

MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF  
KAZAKHSTAN

Non-profit joint-stock corporation  
ALMATY UNIVERSITY OF POWER ENGINEERING AND  
TELECOMMUNICATION named after G. Daukeev  
Department of *Electronics and robotics*

«Allowed to defence»

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(Full name, academic degree, rank)

\_\_\_\_\_ « \_\_\_\_\_ » \_\_\_\_\_ 2020 year  
(sign)

DEGREE PROJECT

On the topic: *Development of pattern recognition system for upper limb prosthesis control*

Done by: *Sharip Tomiris* *PSa-16-3*  
(Surname and initials of a student) (group)

Specialty *5B071600 Instrumentation Engineering*

Research supervisor *Chigambayev T.O. c.t.s., associate professor*  
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\_\_\_\_\_ « \_\_\_\_\_ » \_\_\_\_\_ 2020 year  
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Consultants

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Compliance supervisor: *Fazylova A.R. senior lecturer*  
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\_\_\_\_\_ « \_\_\_\_\_ » \_\_\_\_\_ 2020 year  
(sign)

Almaty, 2020

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KAZAKHSTAN**

**Non-profit joint - stock corporation  
ALMATY UNIVERSITY OF POWER ENGINEERING AND  
TELECOMMUNICATION named after G. Daukeev**

**Institute of** space engineering and telecommunications  
**Department of** Electronics and robotics  
**Specialty** 5B071600 Instrumentation Engineering

**ASSIGNMENT**  
for execution of degree project

**Student** Sharip Tomiris Myrzakhankyzy  
(Full name)

**Topic of the work** Development of pattern recognition system for upper limb  
prosthesis control

Approved by the order of the rector № 147 from « 11 » november 2019 y.

Deadline of the finished work « 8 » june 2020 y.

Initial data required parameters of the results and initial data:

1. Arduino Uno microcontroller
2. MG995 servo
3. MG90S Servo
4. Samsung laptop

List of issues to be developed in a degree project or a summary:

1. Consider the control of a prosthesis based on an image recognition system
2. The choice of equipment, device description and principle of operation of the system
3. Program part
4. Development of life safety measures
5. Economic justification of the project

List of graphical material (with precise indication of mandatory drawings);

This degree project contains 57 figures and tables

Recommended basic literature:

1. Jain, V. and Seung, S. H. (2008). Natural image denoising with convolutional networks. In NIPS'2008

2. Stankevich L. A., Yurevich E. I. Artificial intelligence and artificial intelligence in robotics: textbook. Saint Petersburg: Polytechnic University Press, 2012.
3. S. Korotkiy, "Neural networks". Saint Petersburg, 2002

Consultants for work with indication of the relevant section

Section	Consultant	Date	Sign
<i>Life safety</i>	<i>Begimbetova A.S</i>	<i>16.05.2020</i>	
<i>Economic part</i>	<i>Tuzelbayev B.I</i>	<i>18.05.2020</i>	

### SCHEDULE

Of degree project preparation

№	Title of section, list of issues to be developed	Deadline for submission to instructor	Note
1	<i>Theoretical part</i>	<i>29.01</i>	
2	<i>Engineering part</i>	<i>05.03</i>	
3	<i>Program part</i>	<i>15.05</i>	
4	<i>Life safety</i>	<i>16.05</i>	
5	<i>Economic part</i>	<i>18.05</i>	
6	<i>Conclusion</i>	<i>06.06</i>	

Date of issue of the assignment « 20 » 01 2020 year

The head of department Chigambayev T.O.  
(sign) (Surname and initials)

Supervisor: Fazylova A.R. senior lecturer  
(sign) (Surname and initials)

The assignment for execution is accepted by: Sharip T.M  
(sign) (Surname and initials)

## **Аннотация**

В данном дипломном проекте исследована система распознавания образов на основе управления протезом верхних конечностей, а также принципы ее работы, основные характеристики и структура. Также был произведен обзор существующих протезов верхних конечностей и их характеристик. Разработан опытный макет протеза на основе микрокомпьютера Raspberry PI3.

## **Андатпа**

Дипломдық жобада қол-аяқ протезін басқару негізінде бейнелерді тану жүйесі зерттелді, сонымен қатар принциптері және оның негізгі сипаттамалары және құрылымы. Сонымен қатар қазіргі кездегі қол-аяқ протездері және олардың сипаттамаларына шолу жасалынды. Raspberry PI3 негізінде манипулятордың тәжірибелі макеті жасалынды.

## **Annotation**

In this graduation project, the image recognition system based on upper limb prosthesis control, as well as the principles of its operation, main characteristics and structure is investigated. A review of existing upper limb prostheses and their characteristics was also made. The prototype of the prosthesis based on the microcomputer Raspberry PI3 is developed.

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## **Introduction**

Pattern recognition system is the one of the fastest growing areas at the moment. Application of this system is becoming more and more common. Using of pattern recognition system can be found in all areas of life like marketing, manufacturing, medicine, etc. It will become an integral part of our daily life in the near future. That's logical, because now no one thing in law enforcement and security system cannot do something without the use of image recognition system.

Automatic image analysis has gained such popularity due to the introduction of methods based on machine learning. The algorithms themselves were developed quite a long time ago, but they were implemented relatively recently, thanks to the advent of multi-core GPUs. They allowed neural networks to become so widespread in the field of computer vision. However, it is worth noting that the classic methods of image processing have not lost their relevance, and are actively used in conjunction with the latest algorithms.

Aim of this work is the research of various methods of machine vision, both old classic and new, based on machine learning, for image recognition, classification and detection of objects in the image. To justify the practical value of this analysis, the developed pattern recognition algorithm will be used to control the upper limb prosthesis. The relevance of the work lies in the fact that when we developing the upper limb prosthesis, we was using a method of implementation, which has practical application in everyday life.

## **1 Technological part**

### **1.1 Overview of implantable technology**

The loss of any limb or any organ is a big problem for a person. In some cases, it is necessary to put up with it, but sometimes modern prosthetics can make a person "with disabilities" a person with "augmented capabilities", as representatives of some companies in this industry put it.

The evolution of prosthetics has a long and legendary history: from primitive origins to complex modern structures. As in the development of any other field, some ideas and inventions worked and developed successfully, while others remained on the sidelines of history and became obsolete.

The long and winding road to computerised prosthetics began around 1500 BC. To assess how far humanity has come in the field of prosthetics, we should first look at the experience of the ancient Egyptians. The Egyptians were pioneers of orthopedic technology. Their "rudimentary" prosthetics were made of fabric, and it is believed that they were worn more for a sense of "wholeness" than for the sake of their prosthetic functions. The first functional prosthetic big toe belonging to a person of a noble family was found in Egypt. According to scientists, it was created in the period 950-710 BC. the prosthesis consisted of two wooden parts that were fastened with a leather thread through holes drilled in the wood (figure 1.1). A leather strap attached the toe to the foot with leather threads [1].



Figure 1.1 - The first prosthesis

It is difficult to overestimate the importance of fingers in a person's life, but it is noteworthy that the first real example of prosthetics refers to them, and not to those parts of the body or limbs that may seem more important – for example, the hands or feet. There is an assumption that the creation of such a prosthesis was

forced by the importance of traditional Egyptian sandals in the wardrobe of a noble woman, which could not be worn without having a thumb.

This attention to the aesthetic appeal of prosthetics is quite common among ancient devices and may even be more important than their functionality.

As a result of excavations in 1858 in the Italian city of Capua, the first artificial leg was found, which was made around 300 BC. It is made of bronze and iron, with a wooden core, which was apparently worn below the knee (figure 1.2). There is an exact copy of this prosthesis, which can be seen in the science Museum in London.

The most famous case in the ancient Roman history of prosthetics is described by the Roman scientist Pliny the Elder, and is associated with General mark Sergius, who is considered the first documented carrier of an artificial limb. In the second Punic war, Sergius lost his right arm and received a prosthetic made of iron so that he could hold his shield and continue the battle.

In the history of Ancient Greece is also preserved information about the success of the prosthesis. In 424 BC, the ancient Greek historian Herodotus wrote about a Persian seer who was sentenced to death, but amputated his leg and made a wooden prosthesis to walk almost 50 kilometers to the next city and thus escape from prosecution.



Figure 1.2 - Prosthetic from the city of Capua

In the period 476-1000 years, mankind advanced in prosthetics and created more complex devices than a hand hook or wooden leg. Most prosthetics at that time served more of an aesthetic function and were made to hide deformities or injuries sustained in combat. The knights had prosthetic arms that allowed them to hold the shield and legs so that they could secure it in the stirrup, with little attention to functionality. At that time, only the very rich could afford to wear prosthetics outside of battle.



The design and creation of artificial limbs in the dark ages was mainly engaged in merchants and gunsmiths. But in addition to them, people of other professions contributed to the development of prosthetics. For example, watchmakers were particularly useful for adding complex internal functions using springs and gears.

The Renaissance opened up new perspectives for art, philosophy, science, and medicine. At this time, there was a resurgence in the history of prosthetics: they were made mainly of iron, steel, copper and wood (figure 1.3).



Figure 1.3 - Prosthesis from the Renaissance

In 1508, the German mercenary Getz von Berlichingen had a pair of technologically advanced iron hands made after he lost his right hand in the battle of Landshut (figure 1.4). They could be controlled by springs suspended from leather straps.

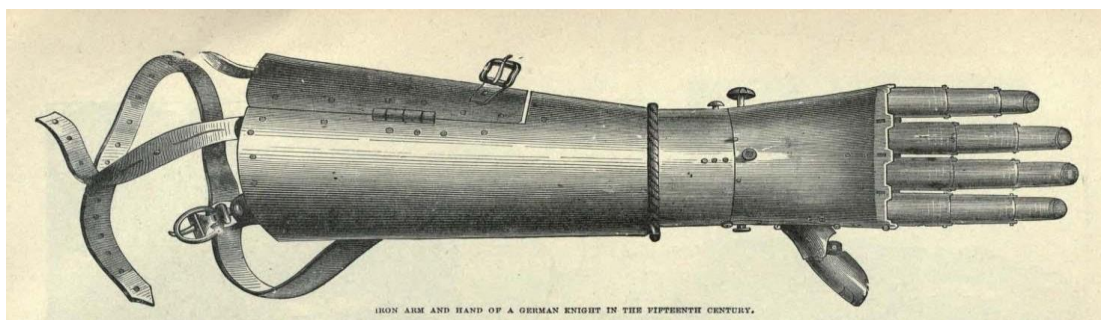


Figure 1.4 - Innovative prosthesis of 1500 years

French army Barber Ambroise Pare, according to many scientists, is the father of modern amputation surgery and orthopedic structures. In 1529, he introduced modern amputation procedures in the medical community, and in 1536,

he made hinged prostheses for the upper and lower limbs. It also modified the artificial leg below the knee, adding adjustable seat belts, knee lock control, and other technical features that are used in modern devices.

His work demonstrated the first true understanding of how a prosthesis should work. A colleague of Pare-Lorraine, a French locksmith, made one of the most important contributions in this field, using leather, paper and glue instead of heavy iron in the manufacture of the prosthesis.

Much of Pare's work undid many of the widespread medical beliefs of the time, some of which did more harm than good. For example, Pare found that if you apply oil to the site of a gunshot wound or any other wound, it does not lead to healing, as previously thought, but in fact has a negative effect. The same goes for moxibustion, another common method that seemed ineffective to the Couple. Instead, Pare used artery ligation, and became perhaps the first doctor to perform this operation.

In 1696, Peter Verdine developed the first prosthetic leg below the knee without additional fixation, which would later become the basis for modern prosthetics of joints and corsets.

In 1800, the Londoner James Potts developed a prosthesis made of a wooden rod with a steel knee joint and a hinged leg that was attached with catgut threads from the knee to the ankle. This prosthesis would later be called the "Anglesey leg" in honor of Henry William Paget, the first person to be awarded the title of Marquess of Anglesey, who lost a leg at the battle of Waterloo and used Potts' invention. In 1839, William Selfo brought this prosthesis to the United States, where it became known as "Selfo's leg" (figure 1.5).



Figure 1.5 - Selfo's leg

Douglas Bligh invented and patented "Dr. Bligh's anatomical leg" in 1858, which he called "the most complete and successful invention ever made among artificial limbs." And already in 1863, Dubois Parmley invented an improved prosthesis with a suction Cup, a polycentric knee, and many joints.

Later, Gustav Herman suggested using aluminum instead of steel to make the prostheses lighter and more functional. Such a lightweight device had to wait until 1912, when Marcel DeSutter, a famous English pilot who lost a leg in a plane crash, made the first aluminum prosthesis with the help of his brother, engineer Charles.

The progress achieved in the development of prosthetics technology for 300 years was insignificant. However, advances in surgery and amputation in the mid-nineteenth century allowed doctors to shape the stump so that it was more susceptible to joining the prosthesis. The prosthetics didn't improve much, but life was becoming more comfortable for those who wore them.

As the civil war in the United States continued, the number of amputations grew catastrophically fast, which forced Americans to develop strongly in the field of prosthetics (figure 1.5). James Hanger, one of the first civil war amputees, developed what he later patented as the Hanger Limb, a prosthetic made of barrel rivets and metal that had articulated joints in the knee and ankle areas. Hanger Limb was at that time the most advanced technology in the history of prosthetics, and the company founded by Hanger continues to be a leader in this field.

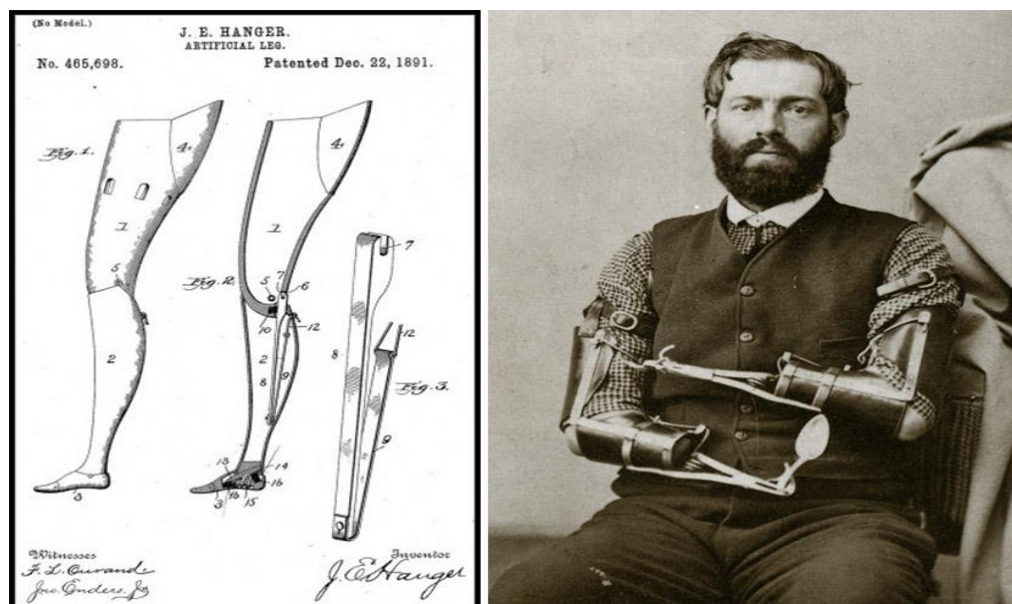


Figure 1.5 - James Hanger

Unlike the civil war, the First world war did not make much progress in this area. Despite the lack of technical advances, surgeons and the military were aware



of the importance of discussing the technology and development of prosthetics (figure 1.6). This eventually led to the formation of the American Association for prosthetics and orthopedic applications (AAPOA).



Figure 1.6 - The process of creating a prosthesis

After world war II, veterans were dissatisfied with the lack of technological solutions and demanded improvements. Then the US government made a deal with military companies to improve prosthetics, not weapons. This agreement opened the way to the development and production of modern prostheses (figure 1.7). The new devices are much lighter – made of plastic, aluminum and composite materials to provide patients with the most functional devices.



Figure 1.7 - Industrial production of prostheses

In the 1970s, inventor Isidro M. Martinez had a huge impact on the prosthetics industry when he developed a lower limb prosthesis that, instead of trying to replicate the movements of a natural limb, was focused on improving gait and reducing friction. By reducing pressure and making walking more

comfortable, Martinez, who was himself disabled, improved the lives of many future patients.

The sharpest difference between modern artificial limbs and those made in the past is at the border between the prosthesis and the part of the body to which it will be attached (figure 1.8). In the past, the suspension system for prosthetic limbs was made of leather or woven belts, and the groove was wooden or metal, lined with fabric. Most modern prostheses combine a plastic socket and suction cups. They are carefully insulated and prevent damage to the part of the limb to which it is attached.



Figure 1.8 - Modern prostheses

Modern connectors also make it easier to put on and remove the prosthesis. This is especially useful when a person is wearing multiple prosthetics. For example, athletes may have multiple prosthetics for running, skiing, Cycling, and other physical activities. Most often, they do not visually resemble human limbs. It is an elaborate construction made of plastic, rubber and carbon fiber that are proportionally adapted to the body. They are carefully monitored and checked during the competition to ensure that no additional advantages, such as a longer limb, are used.

In addition to lighter devices, the emergence of microprocessors, computer chips, and robotics in modern devices is intended to bring patients back to life, instead of just providing basic functionality or a more attractive look. Modern prosthetics are able to mimic the function of a lost limb more accurately than ever before.

Bionics gets significant development at the moment of introduction of microprocessors and other elements of modern technologies. A new direction of prosthetics “bionic prostheses” is being actively developed.

## **1.2 Bionics and new technologies**

Bionics is an applied science that combines biology and technology. Wildlife helps scientists find solutions for technical devices. Simply put, bionics is a combination of biology and technology. Bionics looks at biology and technology from a completely new perspective, explaining what common features and what differences exist in nature and technology.

The name of bionics comes from the ancient Greek word Bion — "cell of life". Studies bionics biological systems and processes in order to apply the knowledge obtained to solve engineering problems. Bionics helps people create original technical systems and technological processes based on ideas found and borrowed from nature.

There are three main types of bionics:

1. biological bionics, which studies the processes occurring in biological systems;
2. theoretical bionics, which builds mathematical models of these processes;
3. technical bionics, which uses models of theoretical bionics to solve engineering problems.

Bionics is closely related to biology, physics, chemistry, cybernetics, and engineering: electronics, navigation, communications, marine science, and others.

We are considering the section technical bionics: it uses models of theoretical bionics to solve engineering problems, as in the case of prosthetics.

Previously, experts meant by "bionic" prostheses such devices that are similar to the part of the body that they replace. From the point of view of modern concepts, these are prostheses that are controlled by electronics and bio-currents, that is, they use myography or encephalogram.

The British company RSLSteeper, which currently has about 90 years of experience in prosthetics, brought the bionic prosthetic hand BeBionic to the international market in 2010. At that time, the artificial hand for an adult had only four functional grips, but it already allowed you to eat, drink, type, turn the key in the lock, use an ATM, and hold small objects (figure 1.9). The user can use the device to break eggs and hold a disposable Cup in his hand, because even the force of pressing is regulated by commands taken by sensors from the muscles.



Figure 1.9 - BeBionic company prosthesis

The lack of mass demand and low competition is the main reason why bionic prostheses are very expensive. In 2013, a prosthetic palm cost up to a hundred thousand dollars.

How to reduce the cost of a prosthesis? This is possible if you make it cheaper to produce it. In 2013, a crowdfunding campaign on IndieGoGo to create an open and affordable prosthetic palm, most of the details for which can be printed on a 3D printer, was successfully completed. The device has independent drives for each finger, tactile feedback, and reads signals through the skin for control. In the palm of the device are electric drives and an Arduino control Board.

Bebionic company is one of the most serious players in the market of prosthetics of hands in the world. It is often said in the media that this company made the first bionic prosthesis.

In June 2016, the first British woman received a BeBionic Small brush-a realistic prosthesis that is suitable for women and teenagers due to its small size. 29-year-old Nicky Ashwell (NickyAshwell) from London was born without a right hand and used a cosmetic prosthesis all her life, which had no functionality (figure 1.10).





Figure 1.10 - Nicky Ashwell

The Bebionic Small prosthesis weighs 390 grams, can hold up to 45 kilograms and has 14 grips.

In may 2016, 26-year-old James Young received a prosthetic made similar to the hand of solid snake-the hero of the Metal Gear Solid series of games. James lost his left arm, injured his left leg and suffered other injuries when he was hit by a train, and received standard prosthetics after the hospital, which he described as "ugly." Now he is "running around" the next prototype of an artificial hand (figure 1.11).



Figure 1.11 - James Young

As can be seen from the examples above, modern bionic prostheses have sufficient functionality for various everyday actions. But there is something else that scientists are working on: the sensitivity of prosthetics. For a person's hand, it is important to understand how much to squeeze something, what exactly you can take in your hand, what you can not. So with an artificial brush – it will greatly improve the ability to feel.



In 2014, Dennis Aabo Sorensen, who lost an arm due to careless handling of pyrotechnic "toys", volunteered to test the prosthesis with feedback (figure 1.12). The electrodes of the prosthesis were connected to the human nervous system. The strength of the signal is calculated by the computer, and Dennis began to feel the size, shape, and texture of the object.

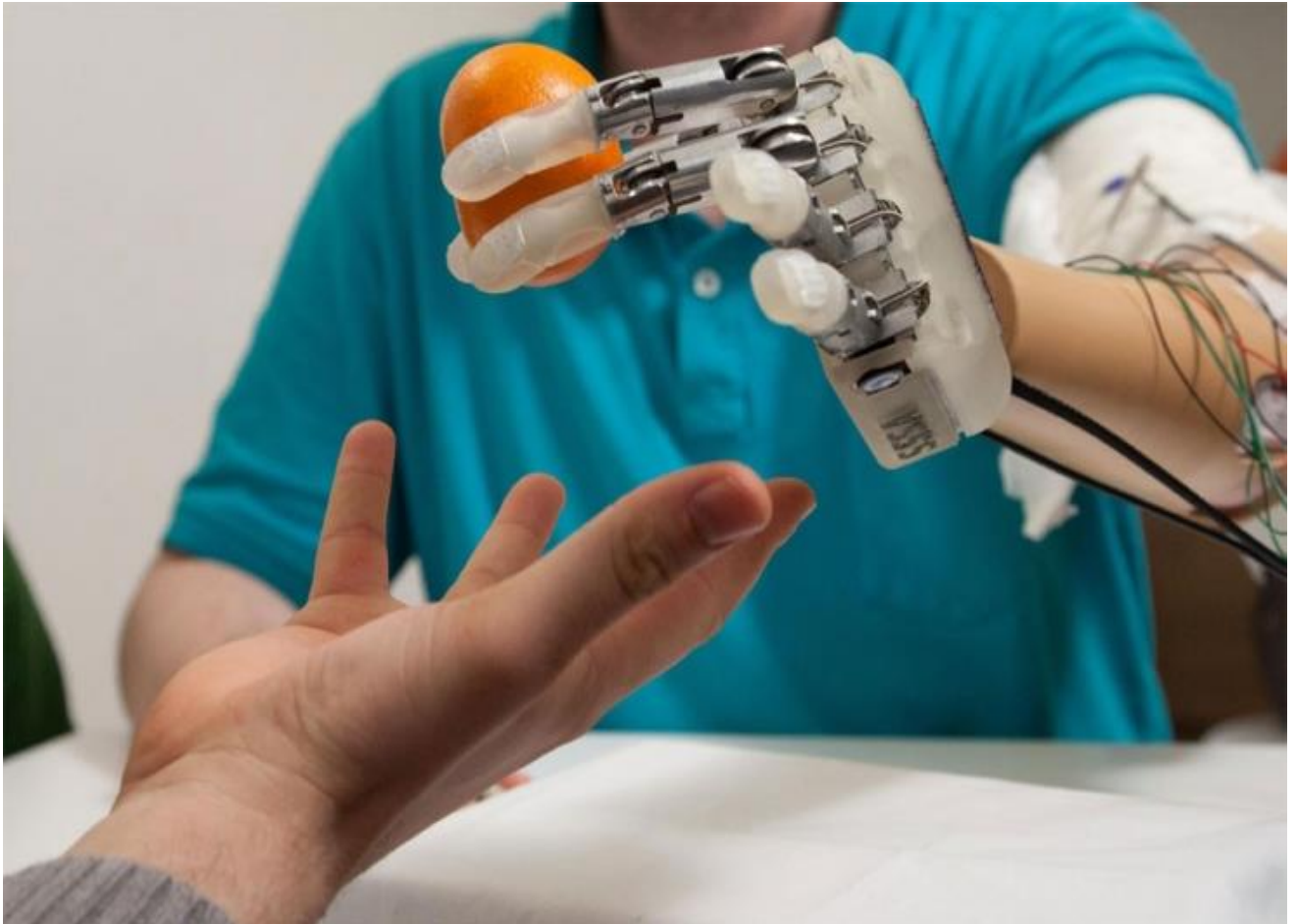


Figure 1.12 - Prosthetic with feedback

### **1.3 Prosthetics in Kazakhstan**

There are not many companies engaged in creating prosthetics on the Kazakhstan market, and there are only a few companies that have introduced bionic prostheses into commercial use. 3D printing now offers a lower cost, but significantly loses in quality.

The development of bionic prostheses is led by the startup "MBionics", which created the first Kazakhstan bionic prosthetic hand. Its founder, Maulen Bekturganov, took up prosthetics while studying at the University. In three years, he made 7 prototypes of bionic prostheses (figure 1.13). Three people have already received its test models through sponsorship. The developer adds special attachments to children's models, for example, for a flashlight or phone.

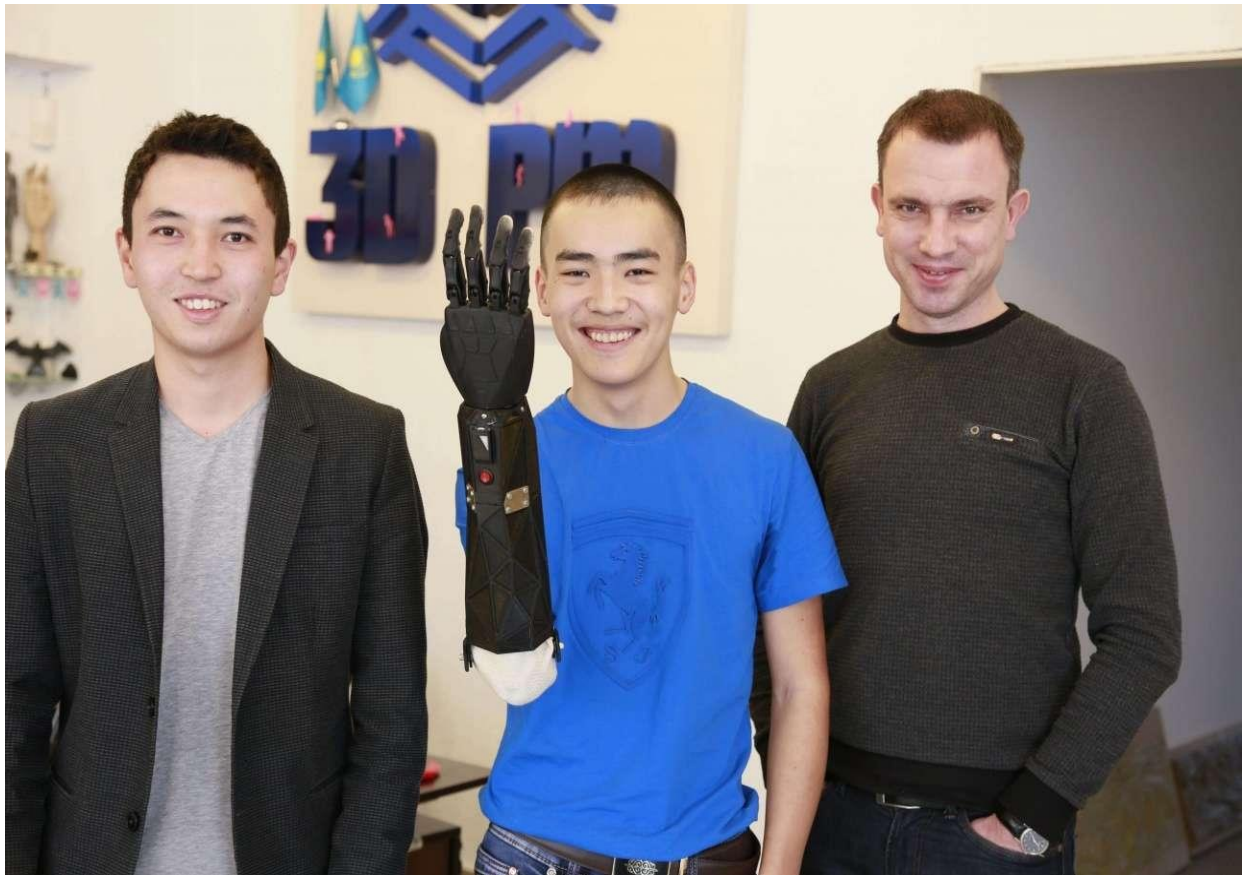


Figure 1.13 - MBionics company prostheses

The 3D PM team makes culture-receiving sleeves and cosmetic linings, reducing the cost of prosthetic production by up to 30%. Prosthetists and technologists together have already provided 12 people with prosthetics.

## 2 Overview of image recognition methods

### 2.1 Histograms of oriented gradients

Image recognition is a term that refers to a set of techniques for analyzing the context of an image in order to find the coordinates of a particular object. Detection accuracy and processing speed vary from method to method. One of the most common methods before 2012 and the advent of neural networks were histograms of oriented gradients, which were combined with some classifier. The original article used the support vector method. The basis of this method is the assumption that you can accurately determine the presence and shape of objects based on the way the image intensity gradients are distributed.

The idea is that the size of color gradients at the edges and corners of objects (areas with a strong change in intensity) is large.

The value of the  $g_x$  and  $g_y$  gradient from the original image is calculated. This can be done by filtering this image with the following cores:

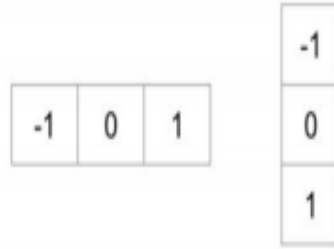


Figure 2.1 - Filter cores

Using  $g_x$  and  $g_y$ , the gradient value and direction are calculated:

$$g = \sqrt{g_x^2 + g_y^2}, \quad (2.1)$$

$$\theta = \arctan\left(\frac{g_y}{g_x}\right), \quad (2.2)$$

Plotting for each non-intersecting cell  $C_{m,n}$ , from  $(w, v)$  pixels of the image a histogram of gradient directions in  $t$  directions  $(0, 2, \pi \dots \pi t, 2)$  as follows:

$$H_{n,n} = \left\{ \sum_{\left| \theta_{i,j} - \frac{2\pi k}{t} \right| \leq \frac{\pi}{t}} |G_{i,j}| \mid (i,j) \in C_{m,n}, k = 0, \dots, t \right\}, \quad (2.3)$$

The cell size and the number of gradient directions  $t$  are important parameters of the method that significantly affect the significance of features and their effectiveness for classification tasks. It should be noted that normalization of

histograms in cells allows you to use cells of different sizes among images. Forming a feature vector from normalized histograms in image cells:

$$HOG(I) = [H'_{0,0} \dots H'_{m,n} \dots], \quad (2.4)$$

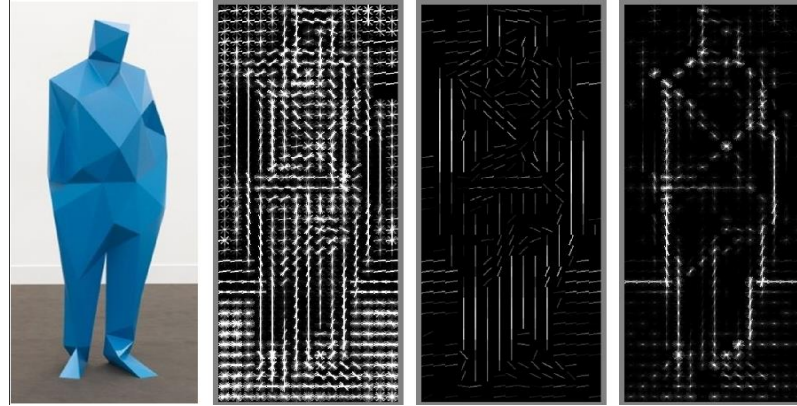


Figure 2.2 - Visualization of hog - descriptors with different cell sizes

### 2.1.1 Training the linear classifier

The support vector method is often used to classification images based on hog - descriptors.

Let there be a training sample:  $(x_1, y_1), \dots, (x_m, y_m)$ ,  $x_i \in \mathbb{R}^n$ ,  $y_i \in \{-1, 1\}$ . The support vector method generates a classifier function  $F$  in the form:

$$F(x) = \text{sign}(\langle w, x \rangle + b), \quad (2.5)$$

where  $\langle \cdot, \cdot \rangle$  is the scalar product,  $w$  is the normal vector to the dividing hyperplane, and  $b$  is an auxiliary parameter. Those objects for which  $F(x) = 1$  fall into one class, and objects with  $F(x) = -1$  fall into another. The choice of this function is justified, since any hyperplane can be roughly defined as  $\langle w, x \rangle + b = 0$  for some  $w$  and  $b$ . This is true for all dimensions.

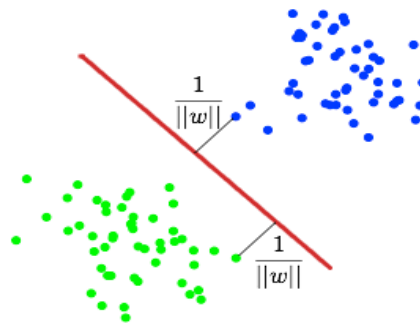


Figure 2.3 - The plane of separation of classes

Next, you must select  $w$  and  $b$  so that the distance to each class is the maximum. We can calculate that this distance is  $\frac{1}{\|w\|}$ . Now we can write this as an optimization problem:

$$\{\min \|w\|^2, \quad y_i(\langle w, x \rangle + b) \geq 1, i = 1, \dots, m. \quad (2.6)$$

The above case is a quadratic programming problem. Such problems can be solved using Lagrange multipliers.

## 2.2 Neural networks

Neural networks are a new and promising computer technology that offers new approaches to the study of dynamic financial problems. Initially, neural networks opened up new opportunities in the field of pattern recognition, and then decision-making and problem-solving tools based on statistical and artificial intelligence were added to the financial sphere.

The most common applications of neural networks:

- classification of the distribution of data in the parameters. For example, when you log in, you specify a group of people, and you need to decide which of them should provide credit and which should not. This work can be performed by a neural network that analyzes information such as age, solvency, creditworthiness, etc.;
- forecasting - ability to predict the next step. For example, the rise or fall of shares, depending on the situation in the stock market.

Recognition or classification is currently the most widely used application of a neural network. Used by Google when searching for a photo or in a phone with a camera, when it detects the position of your face and highlights it, and more. Depending on the type of signal conversion and activation type, different types of neural structures are created. There are deterministic neurons when the activating function uniquely calculates the output signal at the input and probabilistic neurons whose state at time  $t$  is a random function of the potential and state at time  $t-1$ .

Neurons are divided into three main types: input, disappearance, and output. There is also a neural bias and connection. If the neural network consists of a large number of neurons, the term "layer" is introduced.

Accordingly, there is an input layer that receives information,  $n$  hidden layers (usually no more than 3) that process it, and an output layer that outputs the result. Each of the neurons has 2 main parameters: input data and output data. In the case of an input neuron, the input is equal to the output. In other cases, General information about all neurons from the previous level is entered in the input field. It is then normalized using the activation function (currently passed only in  $f(x)$ ) and entered in the output field.

A synapse is a connection between two neurons. Synapses have one parameter - weight. It changes input information as it is passed from one neuron to another. Let's say there are three neurons that transmit information to the next one. Then we have 3 weights that correspond to each of these neurons. In this neuron whose weight is higher, this information will be dominant in the next neuron (for example, color mixing). In fact, the set of weights of a neural network or matrix of weights is a kind of brain of the entire system. Thanks to these weights, the entered information is processed and converted into a result.

Neurons operate with numbers in the range  $[0,1]$  or  $[-1,1]$ . The process of bringing data to the range specified above is called normalization. There are many normalization methods available. They are called activation functions.

The activation function is a way to normalize input data , as mentioned above. That is, if the input is a large number, passing it through the activation function, the output will be in the required range. Let's look at the most common activation functions at the moment.

Linear activation function:

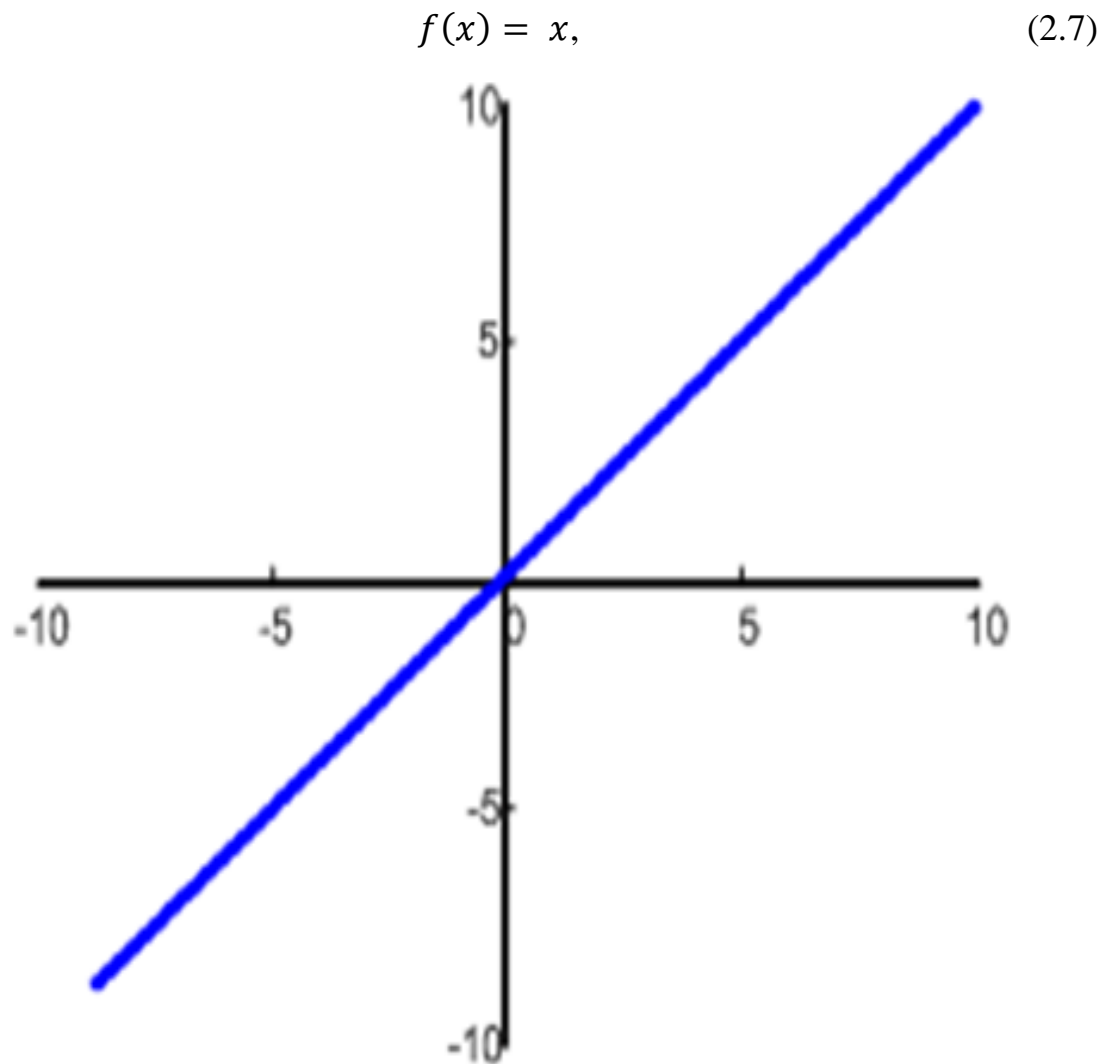


Figure 2.4 - Graph of the linear activation function

This function is almost never used except when testing a neural network or passing a value without conversion.

Sigmoid activation function:

$$f(x) = \frac{1}{1+e^{-x}}, \quad (2.8)$$

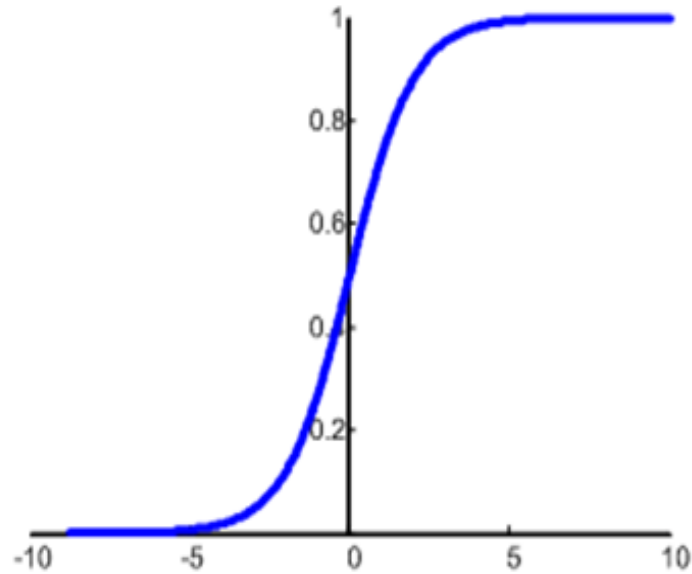


Figure 2.5 - Graph of the sigmoid activation function

This is the most common activation function with a range of values equal to  $[0,1]$ . This shows most of the examples in the network and is sometimes referred to as a logistics function. If you have negative values (for example, stocks can not only rise, but also fall), you will need a function that detects negative values.

Hyperbolic tangent:

$$f(x) = \frac{e^{2x}-1}{e^{2x}+1}, \quad (2.9)$$

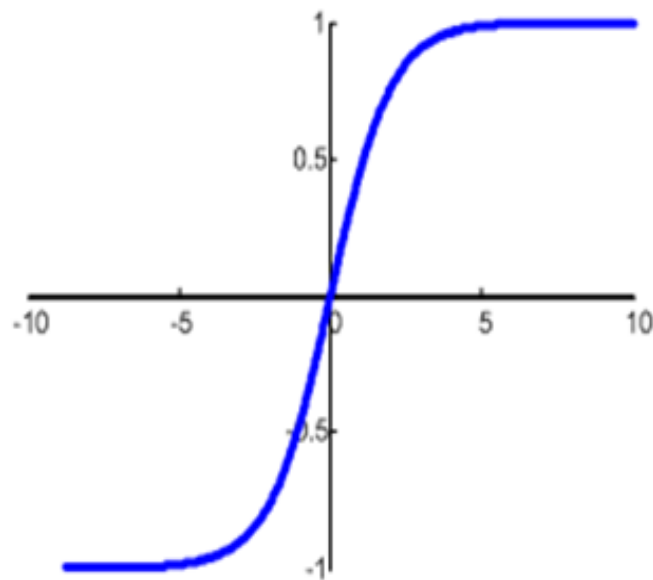


Figure 2.6 - Graph of hyperbolic tangent



It makes sense to use a hyperbolic tangent only if your values can be both negative and positive, since the functional range is  $[-1,1]$ . It is not practical to use this function only with positive values, since this will significantly worsen the results of the neural network.

The name perceptron of the neural network was introduced by the American neurophysiologist F. Rosenblatt, who in 1957 invented the first neuroprocessor element (IPP), a neural network.

Each neural network consists of an input layer and an output layer. Accordingly, independent and dependent variables are provided. Input data is converted by network neurons and compared with output data. If the deviation is greater than the specified one, the weights of the neurons' connections to each other and the threshold values of the neurons change in a special way. Again, the process of calculating the output cost and comparing it with the standard. If the deviation is less than the specified error, the training process is interrupted. In addition to the input and output layers, there are so-called hidden layers in a multi-layer network. These are neurons that do not have direct inputs to the source data, but are connected only to the outputs of the input layer and to the input of the output layer. In this way, hidden layers also transform information and add non-linearity to models.

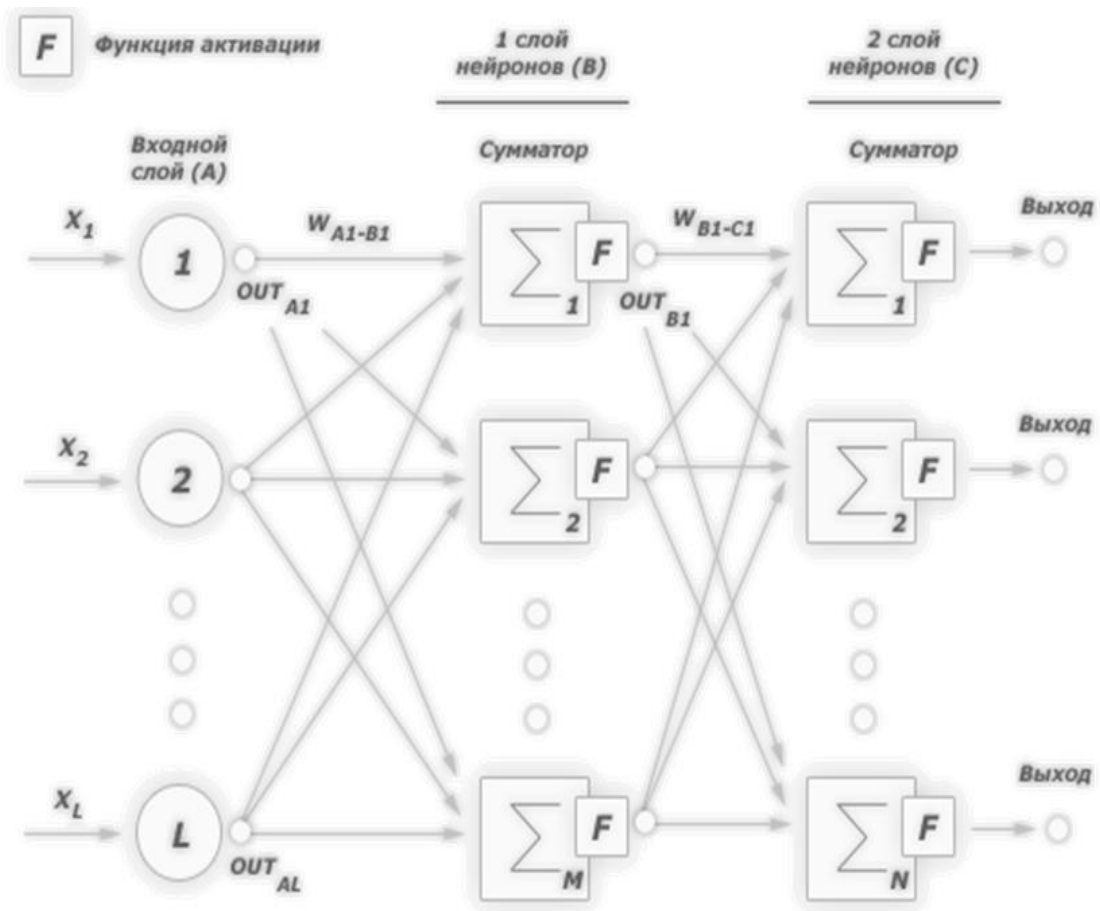


Figure 2.7 - Example of a two-layer perceptron



### 2.2.2 Neural network training

The main difference and advantage of neural networks from classical forecasting and classification tools is their ability to learn. So, what is neural network training? At the training stage, synaptic coefficients are calculated when solving neural network problems in which the desired response is determined not by rules, but by examples generalized in training sets. At the training stage, the neural network itself plays the role of an expert in preparing data for building an expert system. The rules are assumed to be part of the training data structure. Training data is necessary for training with neural networks. They must correspond to representativeness and randomness, or to the order of properties. It all depends on the class of the problem being solved. Such data is a series of examples that give for each of them the value of the output parameter that would be desirable to get. The actions taken in this case may be called supervised learning: "teacher" sends a vector of input data to the network input and reports the desired value of the calculation result to the output node.

Controlled learning of a neural network can be considered as a solution to the optimization problem. Its goal is to minimize the error function  $E$  in a given set of examples by selecting the values of the weights  $W$ . Reaching the minimum is called convergence of the learning process. There was an opportunity to prove this to Rosenblatt. Since the error depends non-linearly on weight coefficients, it is impossible to get a solution in analytical form, and the search for the global minimum is performed using an iterative process called a learning algorithm. More than a hundred different training algorithms have already been developed, which differ from each other in optimization strategies and error criteria. Usually, the average square error (SQO) is taken as a measure of error):

$$E = \sqrt{\frac{\sum_{i=1}^M (d_i - y_i)^2}{M}}, \quad (2.10)$$

where  $M$  is the number of examples in the training set.

The  $E$  value is minimized using gradient methods. The weight change occurs in the direction opposite to the direction of the greatest steepness of the function.

$$W(t + 1) = W(t) + \varepsilon * \frac{\partial E}{\partial W}, \quad (2.11)$$

Here  $\varepsilon$  is a user-defined parameter called the learning coefficient.

A gradient is a vector that defines the steepness of the gradient and indicates its direction relative to one of the points on the surface or on the diagram. To find the gradient, you must take the derivative of the graph at a certain point (as shown in the graph). With each iteration of movement against the gradient, the point "falls" into the "low". In the end, the following result should be achieved:

The next step is to set the calculated gradient values for all the weights of the neural network, respectively. This is called back propagation, or the method of back propagation of an error - ORO.

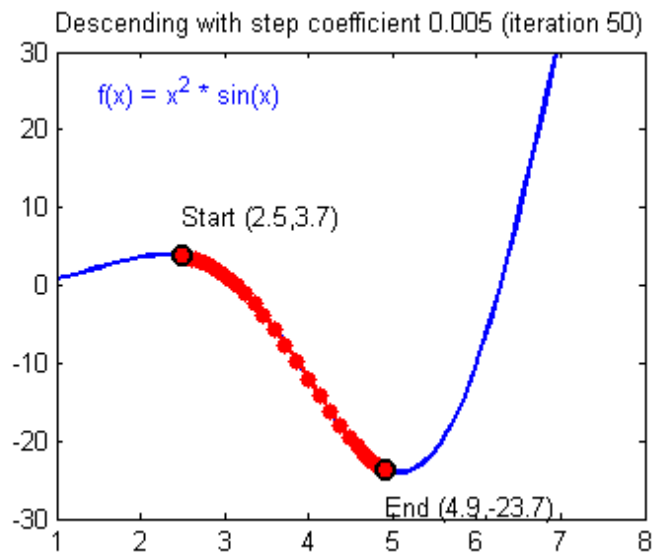


Figure 2.8 - The process of gradient descent on the graph of a neural network function

The ORO algorithm is as follows:

- setting the weights to some random values;
- selecting a training set;
- setting the vector to the network input;
- calculation of network output;
- calculating the difference between the network output and the required output (the target vector of the training pair);
- the adjustment of the network weights to minimize error.

The operations performed in stages 2 and 3 are similar to those performed when an already trained network is functioning, i.e. the input vector is Entered and the resulting output is calculated. Calculations are made in layers.

From the mapping theorem of almost every function to a multi-layer neural network, it follows that the neural network we study can in principle fit any data to minimize the overall quadratic error. To prevent this, use the following method to test the network when training neural networks. To do this, the training sample is randomly divided into two sub-samples before training begins: training and testing.

The training kit is used for the learning process itself and for changing the weight of neurons. The training process uses a test to check the total square error, but the weights do not change. If the neural network shows an improvement in approximation in both the training and test samples, the network is trained in the right direction. Otherwise, the error in the training template can be reduced, but increased in the test template. The latter means that the network has been "retrained" and can no longer be used for forecasting or classification. In this case, the weights of the neurons change slightly to bring the network out of the vicinity of the local error minimum.

Re-learning, as the name implies, is the state of a neural network when it is oversaturated with data. This problem occurs when training a network with the

same data takes too long. In other words, the network begins to learn not from data, but from storing and "filling" it. Accordingly, if you are already sending new data to the input of this NS, there may be noise in the received data that affects the accuracy of the result. For example, if we show NS different photos of apples (only red) and say that it is an apple. If the NS then sees a yellow or green apple, it cannot determine that it is an apple, because it believed that all apples should be red. Conversely, if the NS sees something red and matches the shape of an apple, such as a peach, it will say that it is an apple. It's noise. On the graph, the noise looks like this.

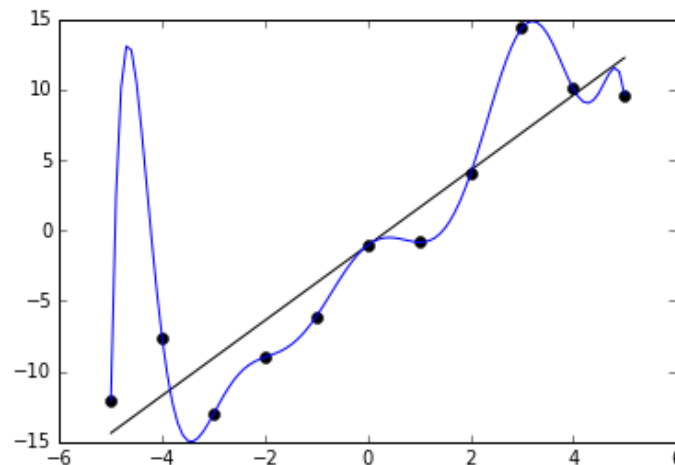


Figure 2.9 - Retrain the neural network

It can be seen that the graph of the function varies greatly from point to point, which is the output (result) of our NS. Ideally, this diagram should be less wavy and straight. To avoid re-training, it will not take long to train an NS with the same or very similar data. Retraining can also be caused by different parameters that you use to enter the National Assembly, or by very complex architecture. Therefore, if you notice any noise (noise) on the output after training, you should use one of the regularization methods, but in most cases this is not necessary. A neural network can be trained with or without a teacher (supervised learning without supervision). Learning with a teacher is a kind of learning that involves problems such as regression and classification (we used them in the example above). In other words, you are playing the role of a teacher, and the neural network is playing the role of a student. You enter the input data, and the desired result, i.e. the student viewing the input data, will understand that you should aim for the result you specified. Training without a teacher - this type of training is less common. There is no teacher here, so the network does not get the desired result or its number is very small. In fact, this type of training is owned by the NS, whose task is to group data by certain parameters.

### 2.3 The Viola - Jones recognition Method

In 2001, Viola and John proposed a facial recognition algorithm that was a breakthrough in facial recognition. The method uses sliding window technology.

Thus, a frame that is smaller than the original image moves with a certain step along the image and determines whether the face is in the window in question using a cascade of weak classifiers. The sliding window method is effectively used in various tasks of computer vision and object recognition.

The method consists of 2 algorithms: the learning algorithm and the recognition algorithm. In practice, the speed of learning the algorithm is not important. The speed of the detection algorithm is extremely important. In accordance with the previously introduced classification, structural, statistical, and neural methods can be used.

The method has the following advantages:

- it is possible to detect more than one face in the image;
- using simple classifiers shows good speed and allows you to use this method in a video stream.

However, the method is difficult to learn because learning requires a large amount of test data and requires a long learning time, measured in days.

Initially, a face-only recognition algorithm was proposed, but it can be used to detect other objects. One of the contributions of Viola and Jones was the application of a table of sums, which they called an integral image. A detailed description of this will be given below. The generalized recognition scheme in the Viola - Jones algorithm is shown in the following figure.

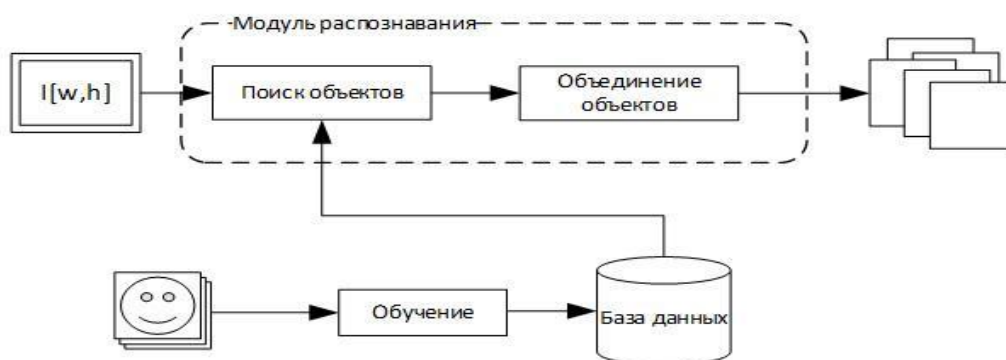


Figure 2.10 - General scheme of recognition

The generalized scheme of the algorithm looks like this: Before starting recognition, the training algorithm based on test images trains a database consisting of features whose parity and boundaries. For more information about parity, attribute, and border, see Following section. The detection algorithm then uses the created database to search for objects at different image scales. The Viola-Jones algorithm provides all non-integrated objects found at different scales at the output. The next task is to decide which of the found objects actually exist in the frame, and which duplicate them.

As a feature of the recognition algorithm, the authors proposed hair features based on hair wavelets. They were proposed in 1909 by the Hungarian mathematician Alfred Haar.

In the face recognition problem, the General observation is that under all faces, the eye area is darker than the cheek area. Look at masks from light and dark areas.



Figure 2.11 - Signs Of Haar

Each mask is characterized by the size of light and dark areas, proportions, and minimum size. Along with other observations, the following hair features have been suggested as a characteristic space for the problem of recognizing a class of people.

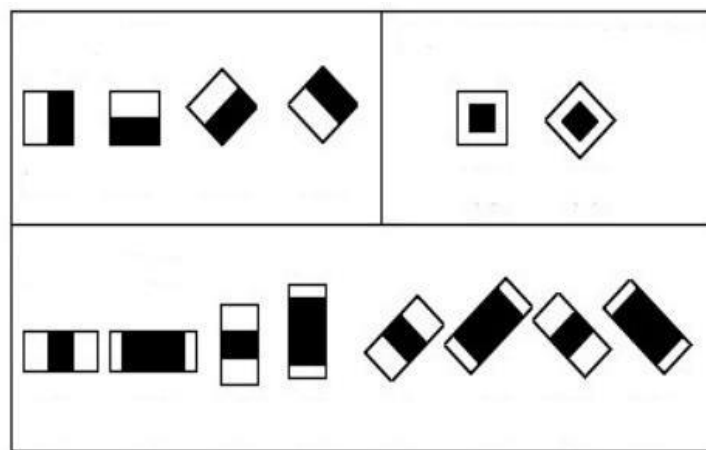


Figure 2.12 - Additional signs of Haar

Haar features give a point value of the brightness difference along the X and Y axes, respectively. Therefore, the common Haar feature for facial recognition is a set of two adjacent rectangles that lie above the eyes and on the cheeks. The attribute value is calculated using the formula:

$$F = X - Y, \quad (2.12)$$

where X is the sum of the brightness values of points covered by the light part of the attribute, and Y is the sum of the brightness values of points covered by the dark part of the attribute.

You can see that taking the sum of intensity values for each trait requires significant computational resources. Viola and Jones were asked to use a holistic representation of the image, more on this later. This representation has become a convenient method for calculating features and is also used in other image processing algorithms, such as SURF.

The generalized scheme of the learning algorithm is as follows. There is a test table of images. The size of the test template is about 10,000 images. The figure shows an example of a training image of faces. The learning algorithm works with grayscale images.



Figure 2.13 - Example of a training selection

If the test image is 24 x 24 pixels in size, the number of object configurations is about 40,000 (depending on the minimum mask size). The current implementation of the algorithm uses about 20 masks. For each mask, each configuration, a weak classifier is trained that gives the smallest error on the entire training base. It is added to the database. The algorithm is trained with this. The result of the algorithm is a database of T weak classifiers. The generalized scheme of the training algorithm is shown in the figure.

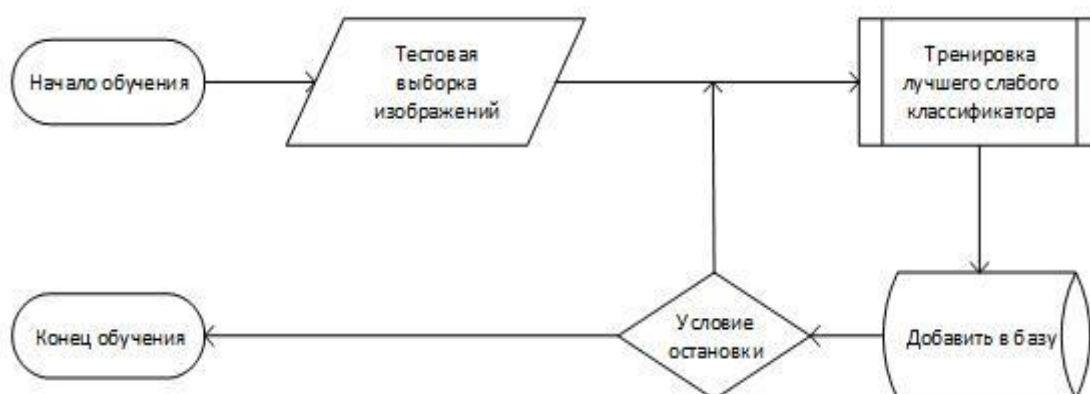


Figure 2.14 - Training scheme

Learning the Viola-Jones algorithm is learning the algorithm with a teacher. For him, there may be such a problem as retraining. It is shown that AdaBoost can

be used to solve a variety of problems, including game theory and forecasting. In this article, the stop condition is to reach a predetermined number of weak classifiers in the database.

### 2.3.1 Integral representation of images

In order to perform any operations on the image, it is necessary to bring it to an integral form.

The integral representation can be represented as a matrix whose dimensions coincide with the dimensions of the original image  $I$ , where each element is calculated as:

$$L(x, y, ) = \sum_{i=0, j=0}^{i \leq x, j \leq y} I(r, c), \quad (2.13)$$

where  $I(r,c)$  is the pixel brightness of the source image.

Each element of matrix  $\Pi[x,y]$  is the sum of pixels in a rectangle from  $(0,0)$  to  $(x,y)$ . The calculation of such a matrix takes linear time. In order to calculate the sum of a rectangular area in the integral representation of an image, only 4 operations of accessing the array and 3 arithmetic operations are required. This allows you to quickly calculate Haar attributes for images in training and recognition. For example, consider the rectangle ABCD.

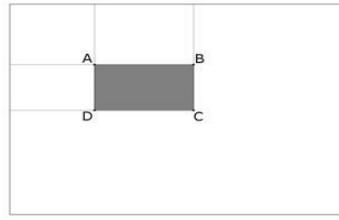


Figure 2.16 - Pixel

The sum inside the ABCD rectangle can be expressed in terms of the sums and differences of adjacent rectangles using the formula:

$$L(x, y) = I(x, y) - L(x - 1, y - 1) + L(x, y - 1) + L(x - 1, y), \quad (2.14)$$

### 2.3.2 Training

Like other classical machine vision algorithms, Haar cascades are only image descriptors. You can use almost any method to classify them. However, the AdaBoost algorithm shows the best result. This is one of the so-called "greedy" algorithms, i.e. it uses not a single classifier, but a whole complex in the  $\{ t=1, \dots, T \}$  cycle. After each call, the distribution of  $D_t$ , weights is updated, which indicate different response areas for each classifier. At each iteration, the weights of each incorrectly classified object increase, so the new classifier Committee "focuses its attention" on these objects.

### 3 Engineering part

#### 3.1 Calculation of parameters of the prototype

When choosing a prototype, we need to study the arm from the point of view of biomechanics. The free upper limb is an open hinge-lever kinematic chain. The links are set in motion by a system of connecting muscle groups. Consider the structural kinematic chain of a limb.

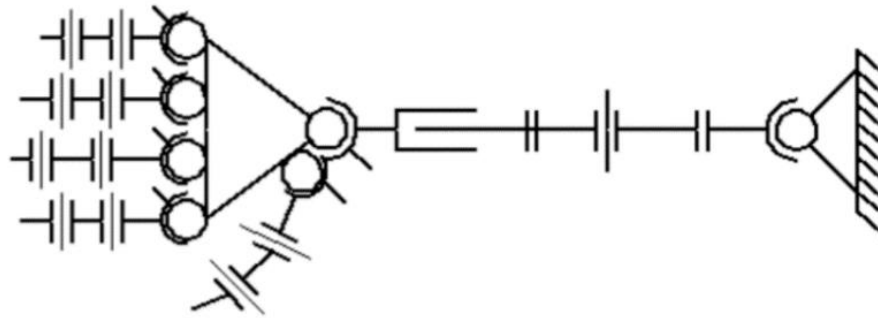


Figure 3.1 - Structural chain of hands

To determine the ability of the hand to occupy different positions in space, it is necessary to determine the degree of mobility. It is necessary to say briefly what it is. The degrees of mobility of the hand (degrees of freedom) are generalized coordinates that determine the positions of its links in space. This parameter is calculated using the Somov-Malyshev formula.:

$$W=6n-p_1-2p_2-3p_3-4p_4-5p_5, \quad (2.1)$$

where,  $n$  is the number of moving links in the kinematic chain,  
 $p_1$  is the number of kinematic pairs of the first class in this chain.  
 $p_2$  – the number of pairs of the second class,  
 $p_3$  – the number of pairs of the third class,  
 $p_4$  – the number of pairs of the fourth class,  
 $p_5$  – the number of pairs of the fifth class.

A link is any fixed element of the device. A kinematic pair is called two touching links, and their relative movement is allowed. The class of a pair is a criterion that shows how many links are superimposed on links when they are combined into a kinematic pair. For example, any free link always has six degrees of freedom.

To illustrate kinematic processes based on kinematic diagrams. The main kinematic scheme is a graphic image showing the rack, moving links, kinematic pairs and their mutual location. The graphical representation of the scheme elements takes into account the accepted symbols. The basic kinematic scheme of the manipulator is shown in figure 3.1.





















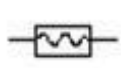
Число подвижностей $n$	Число связей, $s$ . Класс пары	Название	Рисунок	Условное обозначение	Матрицы подвижностей в системе координат 
5	1	Шар - плоскость			$\begin{vmatrix} 1 & 1 & 1 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \end{vmatrix}, \begin{vmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{vmatrix}$
4	2	Цилиндр - плоскость			$\begin{vmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{vmatrix}, \begin{vmatrix} 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{vmatrix}$
3	3	Сферическая			$\begin{vmatrix} 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{vmatrix}, \begin{vmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 \end{vmatrix}$
3	3	Плоскостная			$\begin{vmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \end{vmatrix}, \begin{vmatrix} 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 \end{vmatrix}$
2	4	Цилиндрическая			$\begin{vmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 1 \end{vmatrix}, \begin{vmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \end{vmatrix}$
2	4	Сферическая с пальцем			$\begin{vmatrix} 0 & 1 \\ 0 & 0 \\ 0 & 1 \end{vmatrix}, \begin{vmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{vmatrix}$
1	5	Вращательная			$\begin{vmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{vmatrix}, \begin{vmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{vmatrix}$
1	5	Поступательная			$\begin{vmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \end{vmatrix}, \begin{vmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{vmatrix}$
1	5	Винтовая			

Figure 3.2 - Primitive kinematic pairs

In addition, the human hand has an extremely high flexibility and maneuverability, due to the large number of degrees of freedom – 27 degrees of freedom, while 20 degrees are responsible for the movement of the hand. The number of degrees of freedom in the various joints of the hand is shown in table 3.1.

Table 3.1 - Data on the number of degrees of freedom of the human hand

№	Joints	Number of degrees of freedom of the joint
1	Shoulder	3
2	Ulnar	1
3	Radioulnar	1
4	Wrist	2
5	Carpo-metacarpal of the first metacarpal bone	2
6	Metacarpophalangeal joint of the first finger	1
7	Interphalangeal joint of the first finger	1
8	Metacarpophalangeal joints of 2-5 fingers	8
9	Interphalangeal joints of 2-5 fingers	4
10	The distal interphalangeal joints of 2-5 fingers	4
Total		27

After a detailed analysis and study of the structural diagram of the hand, it was decided to use a model with five phalanges of fingers that can independently perform movements as a prototype. The reason for choosing this brush model is the closest possible approximation of the prototype to the real hand from a morphological point of view.

### 3.2 Modeling in the environment SolidWorks

A computer-aided design system will be required to model a prototype of a bionic hand. The most optimal and stable program is the SolidWorks program. This design environment is an integral part of industrial enterprises, whose tasks include the development and production of devices and products for various purposes. SolidWorks uses the principle of three-dimensional solid-state and surface parametric design, which allows you to create three-dimensional parts, as well as assemble parts in the form of three-dimensional models. Using these models, you can create two-dimensional drawings and specifications in accordance with the ESCD

To test the manipulator for assembly and mobility, we need to create a three-dimensional model of it. Modeling is performed using Solidworks.

SolidWorks (Solidworks) - CAD software that automates the work of an industrial enterprise at the design and production preparation stages. Provides product development of any degree of complexity and purpose. It works in the Microsoft Windows environment. SolidWorks is the first CAD system that supports Solid Modeling for the Windows platform.

With Solidworks, we can create individual parts as well as ready-made devices, create vector drawings, and much more. To get started, you need to create a part. The process of selecting the part creation option is shown in figure 3.3.

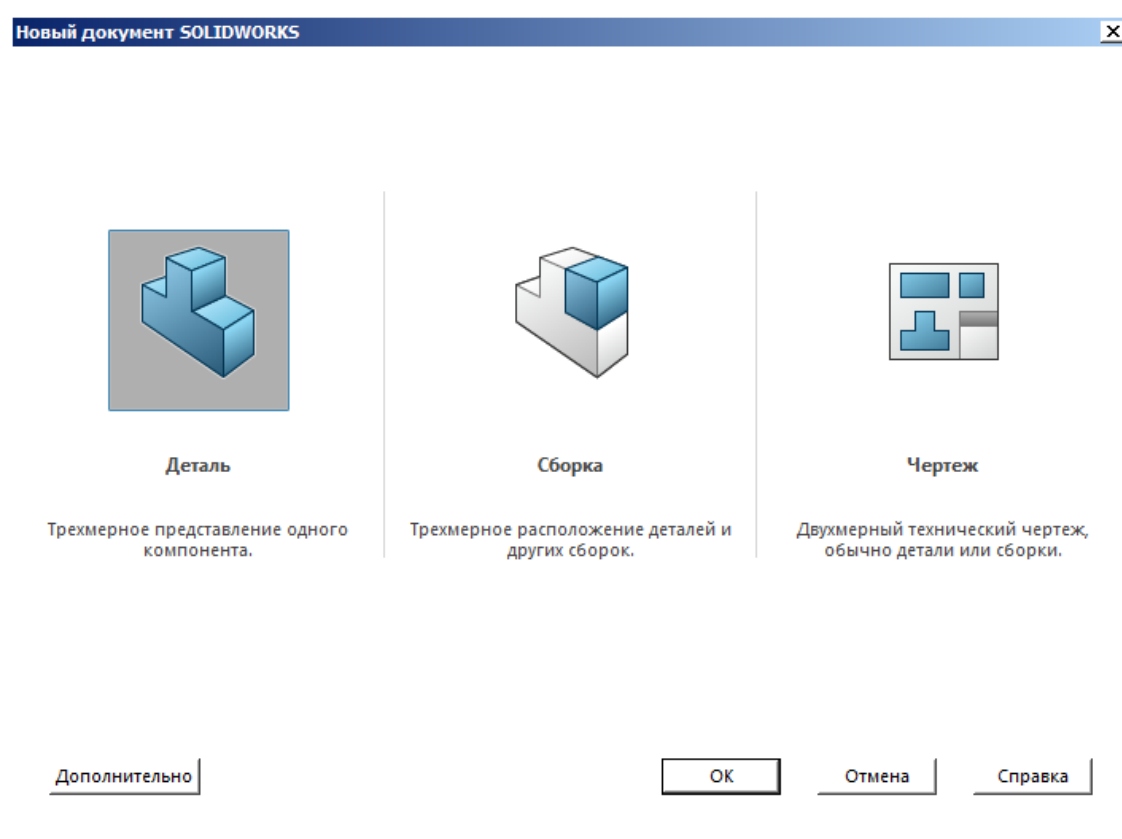


Figure 3.3 – Selection window of «Part» or «Assembly»

3D modeling offers many advantages over conventional two-dimensional design. These include eliminating errors of the assembled product at the design stage. It is also possible to consider the future product from any side and in any volume. In addition, 3D systems allow us to model products without creating drawings and prototypes.

The first stage of modeling is creating fingers. In humans, all fingers except the thumb consist of three phalanges. And the structure of the thumb consists of two phalanges. These phalanges are called the main, middle and nail. When modeling fingers, it was decided to rely on the structure of the real finger (figure 3.4).

The rest of the fingers were modeled on the same principle, but it is necessary to take into account their size relative to each other and maintain their proportions.

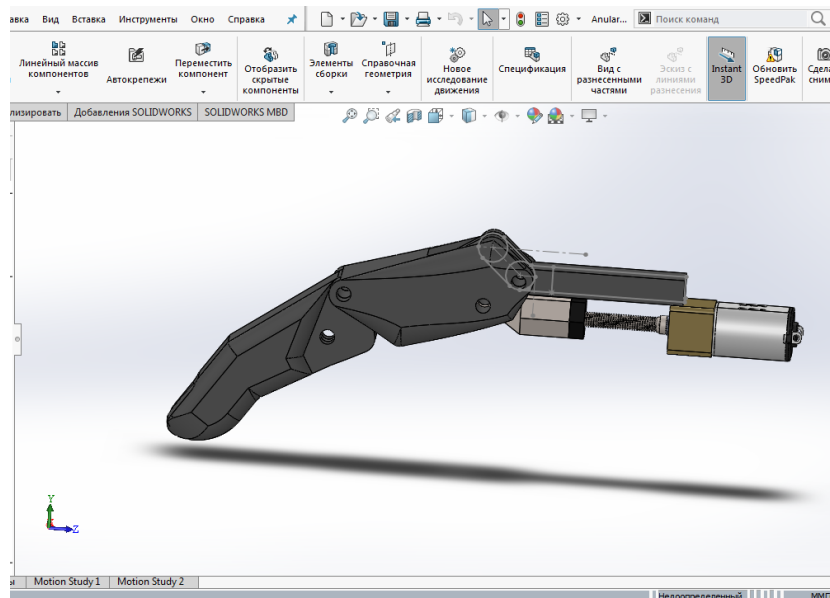


Figure 3.4 - Prototype of the fingers

The next step is to create a prosthetic palm. On the palm model there are 5 necessary finger mounts. It is also necessary to consider the attachment to the part of the forearm. The first model was the palm was complete and without moving elements (figure 3.5).



Figure 3.5 - Assembled model of the brush

In the simulation of the forearm, a hollow structure was chosen that externally imitates the human forearm. The hollow part provides space for installing motors, wires, tension cables, microcontroller, etc. To implement the rotation of the brush, an additional motor was used, connected to the brush by a gear train. Moreover, small holes in the large gear are necessary for the

organization of tension threads. The attachment points of the hand and forearm are identical to each other and are fixed with a threaded bolt. There are also holes for threads in the brush part.

This is the end of the bionic hand prototype simulation stage. As a result, we have a ready-made three-dimensional model. In the future there is the possibility of improving or editing the design (figure 3.5,figure 3.6).



Figure 3.5 – The model of the prosthesis of the upper extremities



Figure 3.6 – Assembled model

### 3.3 Choosing a microcontroller

To control the prototype engines, you need to select a microcontroller device. To do this, it was decided to use the Arduino platform.

Arduino is an entire ecosystem of devices designed for testing and designing various systems based on microcontrollers. It is not very reliable in some cases, but the developed infrastructure of libraries and modules greatly facilitates the design. In addition, Arduino provides convenient circuit generators that are understandable even to non-professionals. For this reason, Arduino is widely used for educational purposes. One of the Arduino boards is shown in the figure below.



Figure 3.7 - Arduino Uno microcontroller board

On the market, there are many single-Board devices based on microcontrollers of varying degrees of quality, cost and performance. However, most of them are not represented on the Kazakhstan market, which makes their use not very convenient. In addition, Arduino offers a number of certain amenities. One of the main ones is its own development environment-Arduino IDE, which has a very friendly interface for beginners, unlike AVR Studio. However, the creators have met experienced developers halfway by adding the ability to transfer code from AVR Studio to the Arduino IDE.

In addition to all of the above, one of the important advantages of Arduino is the ability to use a single Board as a programmer for any microcontroller from the same series as the one located on the main Board. That is, if you have an arduino uno with an atmega328 microcontroller, you can safely program on the "naked" atmega328 as if it is located on the Board. Simply put, with a single arduino uno with a price of about \$ 13, you can safely program with the same convenience via the arduino IDE on atmega328 microcontrollers with a price of about \$ 3. More than four times the savings.

Table 3.2 - Characteristics of the ATmega2560 microcontroller

Microcontroller	ATmega2560
Operating voltage	5 V
Input voltage	7-12V (recommended) 6-20V(limit)
Digital inputs and outputs	54 (14-PWM outputs)
Direct current through input / output	50 mA
Flash memory	256 Kb (8 Kb is required for the system loader)
RAM	8 Kb
EEPROM	4 Kb
Clock frequency	16 MHz

The Arduino Mega 2560 is a microcontroller Board based on the ATmega2560 microcontroller. The Board is equipped with 54 digital inputs / outputs (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UART (hardware serial ports), a 16 MHz quartz oscillator, a USB connector, a power connector, an ICSP connector, and a reset button. All the necessary elements for interaction with the microcontroller are located on the Board. All the user needs to do is connect the Board to the workstation using a USB cable, or turn on the AC to DC adapter or battery to get started. The Arduino Mega 2560 is compatible with most expansion boards that have been designed for the Arduino Duemilanove or Diecimila developed.

### 3.4 Servo selection

The motor elements in human limbs are the muscles whose contraction drives a particular part of the structure. Although scientists are developing artificial muscle fibers, it is too early to use them in real devices. Therefore, for robotic manipulators, stepper motors or servos act as muscles. In some cases, where high power devices are required, pneumatic motors are used instead of servomotors.

A servo is a motor device that operates in a limited space of angles, unlike a stepper motor. Almost all industrial-class servos designed for placement on manipulators are equipped with feedback. This is necessary for the correct implementation of inverse kinematics and the ability to detect a positioning error before it has a negative impact on a certain technological process. However, this is only true for those servos that are designed to control robots. More generally, a servo is any type of mechanical drive that has a sensor (position, speed, force, etc.) in its composition. In addition, the device must be equipped with a drive control

unit that automatically maintains the necessary parameters on the sensor and device according to the specified external value.

In other words, the servo receives the value of the control parameter as input. For example, it can get the angle of rotation. The controller compares this value with the value of its sensor. Based on the comparison result, the drive performs an action, such as "rotates", "accelerates", or "slows", so that the value of the internal sensor approaches the value of the external control parameter as closely as possible. The quality of operation of this pair of controller – sensor strongly depends on the exact position of the servo in the desired angle.



Figure 3.8 - Example of a servo

Usually servos are made in the form of an isolated box, which has wires for control and power, as well as a rotating gear to which the rotating element is attached. An example of a servo can be seen in figure 3.8. Servos consist of several parts. Their General structure is shown in figure 3.9.

The drive is an electric motor with a transmission. To convert electricity into mechanical rotation, an electric motor is needed. However, often the engine speed is too high for practical use. A gearbox is used to reduce speed: a gearbox that transmits and converts torque.



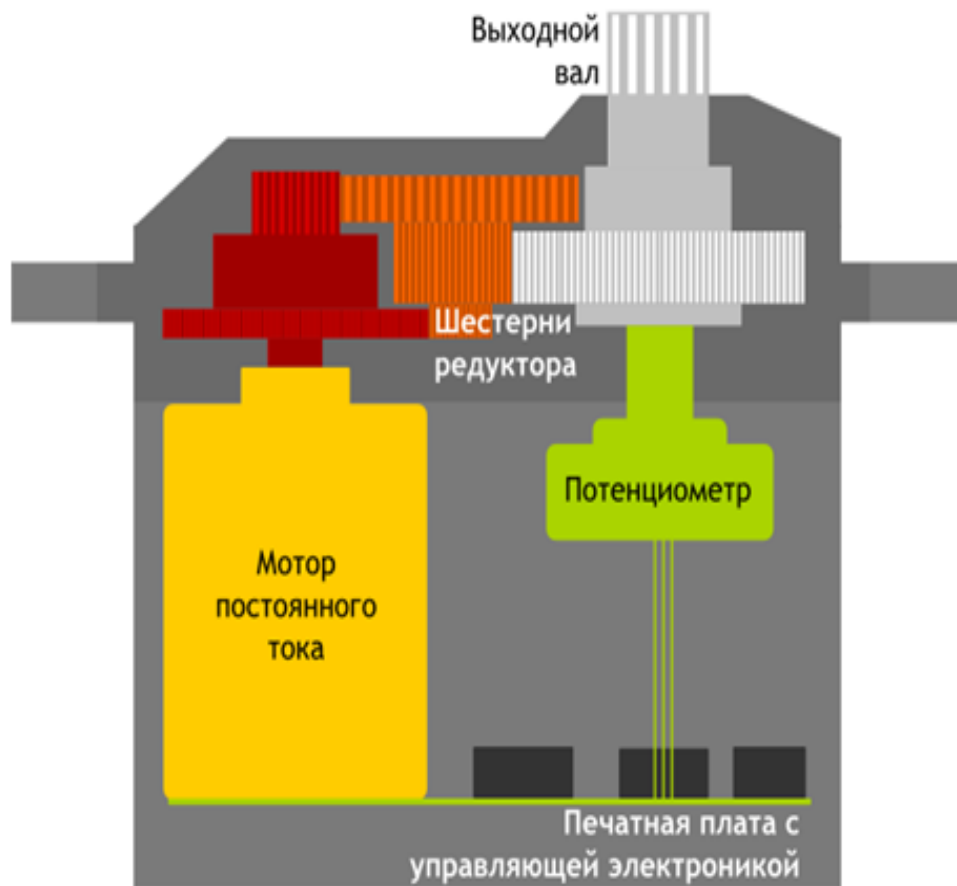


Figure 3.9 - General structure of the servo

Turning the electric motor on and off, you can rotate the output shaft - the final gear of the servo, to which you can attach something that we want to control. However, in order for the position to be controlled by the device, a feedback sensor is required - an encoder that will convert the angle of rotation back into an electrical signal. A potentiometer is often used for this purpose. When the potentiometer slider is rotated, its resistance changes in proportion to the angle of rotation. In this way, it can be used to set the current position of the mechanism.

In addition to the electric motor, gearbox and potentiometer, the servo has an electronic charge that receives an external parameter, reads the values from the potentiometer, compares and turns the motor on and off. It is responsible for maintaining negative feedback.

To indicate the desired position of the servo, the control signal must be sent along the line provided for this purpose. The control signal is a constant frequency and variable width pulse.

The position of the servo depends on the pulse length. When the signal enters the control loop, the pulse generator generates its own pulse, the duration of which is determined by the potentiometer. Another part of the diagram compares the duration of two pulses. If the duration is different, the engine is switched on. The direction of rotation determines which of the pulses is shorter. If the pulse length is the same, the motor stops.

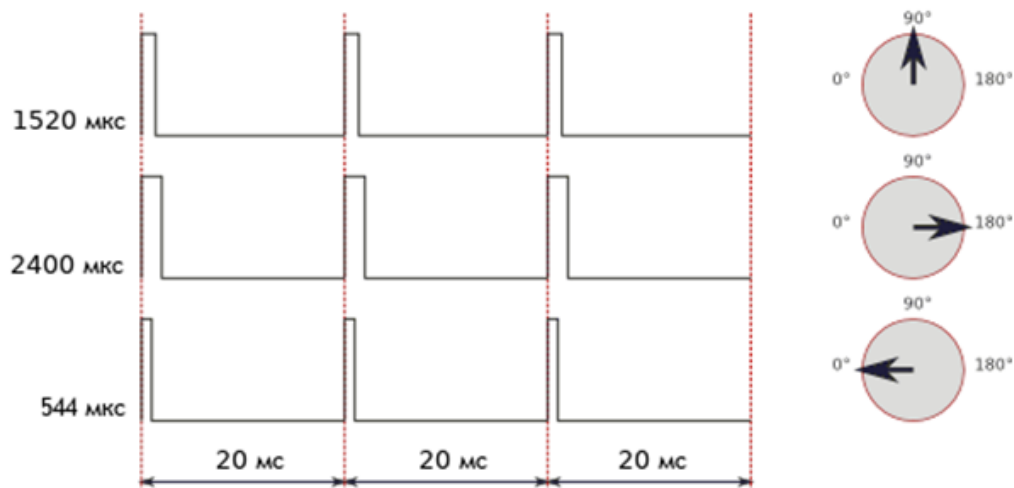


Figure 3.10 - Constant frequency and variable width pulses

Most often, in servos, pulses are produced at a frequency of 50 Hz. This means that the pulse is emitted and received once every 20 MS. This usually means that the servo should take the middle position. Increase or decrease the pulse length. In this case, there are upper and lower bounds on the pulse duration. In the Servo library for Arduino, the following pulse lengths are set by default: 544 MS for 0° and 2400 MS for 180°.

Please note that your device's factory settings may differ from the standard settings. Some servos use a pulse duration of 760 MS. In this case, the average position is 760 MS, as with conventional servos, the average position is 1520 MS.

It is also worth noting that these are just standard lengths. Even within the same servo model, production errors may occur that result in a slightly different operating range of pulse lengths. For accurate operation, each particular servo must be calibrated: experiments force you to choose the correct range of characteristics for it.

What else is worth paying attention to is the confusion in terminology. Often the method of controlling servos is called PWM / PWM (Pulse Width Modulation) or PPM (Pulse Position Modulation). This is not the case, and using these methods may even damage the drive. The correct term is PDM (Pulse Duration Modulation). In it, the length of the pulses is extremely important and the frequency of their occurrence is not so important. 50 Hz is the norm, but the servo will work correctly at both 40 and 60 Hz. The only thing to keep in mind is that with a strong decrease in frequency, it can work in jerks and at low power, and with a strong overestimation of frequency (for example, 100 Hz), it can overheat and fail.

The moment of force or torque is the value of a physical vector corresponding to the product of the vector of the radius drawn from the axis of rotation to the point of application of the force, on the vector of this force. It characterizes the rotational effect of a force on a solid.

Simply put, this characteristic shows how heavy a load the servo is able to hold at rest on a lever of a given length. If the torque of the servo is equal to  $5 \text{ kg} \times \text{cm}$ , it means that the servo will hold a lever of 1 cm length in a horizontal position, on the free end of which 5 kg is suspended. Or, equivalently, a lever of 5 cm length, to which 1 kg was suspended.

The speed of the servo is measured by the time interval it takes for the servo arm to rotate  $60^\circ$ . The  $0.1 \text{ s}/60^\circ$  characteristic means that the servo turns  $60^\circ$  in 0.1 s. From this, it is easy to calculate the speed in the usual value of revolutions per minute, but it happens that this block is used most often in the description of servos. It's worth noting that sometimes you have to compromise between these two functions, because if we need a reliable high-performance servo, we have to be prepared for this powerful setup to spin slowly. And if we want to go very fast, it is relatively easy to leave the balance position. If you are using the same engine balance determines the configuration of the transmission in the powertrain.

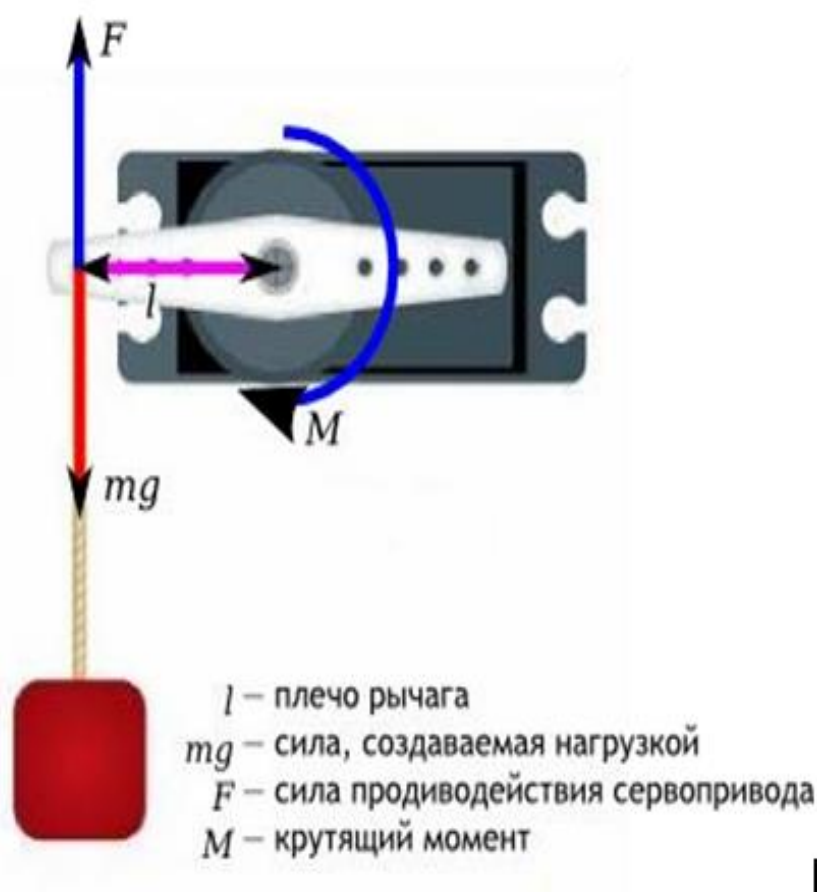


Figure 3.11 - Example the rotational action of a force on a solid

The MG995 was used as the main load-bearing servos of the shoulder, forearm, and base. The appearance is shown in figure 45, and the technical characteristics are shown in table 100.

The MG995 servo is shown in figure 3.12, and its characteristics are shown in table 3.3.

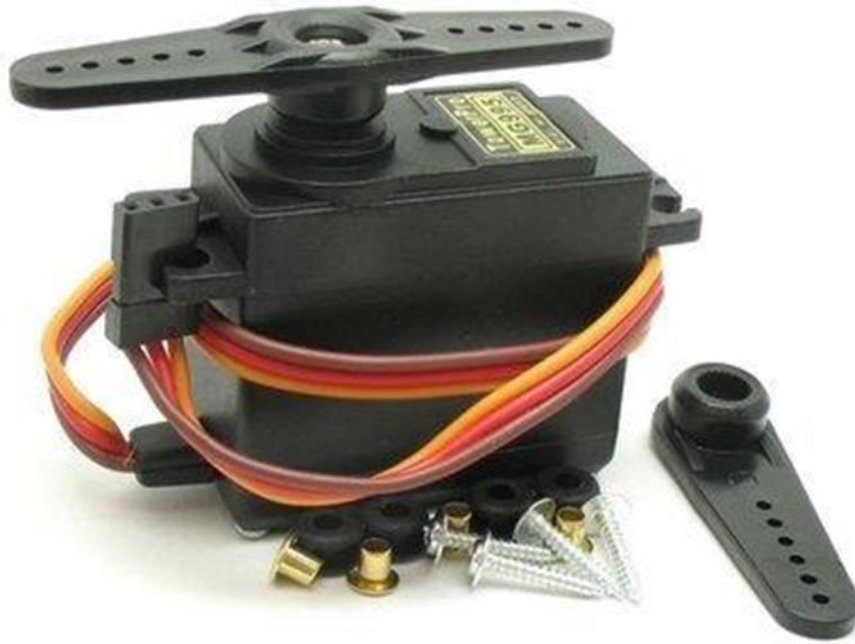


Figure 3.12 - MG995 servo drive

Table 3.3 - Characteristics of the MG995 servo

Parameter	Value
Weight	55 g.
Sizes	40.7 x 19.7 x 42.9 mm
The time of retention	:8.5 kgs*cm (4.8 V), 10 kgs*cm (6 V)
Rate	0.2 s / 60° (4.8 V), 0.16 s/60° (6 V)
Voltage	4.8-7.2 V
Operating range	0°-90° (pulses 1-2 ms respectively)
Dead band	5 mks

To organize the movement of the prototype effector, it was decided to use MG90S. The effector itself does not need to have a high compression force for a given prototype design, so this servo should be sufficient. The appearance is shown in figure 3.13, and the technical characteristics are shown in table 3.4.

Table 3.4 - Characteristics of the MG90S servo

Parameter	Value
Weight	38 g.
Sizes	22.8 x 12.2 x 28.5 mm
The time of retention	:1.8 kgs*cm (4.8 V), 2.2 kgs*cm (6 V)
Rate	0.1 s / 60° (4.8 V), 0.08 s/60° (6 V)
Voltage	4.8-6 V
Operating range	0°-90° (pulses 1-2 ms respectively)
Dead band	5 mks



Figure 3.13 - MG90S Servo

### **3.5 Working prototype of the prosthesis**

In figure 3.14, we can see the connection diagram of the servos to the Arduino. All servos are included in a separate circuit with a 5V power supply and a rated current of 2A. In the diagram below, the earth (GND) is indicated in black. Power cables are red. Signal cables are yellow. The Arduino receives power via a USB connection.

## 4 Life safety

The employee can be exposed to various dangers in the process of labor activity, both due to the danger of the production process and the type of work, and the unsatisfactory microclimate of the premises in which this work is carried out. One of the microclimate violations is insufficient lighting of the workplace.

The main information about the world around us (up to 90%) comes through the visual analyzer (a sensitive device), consisting of the eyes, optic nerves, and the visual center located in the occipital lobe of the cortex. Information is received and analyzed in the light range of 380-760 nm of electromagnetic wave lengths.

For the visual analyzer, the diversity of the surrounding world is represented by various objects, objects characterized by the size, brightness, contrast of the object with the background and distance from the eyes. There is therefore a relationship between the illuminance of the object, the nature of the visual work (size of object of distinction, the contrast of object of distinction with the background characteristics of the background) and the functional state of the visual analyzer.

Performing visual work with insufficient illumination of the workplace can lead to the development of certain eye defects: false and true myopia; true farsightedness and senile MZH.

The following requirements apply to industrial lighting regardless of the light source:

- sufficient illumination, i.e. the illumination of the object should provide comfortable conditions for overall performance;
- uniformity of lighting, i.e. illumination should be uniform in time and space;
- lack of brilliance in the field of view of workers.

Consider the characteristics of lighting.

Luminous flux – the power of light energy, estimated by the light sensation experienced by the eye. The unit of measurement of light flux is lumen (LM). The amount of light flux is not only physical, but also physiological.

Illumination – the surface density of the luminous flux; the unit of illumination-Lux (LX). This is the illumination of one square meter of the surface when a light flux of one lumen falls on it.

Light intensity – the spatial density of the light flux within the solid angle, steradian. The unit of light intensity is the Candela (and CD).

Brightness – the surface density of the light intensity in a given direction, which is determined from the ratio of the light intensity of the radiated surface in that direction to the projection of the luminous surface on the plane.

The reflection coefficient  $p$  characterizes the ability of a surface to reflect the light flux incident on it. If  $p < 0.2$  – the background is considered dark; if  $0.2 < p < 0.4$  – medium; if  $p > 0.4$  – light.

The contrast of an object with the background  $K$  is determined from the ratio  $p$  of the brightness of the object under consideration and the background.

The contrast of an object with the background is considered small, if  $K < 0.2$ , medium - at  $0.2 < K < 0.5$ , and large at  $K > 0.5$ .

Visibility – the ability of the human eye to distinguish an object. It depends on the illumination, size of the object, its brightness, contrast of the object with the background, mobility, and distance to the object. The visibility of the  $l$  is estimated by the number of threshold contrasts contained in the actual contrast.

Brilliance is the property of lighting devices or luminous surfaces in an unfavorable relationship between their brightness, light intensity and the brightness of the surrounding space to violate the conditions of comfortable vision, or to worsen contrast sensitivity, or to have both of these actions simultaneously. If areas of high brightness emit light, they have a direct brilliance, if they are created by the reflection of light-emitting elements from other surfaces of the field of view, they have a reflected brilliance.

The blindness index is a criterion for evaluating the blinding effect of a light source.

The illumination ripple coefficient is a criterion for evaluating changes in surface illumination due to periodic changes in the light flux of a light source over time. The need for the indicator “ripple coefficient” is caused by the widespread use of gas-discharge lamps. When they are fed with alternating current, there is a pulsation in time of the value of the light flux of these sources with a frequency twice the frequency of the current in the network.

Insufficient lighting of the workplace makes it difficult to perform work, causes fatigue, and increases the risk of industrial injuries. A long stay in conditions of insufficient lighting is accompanied by a decrease in the intensity of metabolism in the body, a weakening of its reactivity, which contributes to the development of myopia. The same consequences are caused by working with a limited spectral composition of light and monotonous lighting mode. Excessively bright light blinds, reduces visual functions, leads to overexcitation of the nervous system, and reduces performance.

Three types of lighting are used: natural, artificial, and combined (a combination of natural and artificial light).

Natural lighting, created by natural light sources (direct sunlight, diffuse light of the sky), is the most biologically valuable type of lighting, to which the human eye is maximally adapted.

In this work we'll consider the calculation of artificial lighting in a room.

#### **4.1 Analysis of working conditions**

This production room for visual work tasks, according to the SNiP, belongs to the first group (the room in which the objects of visual work are distinguished with a fixed direction of the line of vision of the working objects on the surface). The type of work performed belongs to medium-precision visual works with low and medium contrast of the object being distinguished from the background.

Figure 4.1 shows the layout of the room where the dispatcher will work.



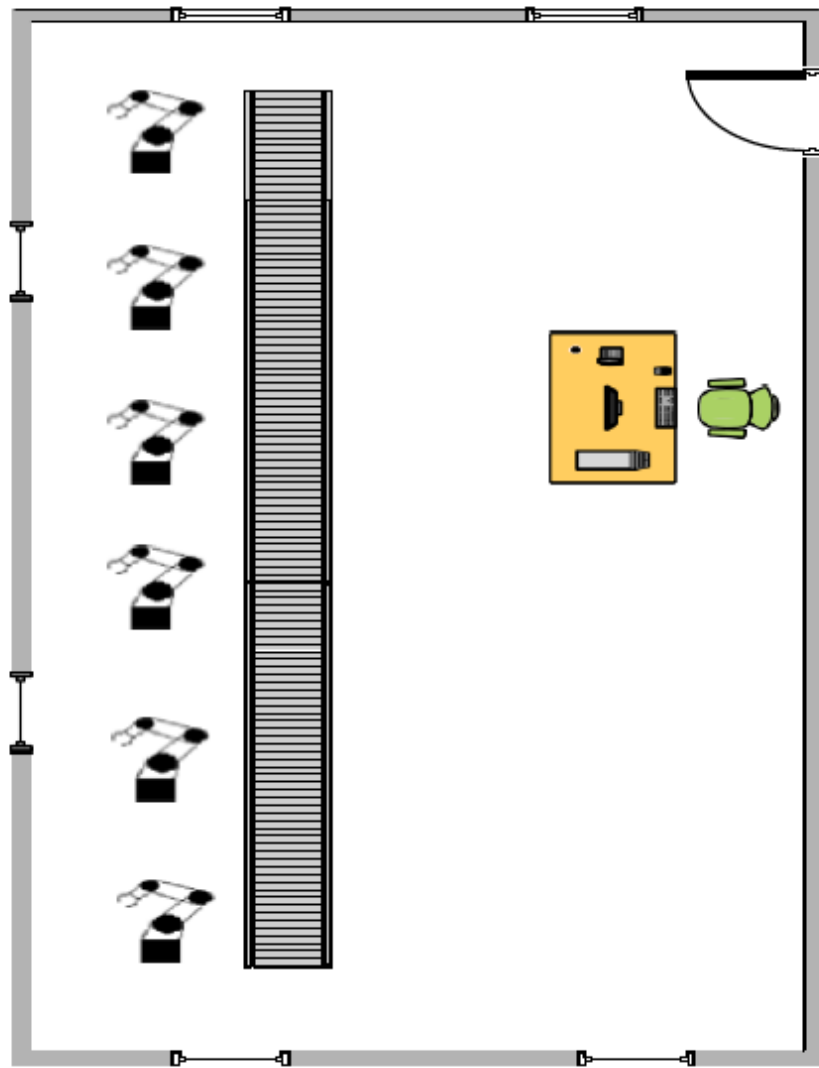


Figure 4.1 - Floor plan

At the control room 1 person works, for work it is necessary to have a computer on which the software will work.

The workplace is located closer to the windows to provide more natural light to the work area. Artificial lighting is also used in the room.

As follows from the plan of the room, the length of the room is 12 m, width – 6 m, height – 5 m. The height of the conditional working surface (table) is 0.75 m, the height from the floor to the window is 1.1 m, the height of the window openings is 160 cm, and the width of the window is 550 cm. The windows are double-hung.

#### **4.2 Calculation of artificial lighting**

To ensure the conditions necessary for visual comfort, the following prerequisites must be implemented in the lighting system:

- 1) uniform lighting;
- 2) optimal brightness;
- 3) no glare;

- 4) corresponding to the contrast;
- 5) correct color scheme;
- 6) no stroboscopic effect or flickering light.

Types of artificial lighting are: general, when lighting devices are placed in such a way as to provide sufficient illumination in the work area, and combined, when in addition to general lighting, local lighting fixtures are installed to create higher levels of illumination in workplaces where intense visual work is performed. It is forbidden to use only local lighting in the premises.

The main task of this subsection is to determine the number of lamps and their location in the room. To calculate artificial lighting, the method of the light flux utilization coefficient was chosen.

Using this method, the calculation of illumination on a horizontal surface is calculated taking into account the light flux that falls from the lamps directly on the surface and the reflected light from the walls of the ceiling and the surface itself. This method is used for rooms with light ceilings and walls, since the main role is played by the reflection of light.

When calculating the coefficient of use method the required luminous flux of lamps in each lamp  $\Phi$  is determined by the formula:

$$\Phi = \frac{E_n \cdot S \cdot Z \cdot K_3}{N \cdot \eta}, \quad (4.1)$$

where  $E_n$  - the minimum normalized illumination, 200 Lux (when the discharge of visual work V r);

$S$  - illuminated area, 72 m<sup>2</sup>(12x6);

$K_3$  - reserve coefficient, which takes into account the contamination of lamps, 1.4 (reference value);

$Z$  - coefficient of uneven lighting, 1.1 (reference value);

$N$  - the number of lamps;

$\eta$  - the coefficient of use of the light flux of lamps, depending on the efficiency and light distribution curve of the lamp, the coefficient of reflection of the ceiling  $\rho_{\text{ПОТ}}$ , floor  $\rho_{\text{ПОЛ}}$  and walls  $\rho_{\text{СТЕН}}$ , the height of the suspension of lamps in the room  $i$ .

Luminescent lamps of the LB-40 type were selected for lighting, the characteristics of which can be seen in table 4.1.

Table 4.1 - Characteristics of the LB-40 fluorescent lamp

Lamp type	Power, W	Voltage, V	Lamp current, A	Luminous flux, LM	The length of the lamp, mm	The diameter of the lamp, mm
LB-40	40	103	0.43	3000	1213	40

The two-lamp LB-40 was chosen as a lamp, which can be seen in figure 4.2.

The utilization factor of a lighting system is the ratio of the light flux falling on the work surface to the light flux emitted by the source.

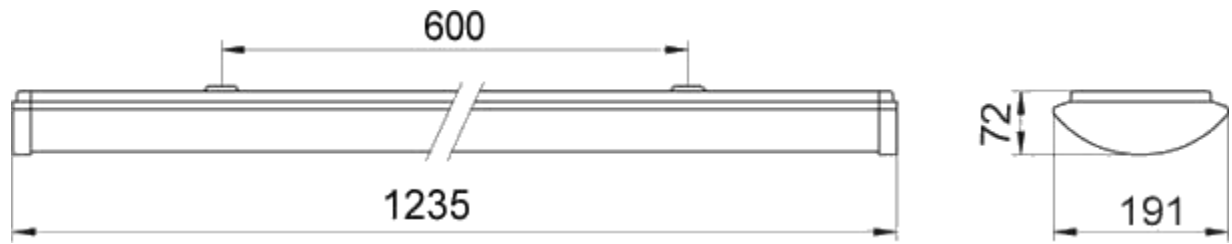


Figure 4.2 - Two-lamp fluorescent lamp LPO 46 2x36

The coefficient of use depends on the type of lamp, the geometric dimensions of the room and the reflection coefficients of surfaces.

To determine the utilization rate, you must determine the room index:

$$i = \frac{A \cdot B}{H \cdot (A + B)}, \quad (4.2)$$

where A and B - are the length and width of the room;

$h$  - is the height of suspension of fixtures.

$$h = H - h_{\text{pn}} - h_{\text{cl}}, \quad (4.3)$$

where  $h$  - is the suspension height, m;

$h_{\text{pn}}$  - height of working surfaces, m;

$h_{\text{cl}}$  - lamp overhang height, m;

$H$  - room height, m.

The height of the working surface is 0.8 m, the height of the lamp overhang is zero, and the height of the room, as indicated above, is 5 m.

$$h = 5 - 0.75 - 0 = 4.25 \text{ (m)},$$

$$i = \frac{12 \cdot 6}{4.25 \cdot (12 + 6)} = 0.94.$$

In addition, it is necessary to evaluate the reflection coefficients of the room ceiling  $\rho_{\text{пот}}$ , floor  $\rho_{\text{пол}}$  and walls  $\rho_{\text{стен}}$ , in order to determine the coefficient of light flux utilization of lamps. In this case  $\rho_{\text{пот}} = 70\%$ ,  $\rho_{\text{пол}} = 50\%$ ,  $\rho_{\text{стен}} = 10\%$ . For the lamp LPO46 2x36, belonging to 1 group of lamps with the room index  $i = 0.94$ , the coefficient of use of the light flux of lamps is equal to  $\eta = 0.45$ .

Now we'll determine the number of lamps and fixtures in the room using the formula (4.1):

$$N_{\text{л}} = \frac{300 \cdot 72 \cdot 1.4 \cdot 1.1}{3000 \cdot 0.45} = 24.64.$$

The number of lamps is determined by the formula:

$$N_c = \frac{N_{\text{л}}}{n}, \quad (4.4)$$

$$N_c = 24/2 = 12.$$

After we find the number of lamps in the room, we'll determine the total power consumption of the lighting system:

$$P = P_{\text{л}} * P_{\text{л}}, \quad (4.5)$$

where P - is the total power consumption, W;

P - power of one lamp, 40 W.

$$P = 40 * 24 = 960 \text{ (W)}.$$

After we'll having calculated the number of necessary lamps, we can determine the validity of our calculations, using the formula (4.1) we get the actual illumination:

$$\Phi_{\text{расч}} = \frac{300 * 72 * 1,4 * 1,1}{24 * 0,45} = 3080 \text{ lm.}$$

Determine the deviation of the  $\Phi_{\text{л}}$  from the acceptable value using the formula:

$$D = (\Phi_{\text{л}} - \Phi_{\text{расч}}) / \Phi_{\text{расч}} * 100\%, \quad (4.6)$$

$$D = (3000 - 3080) / 3080 * 100\% = -2.597 \text{ \%}.$$

A deviation from -10% to +20% is allowed, which means that the calculated luminous flux has an acceptable value.

Next, consider the placement of lamps in the room and determine the favorable distance between them [17].

$$L = \lambda * h, \quad (4.7)$$

where L - is the distance between adjacent lamps or rows of fluorescent lamps;

h - height of the lamp suspension above the work surface;

$\lambda = 1.3-1.5$  (When using fluorescent lamps).

$$L = 1.5 * 4.25 = 6.375 \text{ (m)}.$$

Luminaires with fluorescent lamps are recommended to be installed in rows parallel to the long side of the room or the wall with Windows. Between the lamps and their rows 6.375 m. The location of the lamps is shown in figure 4.3 [15].

### 4.3 Calculation of natural lighting of the workplace

Natural light can vary very widely depending on the time of day, year, geographical location, meteorological factors, cloud cover and reflecting properties of the earth's surface. To reduce the influence of these random factors in the evaluation of the natural lighting adopted – the daylight factor (KEO), which is expressed as a percentage of natural light at some point in a given plane inside the

$E_B$  and the simultaneous value of external horizontal illuminance  $E_H$ , created by the light is the open sky:

$$KEO = \frac{E_B}{E_H} * 100, \quad (4.8)$$

where KEO - is the coefficient of natural light;

$E_B$  - illumination in the nutria of the room, LC;

$E_H$  - illumination outside the room, LC.

In our case, the KEO must be at least 2%. The source of natural light in the rooms of the traction substation will be window openings in the side walls of the substation building. Therefore, the calculation task is to determine the size, shape and location of light openings that provide lighting conditions not lower than 50 standard. The required area of the light openings with side lighting, which provides a normalized value of KEO.

$$S_0 = [(e_N \cdot k_3 \cdot \eta_0 \cdot S_{\Pi}) / (100 \cdot \tau_0 \cdot r_1)] \cdot k_{3A}, \quad (4.9)$$

where,  $S_0$  – the area of light openings in side lighting,  $m^2$ ;

$S_{\Pi}$  – floor area of the room,  $m^2$ ;

$e_N$  – normalized value of Keo, %;

$k_{3A}$  – factor of safety;

$\eta_0$  - light characteristic of the window;

$\tau_0$  - total light transmission coefficient;

$k_{3A}$  - coefficient that takes into account the shading of Windows by neighboring buildings;

$r_1$  - coefficient that takes into account the increase in KEO in side lighting due to light reflected from the surfaces of the room and the underlying layer adjacent to the building.

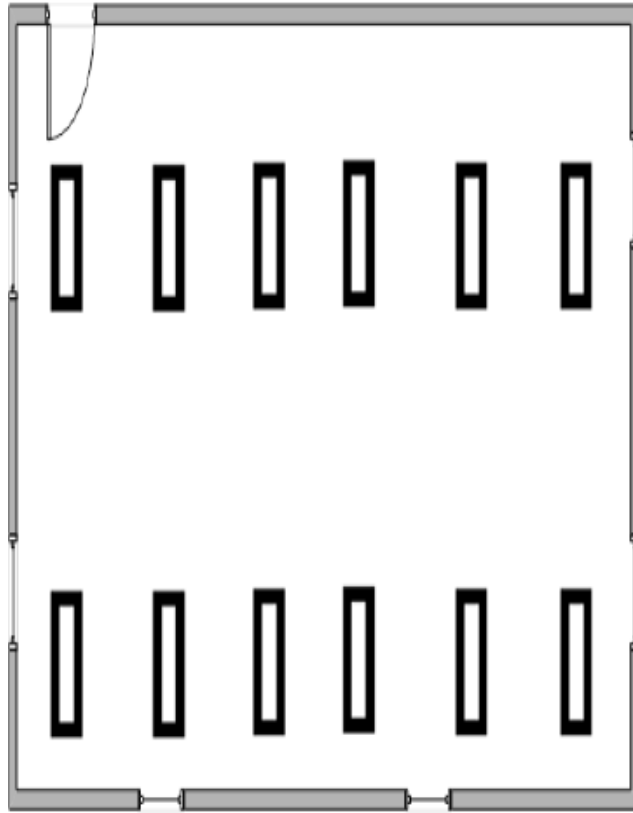


Figure 4.3 - Location of lamps

The normalized KEO value is determined by the formula:

$$e_N = m_H * m, \quad (4.10)$$

where,  $e_N$  - is the normalized KEO value, %;

$m_H$  - coefficient that takes into account the light climate of the administrative region.

The total light transmission coefficient is determined by the formula:

$$\tau_0 = \tau_1 \cdot \tau_2 \cdot \tau_3 \cdot \tau_4 \cdot \tau_5, \quad (4.11)$$

where,  $\tau_1$  - is the light transmission coefficient of the material;

$\tau_2$  - coefficient that takes into account the loss of light in the binding of the light opening;

$\tau_3$  - coefficient that takes into account light losses in load-bearing structures;

$\tau_4$  - coefficient that takes into account the loss of light in sun protection devices;

$\tau_5$  - coefficient that takes into account the loss of light in the protective grid.

Substituting the values in the formula (4.11) we get:

$$\tau_0 = 0,8 \cdot 0,7 \cdot 1 \cdot 0,8 = 0,448.$$

Substituting the values in the formula (4.10) we get:

$$e_N = 1,5 \cdot 0,8 = 1,2 \, \%$$

Thus, the required area of light openings:

$$S_0 = (1,2 \cdot 1,6 \cdot 7,5 \cdot 24) / (100 \cdot 0,448 \cdot 1,2) = 6,428 \, m^2.$$

There are two windows in the side opening, so the area of each of them is  $3,214 \, m^2$ .

The window sizes are respectively  $2 \times 1,607 \, m$ . Therefore, the current position of the windows is quite suitable for the conditions of natural lighting.

#### **4.4 Conclusion on the part of life safety**

After making calculations, it was found that a large number of factors affect the normal illumination, which include: the color of the walls, flooring, the width of window openings, the position of the workplace, etc.

After performing a number of calculations, it was found that the required number of lamps for optimal illumination of a room with an area of  $72 \, m^2$  is 12 lamps (2 rows of 6 lamps). The optimal number of lamps creates a comfortable working environment for engineers.

It was also determined that the existing number and position of windows suits the results of natural lighting calculations. The window sizes are respectively  $2 \times 1,607 \, m$ . Therefore, the current position of the windows is quite suitable for the conditions of natural lighting.



## 5 Technical and economic part

The general aim is to purchase the necessary equipment for the assembly of the prosthesis, as well as to create a software product that is responsible for managing the mechanism.

The program is written on Arduino. The Arduino programming language is based on C/C++. It is easy to understand and use, and currently Arduino is the most suitable way to program devices on microcontrollers.

Arduino is a small board with its own processor and memory. The board has a couple of dozen contacts that connect to all sorts of components, ranging from light bulbs to routers. You can connect any components that run on electricity to the Board.

A program is loaded into the Arduino processor that controls devices and components connected to the board using the program's algorithm.

### 5.1 Calculating the cost of developing a control scheme and software

The commercial cost of developing and debugging the control scheme and software  $C_{nc}$  is calculated according to formula 5.1:

$$C_{CD} = C_{MB} + C_{MT} + C_{other}, \quad (5.1)$$

where  $C_{CD}$  - commercial cost of development;

$C_{MB}$  - salary and social charges for developers control schemes;

$C_{MT}$  - the cost of materials;

$C_{other}$  - other expenses.

### 5.2. Calculation of salaries and social contributions for developers of the management scheme

The development of the control scheme requires the participation of four people: one project manager consultant, two electronic engineers and one software engineer.

The following payments are made to developers : project manager - 60,000 tenge / month; electronics engineer - 50,000 tenge/month; software engineer - 45,000 tenge / month . The management system development period is 6 months.

The formula 5.2 is used to calculate payroll costs:

$$C_{pc} = C_S * M_p * N, \quad (5.2)$$

where  $C_S$  - the salary of each specialist, Tg. / month.;

$M_p$  - term for developing the management scheme, months.

$N$  - number of employees engaged in development, people.

$$C_{pc} = 60000 * 6 + 50000 * 6 * 2 + 45000 * 6 = 1230000 \text{ tenge.}$$

$$C_{OH} = C_{pc} - CAP - MCI = 1230000 - 0,1 * 1230000 - 2778 * 6 * 4 = 1040328 \text{ tenge.}$$

The cost calculation for the "social contributions" item is calculated as 20% of the developer's salary costs:

$$C_{Soc} = 15 * MCI * 9,5\% + (C_{OH} - 15 * MCI) * 15\%, \quad (5.3)$$

where CAP - contributions to the accumulative pension fund;  
MCI - monthly calculation indicator.

$$C_{Soc} = 15 * 2778 * 0,095 * 4 * 6 + (1040328 - 15 * 2778) * 0,15 = 244806,3 \text{ tenge.}$$

### 5.2.1 Calculation of the commercial cost of software development and debugging (software)

The group of performers consists of three people: a team leader and two engineers. The following payments are set: manager - 55000 tenge/month; software engineer - 50000 tenge/month.

Directly involved in the development of programs is carried out according to the formulas 5.4-5.6:

$$C_A = K_A * T, \quad (5.4)$$

where  $K_A$  - the average tariff rate of the organization's specialist engaged in software development, Tg. /person.days;

$T$  - complexity of software development, people.days.

$$K_A = \frac{F_S}{N * F_{PB}}, \quad (5.5)$$

where  $F_S$  - salary fund of the organization engaged in software development for the previous year, tenge;

$N$  - the average number of organizations engaged in software development over the past year, people;

$F_{PB}$  - fund of working time of one employee of the organization engaged in software development for the previous year, days.

$$F_S = Salary * N * M, \quad (5.6)$$

where *Salary* - the salary of one employee, tenge/ month;

$M$  - number of months in the year.

Substituting the required values in expressions 5.4-5.6, we get:

$$F_S = 55000 * 12 + 2 * 50000 * 12 = 1860000 \text{ tenge,}$$

$$K_A = \frac{1860000}{3 * 260} = 2384,62 \text{ tg./person.day.}$$

To calculate the complexity of software development, the coefficients shown in table 5.1 are required.

Table 5.1 - Coefficients required for calculations

№	The name of the coefficient	Value of coefficient
1	The coefficient of novelty, $K_H$	1,00
2	Difficulty coefficient, $K_{cl}$	0,27
3	Coefficient of use of PS W, $K_T$	1,00
4	Coefficient that takes into account the programming language, $K_{lan}$	0,50

Labor costs for software development are summarized in table 5.2. They are determined depending on the volume of software (thousands of conditional machine commands), taking into account the complexity of the software being developed. The total volume of software being developed is determined by the sum of the volumes of all functions.

Table 5.2 - Determination of labor intensity

№	The name of the laboriousness	Formula	The value of laboriousness, people days.
1	Labor costs for the development of PS, $T_p$ (0,2489 - automation coefficient)	$V_{\Phi} * 0,2489 * K_{lan}$	541,36
2	Total laboriousness, $T_0$	$K_{cl} * T_p$	146,17
3	The laboriousness of the stage «Technical task», $T_1$	$0,05 * K_H * T_0$	7,31
4	The laboriousness of the stage «Preliminary design», $T_2$	$0,09 * K_H * T_0$	13,16
5	The laboriousness of the stage «Technical project», $T_3$	$0,06 * K_H * T_0$	8,77
6	The laboriousness of the stage «Worker project», $T_4$	$0,60 * K_T * K_H * T_0$	87,7
7	The laboriousness of the stage «Implementation», $T_5$	$0,20 * K_H * T_0$	29,23
8	The complexity of developing a PS BT, T	$T_1 + T_2 + T_3 + T_4 + T_5$	146,17

The cost of wages  $C_3$  in accordance with the values of the tariff rate and the complexity of software development is:

$$C_A = 146,17 * 2384,62 = 348560 \text{ tenge.}$$

The calculation of expenses under the item "Social contributions" is as follows:

$$C_{soc} = (348560 - 34856 - 1092 * 3) * 0,2 = 62085,6 \text{ tenge.}$$

#### 5.2.2 Cost of the element base

This type of expense includes expenses necessary for the purchase of technical required materials, paper for circuit design and software. In addition, this item of expenditure includes the cost of purchasing and preparing materials for special scientific and technical information, as well as the cost of purchasing special educational literature. The cost of the element base is shown in table 5.3.

#### 5.2.3 Costs of the installation and debugging

Two people are required for installation and debugging: for mounting the printed circuit Board and mounting the entire system. The worker's monthly salary is 35,000 tenge. The system installation and debugging period is 15 days. The calculation of payroll expenses  $C_{am}$  is calculated as follows:

$$C_{am} = \frac{SAL_M}{D_M} * D_p, \quad (5.7)$$

where  $SAL_M$  - monthly salary;

$D_M$  - number of working days per month;

$D_p$  - the number of days required for installation and debugging.

$$C_{am} = \frac{35000 * 2}{22} * 15 = 47727 \text{ tenge.}$$

Expenses under the item "Social contributions" are as follows:

$$C_{soc} = (47727 - 4772,7 - 1092 * 2) * 0,2 = 8154 \text{ tenge.}$$

#### 5.2.4 Calculation of «Other expenses»

To debug the program, we need to calculate the cost of one machine hour. The calculation of machine time costs is based on the expression:

$$C_M = K_M * S_M, \quad (5.8)$$

where  $K_M$  - the tariff cost of one hour of machine time, taken at the planned cost of an hour of machine time in an organization engaged in software development;

$S_M$  - used machine time for software development, hour (1056 hours);

The cost of one machine hour is based on the formula:

$$K_M = \frac{F_S + C_{cpc} + C_A + C_{PEM} + C_{EVM}}{F_{year}}, \quad (5.9)$$

where  $F_S$  - salary aund of the organization that develops software;

$C_{EVM}$  - the cost of electricity consumed by the PC, Tg. / year;

$C_{cpc}$  - the cost of PC repair. Tg./year;

$C_A$  - depreciation per PC, Tg. / year;

$F_{year}$  - annual fund of computer working time, hour (2080\*3).

Electricity costs are calculated as follows:

$$C_{EVM} = W_{PC} * P_{EH} * F_{year}, \quad (5.10)$$

where  $W_{PC}$  – the power of the PC, 0,73 kW/h;

$P_{EH}$  - the cost of electricity.

$$C_{EVM} = 0,73 * 17,8 * 6240 = 81082,56 \text{ Tg./ year}$$

The cost of PC repair is 9500 tenge / year.

Depreciation is calculated according to the depreciation rate for PCs per year, respectively:  $H_A = 12,5\%$

$$C_A = H_A * C_{PC} = 0,125 * 90000 * 3 = 33750 \text{ tenge / year.}$$

where  $C_{PC}$  - is the cost of all PCs used in software development and debugging.

When substituting the above values, the cost per machine hour will be:

$$K_M = \frac{1860000 + 237394 + 33750 + 9500 + 81082,56}{6240} = 356,05 \text{ tenge / year}$$

The cost of machine time will be according to 5.8:

$$C_M = 356,05 * 1056 = 375984,5 \text{ tenge}$$

The calculation of expenses under the item "Overhead" is made as 1.5% of the salary of the developers of the management scheme:

$$C_H = 0,015 * 1230000 = 18450 \text{ tenge}$$

Accordingly other expenses are:

$$C_{other} = C_M + C_H = 375984,5 + 18450 = 394434,5 \text{ tenge}$$

### 5.2.5 Commercial cost of the project

According to expression 5.1 all components of the project cost are summarized in table 5.3

Table 5.4 – Estimated cost of the development to control the prosthesis

№	Name of cost items	Amount, tenge
1	Salary of an electronic engineer	1230000
2	Deductions for social needs of an electronic engineer	171275
3	Salary of a software engineer	348560
4	Deductions for social needs of software engineer	62086
5	Materials	129380
6	Other expenses	394435
TOTAL:		2326922

### 5.3 Cost effectiveness of upper limb prosthesis

As a result of calculations carried out in section 5.2, the commercial cost of developing and manufacturing a robot control system was obtained, equal to 2248804.8 tenge. This section discusses the strengths and weaknesses of the work being done. It is determined that in comparison with the known control methods, the method presented in this paper has a number of advantages. In operation, the device, which can be developed based on the method presented in the work, is convenient and practical, allows you to perform actions that are not available to competitors, namely: to perform active actions with each finger of the brush. This feature of work is very important for people who still have the activity of the forearm muscles. This method does not require the introduction of electrodes in the human body, which is also a huge advantage.



## **Conclusion**

This work consists of five main parts. The first and second parts are theoretical. The first part is devoted to a brief overview of the history of prosthetics, their types, classification and management systems. The second overview section describes the main approaches to image recognition.

This degree project includes research and development of upper limb prostheses. Aesthetic prostheses and bionic prostheses were considered, as well as their characteristics. The program is written in the C++ programming language.

In the third part, the choice of the test manipulator design is justified, and a three-dimensional model is developed in the SolidWorks graphic design environment.

In the section "Life safety", its main concepts were considered and studied, as well as calculations were made that are not related to the diploma project, in particular, the installation of artificial lighting, which is necessary for the safety and normal operation of the operator.

In the fifth part of the project was performed economic calculation of capital investment, profits, expenses, wages, total cost and price of the product, profitability of production, the economic efficiency and the payback period of the project.

Based on the results of this work, we can conclude that the use of 3D printing in the field of prosthetics can significantly reduce the cost of manufacturing a prosthesis, as well as the ability to modify the model for each patient individually, without any difficulties. The Arduino microprocessor Board has a wide range of functionality that allows you to experiment with various elements when prototyping devices.

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