
5	Topic 5. Multi-sensor systems. Features of the use and processing of sensory information in multisensory systems. Integration sensory systems.	PP-7	6	-	8.00/ 8.00	10	Interview, defense laboratory work
	TOTAL		32.00/ 0	-	32.00/ 32.00	44.00	

3 METHODOICAL RECOMMENDATIONS FOR THE STUDY OF THEORETICAL MATERIAL

When working with the recommended literature and sources, the student should, first of all, pay attention to the following points:

1. Carefully study the materials characterizing the course and the topics of independent study, which are set out in the educational and methodological complex for the discipline. This will allow you to clearly imagine both the range of topics studied and the depth of their comprehension.

2. Make a selection of literature sufficient to study the proposed topics. In the educational and methodological complex or methodological recommendations, the main and additional lists of literature available to students must be presented. They are advisory in nature, which means that there is always literature that may not be included in this list, but is necessary for mastering the topic. At the same time, it should be borne in mind that literature of various types is needed:

- textbooks, teaching aids and teaching aids;
- monographs, collections of scientific articles, publications in journals;
- reference literature - encyclopedias, dictionaries, thematic, terminological reference books;

3. The student should make his own intellectual efforts, and not only mechanically memorize concepts and statements.

1. Criteria for assessing competencies

An "**excellent**" grade is given to a student if: there is solid and reasoned knowledge; there are skills necessary for confident solution of professional problems; there are versatile skills for solving problems of professional activity.

A "**good**" grade is given to a student if: there is knowledge in the amount necessary to solve standard problems of professional

activities; have the skills necessary to solve the problems of professional activity; possess the necessary techniques and skills for solving problems of professional activity.

A **"satisfactory"** grade is given to a student if: in certain sections of the training course, he demonstrates a level of knowledge insufficient to solve standard tasks of professional activity; there are mediocre skills necessary for solving problems of professional activity; he has weak skills necessary for solving problems of professional activity.

The grade **"unsatisfactory"** is given to a student if: there is no knowledge; there are no skills necessary to solve the problems of professional activity; there are no skills necessary to solve the problems of professional activity.

2. Methodological materials that determine the procedures for assessing knowledge, skills, and (or) work experience that characterize the stages of competence formation

The procedure for conducting this appraisal activity includes an interview on the issues specified in the sections. It is necessary to focus on the number of tasks specified in the Passport of the Appraisal Tools Fund (summary table).

The tasks offered to the student allow you to check the formation of the competence of OPK-4.

To prepare for this assessment event, it is necessary to study the recommended literature indicated in the Work Program of this discipline. When receiving the task, the student must immediately, without preparation, answer the interview questions.

When preparing for the answer, the student is given the right to use technical means to perform computational and graphic tasks,

cards, reference books, tables and Other Reference literature only with the appropriate permission of the department.

When checking the level of mastery of topics submitted for independent study, the following are assessed:

- completeness of knowledge;
- consistency and generalization of knowledge;
- depth of knowledge;
- efficiency of knowledge.

Scorecard

No p/n	Student's Name	Points (0 – 0.5 – 1)				
		Answers to all given Basic Level Questions	Understanding the essence of the material presented	Speech is literate, clear, Accurate	Analysis of the essence of the issue, giving your own examples	Answers to questions of an advanced level were given
1.						
2.						

4 METHODOICAL INSTRUCTIONS FOR PREPARING FOR PRACTICAL WORK

When conducting laboratory work in the discipline "Sensor and Detector Technologies", the student must know and possess the skills, the content of which is presented in the program for the discipline.

5.1. Methodical instructions for preparing for practical work

Preparation for practical work is recommended to be carried out in the following sequence:

- to understand the topic and purpose of the upcoming lesson;
- study theoretical material in accordance with the topic of the lesson (it is recommended to use recommended literature, lecture notes, textbook (workshop)).

5.2. Methodical Directions with performance Tasks of practical work

When performing the task of practical work, students must strictly observe the established rules of labor protection.

When completing the task, students are recommended:

- to understand the purpose of the tasks performed and ways to solve them;
- tasks, perform in the sequence in which they are indicated in the workshop;
- use the help of the teacher when performing the task and studying the theoretical material;
- draw up a report on practical work;
- answer control questions.

5.3. Methodical instructions for preparing for the defense of practical work

When preparing for the defense of practical work tasks, students are recommended:

- prepare a report on laboratory work;
- be able to substantiate the conclusions made;
- consolidate knowledge of theoretical material on the topic of the lesson (it is recommended to use control questions);
- know the procedure for making calculations (conducting research).

The defense of practical work tasks is carried out by interviewing the student with the teacher. During the interview, the student submits a report on the laboratory work for verification.

An interview with a student applying for an "excellent" grade is conducted on issues of an advanced level of learning.

An interview with a student who does not apply for an "excellent" grade is conducted on basic level questions that are given in the fund of assessment tools for the discipline.

1. Criteria for assessing competencies

An "**excellent**" grade is given to a student if: there is solid and reasoned knowledge; there are skills necessary for confident solution of professional problems; there are versatile skills for solving problems of professional activity.

A "**good**" grade is given to a student if: there is knowledge in the amount necessary to solve standard tasks of professional activity; there are skills necessary to solve the problems of professional activity; owns the necessary techniques and skills for solving problems of professional activity.

A "**satisfactory**" grade is given to a student if: in certain sections of the training course, demonstrates the level of knowledge,

insufficient to solve standard tasks of professional activity; there are mediocre skills necessary for solving problems of professional activity; has weak skills necessary for solving problems of professional activity.

The grade "**unsatisfactory**" is given to a student if: there is no knowledge; there are no skills necessary to solve the problems of professional activity; there are no skills necessary to solve the problems of professional activity.

2. Methodological materials that determine the procedures for assessing knowledge, skills, and (or) work experience that characterize the stages of competence formation

The procedure for conducting this appraisal activity includes an interview on the issues specified in the sections. It is necessary to focus on the number of tasks specified in the Passport of the Appraisal Tools Fund (summary table).

The tasks offered to the student allow you to check the formation of the competence of OPK-4.

To prepare for this assessment event, it is necessary to study the recommended literature indicated in the Work Program of this discipline. When receiving the task, the student must immediately, without preparation, answer the interview questions.

When preparing for the answer, the student is given the right to use technical means for performing calculation and graphic tasks, maps, reference books, tables and other reference literature only with the appropriate permission of the department.

When checking the task, the following are evaluated:

- the sequence of the task presented in the practical work;

- Rationality Performance tasks, submitted in laboratory work;
- accuracy of calculations when performing the task presented in the laboratory work.

Scorecard

No p/n	Student's Name	Points (0 – 0.5 – 1)				
		Answers to all given Basic Level Questions	Understanding the essence of the material presented	Speech is literate, clear, Accurate	Analysis of the essence of the issue, giving your own examples	Answers to questions of an advanced level were given
1.						
2.						

LIST OF RECOMMENDED LITERATURE

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