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«As a manuscript»

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Diploma thesis

for a bachelor's degree

under the educational and professional program "Medical Engineering"

specialty 163 "Biomedical engineering"

on the topic: " Algorithm for the use of thermograms in ophthalmology "

Completed:
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I certify that in this master's dissertation there are no borrowings from the works of other authors without appropriate references.
Student ________
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Kyiv – 2025

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«КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ
імені ІГОРЯ СІКОРСЬКОГО»
ФАКУЛЬТЕТ БІОМЕДИЧНОЇ ІНЖЕНЕРІЇ
(повна назва інституту/факультету)

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на здобуття ступеня бакалавра
за освітньо-професійною програмою «Медична інженерія»
спеціальності 163 «Біомедична інженерія»
на тему : «Алгоритм застосування термограм в офтальмології»

Виконав:
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Засвідчую, що у цій магістерській дисертації немає запозичень з праць інших авторів без відповідних посилань.
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“IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE”

FACULTY OF BIOMEDICAL ENGINEERING
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Level of education Level 6 (bachelor), QF-EHEA
Specialty 163 «Biomedical engineering»
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«Admission to the defense»
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“ _14___ ” ___04______2025

TASK
For student`s bachelor thesis

Абдалгадер Моханед Сайфеліслам Мохамед
(Full Name)

1. topic Algorithm for the use of thermograms in ophthalmology

scientific supervisor of the dissertation Head of the department of Biomedical Engineering, Doctor of Technical Science, Assoc. prof. Vladyslav SHLYKOV
(last name, first name, patronymic, academic degree, academic title)

approved by the order of the university № 35/25-si from 27.05.2025

2. The deadline for students to submit a dissertation 13.06.2025
3. The object of research is the temperature field over the entire area of the two eyes and in the area of the eyeball around the pupils.
4. The subjects of the study is the values of the absolute temperature difference, which are a diagnostic criterion for diagnosing vision in the proposed diagnostic method.
5. List of tasks to be carried out: The study to using two thermal imagers and data taken from 9 people with different visual conditions. The development of special program in MatLab to process thermograms. The comparison of the results obtained by FLIR and processed in MATLAB and FLIR QuickReport for the typical shape of the temperature field over the entire area of the two eyes and in the area of the eyeball around the pupils. The development of the temperature index, which in the "temperature equilibrium" to indicates the absence of pathology in the area of the eye.
6. Approximate list of graphic material 30 table, 26 figures

7. Approximate list of publications: there is not
8. Final deadline 19.06.2025

SCHEDULE

№ з/п	Name of stages of execution diploma thesis	Deadline for stages diploma thesis	Note
1	Receiving a task for bachelor thesis	14.04.2025	Done
2	Analysis of literature and analogues	21.04.2025	Done
3	Development of an analysis algorithm of thermoframs	28.04.2025	Done
4	Writing program code in MatLab 2014a	12.05.2025	Done
5	GUI development	26.05.2025	Done
6	Plotting tables and graphs with results	02.06.2025	Done
7	Writing a thesis report	09.05.2025	Done

Student ______ (signature) Mohaned Saifelislam Mohamed Abdalgader (initials, surname)

Supervisor of the dissertation ______ (signature) Vladyslav SHLYKOV (initials, surname)

ABSTRACT

Diploma thesis “Algorithm for the use of thermograms in ophthalmology”, Department of Biomedical Engineering, the National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, 2025.

In the process of work, an analysis algorithm of patterns of speckle-interference was developed, and a program for analysis of correlation dependences of speckle pattern for the normal and pathological conditions objects.in MATLAB 2014a environment.

In this paper, a new method of vision diagnostics to using thermography was considered and investigated. It is shown that the analysis of thermal processes allows to obtain a variety of information about the state of the object of study and the course of physical processes in the area of the eyeball around the pupils.

A study was conducted using two thermal imagers and data taken from 9 people with different visual conditions, and a special program was created in MatLab to process thermograms. The results were confirmed by the real values obtained by other existing diagnostic methods used in medicine today.

The results of the study showed that the comparison of the results obtained by FLIR and processed in MatLab and FLIR QuickReport shows their coincidence, which is reflected in the typical shape of the temperature field over the entire area of the two eyes and in the area of the eyeball around the pupils, as well as in the values of the absolute temperature difference.

This shows that the methods of IR image processing performed by MatLab can be used to analyse thermograms.

Processing of the temperature relief allows detecting "temperature equilibrium areas" in which the temperature difference between the average temperature in the area and the average temperature of the entire profile can vary from 0.016°C to 0.027°C. To assess the presence or absence of pathology in the eye area, the temperature index is proposed, which in the "temperature equilibrium" areas has a value of 0.3 and 0.9. It is assumed that if the index value does not exceed 0.55, this indicates the absence of pathology in the area of the eye under study.

РЕФЕРАТ

Дипломна робота «Алгоритм застосування термограм в офтальмології», кафедра біомедичної інженерії, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, 2025 р.

У роботі розглянуто та досліджено новий метод діагностики зору за допомогою термографії. Показано, що аналіз теплових процесів дозволяє отримати різноманітну інформацію про стан об'єкта дослідження та перебіг фізичних процесів в області очного яблука навколо зіниць.

Дослідження було проведено з використанням двох тепловізорів та даних, взятих від 9 осіб з різними зоровими умовами, а також створено спеціальну програму в MatLab для обробки термограм. Результати були підтверджені реальними значеннями, отриманими іншими існуючими діагностичними методами, що використовуються сьогодні в медицині.

Результати дослідження показали, що порівняння результатів, отриманих за допомогою FLIR та оброблених у MatLab та FLIR QuickReport, показує їх збіг, що відображається в типовій формі температурного поля по всій площі двох очей та в області очного яблука навколо зіниць, а також у значеннях абсолютної різниці температур.

Це показує, що методи обробки ІЧ-зображень, виконані MatLab, можуть бути використані для аналізу термограм.

Обробка температурного рельєфу дозволяє виявити «області температурної рівноваги», в яких різниця температур між середньою температурою в області та середньою температурою всього профілю може змінюватися від 0,016°C до 0,027°C. Для оцінки наявності або відсутності патології в області ока запропоновано температурний індекс, який в областях «температурної рівноваги» має значення 0,3 та 0,9. Вважається, що якщо значення індексу не перевищує 0,55, це свідчить про відсутність патології в досліджуваній області ока.

TABLE OF CONTENTS

INTRODUCTION

The thesis was written at the Department of Biomedical Engineering, Faculty of Biomedical Engineering, National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”.

Thermography is based on the simple principle of temperature change. A diseased organ has a different temperature. It is the thermograph that measures the temperature of the organs. The temperature difference between normal and diseased tissue is very important.

Thermography is an infrared analysis system. Infrared waves are an extension of the visible range from the red spectrum, so they are called infrared.

Thermography provides a huge amount of information that is processed using specialized and then printed in the form of a color image. The color images of the temperature relief are interpreted by a doctor specializing in thermography.

The purpose of the thesis is to develop an algorithm for using eye thermograms as a diagnostic criterion, in particular, a new method of diagnosing vision - using thermography - is considered and investigated. A special program was created in the MatLab environment for processing thermograms. The results of the work are confirmed by the obtained shape of the temperature field over the entire area of the two eyes and in the area of the eyeball around the pupils, as well as in the values of the absolute temperature difference, which is a diagnostic criterion for diagnosing vision in the proposed diagnostic method.

This thesis uses the method of thermography to obtain thermograms of human eyes. A methodology for determining pathology by the temperature relief of the thermogram is proposed, which allows using them to obtain data on the state of vision.

LIST OF ABBREVIATIONS, SYMBOLS AND TERMS

IR	– infrared radiation;
IRT	– infrared thermography;
TIS	– thermal imaging systems;
Software	– software programs;
PC	– personal computer;
TD	– thermal imaging diagnostics;
BO	– Biological object is a biological object.

1 OVERVIEW OF THERMAL RESEARCH METHODS IN MEDICINE

1.1 Selection of the system under study

The analysis of thermal processes allows obtaining various information about the state of the object of study and the course of physical processes in many areas of human activity.

Thermograms of the human body contain the most valuable information, i.e., the temperature distribution over its surface.

Infrared, or thermal radiation, occurs as a result of the excitation of particles of matter containing electric charges (atoms, molecules, ions, etc.). It occupies a special place among other types of radiation due to its property of being in equilibrium with the internal energy of the radiating body.

Electromagnetic radiation propagates throughout the body, reaches the surface and, having passed through the skin, is partially transmitted to the environment. The intensity of these processes is proportional to the body temperature and, therefore, to its emissivity.

Visualized temperature fields provide information about the state of peripheral blood flow and the underlying processes in the body.

The IMT method has been tested and is used in the following areas of medical diagnostics:

1) Oncology (tumors of the mammary glands, thyroid gland, lymph nodes, bones, etc.)

2) Neurology (pathology of the peripheral nerves of the extremities, neurological syndromes of osteochondrosis of various parts of the spine).

3) Angiology (various diseases of the main arteries and veins of the extremities).

4) Traumatology and orthopedics (scoliosis, spinal fractures, arthrosis of large joints, early diagnosis of the depth of burn damage, etc.)

5) General surgery (acute inflammatory pathology of the abdominal cavity, especially in children).

6) Reconstructive and restorative surgery (diagnostics of the viability of transplanted and reimplanted segments and grafts).

7) Arthrology (diseases of large and small joints of the extremities of various genesis).

8) Otolaryngology (inflammatory diseases of the paranasal sinuses).

9) Endocrinology (thyroid diseases, vascular and neurological complications of diabetes mellitus).

Thus, the current level of development of thermal imaging technology makes it possible to reliably diagnose a wide range of diseases (up to 150 different forms), which is the reason for the active introduction of the IRT method into world clinical practice along with other modern methods available in the arsenal of doctors.

1.2 Brief historical background

The use of thermal radiation in biomedicine for research and diagnostic purposes is relevant due to the high informational content of the method itself and the complete safety of its application for the object of research.

It is officially believed that thermal radiation (heat rays) was discovered in 1800 by the English physicist and astronomer William Herschel, who gave it the name "infrared radiation" (IR), i.e. radiation that lies beyond the red limit of the visible spectrum. The lower boundary of IR radiation starts at 0.78 microns, and the upper boundary is adjacent to the microwave region (about 1 mm). In 1840, the first so-called "thermal picture" was obtained, which was called a "thermogram", which is still used today in modern terminology.

This method was first implemented in clinical practice by a Canadian surgeon, Dr. R. Lawson, in 1956. He used a military night vision device for the early diagnosis of malignant breast tumors in women, which marked the beginning of medical thermography. The probability of detecting this pathology, especially at an early stage, was then about 60-70%, which justified the cost-effectiveness of thermal imaging in mass examinations.

Since the discovery of infrared radiation, scientists have conducted a large number of studies on its nature from the human surface and the use of these features to diagnose various pathologies.

In Ukraine, the first thermography studies were performed by Professor A.I. Pozmogov in the 70s of the last century, at the Kyiv Research X-ray Radiology Institute of the Academy of Medical Sciences of Ukraine, using a Raduga type cooled thermograph.

However, despite a large number of monographs, articles and other publications in the field of medical thermography, this method has not yet taken its rightful place in practical medicine alongside existing methods of functional diagnostics, and for Ukraine, this completely non-invasive method is more exotic than real.

Even though thermal imaging diagnostic methods are available in medical protocols, the usefulness of infrared thermography (IRT) for biomedical applications has not yet been fully understood.

The general situation, according to many researchers, is to some extent related to the fact that thermographs of the first generations, due to their imperfections, slowed down the development and implementation of thermodiagnostics in clinical practice and caused a persistent rejection among doctors, which is still being overcome. The fact is that the first devices were bulky, had special operating conditions and practically lacked thermogram processing. All of this required additional knowledge of the staff and skills in interpreting thermal images. In addition, doctors (unfortunately, still do not fully understand the capabilities of modern thermography for medical tasks and the specifics of information obtained using thermal imaging to diagnose various pathologies, especially in the early stages of their manifestation and monitor the effectiveness of treatment.

Nowadays, due to the emergence of a new generation of thermographs with high temperature and spatial resolution, there is renewed interest in this non-invasive diagnostic method.

1.3 Main trends in the development of thermal imaging systems

The paper presents an overview analysis of the main trends in the development of thermal imaging systems (TIS) - in the English-language literature, IRIS, from infrared imaging systems – which showed that today, the most common are the new generation of matrix IR devices that use matrices of radiation receivers located in the focal plane of the optical system (FPA – focal plane arrays). The main advantages of these devices are: the absence of an optical-mechanical scanning system and, accordingly, low weight, dimensions and power consumption, quiet operation, high signal-to-noise ratio and image quality, as well as a wide dynamic range. There are two types of matrices: cooled and uncooled. Although the radiation receivers based on uncooled matrices are inferior in their limiting parameters to the radiation receivers requiring cooling, they have a number of characteristics that make them indispensable in a wide range of applications. That is why another name for such devices is popular in the English-language literature: uncooled focal plane array receivers (UFPA). The number of elements in such matrices can be from 256×256 and more, scanning is not used, temperature sensitivity reaches 0.01°C, and spatial resolution on the matrix is up to $3\text{-}10^{(-5)\ m}$. Such parameters provide an opportunity to take a fresh look at the processes in biomedicine related to both heat production and mobility of substances arising under the influence of local temperature gradients, as well as information processes of detection, recognition and classification.

Modern FPA matrices of the infrared range are made on the basis of various materials: lead chalcogenides (Pb, PbSe), HgCdTe, InSb, PtSi compounds, silicon (Si:x) and germanium (Ge:x) impurities, multilayer QWIP (quantum well infrared photodetector) structures on GaAs-GaAlAs compounds, microbolometers and pyroelectric radiation receivers.

Most modern devices for thermal imaging use FPA-matrix chips connected to an electronic circuit for reading signals from matrix detectors (ROIC - readout integrated circuits).

Today, the dimensions of individual elements of FPA receivers are approaching the theoretical limit due to the capabilities of optics (diffraction scattering). To create a ROIC element on an area corresponding to the size of one pixel of the matrix, the most advanced technological methods of multilevel circuits with submicron dimensions are used.

The theoretical foundations of thermal imaging technology are well developed and discussed in the scientific and technical literature.

The paper also analyses and compares the main characteristics of some modern TVSs based on cooled and uncooled radiation receivers.

To summarize the review of modern thermal imaging technology, we can say that the usefulness of thermal imaging diagnostics for medicine has been proven over the past decades and is confidently included in the list of modern diagnostic methods.

Interest in medical thermal imaging is growing in all developed countries. The leaders in the production of thermal imaging equipment are the United States, Japan, Sweden, Russia, and China.

1.4 Principles and techniques of infrared thermography

The principle of operation of a modern thermograph (equivalently called a thermal imager or thermal imaging camera) is based on the conversion of natural thermal radiation from research objects into a visible image (Fig. 1.1).

The thermal field signal from the object of study passes along the path: IR lens - 1, matrix of IR photodetectors - 2, preamplifiers - 4, multiplexer - 5, analog signal inhomogeneity corrector - 6, analog-to-digital converter - 7, digital signal inhomogeneity corrector - 8, corrector of non-working photodetectors of the matrix - 9, image formation unit with microprocessor processing - 10, clock generator - 11, video monitor - 12, output for connecting a personal computer (PC) - 14.

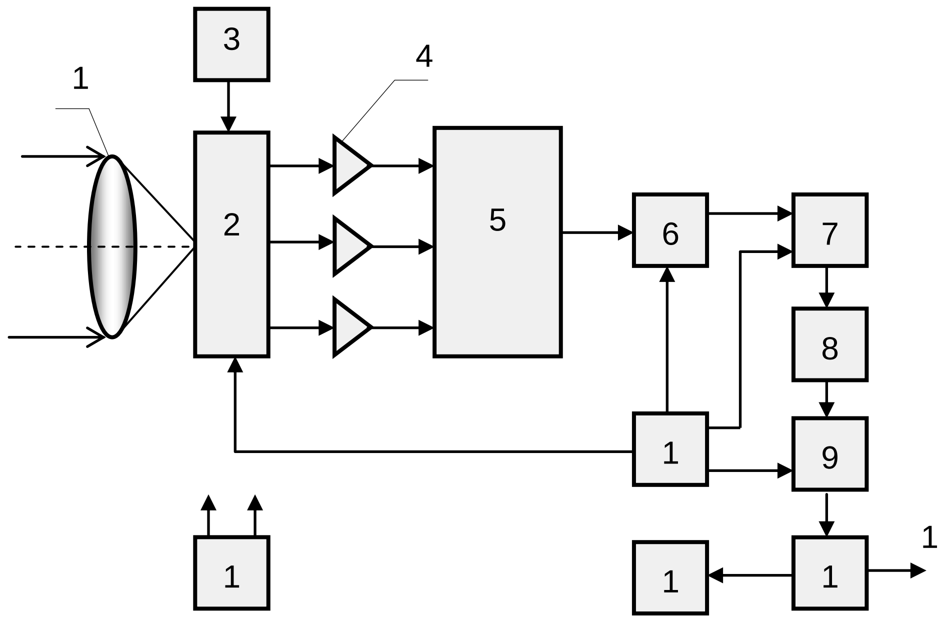


Figure 1.1 – Block diagram of a modern thermograph

The cooling or thermal stabilization unit (3) maintains the matrix in a stable functional state, and the power supply (13) provides the necessary voltages to all systems of the device. Signal in homogeneities of the matrix elementary photodetectors are pre-corrected in analog form, converted to digital form and corrected using the data obtained during the calibration process. At the output of the image forming unit (10), the information is provided either as a video signal supplied to a video monitor or in digital form for transfer to a personal computer.

The mathematical software of modern thermographs makes it possible to perform digital processing of IR images in real time, calculate thermal relief parameters, create databases of IR images and compare thermal images obtained at different times. This technology is developing rapidly and is used to localize thermal anomalies characterized by areas of the skin surface with low or high temperatures.

The physiological basis of thermography is the correlation between temperature and the functional state of the body - an increase in the intensity of infrared radiation over the pathological area (due to increased blood supply and metabolic processes in this area) or a decrease in its intensity in areas with reduced regional blood flow and accompanying changes in tissues and organs. In other words, inflammation leads to hyperthermia, while the decline in muscle activity and insufficient blood supply (perfusion) give a picture of hypothermia.

The presence of a pathological process is characterized by one of three qualitative thermography signs: the appearance of abnormal zones of hyper- or hypothermia, a change in the normal thermography of the vascular pattern, and the presence of a temperature gradient in the examined area.

Normally, the thermography picture is characterized by a symmetrical pattern about the center line. The difference between the symmetrical sides normally does not exceed 0.2-0.4°C. But each person has an individual temperature distribution.

The knowledge and experience gained in the field of medical thermography allow us to assert that a person's thermal production (his or her thermal portrait) can provide the researcher with a lot of valuable information about the functioning of various body systems.

1.5 Methodology for thermal imaging diagnostics

The diagnostic value of the results of thermal imaging studies largely depends on the precise implementation of the methodology for conducting thermal imaging diagnostics (thermography). If simple requirements for conducting research are not met, a large percentage of false results arise, which often leads to sceptical conclusions about this method. Due to the fact that thermal imaging examination consists in registering the temperature distribution over the patient's body surface, the main requirements are imposed on the temperature regime of the room (thermography room) where the examination is performed.

The room should be kept at a constant temperature in the range of 20-25°C. This temperature is optimal for humans, i.e. the difference between the ambient temperature and the average temperature of human skin should be within 10-15°C. When examining in a warmer room, the contrast of thermograms decreases, and at air temperatures above 30°C, it becomes almost impossible to conduct thermal imaging studies. In such a room, human thermoregulatory mechanisms (such as sweating) are activated, and therefore, the thermal imaging picture can change dramatically.

When conducting an examination in a cold room, a person cools down, redistribution of skin blood flow and muscle tremors occur. These factors can also greatly change the thermal imaging picture (thermogram), which leads to diagnostic errors. In addition, the thermography room, or the room where the examination is performed, should be free of extraneous sources of infrared radiation, such as electric heaters, incandescent lamps, etc. and cold air flows (drafts). Direct sunlight also greatly affects the quality of the thermograms obtained, so the windows in the room should be covered with curtains.

Another important factor in obtaining objective results of thermal imaging examination is the patient's adaptation to the examination conditions. Holding a certain time before conducting thermal imaging examinations is necessary in order to establish certain stable temperature relations between the patient's body and the surrounding air (Fig. 1.2).

This time also depends on the functional characteristics of the patient. For example, children under the age of 10 need less adaptation time, while elderly patients adapt more slowly to the room temperature and should have their adaptation time extended.

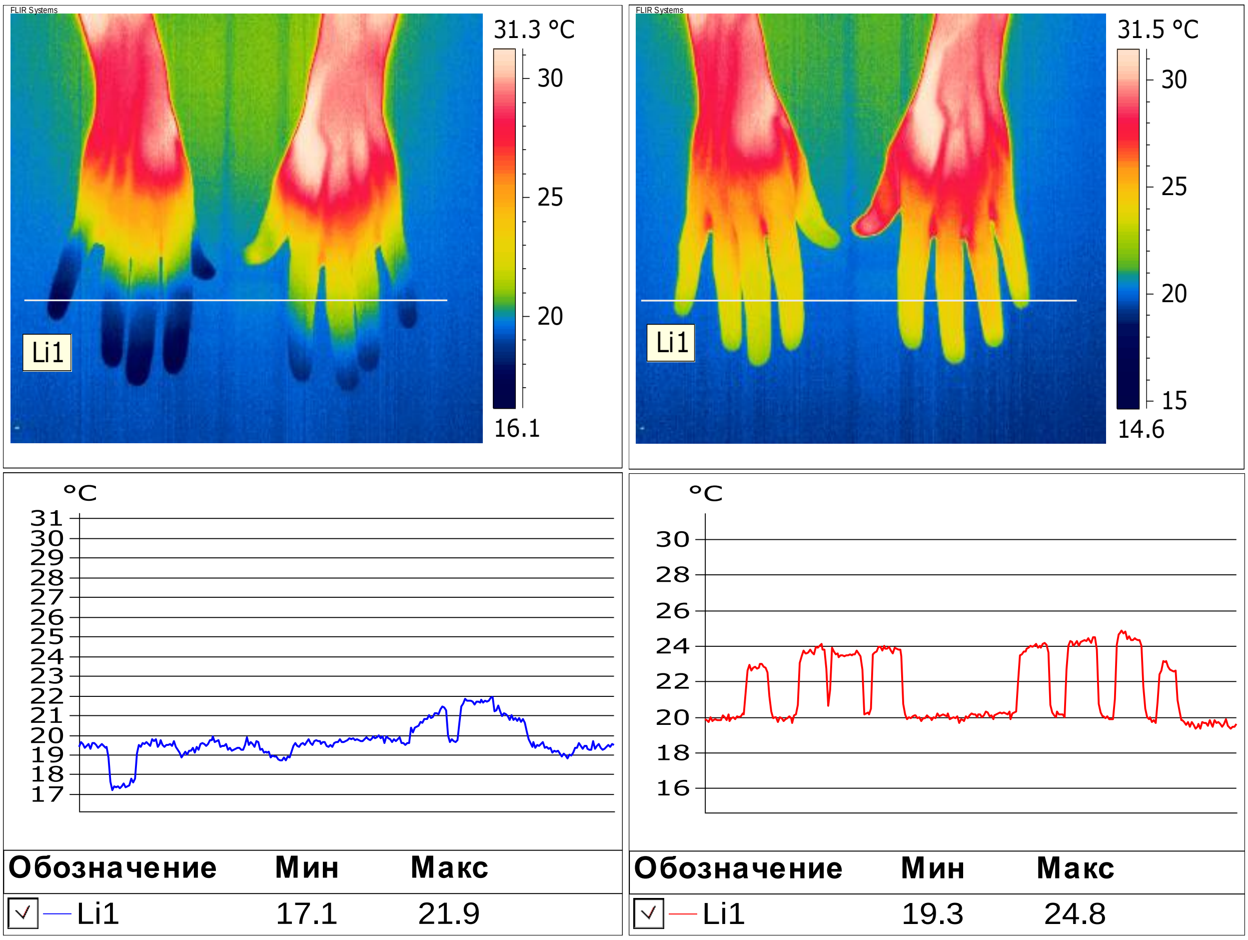


Figure 1.2 – Thermograms and corresponding thermo-sections of the extremities: a - impaired blood flow during cooling, b - recovery at room temperature for 15 minutes

When examining patients outdoors, in the cold season, it is necessary to take into account the biphasic dynamics of skin vascular reactions of exposed areas of the body. In the first 3-4 minutes, during the transition from cold to warmth, the skin vessels dilate, so the thermal image of the face and hands will be bright and homogeneous. Then comes the phase of vasoconstriction, which is why hyperthermic spots (patterns) are detected on thermograms. The duration of the second phase strongly depends on the individual characteristics of the patient and on average it lasts 15-30 minutes. Naturally, in such cases, the duration of the adaptation period should be extended. An exemplary benchmark for the end of the second phase of vasomotor reactions is the detection of persistent homogeneous hypothermia of the nose and cheeks, as well as the stabilization of the temperature gradient between the center of the palm and the middle of the hypothermic pad.

When the skin is cooled, its blood supply changes, and since healthy and pathologically altered tissues react differently to cooling, this leads to an increase in contrast and information content of thermal imaging examinations.

1.6 Requirements to the conditions of thermography studies of biological objects

Based on the above, when analysing human thermal fields, in order to exclude artifacts, it is necessary to take into account the influence of the environment or external factors that can significantly change the temperature of the body and, accordingly, the thermal picture of the studied areas, it is very important to know the conditions under which thermography studies are carried out.

In order to formulate the requirements for thermography research, as well as the procedure for such research, the paper analyses the temperature of a person as a biological object in a confined space and in the open air in order to expand the requirements for the conditions of thermography research.

A typical view of a human thermal portrait is shown in Fig. 1.3.

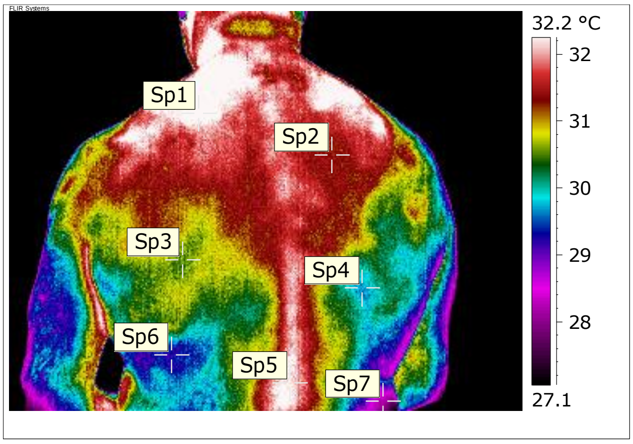


Figure 1.3 – Fragment of a human thermal portrait

The temperature values at the marked points correspond to: Sp1 - 32.6°C; Sp2 - 31.5°C; Sp3 - 30.5°C; Sp4 - 29.8°C; Sp5 - 32.1°C; Sp6 - 29.1°C; Sp7 - 28.2°C. The lowest temperature is recorded in the legs - in the foot area (about 29°C), and a relatively high temperature (about 36.5°C) in the eye sockets. That is, in areas of exposed body surface, the temperature difference can reach 6-7°C.

As a result of the analysis of the factors influencing the results of thermography, requirements were formulated for the room where thermography studies are conducted, as well as for the procedure for such studies:

1) The control of temperature distribution on the body surface should be carried out in the range of comfortable temperatures, when the difference between the temperature of the object of study T_0 and the environment T_{ns} is constant. The selected "reference point" for the temperature scale can be, for example, the temperature of the eye socket near the bridge of the nose, which is relatively stable in the normal state and has a value of T_0= 36.5°C.

The comfortable air temperature T_{ns} in a room at normal pressure and humidity in the absence of forced ventilation for a naked person is about 22-24°C. Due to the seasonal adaptation of the body, the temperature is 1°C lower in winter, i.e., T_{ns} = 22-23°C, and higher in summer, i.e., T_{ns} = 23-24°C.

2) The patient should undergo adaptation in a room with a temperature close to the temperature of the thermography room before the examination. The time required to establish the skin temperature corresponding to the room temperature is individual. It depends on factors such as metabolic rate, skin fat, state of the blood vessel system and other physiological parameters, as well as the degree of cooling before the examination, especially in winter.

From the balance of the amount of heat transferred through the skin per unit time and the amount of heat produced inside the body, it is possible to estimate the amount of time for body tissue heating τ to the temperature T_0:

$$\tau = \frac{c\rho l^2}{\lambda}, \tag{1.1}$$

where c – is the weight specific heat capacity of the skin;

ρ – is the specific gravity of the skin;

l – skin thickness, including the fat layer;

λ – is the thermal conductivity.

The parameters included in formula (1.1) (some of which depend on temperature) vary within the following limits: c = (2-4)-10^{-3}kJ-g^{-1}deg K^{-1}, ρ = 1.02-10^{3}kg-m^{-3}, λ = (0.2-2)kJ-$m^{-1}h^{-1}$deg K^{-1}, l = (5-10)-10^{-3} m. The order of estimation is important, since the exact quantitative assessment of τ does not make much sense due to the significant individuality of these parameters for each research object.

Substituting the above values into formula (1.1), we obtain the measurement limits of τ from 3 to 30 minutes. Since the heating process has an exponential dependence, the adaptation time is estimated to be 3τ, i.e., from 9 to 90 minutes. Experiments show that in order to avoid errors in thermography studies, on average, at least 30-40 minutes should be spent on temperature adaptation of a patient at an outdoor temperature below -5°C.

3) The position of the patient in front of the thermograph lens should also be taken into account. Measurement results for a lying patient and a standing patient will differ. The first reason is related to the different redistribution of blood inside the body in different body positions. The second is due to the fact that the human body is a humid object with a higher temperature, so there is always weak air convection in the room around the patient. The average value of the measurement spread can reach 10%.

4) To avoid thermal interference from the equipment, as well as to exclude transient convection processes of air movement, the area of the office should be at least 15 m2 and there should be no directional heating and lighting devices. The walls should have a heat-absorbing coating.

5) When conducting thermography studies, it is also desirable to take into account fluctuations in the patient's temperature, which can be maximum 37.0-37.1°C at 16-18 hours and minimum 36.2-36.0°C at 3-4 hours in the morning. During physical work, training and sports competitions, body temperature may increase by 1-2°C or more. Changes in the physiological state of the body and nervous excitement also affect body temperature. In elderly people, body temperature can drop to 35-36°C.

6) It is desirable to have the ability to change the air heating and cooling mode inside the thermography room. In our opinion, a room in the form of a thermal booth would be optimal, where it would be possible to change the above modes, for example, with the help of air conditioning, which additionally makes it possible to maintain a certain humidity.

The cost of the appropriate equipment, compared to the cost of a thermograph, does not increase the cost of equipping the room by much, but meeting these requirements significantly expands the research and diagnostic applications of thermal imaging.

1.7 Study of the causes of changes in the local surface temperature of biological objects

For a better understanding of the capabilities of infrared thermography and its place in biomedical research, diagnostic and treatment processes, both developers of thermal imaging equipment and practical users need knowledge and a clear understanding of the normal and pathological causes of changes in local body temperature.

Many pathological processes change the normal temperature distribution on the body surface, and these changes are more pronounced the closer the pathological area is to the surface. In many cases, local temperature changes are ahead of other clinical manifestations, which is very important for early diagnosis and timely treatment.

The analysis of literature sources makes it possible to determine the causes of increase and decrease in the local temperature of the surface of the BW.

The main reasons for the increase in local temperature:

- inflammation, in which there is a local dilation of the vessels of the microcirculatory bed and increased metabolic processes;
- malignant tumors, which also activate metabolic processes. Local thermodiagnostics is especially effective for malignant tumors of the skin and breast;
- impaired venous outflow and venous stasis;

- irritation of the spinal roots and peripheral nerves. In this case, the temperature rise is observed in the area of their innervation;

- increase the metabolic rate of various organs.

The main reasons for the decrease in local temperature:

- disorders of arterial blood supply (atherosclerotic lesions of the arteries, thrombosis, etc.);

- Reduced microcirculation (microangiopathies of various genesis, impaired autonomic regulation of vascular tone);

- decreased metabolism of various organs due to age or pathological conditions;

- degenerative processes with the replacement of functionally active tissue with connective tissue;

- pronounced dysfunction of the spinal roots and peripheral nerves (in the respective areas of innervation).

The main factor affecting local temperature is the level of microcirculation, so when studying thermoanomalous zones on the surface of the skin, along with knowledge of normal and pathological causes of changes in local body temperature, a clear understanding of the distribution of internal temperature is necessary, which makes it possible not only to assess the biomedical capabilities of the method, but also to correctly interpret the thermal picture, which is important when monitoring the functional state of the body in vivo.

Knowledge about the causes of changes in local temperature opens up new opportunities for scientific research in biomedicine and more efficient work of doctors of almost all specialties.

1.8 Analysis of thermographs of different ranges for medical research

The analytical review and capabilities of modern thermographs in terms of obtaining reliable diagnostic information are discussed above and presented in this paper.

Since we used thermographs of two spectral ranges for our research, and with different radiation receivers (with and without cooling), it is necessary to analyse the thermograms obtained in different ranges of the infrared spectrum in order to assess the capabilities of these diagnostic tools.

Cooled thermographs are several times more expensive than uncooled thermographs. Their price, ceteris paribus, depends on the cost of manufacturing the IR matrix and its thermal stabilization device, which is also a deterrent to the introduction of IRT methods into clinical practice. In addition, thermographs in the range of 3-5 microns with cooling are more sensitive to external sources of thermal radiation, which is associated with a better match of their spectral sensitivity with the radiation spectra of electric lighting and heating devices. For thermographs in the range of 8-14 microns, the influence of such sources is insignificant.

In this paper, the authors quantified the accuracy of temperature measurement in different parts of the human body using two thermographs of different ranges. It is shown that for all thermographs (regardless of their structure), at each point of the human body, the measured and own (true) temperatures will be related by the following linear relationship:

$$T_{vim} = \varepsilon \cdot T_c + (1-\varepsilon) \cdot T_{ns} \ , \qquad (1.2)$$

where T_{vim} – is the measured temperature of the skin area;

ε – is the emissivity of the skin;

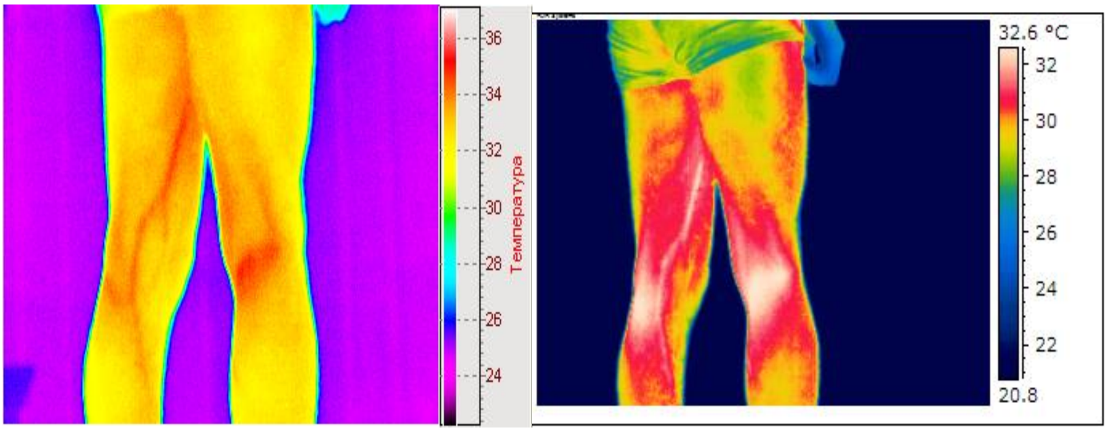
T_c – is the intrinsic temperature of a given skin area;

T_{ns} – ambient temperature (temperature in the thermography room).

After taking into account the corrections, the thermal portraits of patients in the 3-5 and 8-12 microns ranges are almost the same.

Taking into account the above, as well as our own experience in similar studies, we conducted a comparative qualitative analysis of thermograms obtained using thermographs of two spectral ranges (3-5 and 8-14 microns) with and without cooling. First of all, we were interested in various vascular pathologies, as the most typical example in thermal imaging diagnostics.

Figure 1.4 shows a thermogram of the same patient with signs of vascular pathology of the veins of the lower extremities in two spectral ranges.



а б

Figure 1.4 – Thermograms for comparison were taken in different ranges: a - in the range of 3-5 microns, b - in the range of 8-14 microns

Visually, there is practically no difference, and it is safe to say that uncooled and, accordingly, cheaper thermographs can also be successfully used in the primary diagnosis of various pathological conditions of a person on a par with cooled ones.

As a result, we can outline the areas of application of modern thermal imaging for medical tasks (Fig. 1.5).

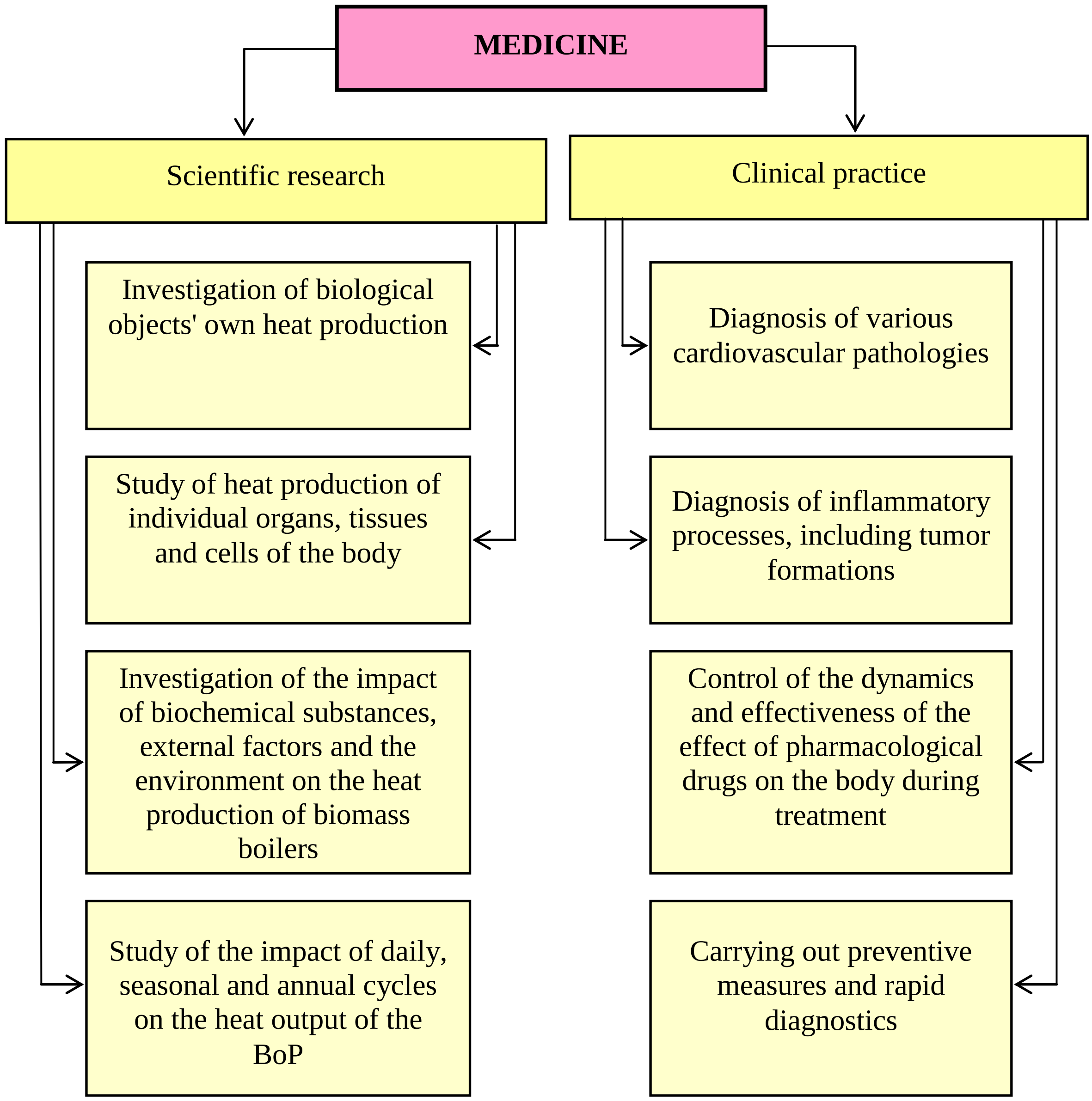


Figure 1.5 – Using modern thermal imaging for medical applications

Conclusions to Section 1

The use of thermal radiation in biomedicine for research and diagnostic purposes is relevant due to the high information content of the method itself and the complete safety of its application for the object of research. The most valuable information is contained in the thermograms of the human body, i.e., the temperature distribution over its surface.

In Ukraine, the first thermography studies were performed by Professor A.I. Pozmogov in the 70s of the last century. However, despite the large number of monographs, articles and other publications in the field of medical thermography, this method has not yet taken its rightful place in practical medicine along with the existing methods of functional diagnostics, and for Ukraine this completely non-invasive method is more exotic than real. That is why the method of thermal imaging diagnostics provides a wide field for its research and application.

2 DEVELOPMENT OF AN ALGORITHM FOR THE USE OF THERMOGRAMS IN OPHTHALMOLOGY

2.1 Initial data

The following tools were used for this work:

1) Fluke Ti9 thermal imager and Flir i7 thermal imager;

2) A personal computer with the FLIR QuickReport thermal imaging software;

3) Special software (MatLab 2010, Microsoft Excel 2007).

The main and general technical characteristics of the thermal imager used in the study are presented in Table 2.1 and Table 2.2.

Table 2.1 – Main technical characteristics of the Fluke Ti9 thermal imager

Temperature	Temperature range	From -20°C to +250°C
Image characteristics	Field of view	23° x 17°
	Minimum focusing distance	Thermal imager lens: 15cm
	Focusing	Manual
	The frequency of staff changes	Refresh rate 9Hz
	Type of radiation receiver	160x120 matrix in the focal plane
Saving images and measuring data	Drive	SD memory card (2 GB)
	File formats	Radiometric (.bmp) or (.is2)

Continuation of Table 2.1

1	2	3
	Export file formats using Smart View software	JPEG, BMP, GIF, PNG, TIFF, WMF, EXIF, EMF

Table 2.2 – General technical characteristics of the Fluke Ti9 thermal imager

Temperature	For measurements: From -10°C to +50°C; For storage -20°C to +50°C without battery
Relative humidity	10% to 90% without condensation
Display	VGA (640x480) color landscape LCD display with a diagonal size of 9.1 cm (3.6 inches) with backlight
Power supply	Battery: Built-in rechargeable battery pack (included). Battery life using a mains or car adapter / charger - 2 hours on a full charge
Operation/charging from the mains	Mains adapter/charger (110/220V, 50/60Hz)
Energy saving functions	Switching to standby mode after 5 minutes of inactivity; automatic shutdown after 20 minutes of inactivity
Dimensions	0.27m x 0.13m x 0.15m
Weight	1.2 kg

The general view of the used thermal imagers "Fluke Ti9" and its kit and "Flir - i7" is shown in Figs. 2.1 - 2.3.

Figure 2.1 – Fluke Ti9 thermal imager

Figure 2.2 – Fluke Ti9 thermal imager kit

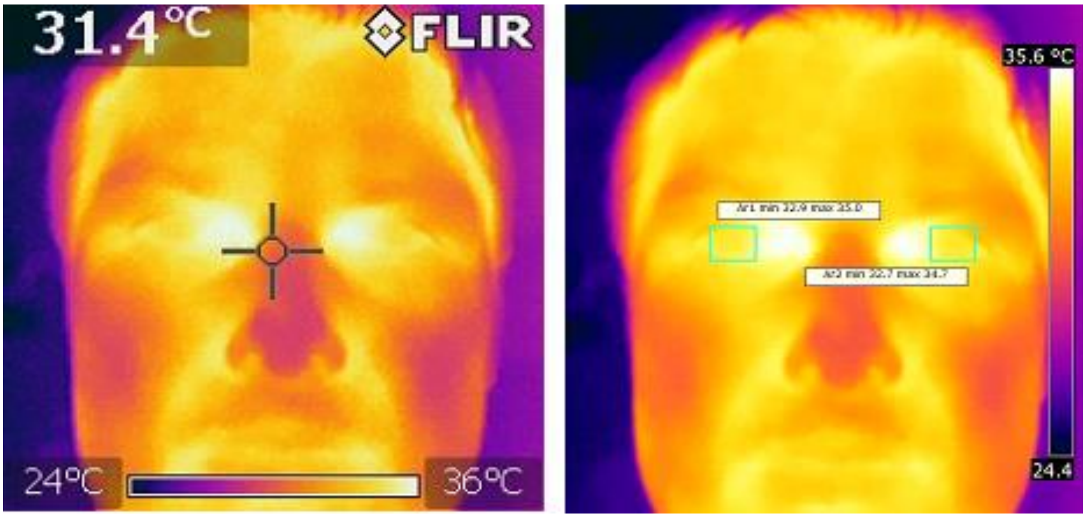
Figure 2.3 – Thermal imager "Flir - i7"

2.2 Conducting research and processing data

To enable the use of the thermography method in ophthalmology, a group of 9 people of different sexes and ages with different visual conditions was recruited to collect data. After obtaining thermal images, they were processed in the MatLab software environment. To do this, we created a special analysis program that plots the difference between the absolute values of the radiation intensity of the area (Appendix A). Using the obtained numerical values, we constructed diagrams of compliance with the state of vision.

The study involved two thermal imagers (Flir i7 and Fluke Ti9) and different software for data calculation. This approach made it possible to evaluate and compare the results of the experiment with greater and more accurate reliability. The Flir i7 thermal imager is much more expensive to use. The thermograms obtained from it were processed in the FLIR QuickReport program.

To assess the reliability of the results obtained the FLIR thermal imager, the calculations processed using the algorithm in MatLab and the specialized FLIR QuickReport software are compared. Thermal images obtained by the FLIR-i7 thermal imager are shown in Fig. 2.4.



a b

Figure 2.4 – Thermograms of FLIR-i7: a - calibration, b - selection of the studied areas

1) The processed files in the FLIR QuickReport program are presented in Tables 2.1 - 2.3 and Fig. 2.5.

Table 2.1 – Temperature values of the right eye

32,92	33,13	33,17	33,42	33,76	33,84	33,91	34,06	34,03	34,28	34,35	34,53	34,74
33,28	33,38	33,67	33,63	33,82	33,91	33,98	33,95	34,08	34,22	34,4	34,49	34,74
33,77	33,83	33,82	33,71	33,79	33,84	33,85	33,86	34	34,2	34,33	34,51	34,66
33,9	33,98	33,8	33,77	33,68	33,79	33,86	33,87	34,01	34,08	34,31	34,44	34,8
33,98	33,84	33,91	33,89	33,8	33,84	33,88	33,89	33,99	34,25	34,32	34,59	34,68
34,13	33,98	33,97	33,89	33,83	33,78	33,93	33,82	33,97	34,15	34,19	34,57	34,97
34,09	33,97	34,08	33,95	33,97	33,95	33,93	33,95	33,92	34,39	34,49	34,6	34,87
33,97	34,1	34,14	34,09	34,13	34,12	34,2	34,25	34,25	34,4	34,53	34,73	34,81
33,76	33,9	33,86	33,93	34,06	34,15	34,17	34,21	34,45	34,46	34,6	34,53	34,69
33,61	33,64	33,75	33,8	33,92	33,98	34,15	34,19	34,34	34,26	34,46	34,57	34,68

Table 2.2 – Temperature values of the left eye

2,74	2,81	2,96	33,1	3,38	3,53	3,6	3,76	4,05	4,05	4,29	4,66	4,66
32,66	32,9	32,97	33,06	33,34	33,47	33,68	33,86	33,94	34,07	34,25	34,34	34,72
32,68	32,74	32,98	33,32	33,46	33,74	33,77	33,76	33,98	33,98	34,31	34,35	34,42
32,81	32,89	33,18	33,77	33,82	33,8	33,78	33,82	33,93	33,96	34,29	34,38	34,48
33,04	33,56	33,69	33,82	33,77	33,85	33,81	33,73	33,83	33,96	34,16	34,43	34,57
33,83	34	33,91	33,83	33,69	33,74	33,86	33,85	33,88	34,02	34,06	34,42	34,52
33,97	34,02	33,93	33,94	33,86	33,83	33,89	33,82	33,85	34	34,36	34,43	34,62
34,03	34,07	33,93	33,9	33,77	33,76	33,85	33,84	33,95	33,95	34,34	34,54	34,65
33,99	34,05	33,94	33,97	33,94	33,92	34,07	34,05	34,06	34,31	34,5	34,64	34,65
33,73	33,91	33,96	34,01	33,98	33,97	34,04	34,13	34,13	34,22	34,43	34,39	34,51

Find the difference in the temperatures of the right and left eyes using the data in the table and draw a diagram of the temperature difference.

Table 2.3 – Absolute temperature difference

0,18	0,32	0,21	0,32	0,38	0,31	0,31	0,3	0,02	0,23	0,06	0,13	0,08
0,62	0,48	0,7	0,57	0,48	0,44	0,3	0,09	0,14	0,15	0,15	0,15	0,02
1,09	1,09	0,84	0,39	0,33	0,1	0,08	0,1	0,02	0,22	0,02	0,16	0,24
1,09	1,09	0,62	0	0,14	0,01	0,08	0,05	0,08	0,12	0,02	0,06	0,32
0,94	0,28	0,22	0,07	0,03	0,01	0,07	0,16	0,16	0,29	0,16	0,16	0,11
0,3	0,02	0,06	0,06	0,14	0,04	0,07	0,03	0,09	0,13	0,13	0,15	0,45
0,12	0,05	0,15	0,01	0,11	0,12	0,04	0,13	0,07	0,39	0,13	0,17	0,25
0,06	0,03	0,21	0,19	0,36	0,36	0,35	0,41	0,3	0,45	0,19	0,19	0,16
0,23	0,15	0,08	0,04	0,12	0,23	0,1	0,16	0,39	0,15	0,1	0,11	0,04
0,12	0,27	0,21	0,21	0,06	0,01	0,11	0,06	0,21	0,04	0,03	0,18	0,17

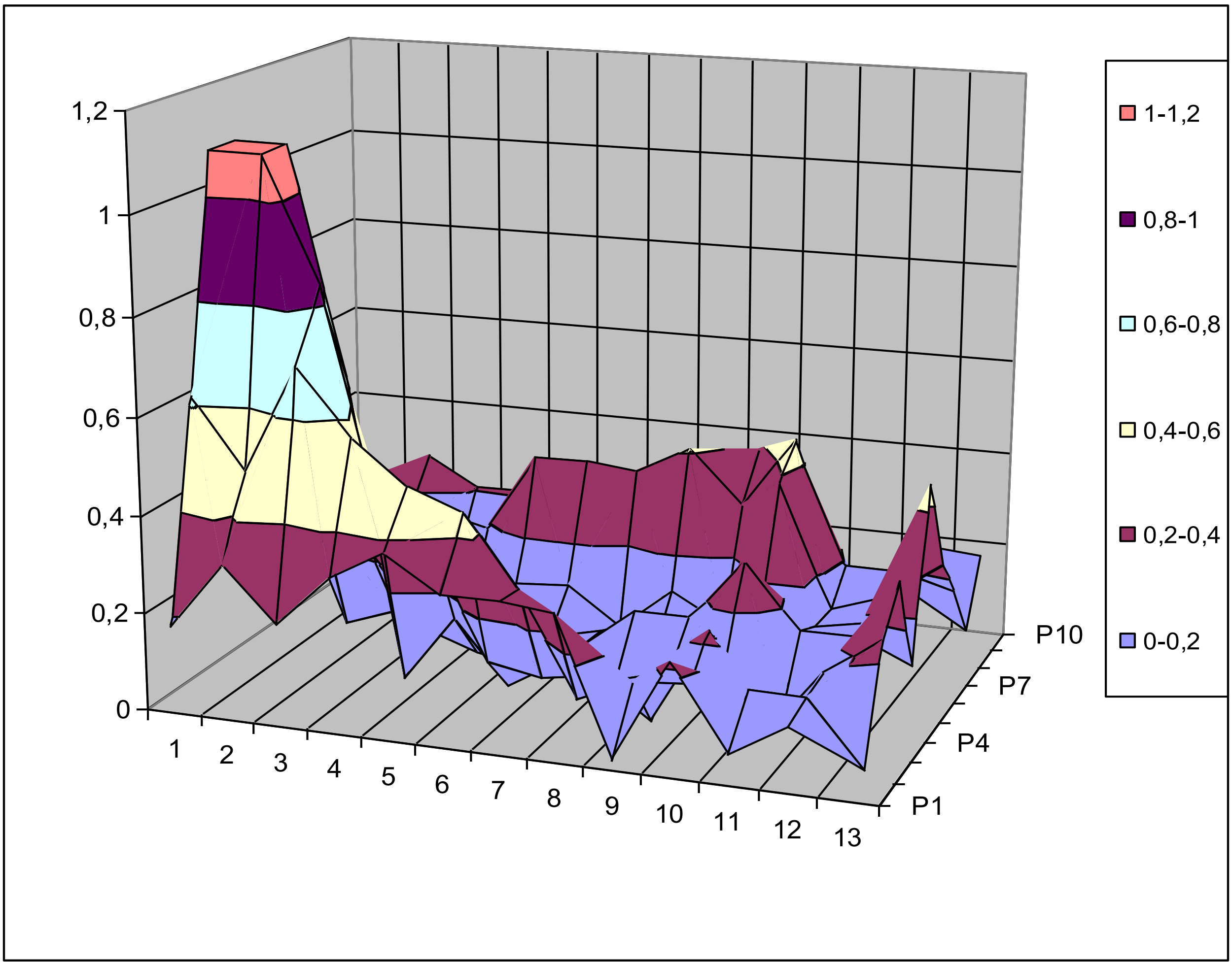


Figure 2.5 – Temperature difference diagram

2) The processed files in the MatLab program are shown in Figs. 2.6 - 2.8.

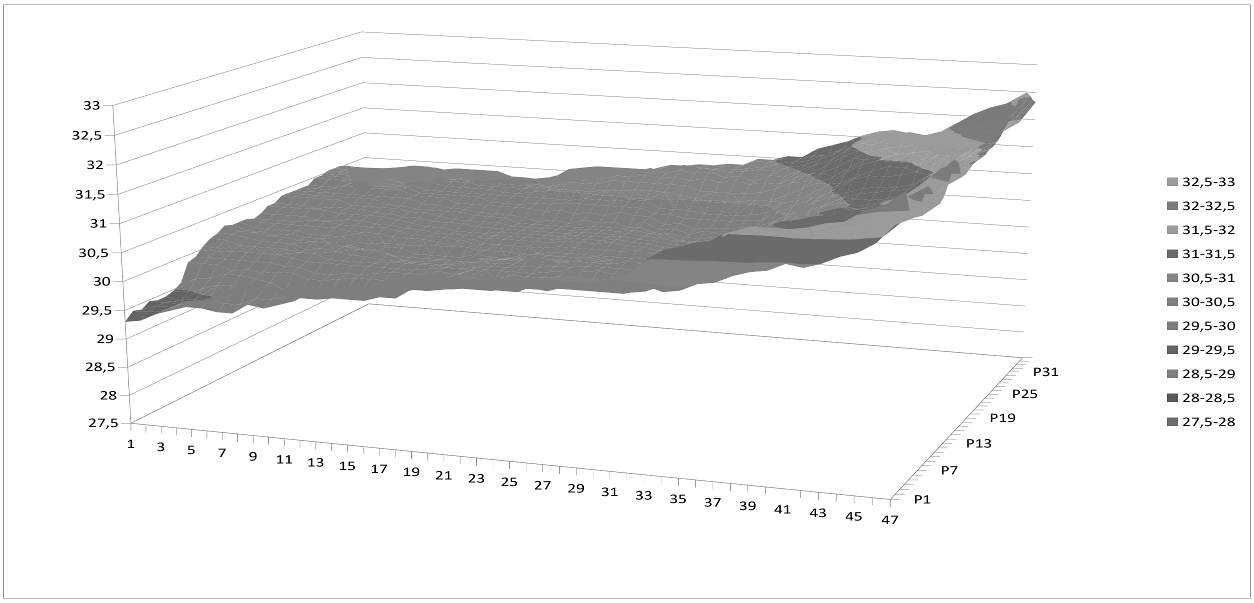


Figure 2.6 – Temperature values of the right eye

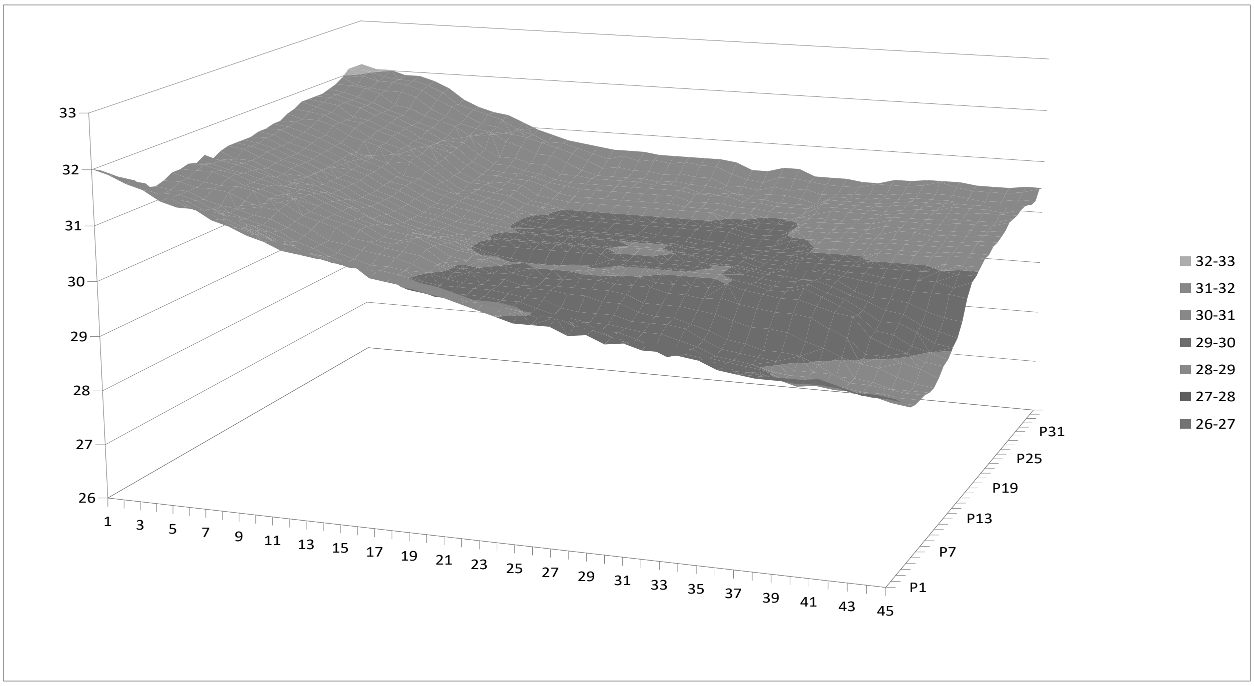


Figure 2.7 – Temperature values of the left eye

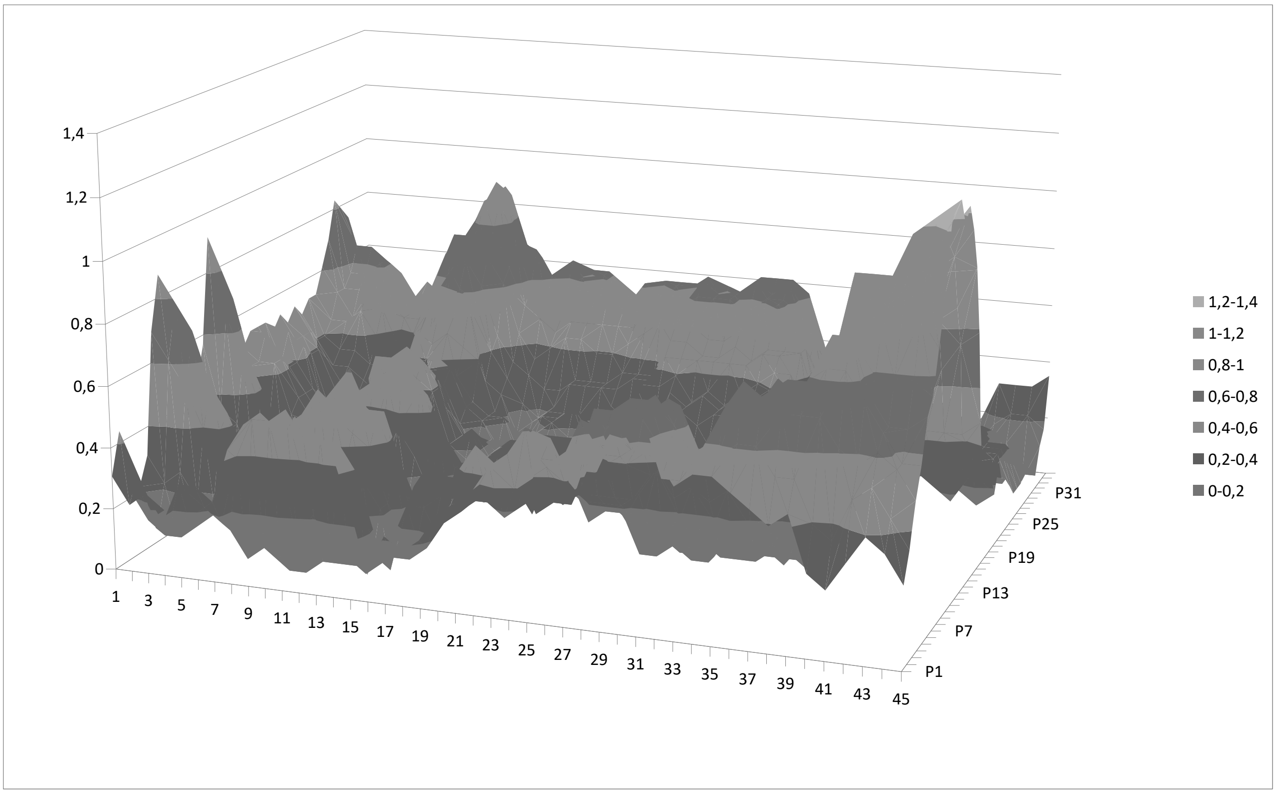


Figure 2.8 – Absolute temperature difference

2.3 Methodology for determining pathology by temperature relief

To apply the method of determining eye pathology by temperature relief, the following steps were performed:

1) Calculate the temperature array for a given area on the thermogram (Fig. 2.9, 2.10)

a b

Figure 2.9 – Selected area from the thermogram: a - right eye, b - left eye

0,04375	0,21875	0,21875	0,175	0,30625	0,30625	0,35	0,30625	0,2625	0,21875	0,21875	0,21875	0,2625	0,35	0,2625	0,30625	0,2625	0,30625
0,13125	0,2625	0,2625	0,21875	0,30625	0,2625	0,30625	0,2625	0,2625	0,175	0,175	0,175	0,175	0,13125	0,175	0,175	0,175	0,0875
0,13125	0,21875	0,21875	0,175	0,2625	0,2625	0,21875	0,21875	0,175	0,175	0,175	0,0875	0,0875	0,13125	0,13125	0,0875	0,04375	0,04375
0,21875	0,175	0,13125	0,175	0,21875	0,21875	0,175	0,21875	0,0875	0,13125	0,13125	0	0	0,04375	0	0	0,0875	0,0875
0,21875	0,175	0,21875	0,21875	0,175	0,175	0,175	0,21875	0,13125	0,13125	0,0875	0,04375	0,04375	0	0	0	0,0875	0
0,0875	0,21875	0,2625	0,2625	0,21875	0,21875	0,21875	0,2625	0,21875	0,21875	0,13125	0,04375	0,04375	0	0	0,0875	0,13125	0,0875
0,0875	0,175	0,2625	0,2625	0,30625	0,30625	0,30625	0,30625	0,2625	0,13125	0,13125	0,0875	0,04375	0,04375	0,04375	0,04375	0,13125	0,0875
0,175	0,21875	0,21875	0,175	0,175	0,21875	0,175	0,175	0,175	0,13125	0,13125	0,0875	0,13125	0,13125	0,13125	0,13125	0,04375	0,0875
0,175	0,175	0,175	0,13125	0,13125	0,175	0,175	0,21875	0,175	0,13125	0,13125	0,0875	0,13125	0,13125	0,175	0,175	0,13125	0,175
0,175	0,21875	0,21875	0,175	0,175	0,21875	0,21875	0,2625	0,21875	0,175	0,175	0,13125	0,175	0,175	0,175	0,175	0,13125	0,21875
0,175	0,175	0,175	0,13125	0,13125	0,175	0,175	0,21875	0,175	0,175	0,175	0,13125	0,175	0,175	0,175	0,175	0,21875	0,21875
0,175	0,13125	0,175	0,175	0,175	0,21875	0,21875	0,2625	0,21875	0,21875	0,21875	0,175	0,21875	0,21875	0,2625	0,2625	0,2625	0,2625
0,13125	0,175	0,175	0,13125	0,13125	0,21875	0,21875	0,2625	0,21875	0,21875	0,21875	0,175	0,21875	0,21875	0,2625	0,2625	0,30625	0,30625
0,0875	0,175	0,21875	0,175	0,175	0,21875	0,21875	0,30625	0,2625	0,30625	0,30625	0,2625	0,30625	0,30625	0,35	0,35	0,39375	0,35
0,13125	0,21875	0,21875	0,2625	0,175	0,2625	0,21875	0,35	0,21875	0,35	0,30625	0,35	0,30625	0,35	0,35	0,39375	0,39375	0,2625
0,175	0,21875	0,21875	0,21875	0,175	0,2625	0,21875	0,35	0,35	0,39375	0,30625	0,35	0,30625	0,35	0,39375	0,4375	0,4375	0,21875
0,175	0,21875	0,30625	0,30625	0,30625	0,30625	0,35	0,35	0,4375	0,4375	0,4375	0,4375	0,4375	0,4375	0,48125	0,48125	0,39375	0,21875
0,2625	0,2625	0,30625	0,30625	0,30625	0,35	0,35	0,35	0,48125	0,48125	0,4375	0,4375	0,48125	0,4375	0,48125	0,48125	0,48125	0,30625

Figure 2.10 – Temperature array for a given area on the thermogram

2) Calculated the average temperatures for the horizontal and vertical temperature profiles of the thermogram (Fig. 2.11)

0,04375	0,21875	0,21875	0,175	0,30625	0,30625	0,35	0,30625	0,2625	0,21875	0,21875	0,21875	0,2625	0,35	0,2625	0,30625	0,2625	0,30625		0,214773
0,13125	0,2625	0,2625	0,21875	0,30625	0,2625	0,30625	0,2625	0,2625	0,175	0,175	0,175	0,175	0,13125	0,175	0,175	0,175	0,0875		0,18892
0,13125	0,21875	0,21875	0,175	0,2625	0,2625	0,21875	0,21875	0,175	0,175	0,175	0,0875	0,0875	0,13125	0,13125	0,0875	0,04375	0,04375		0,173011
0,21875	0,175	0,13125	0,175	0,21875	0,21875	0,175	0,21875	0,0875	0,13125	0,13125	0	0	0,04375	0	0	0,0875	0,0875		0,180966
0,21875	0,175	0,21875	0,21875	0,175	0,175	0,175	0,21875	0,13125	0,13125	0,0875	0,04375	0,04375	0	0	0	0,0875	0		0,173011
0,0875	0,21875	0,2625	0,2625	0,21875	0,21875	0,21875	0,2625	0,21875	0,21875	0,13125	0,04375	0,04375	0	0	0,0875	0,13125	0,0875		0,157102
0,0875	0,175	0,2625	0,2625	0,30625	0,30625	0,30625	0,30625	0,2625	0,13125	0,13125	0,0875	0,04375	0,04375	0,04375	0,04375	0,13125	0,0875		0,163068
0,175	0,21875	0,21875	0,175	0,175	0,21875	0,175	0,175	0,175	0,13125	0,13125	0,0875	0,13125	0,13125	0,13125	0,13125	0,04375	0,0875		0,178977
0,175	0,175	0,175	0,13125	0,13125	0,175	0,175	0,21875	0,175	0,13125	0,13125	0,0875	0,13125	0,13125	0,175	0,175	0,13125	0,175		0,18892
0,175	0,21875	0,21875	0,175	0,175	0,21875	0,21875	0,2625	0,21875	0,175	0,175	0,13125	0,175	0,175	0,175	0,175	0,13125	0,21875		0,208807
0,175	0,175	0,175	0,13125	0,13125	0,175	0,175	0,21875	0,175	0,175	0,175	0,13125	0,175	0,175	0,175	0,175	0,21875	0,21875		0,18892
0,175	0,13125	0,175	0,175	0,175	0,21875	0,21875	0,2625	0,21875	0,21875	0,21875	0,175	0,21875	0,21875	0,2625	0,2625	0,2625	0,2625		0,214773
0,13125	0,175	0,175	0,13125	0,13125	0,21875	0,21875	0,2625	0,21875	0,21875	0,21875	0,175	0,21875	0,21875	0,2625	0,2625	0,30625	0,30625		0,220739
0,0875	0,175	0,21875	0,175	0,175	0,21875	0,21875	0,30625	0,2625	0,30625	0,30625	0,2625	0,30625	0,30625	0,35	0,35	0,39375	0,35		0,264489
0,13125	0,21875	0,21875	0,2625	0,175	0,2625	0,21875	0,35	0,21875	0,35	0,30625	0,35	0,30625	0,35	0,35	0,39375	0,39375	0,2625		0,288352
0,175	0,21875	0,21875	0,21875	0,175	0,2625	0,21875	0,35	0,35	0,39375	0,30625	0,35	0,30625	0,35	0,39375	0,4375	0,4375	0,21875		0,302273
0,175	0,21875	0,30625	0,30625	0,30625	0,30625	0,35	0,35	0,4375	0,4375	0,4375	0,4375	0,4375	0,4375	0,48125	0,48125	0,39375	0,21875		0,36392
0,2625	0,2625	0,30625	0,30625	0,30625	0,35	0,35	0,35	0,48125	0,48125	0,4375	0,4375	0,48125	0,4375	0,48125	0,48125	0,48125	0,30625		0,395739
0,153125	0,201736	0,221181	0,204167	0,213889	0,243056	0,238194	0,272222	0,240625	0,233333	0,216319	0,182292	0,196875	0,201736	0,213889	0,223611	0,228472	0,184722		

Figure 2.11 – Temperature array with horizontal and vertical averages

3) Calculate the average temperature for the entire area of the T-Middle thermogram (Fig. 2.12).

0,04375	0,21875	0,21875	0,175	0,30625	0,30625	0,35	0,30625	0,2625	0,21875	0,21875	0,21875	0,2625	0,35	0,2625	0,30625	0,2625	0,30625		0,214773	
0,13125	0,2625	0,2625	0,21875	0,30625	0,2625	0,30625	0,2625	0,2625	0,175	0,175	0,175	0,175	0,13125	0,175	0,175	0,175	0,0875		0,18892	2
0,13125	0,21875	0,21875	0,175	0,2625	0,2625	0,21875	0,21875	0,175	0,175	0,175	0,0875	0,0875	0,13125	0,13125	0,0875	0,04375	0,04375		0,173011	3
0,21875	0,175	0,13125	0,175	0,21875	0,21875	0,175	0,21875	0,0875	0,13125	0,13125	0	0	0,04375	0	0	0,0875	0,0875		0,180966	
0,21875	0,175	0,21875	0,21875	0,175	0,175	0,175	0,21875	0,13125	0,13125	0,0875	0,04375	0,04375	0	0	0	0,0875	0		0,173011	
0,0875	0,21875	0,2625	0,2625	0,21875	0,21875	0,21875	0,2625	0,21875	0,21875	0,13125	0,04375	0,04375	0	0	0,0875	0,13125	0,0875		0,157102	6
0,0875	0,175	0,2625	0,2625	0,30625	0,30625	0,30625	0,30625	0,2625	0,13125	0,13125	0,0875	0,04375	0,04375	0,04375	0,04375	0,13125	0,0875		0,163068	7
0,175	0,21875	0,21875	0,175	0,175	0,21875	0,175	0,175	0,175	0,13125	0,13125	0,0875	0,13125	0,13125	0,13125	0,13125	0,04375	0,0875		0,178977	
0,175	0,175	0,175	0,13125	0,13125	0,175	0,175	0,21875	0,175	0,13125	0,13125	0,0875	0,13125	0,13125	0,175	0,175	0,13125	0,175		0,18892	
0,175	0,21875	0,21875	0,175	0,175	0,21875	0,21875	0,2625	0,21875	0,175	0,175	0,13125	0,175	0,175	0,175	0,175	0,13125	0,21875		0,208807	
0,175	0,175	0,175	0,13125	0,13125	0,175	0,175	0,21875	0,175	0,175	0,175	0,13125	0,175	0,175	0,175	0,175	0,21875	0,21875		0,18892	
0,175	0,13125	0,175	0,175	0,175	0,21875	0,21875	0,2625	0,21875	0,21875	0,21875	0,175	0,21875	0,21875	0,2625	0,2625	0,2625	0,2625		0,214773	12
0,13125	0,175	0,175	0,13125	0,13125	0,21875	0,21875	0,2625	0,21875	0,21875	0,21875	0,175	0,21875	0,21875	0,2625	0,2625	0,30625	0,30625		0,220739	13
0,0875	0,175	0,21875	0,175	0,175	0,21875	0,21875	0,30625	0,2625	0,30625	0,30625	0,2625	0,30625	0,30625	0,35	0,35	0,39375	0,35		0,264489	
0,13125	0,21875	0,21875	0,2625	0,175	0,2625	0,21875	0,35	0,21875	0,35	0,30625	0,35	0,30625	0,35	0,35	0,39375	0,39375	0,2625		0,288352	
0,175	0,21875	0,21875	0,21875	0,175	0,2625	0,21875	0,35	0,35	0,39375	0,30625	0,35	0,30625	0,35	0,39375	0,4375	0,4375	0,21875		0,302273	
0,175	0,21875	0,30625	0,30625	0,30625	0,30625	0,35	0,35	0,4375	0,4375	0,4375	0,4375	0,4375	0,4375	0,48125	0,48125	0,39375	0,21875		0,36392	
0,2625	0,2625	0,30625	0,30625	0,30625	0,35	0,35	0,35	0,48125	0,48125	0,4375	0,4375	0,48125	0,4375	0,48125	0,48125	0,48125	0,30625		0,395739	
0,153125	0,201736	0,221181	0,204167	0,213889	0,243056	0,238194	0,272222	0,240625	0,233333	0,216319	0,182292	0,196875	0,201736	0,213889	0,223611	0,228472	0,184722			
2	**3**			**6**	**7**					**12**	**13**									
T-Mid-V	0,185938			**T-Mid-V**	0,2625					**T-Mid-V**	0,196875							**T-Midle**	0,212993	
C-T-V	0,027056			**C-T-V**	0,049507					**C-T-V**	0,016118									
I-T-V	0,546512									**I-T-V**	0,325581									
Вывод:	**В норме**										**В норме**									

Figure 2.12 – Temperature array with the average temperature for the entire region

4) Draw a temperature equilibrium graph for average temperatures (Fig. 2.13).

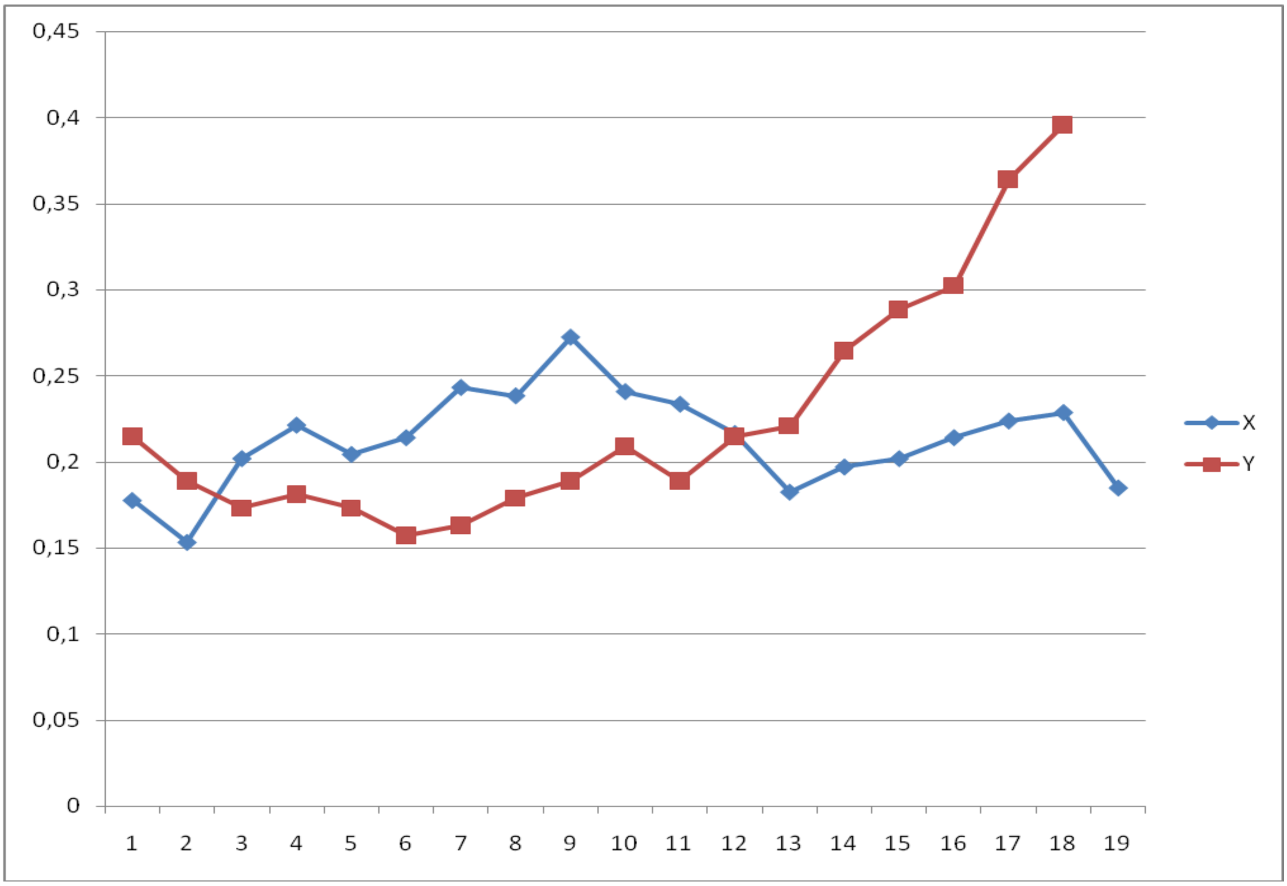


Figure 2.13 – Graph of temperature equilibrium of the array for average temperatures

5) Determine the temperature equilibrium regions - the intersection of the graphs, and determine the average T-Mid-V temperatures in these regions (temperature matrix nodes 2-3 and 12-13) (Fig. 2.12).

6) Determine the area of maximum temperature difference - the largest difference in the graphs, and determine the average temperature value T-Mid-V in this area (nodes of the temperature matrix 6-7) (Fig. 2.12).

7) We calculated the temperature deviations C-T-V, which represent the difference in average temperatures between the equilibrium nodes and the maximum temperature difference (Fig. 2.12).

8) We calculated the temperature index I-T-V, which represents the ratio of temperature deviations for equilibrium nodes and the maximum and minimum temperature difference (Fig. 2.12).

9) Normally, the I-T-V temperature index should not exceed 0.5+5% of the index change range.

The methodology for determining pathology by temperature relief was applied to the thermogram obtained using a FLIR i7 thermal imager. The processing of the obtained temperature relief revealed two temperature equilibrium regions, in which the temperature difference C-T-V between the average temperature in the region and the average temperature of the entire profile is 0.027°C and 0.016°C, respectively. The temperature index I-T-V in the equilibrium regions is 0.54 and 0.32, respectively, which does not exceed the value of 0.5 + 0.05 and indicates the absence of pathology in the area of the eye under study.

Conclusions to Section 2

Comparison of the FLIR results with those processed in MATLAB and FLIR QuickReport shows their coincidence, which is reflected in the typical shape of the temperature field over the entire area of the two eyes and in the area of the eyeball around the pupils, as well as in the values of the absolute temperature difference, which coincide for the IR images processed in MATLAB and FLIR QuickReport.

This shows that the methods of IR image processing performed MATLAB can be used to analyse thermograms.

3 OCCUPATIONAL HEALTH AND SAFETY IN EMERGENCY SITUATIONS

Introduction

The thesis was conducted on the basis of the Department of BMI, NTUU "KPI". The purpose of this section is to analyse the impact of harmful factors and working conditions at work, as well as appropriate measures to eliminate factors that adversely affect the staff.

The article considers the Fluke Ti9 thermal imager and the acquisition of thermal images that will be used in ophthalmology.

The aim of the study was to develop a system for assessing the state of vision using thermograms.

3.1 Characteristics of the thermography room

Table 3.1 shows all the necessary characteristics of a thermography room

Table 3.1 – Characteristics of the thermography room

Length of the cabinet, L	6 m
Cabinet width, W	3 m
Ceiling height, H	3 m
Number of employees	1
Natural lighting	window
Artificial lighting	2 lamps LB 40
Natural ventilation	general ventilation
Heating	low-pressure central water heating
Floor	concrete covered with linoleum
Walls	covered with heat-absorbing paint

Figure 1 shows the plan of the thermography room, and Table 2 shows its objects and their characteristics.

Table 3.2 – Objects of the thermography room

Name of the object	Characteristics	The number in the figure
Thermal imager Fluke Ti9	Overall dimensions: 270x130x150 mm; Field of view: 23 x 17; The measuring temperature range is from -20C to +250C; Power supply: lithium-ion rechargeable battery with rechargeable AC 90-260V; Battery life: 3-4 hours.	1
Computer.	Intel type PC/ATX and 17" CRT , Samsung monitor 755 VA	2
Working chair	40x40 cm	3
	100x60 cm	4
Chair	40x40 cm	5
Battery	130x50 cm	6
Window.	130x120 cm	7
Bucket	d 30 cm	8
Hanger	50x15 cm	9
Sink	d 40 cm	10

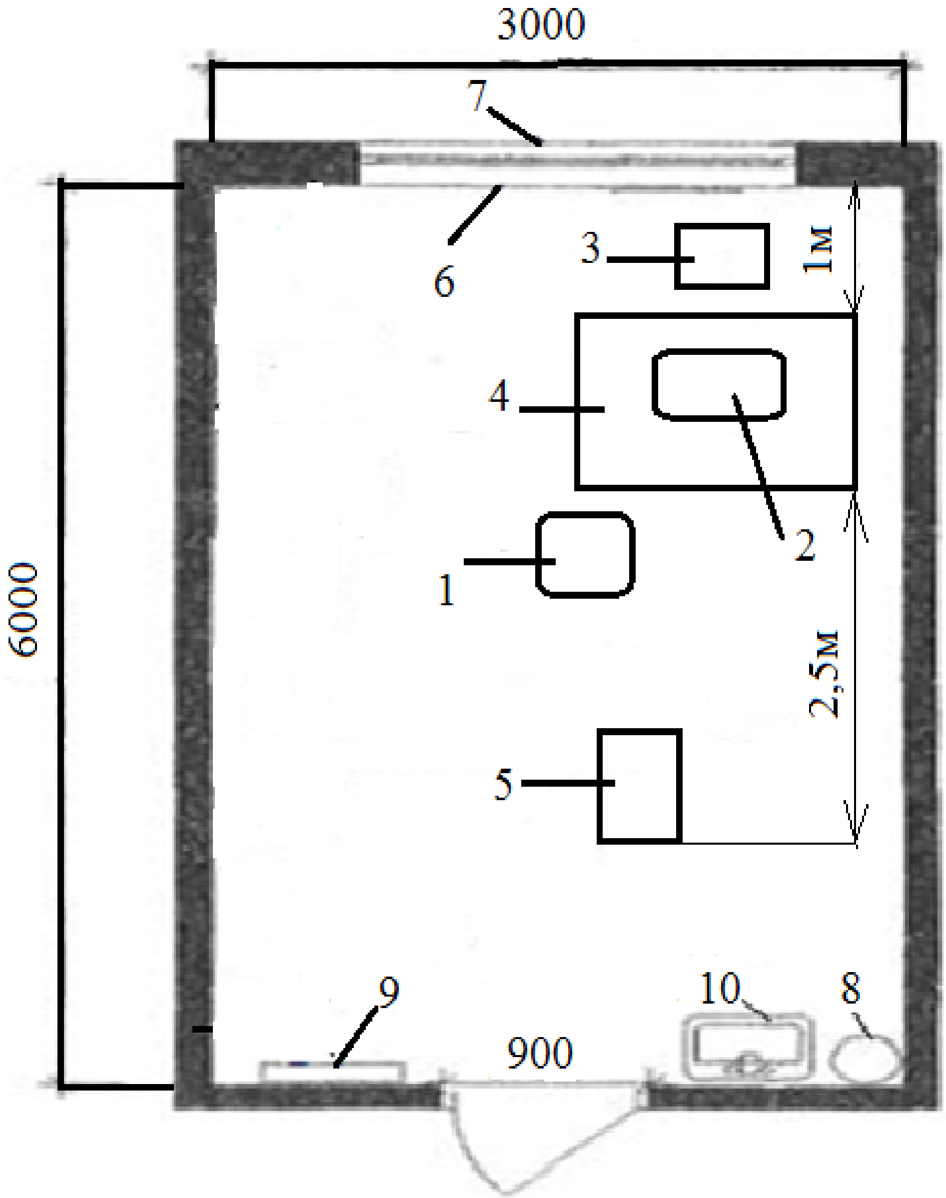


Figure 3.1 – Plan of the thermography room

The area of the premises is:

$$S = a \times b \, , \qquad (3.1)$$

where a – is the length of the room, [m];

b – width of the room, [m].

Let's substitute values into formula (3.1):

$$S = 3 \times 6 = 18 \ m^{2}, \qquad (3.2)$$

The volume of the room is:

$$V = a \times b \times h \, , \qquad (3.3)$$

where h – is the height of the room, [m].

Let's substitute the values for calculating the volume in formula (3.3):

$$V = 6 \times 3 \times 3 = 54\ m^{3.}, \qquad (3.4)$$

Let's calculate the area and volume of the room per person:

$$S_l = S / n, \qquad (3.5)$$

where n – is the number of people.

Substitute the values in formula (3.5):

$$S_l = 18 / 2 = 9m^3, \qquad (3.6)$$

$$V_l = V / n, \qquad (3.7)$$

Substitute the values into formula (3.7):

$$V_l = 54 /2 = 27m^3, \qquad (3.8)$$

Let's enter the calculated indicators in the table (Table 3.3) and equate them to the sanitary standards in accordance with the norms of DSanPiN 3.3.6.042-99, DSanPiN 3.3.2.007-98.

Table 3.3 – Compliance of the premises layout with sanitary and hygienic standards

Parameters.	Sanitary standards	This room
Area of the thermography room S, m^2	Not less than 15	18
Area per person S, m^2	Not less than 6	9
Volume per person V, m^3	20	27
Distance between the workplace and the wall, m	Not less than 1	1
Minimum distance between workplaces, m	Not less than 1.2	2.5

The parameters of the thermography room meet the requirements of sanitary standards, which ensure safe and comfortable examination and diagnostics.

3.2 Assessment of hazardous and harmful production factors

All possible hazards and harmful factors are listed in Table 3.4.

Table 3.4 – Hazardous and harmful production factors

Physical	Chemical	Biological
The microclimate of the room; Lighting; Noise; Electrical hazard; Fire safety.	Disinfectants.	Viruses; Bacteria.

3.3 Microclimate

The microclimate affects the work of employees and the condition of patients in the office. Since indoor work is carried out both in warm and cold seasons, it is important to maintain optimal microclimate parameters in accordance with the standards (Table 3.5).

Table 3.5 – Category of work performed in the office

Category of work	1b - performed while sitting, standing and associated with walking and accompanied by some physical exertion
Energy consumption during work performance	121-150 kcal/hour

Table 3.6 – Compliance of air temperature with respect to humidity and air velocity

Period of the year	Category of work	Air temperature, t, ^{0}C	Relative humidity, %.	Air movement speed, m/s
Optimal values				
cold	Light - 1b	21-23	40-60	0.1
warm	Light - 1b	22-24	40-60	0.2
Normative values				
cold	Light - 1b	17-25	75	No more than 0.2
warm	Light - 1b	19-30	60 at $27^{0}C$	0.3-0.1
Real values				
cold	Light - 1b	19-22	40-60	0.1
warm	Light - 1b	22-29	40-60	0.2

The room is regularly ventilated with the help of one window, which opens to (0.7m). Total area through which ventilation occurs:

$$S_{age} = 0.7*1.5 = 1.05\ m^2$$

Calculation of natural ventilation (Kp=4 for the office)

$$L = Vcab * Kp = 54 * 4 = 216\ (m^3/h),$$

Table 3.7 - Ventilation of the thermography room

The rate per person	$30m^3/h$
Real value per person	$216m^3/h$

Table 3.8 – Means of maintaining temperature during the running period

ating	a battery consisting of 6 sections; lighting devices.

In the warm season, the optimum temperature is maintained by the Samsung AQ12UGF air conditioner.

Normative metrological conditions, microclimate parameters and concentration of harmful substances are ensured in accordance with the requirements of GOST 12.1.005-88 and DSTU 3.3.6.042-99.

3.4 Lighting

Insufficient or excessive illumination, uneven illumination in the field of view tires the eyes, leads to a decrease in labor productivity, and increases the potential for mistakes and accidents. Excessive brightness of light sources can cause headaches, eye stinging, and visual acuity disorders.

In this room, we work with objects located on a 9.1 cm (3.6 inches) VGA (640 x 480) color landscape LCD display with backlight (selectable or automatic brightness adjustment) located on a thermal imager and on a PC monitor, the size of objects is on average 4-6 pixels, i.e. 2 - 3 mm and the size of the minimum objects is 3 pixels - 1 mm, so the accuracy of visual work is average. The characteristics of visual work are shown in Table 3.9.

Table 3.9 Characteristics of visual work

Characteristics of visual work	Smallest size of the object to be distinguished, mm	Category of visual work	Subdivision of visual work	Contrast of the object to be recognized with the background	Characterization of the background	Natural lighting lateral
Medium accuracy	More than 0.5 to 1	IV	B	Small Medium Big	Light Light Medium	1,5

Natural and artificial lighting is used in the office. The natural light is side one-sided, provided through a skylight - a window measuring 1.7m × 2m.

The total area of natural light is:

$$S = 1.7*2= 3.4\ m^2, \quad (3.9)$$

Let's determine the ratio of window light area to room area. Then we have (Table 3.10):

$$i = S/S_n= 3.4 / 18 = 0.18$$

Table 3.10 - Natural lighting

Norma	Real parameters
From 0.16 to 0.3	0,18

Artificial lighting is provided by (Table 3.11):

Table 3.11 - Artificial lighting

Number of luminaires	2 pcs.
Lamps	LPO 01 series with light-transmitting sidewalls
Type of fluorescent lamps	warm white color LB 40
Number of lamps	4 pcs, 40 W power
Height above the floor	3м

Natural and artificial lighting meets the requirements of regulatory documents (DBN V.2.5-28-2006 and SanPiN 3.3.2.007-98 or DNAP 0.00-1.31-99 – at least 2.5 m).

3.5 Noise

At the workplace with a thermal imager and a computer, the noise sources are: the computer cooler and external noise. The actual and standard values of the noise level are given in Table 3.12.

Table 3.12 - Actual and standard values for sound and noise

Indicators	Real values	Normative values
Noise level of the thermal imager	<6dBA	
Average noise level from a PC	25 dBA	50 dBA
Air Conditioning.	26dBA	

The sound level in the room does not exceed the established standards according to DSTU 3.3.6.037-99 "Sanitary norms of industrial noise, ultrasound and infrasound".

Table 3.13 – Means and measures of protection against noise loads

Technical	- Sealing around the perimeter of window and door openings; - The thermal imager uses a housing with silicone insulation at all drive mounting points; - The PC uses 90 mm fans that produce less noise.
Organizational	- Compliance with the rules of technical operation; - Conducting scheduled inspections and repairs.
Personal protective equipment	- Preliminary and periodic medical examinations; - Use of rational work and rest regimes for employees.

3.6 Chemical sources of hazardous and harmful production factors

Various chemicals are used for patient examination and sterilization of instruments. Hygienic standardization of harmful substances is carried out by maximum permissible concentrations: for workplaces, the maximum permissible concentration in the working area is determined - MPCmr, sd (GOST 12.1.005-88, SN 245-71).

Table 3.14 – Content of harmful chemicals in the functional diagnostics room

Name of the substance	Normative value of MPCmr, mg/м³	Actual value of MPCsd, mg/м³	Hazard class
Ethyl alcohol	1,0	0,5	3
Chlorine	0,1	0,03	2

Table 3.15 – Chemical protection equipment and measures

Technology	- chemicals are kept in a locked cabinet; - availability of a sink; - are used only by the employee.
Organizational	- instructing employees; - use chemicals according to the instructions.
Personal protective equipment	- use of protective clothing (rubber gloves, white coat, etc.).

3.7 Risk of electric shock to persons

In accordance with ONTP24-86 and PUE-87, the premises are classified as premises without an increased risk of electric shock to personnel, relative humidity does not exceed 60%, air temperature does not exceed $25^{(0)}$ C, and there are no chemically aggressive environments.

Electrical appliances inside the premises are powered from a three-phase grounded network with a voltage of 220V and a frequency of 50Hz using current protection circuit breakers.

The main consumers of electricity are the thermal imager, PC, monitor, and lighting sources.

Table 3.16 – Cases of human electric shock

touching exposed live parts;
through conductive elements of the equipment that have been energized as a result of insulation failure.

Table 3.17 - Electrical safety measures

Technology	- The thermal imager (class II type BF) during normal operation has reinforced insulation of the mains circuit relative to the working part and the device body, tested with a voltage of 350V, ensuring the safety of the patient and personnel without the use of protective grounding; - In case of emergency operation, the thermal imager has the following features: an emergency signal of electrical cable failure, automatic shutdown. - Inaccessible and insulated live parts in the devices; - The system unit case is connected to a grounded wire, and if the insulation is broken, a protective shutdown occurs; - All devices are regularly diagnosed for damage.
Organizational	- Electrical safety training; - Timely inspection and preventive measures by employees; - Strict adherence to the rules and regulations set forth in the applicable regulatory documents.

Continuation of Table 3.17

Personal protective equipment	- Use of eyeglasses, shoe covers, and disposable gloves for inspection; - Strict adherence to the rules and regulations when using electrical appliances.

In accordance with GOST-12.2.007.0-75, all equipment of the first level (except for PC-II class) belongs to class I, it has operational insulation in accordance with GOST 12.1.009-76. No additional measures are required to improve electrical safety.

3.8 Fire safety in emergency situations

Fire safety parameters are shown in Table 3.18.

Table 3.18 – Fire safety parameters

Causes of the fire	- short circuit; - use of unexpected electrical appliances; - non-compliance with fire safety rules.
Combustible materials	Paper, wood, electrical equipment
Fire class	A - combustion of solids, (E) - combustion of electrical installations under electric current voltage up to 1000 V.
Fire subclass	A2 - combustion is not accompanied by smoldering
Explosion and fire hazards of the premises	Category B (fire hazardous)
Class of fire hazardous area	P-IIIa

All the requirements of SNiP 2.01.02-85 and SNiP 2.09.02-85 regarding the building's fire resistance, evacuation time in case of fire, and the width of evacuation passages were met.

For this equipment, the corresponding characteristics of evacuation exits have been developed (Table 3.19).

Table 3.19 – Characteristics of emergency exits

	Standard values, m	Existing values, m
Corridor width	> 2,0	2,5
Door width	> 0,8	0.9
Door height	> 2,0	2,1

Table 3.20 - Fire safety measures

Technology.	- free access to the mains switches and circuit breakers is provided; - in the common corridor, next to the office, there is a carbon dioxide fire extinguisher OU-2 - three TPT-3 sensors with a 2.5-meter radius of observation are installed on the ceiling in the room. - timely preventive inspections and equipment repairs.
Organizational	- fire evacuation plan (Figure 3.2); - fire safety training; - organization of fire protection exercises; - Strict adherence to the rules and regulations set forth in the applicable regulatory documents
Personal protective equipment	- cotton gauze bandages

All fire safety requirements are met in the premises in accordance with the requirements of NAPB A.0.001-95 "Fire Safety Rules in Ukraine".

Evacuation plan on the floor in case of fire (Fig. 3.2)

Conventional notation:

 - fire hydrant

 - fire extinguisher

Figure 3.2 – Evacuation plan on the floor

Conclusions to Section 3

In terms of microclimate and lighting, this room meets the standards, and there are no comments on electrical safety, thermal safety and fire safety.

4 FEASIBILITY STUDY OF THE DEVELOPMENT

4.1 Design problem statement

Analysing a new method of assessing the state of vision by processing thermograms. Development of an algorithm for using thermograms, on the basis of which it is possible to make a diagnostic criterion of vision. The algorithm is developed on the basis of Microsoft Office Excel 2007. Data acquisition is performed using a Fluke-Ti9 thermal imager and a SHL-2B-ID density lamp. The algorithm can be used in the Microsoft Windows 98/2000/7 environment.

This section presents a feasibility study of the new method of vision diagnostics and compares the feasibility of its use with existing methods.

4.2 Justification of the functions of the software product

Based on the specific goals realized by the algorithm, let's highlight its main functions:

F1 - pre-processing of medical images received from devices;

F2 - building a heatmap;

F3 - perform measurements;

F4 - conclusion on the state of vision;

Each of the main functions can have several variants.

For F1:

a) thermal imager;

b) a flame lamp.

For F2:

a) based on the data collected.

For F3:

a) using Excel;.

For F4:

a) diagnosis of vision.

Based on the considered options, we build a morphological map (Fig. 4.1).

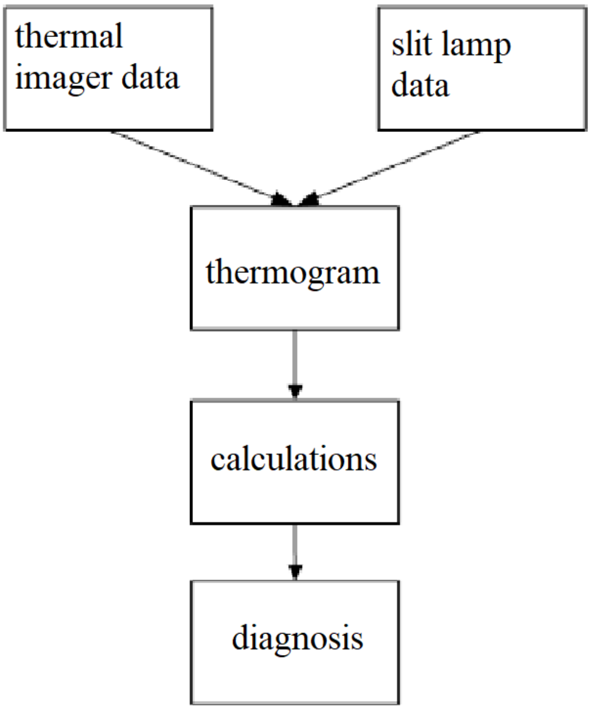


Figure 4.1 – Morphological map

Based on this map, a positive-negative matrix is built (Table 4.1).

Table 4.1 – Positive-negative matrix

Main function	Realization option	Advantages.	Disadvantages
F1	a	Versatility of application	High costs
	б	High processing efficiency	Not always effective, execution time
F2	a	Speed of construction	Additional algorithm
F3	a	Ease of implementation	The possibility of making mistakes
F4	a	Speed of diagnosis	The need for additional examination

4.3 Justification of the parameter system

The following parameters can be used to characterize the algorithm being developed:

X1 - time of measurement;

X2 - time of calculation execution;

X3 - the speed of building a heatmap;

X4 - the amount of memory occupied by the program on the hard disk;

X5 - the amount of RAM required for the program;

X6 - diagnosis.

From the technical literature, we determine the permissible, average, and achievable values of the parameters. The results are shown in Table 4.2.

Table 4.2 – Basic program parameters.

Parameter	Designation parameter	Maximum permissible value	The value of the parameter	
			Average amount received	What to achieve
Measurement execution time, ms	X1	300 000	200 000	100 000
Calculation time, ms	X2	600 000	800 000	300 000
Heatmap generation speed, ms	X3	1 500 000	1 200 000	1 100 000
The amount of memory occupied by the program on the hard disk, MB	X4	10	10	10
The amount of RAM required for the program, MB	X5	128	12	12

Based on the data in Table 4.2, we build graphical characteristics (Figures 4.2-4.6).

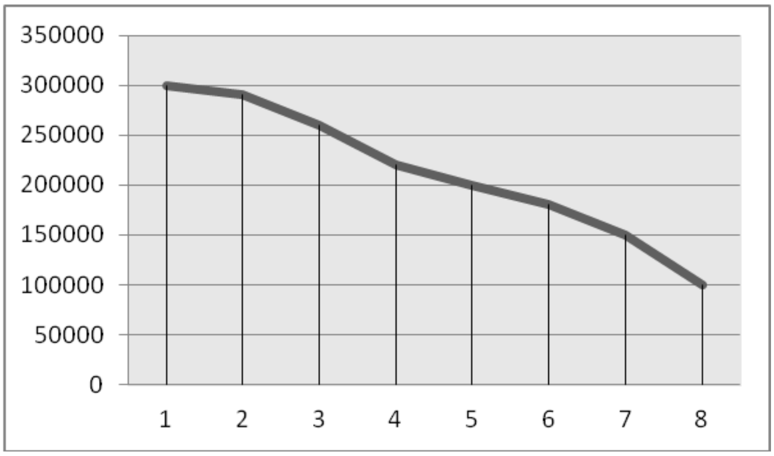


Figure 4.2 – Time for taking measurements

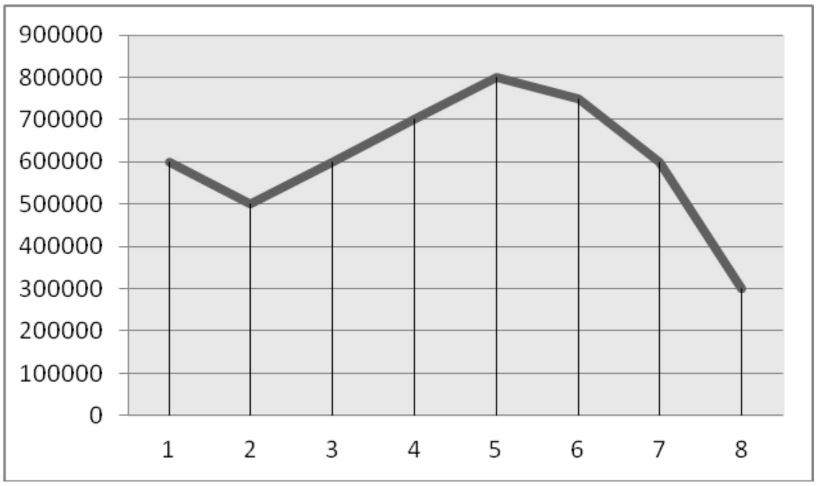


Figure 4.3 – Calculation time

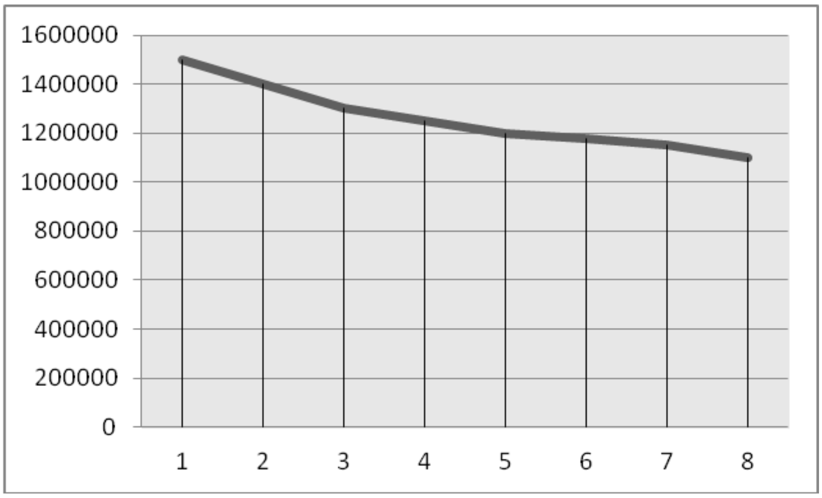


Figure 4.4 – Heatmap generation speed

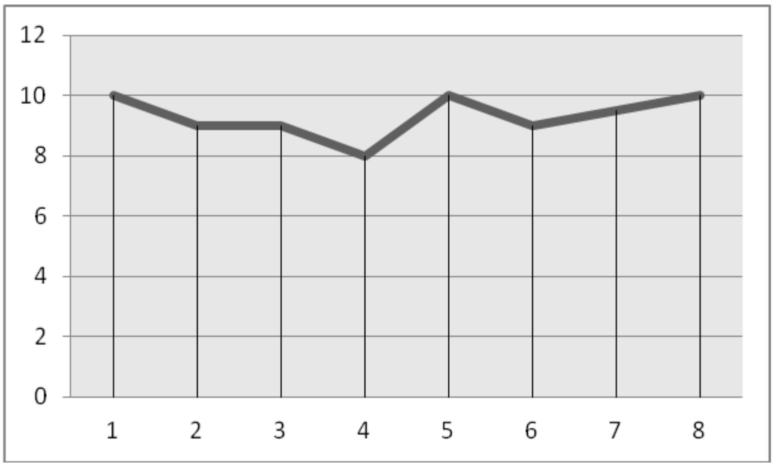


Figure 4.5 – The amount of memory occupied by the program on the hard disk

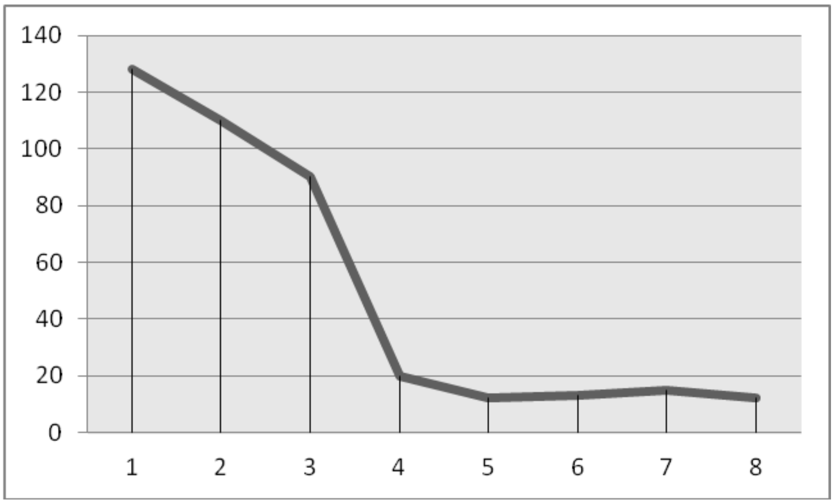


Figure 4.6 – The amount of RAM required for the program

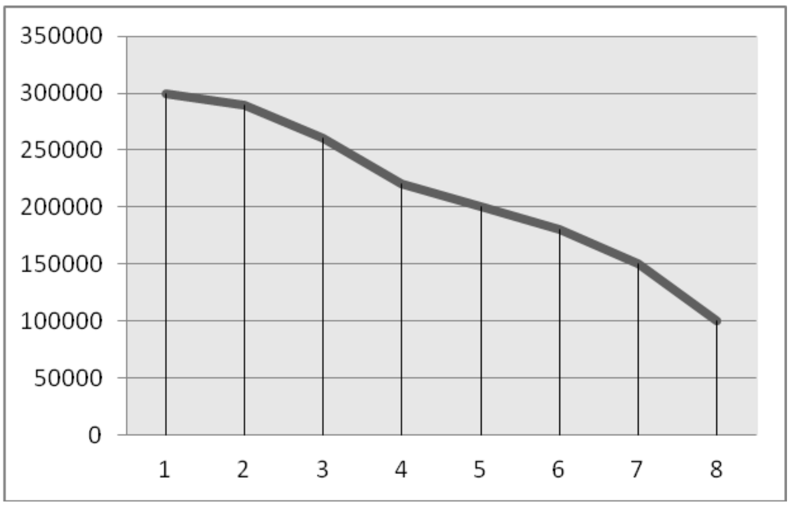


Figure 4.7 – Time to diagnosis

According to the data in Table 4.3, we calculate the concordance coefficient using formula (4.2):

Table 4.3 – The result of the parameters ranking

Parameters	Rank of the parameter according to the expert's assessment							Sum of ranks, R_i	Deviations, Δ_i	The square of the deviation, $(\Delta_i)^2$
	1	2	3	4	5	6	7			
x1	6	6	5	6	6	5	5	39	18	324
x2	2	1	1	1	2	2	2	11	-10	100
x3	1	4	3	3	1	3	3	26	5	25
x4	4	2	2	4	5	4	1	22	1	1
x5	5	5	6	5	4	6	6	37	16	256
X6	3	3	4	2	3	1	4	20	-1	1
Total	21	21	21	21	21	21	21	147		707

Find the total sum of the squared deviations:

$$S = \sum_{i=1}^{n} \Delta_i^2 = 202, \qquad (4.1)$$

where $(\Delta_i)^2$ is the square of the deviation.

Next, we determine the coefficient of consistency (concordance) using the formula:

$$W = \frac{12S}{N^2(n^3 - n)}, \qquad (4.2)$$

where N is the number of experts;

n – number of evaluation parameters

$$W = 12 \times 707/(7^2 (6^3 - 6)) = 0{,}82.$$

Since the calculated value of the concordance coefficient is higher than the standard W>0.67, we can use the results of the expert survey for further calculations.

The weight of the parameters is determined by the method of pairwise comparison, using the results of expert assessments (Table 4.4).

Table 4.4 – Pairwise comparison of parameters

Parameters. (8)	Experts							Final evaluation (9)	Numerical Meaning. (10)
	1	2	3	4	5	6	7		
x1 and x2	<	<	<	<	<	<	<	<	0.5
x1 and x3	<	<	<	<	<	<	<	<	0.5
x1 and x4	<	<	<	<	<	<	<	<	0.5
x1 and x5	<	<	>	<	<	>	>	<	0.5
x1 and x6	<	<	<	<	<	<	<	<	0.5
x2 and x1	>	>	>	>	>	>	>	>	1.5
x2 and x3	<	>	>	>	>	>	>	>	1.5
x2 and x4	>	>	>	>	>	>	<	>	1.5
x2 and x5	>	>	>	>	>	>	>	>	1,5
x2 and x6	>	>	>	<	>	<	>	>	1.5
x3 and x1	>	>	>	>	>	>	>	>	1.5
X3 and x2	>	<	<	<	<	<	<	<	0,5
X3 and X4	>	<	<	>	>	>	<	>	1,5
X3 and X5	>	>	>	>	>	>	>	>	1.5
X3 and X6	>	<	>	<	>	<	>	>	1,5
X4 and x1	>	>	>	>	>	>	>	>	1.5
X4 and x2	<	<	<	<	<	<	>	<	0,5
X4 and x3	<	>	>	<	<	<	>	<	0,5
X4 and X5	>	>	>	>	<	>	>	>	1,5
X4 and X6	<	>	>	<	>	<	<	<	0,5
X5 and x1	>	>	<	>	>	<	<	>	1,5
X5 and x2	<	<	<	<	<	<	<	<	0,5

Continuation of Table 4.4

8	1	2	3	4	5	6	7	9	10
X5 and x3	<	<	<	<	<	<	<	<	0,5
X5 and X4	<	<	<	<	>	<	<	<	0,5
X5 and X6	<	<	<	<	<	<	<	<	0,5
X6 and x2	<	<	<	>	<	>	<	<	0,5
X6 and x3	<	>	<	>	<	>	<	<	0,5
X6 and x4	>	<	<	>	>	>	>	>	1,5
X6 and x5	>	>	>	>	>	>	>	>	1,5

Table 4.5 – Calculation of the weight of the PP parameters

Previous meters xi	Parameters xj							The first step	
	x1	x2	x3	x4	x5	X6	X7	b_i	$K_{(v)}$.
x1	1	0,5	0,5	0,5	1,5	0,5	1,5	6	0,146
x2	1,5	1	1,5	1,5	1,5	1,5	0,5	9	0,22
x3	1,5	1,5	1	1,5	1,5	0,5	0,5	8	0,195
x4	1,5	1,5	0,5	1	0,5	0,5	1,5	7	0,171
x5	1,5	0,5	1,5	0,5	1	0,5	0,5	6	0,146
X6	0,5	1,5	0,5	0,5	1,5	1,5	1	5	0,122
In general:								41	1

As you can see from the table, the difference in weighting coefficients does not exceed 2%, so no more iteration are required.

4.4 Analysis of options for implementing functions

Options:

- F1a + F2 + F3 + F4 - data acquisition by thermal imager
- F1b + F2 + F3 + F4 - data acquisition with a dense lamp.

Let's calculate the quality indicators of the PP using formula 4.2:

$$K_я(j)=\sum_{i=1}^{n} K_{bi\,j} B_{ij} \tag{4.3}$$

The results of the calculations are presented in Table 4.6.

Table 4.6 – Calculation of quality indicators for options for implementing the main functions of the PP

Main function	Option. realizations	Scoring of the parameter	Parameter weighting factor	Quality factor
F1	A	10	0,146	1,46
	Б	8	0,22	1,76
F3	A	7	0,195	1,365
F2	A	6	0,146	0,876
F4	A	5	0,122	0,61

According to the table and formula 4.2 and Fig. 4.5, we determine the quality level indicator for each of the PP options.

K_y1 = 1.46 + 1.365 + 0.876 + 0.61 = 4.3; (4.4)

K_y2 = 1.76 + 1.365 + 0.876 + 0.61 = 4.6 (4.5)

4.5 Economic analysis of software product development options

All two options include 4 tasks each. Moreover, for each option, three tasks will be common.

For the first task of option (a), based on the time standards for tasks of a calculating nature of the degree of novelty B and the complexity group of the algorithm 1, the labour intensity T_p= 64 man-days. Correction factor that takes into account the type of information used for the first task: K_{pk}= 1.02. Correction factor that takes into account the complexity of controlling the input and output information for the tasks: K_c= 1. Since standard modules are used in the development of the first task, we take this into account with the coefficient K_{st}= 0.8. The coefficients K_m and $K_{st.p}$, which take into account low-level programming and standard software development, respectively, for all tasks are 1: K_m= $K_{st.p}$= 1.

Thus, the total labour intensity of programming the first task of option (a) is equal to (K_s, K_m) and $K_{st.p}$ can be ignored):

T_o= 64 - 1.02 - 0.8 = 52.22

Let's make similar calculations for other tasks.

For the first task, option b) (the algorithm of the first group of complexity is used, the degree of novelty is A):

T_p= 90 man-days;

K_p= 1.7; K_{st}= 0.8

T_o= 90-1.7-0.8 = 122.4 man-days

For the second task (using the algorithm of the first group of complexity, degree of novelty B):

T_p= 43 man-days;

K_p= 0.72; K_{st}= 0.8;

T_o= 43 - 0.72 - 1 = 24.77.

For the third task (using the algorithm of the first group of complexity, degree of novelty B):

T_p= 43 man-days;

K_p= 0.81; K_{st}= 0.8;

T_o= 43 - 0.81 - 0.8 = 27.86.

For the fourth task (using the algorithm of the first group of complexity, degree of novelty G):

T_p= 27 man-days;

K_p= 0.49; K_{st}= 0.8;

T_o= 27 - 0.49 - 0.8 = 10.58.

Let's add up the labour intensity of the corresponding tasks for each of the four selected program implementation options to get their labour intensity:

T_I= (52.22 + 24.77 + 27.86 +10.58) - 8 = 923.44 man-hours;

T_{II}= (122.4 + 24.77 + 27.86 + 10.58) - 8 = 1484.88 man-hours;

Obviously, option I has the highest labour intensity.

The development involves one programmer with a salary of 4000 UAH. Let's determine the programmer's salary per hour:

$$C_{\text{salary}} = \frac{1*4000}{21.1 \cdot 8} = 23.8\,\text{UAH} \quad (4.6)$$

Then the salary of developers by option is according to formula (4.6):

I. S_{wage} = 23.8 - 923.44 - 1.2 = UAH 26373

II. S_{salary} = 23.8 - 1484.88 - 1.2 = 42408 UAH

Deductions for all types of social insurance according to the options:

I. C_o= 26373 - 0.42 = 11076 UAH

II. C_o= 42408 - 0.362 = 15351 UAH

Next, let's determine the cost of paying for one machine hour (C_m).

Since the computer is serviced by two specialists with a salary of 4000 UAH, with an employment rate of 0.2, we get the following for one machine:

C_d= 2 - 4000 - 0.2 = 1600 UAH

Including additional salary

S_{salary} = 1600 - (1 + 0.2) = 1920 UAH

Deductions for a single social contribution:

S_{wages} = S_{salary} - 0.362 = 1920 - 0.362 = UAH 695.04

The depreciation charges are calculated using formula (4.7) (at a depreciation rate of 25% and a computer cost of UAH 17,000):

C_a= 1.15 - 0.25 - 17000 = 4887.5 UAH

The cost of repair and maintenance is calculated using formula (4.8):

C_{rem}= 1.15 - 17000 - 0.05 = UAH 977.5

We calculate the effective hourly time fund of a PC for a year using formula (4.7):

T_{ef} = (365 - 104 - 8 - 16) - 8 - 0.9 = 1706.4 hours

Electricity costs are calculated using formula (4.6):

C_{el}= 1706.4 - 0.156 - 0.2436 - 2 = 129.7 UAH

Overhead costs:

C_{nak} = 1600 - 0.67 = 1072 UAH

Then, the annual operating costs:

C_{EX}= 1920 + 695.04 + 4887.5 + 977.5 + 129.7 + 1072 = UAH 9681.74

The cost of one machine hour of a computer will be equal:

$C_{M-G} = C_{ex}/ T_{eff}$ = 9681.74 / 1706.4 = 5.7 UAH/hour

Since in this case all the work related to the development of a software product is carried out on a computer, the cost of paying for machine time, depending on the chosen package implementation option, will be:

I. $S_{m.h.}$= 5.7 - 923.44 = UAH 5263.6

II. $C_{m.h.}$= 5.7 - 1484.88 = 8463.8 UAH

Overhead costs account for 67% of the salary:

I. S_{nak} = 5263.6 - 0.67 = 3526.6 UAH

II. C_{nak} = 8463.8 - 0.67 = 5670.7 UAH

Let's determine the cost of developing a software product by options:

I. C_{PP} = 26373 + 11076 + 5263.6 + 3526.6 = 46239.2 UAH

II. C_{PP} = 42408 + 15351 + 8463.8 + 5670.7 = 71893.5 UAH

Choosing the best option for a software product technical and economic level

The coefficient of technical and economic level is calculated by formula (51):

$K_{TER}1 = 4.3 / 46239.2 = 9.3 - 10^{-5}$;

$K_{TER}2 = 4.6 / 71893.5 = 6.4 - 10^{-5}$;

As a result of the calculation of the efficiency criterion, the first option for implementing the program, using a thermal imager with a technical and economic level coefficient $K_{TER}1 = 9.3\text{-}10^{-5}$, is the most effective.

Conclusions to Section 4

According to the results of the calculations, the most cost-effective implementation option is the first option: F1a + F2+ F3+F4.

Based on a comparative analysis of the options for implementing the functions by their advantages and disadvantages and the weighting coefficients of the program parameters, two options for implementing the functions were selected. The first option is the most effective. Since it has the highest technical and economic level, it is the best option for developing a software product based on the data captured by the thermal imager.

The development of an algorithm for diagnosing vision using thermograms does not require large expenditures. The algorithm is used on a PC by a programmer, and calculations are made based on the results already obtained. Implementation is not time-consuming and can pay for itself from an organizational point of view.

GENERAL CONCLUSIONS

In this paper, a new method of vision diagnostics - using thermography - was considered and investigated. After all, the analysis of thermal processes allows to obtain a variety of information about the state of the object of study and the course of physical processes in many areas of human activity.

A study was conducted using two thermal imagers and data taken from 9 people with different visual conditions, and a special program was created in MatLab to process thermograms. The results were confirmed by the real values obtained by other existing diagnostic methods used in medicine today.

The results of the study showed that the comparison of the results obtained by FLIR and processed in MATLAB and FLIR QuickReport shows their coincidence, which is reflected in the typical shape of the temperature field over the entire area of the two eyes and in the area of the eyeball around the pupils, as well as in the values of the absolute temperature difference, which coincide for the IR images processed in MATLAB and FLIR QuickReport.

This shows that the methods of IR image processing performed by MATLAB can be used to analyse thermograms.

Processing of the temperature relief allows detecting "temperature equilibrium areas" in which the temperature difference C-T-V between the average temperature in the area and the average temperature of the entire profile can vary from 0.027°C to 0.016°C. To assess the presence or absence of pathology in the eye area, the temperature index I-T-V is proposed, which in the "temperature equilibrium" areas has a value of 0.9 and 0.3. It is assumed that if the index value does not exceed 0.55, this indicates the absence of pathology in the area of the eye under study.

A plan for the thermography room was developed. Since the room is intended for thermography, we calculated all the dangerous and harmful production factors.

The software and hardware does not require large financial costs for implementation, is not labour intensive, and can pay for itself from an organizational point of view.

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APPENDIX A

A program for analysing the difference between the absolute values of the radiation intensity of a region:

```
fmin01 = 66.2;
fmax01 = 96.8;
filename01 = 'IR000443_L.jpg';

fmin02 = 66.2;
fmax02 = 96.8;
filename02 = 'IR000443_R.jpg';

fo = 5/9;
tmin = fo*(fmin01 - 32);
tmax = fo*(fmax01 - 32);
kt = 256/(tmax - tmin);

[img, map] = imread(filename01,'JPG');
ndims(img);
xImage = [-0.1 0.1];              %# The x data for the image corners
yImage = [0.1 -0.1];              %# The y data for the image corners

% figure(1);
% hold on; %# Add to the plot
% image(xImage,yImage,img); %# Plot the image
% title('Color Heat Map');

% imtool(img,map); %# Plot the image
% title('Pixel Map');

kr = 0.299;
kg = 0.114;
kb = 0.587;
[m01,n01,k01] = size(img);
F = zeros(m01,n01);
T01 = zeros(m01,n01);                 %# Preallocate matrix
for x = 1:m01
    for y = 1:n01
        F(x,y) = (kr * img(x,y,1))+(kg * img(x,y,2))+(kb * img(x,y,3));
        if (F(x,y) <= 0.0)
            F(x,y) = 0.01;
        end
        T01(x,y) = tmin + F(x,y)/kt;
    end
end

% figure(6); %# Plot of peaks the image
% hold on;
% load clown
% surface(peaks,T01,...
% 'FaceColor','texturemap',...
% 'EdgeColor','none',...
% 'CDataMapping','direct')
% colormap(map);
% title('Peaks Heat Map');

figure(7);                         %# Plot the image
hold on;
```

```
load clown
surface(T01,...
   'FaceColor','texturemap',...
   'EdgeColor','none',...
   'CDataMapping','direct')
colormap(map)
view(size(T01,1),size(T01,2));
title('Temperature Heat Map');

% Write data to file
fid2 = fopen('C:\Temp\temperature01.txt','w');
dlmwrite('C:\Temp\temperature01.txt', T01, 'delimiter', '\t', ...
         'precision', 6)
fclose(fid2);

fo = 5/9;
tmin = fo*(fmin02 - 32);
tmax = fo*(fmax02 - 32);
kt = 256/(tmax - tmin);

[img, map] = imread(filename02,'JPG');
ndims(img);
xImage = [-0.1 0.1];                %# The x data for the image corners
yImage = [0.1 -0.1];                %# The y data for the image corners
% figure(8);
% hold on; %# Add to the plot
% image(xImage,yImage,img); %# Plot the image
% title('Color Heat Map');

% imtool(img,map); %# Plot the image
% title('Pixel Map');

kr = 0.299;
kg = 0.114;
kb = 0.587;
[m02,n02,k02] = size(img);
F = zeros(m02,n02);
T02 = zeros(m02,n02);               %# Preallocate matrix
for x = 1:m02
    for y = 1:n02
        F(x,y) = (kr * img(x,y,1))+(kg * img(x,y,2))+(kb * img(x,y,3));
        if (F(x,y) <= 0.0)
            F(x,y) = 0.01;
        end
        T02(x,y) = tmin + F(x,y)/kt;
    end
end

% figure(9); %# Plot of peaks the image
% hold on;
% load clown
% surface(peaks,T02,...
% 'FaceColor','texturemap',...
% 'EdgeColor','none',...
% 'CDataMapping','direct')
% colormap(map);
% title('Peaks Heat Map');

figure(10);                           %# Plot the image
hold on;
load clown
surface(T02,...
   'FaceColor','texturemap',...
```

```
    'EdgeColor','none',...
    'CDataMapping','direct')
colormap(map)
view(size(T02,1),size(T02,2));
title('Temperature Heat Map');

% Write data to file
fid2 = fopen('C:\Temp\temperature02.txt','w');
dlmwrite('C:\Temp\temperature02.txt', T02, 'delimiter', '\t', ...
         'precision', 6)
fclose(fid2);

T0R = fliplr(T02);                  %# Returns Matrix with columns in the left-
right
[m02,n02] = size(T0R);
if (m02 > m01)
    m0 = m01;
else
    m0 = m02;
end
if (n02 > n01)
    n0 = n01;
else
    n0 = n02;
end

T0D = zeros(m0,n0);
for x = 1:m0
    for y = 1:n0
        T0D(x,y) = abs (T01(x,y) - T0R(x,y));
    end
end

figure(11);                          %# Plot the image
hold on;
load clown
surface(T0D,...
    'FaceColor','texturemap',...
    'EdgeColor','none',...
    'CDataMapping','direct')
colormap(map)
view(size(T0D,1),size(T0D,2));
title('Temperature Heat Map');

% Write data to file
fid2 = fopen('C:\Temp\d0temperature.txt','w');
dlmwrite('C:\Temp\d0temperature.txt', T0D, 'delimiter', '\t', ...
         'precision', 6)
fclose(fid2);

m = round(m0/4);
n = round(n0/4);
T4D = zeros(m0-2*m,n0-2*n);
for x = 1:(2*m)
    for y = 1:(2*n)
        T4D(x,y) = abs (T01(x+m,y+n) - T0R(x+m,y+n));
    end
end

figure(12);                          %# Plot the image
hold on;
load clown
surface(T4D,...
```

```
   'FaceColor','texturemap',...
   'EdgeColor','none',...
   'CDataMapping','direct')
colormap(map)
view(size(T4D,1),size(T4D,2));
title('Temperature Heat Map');

% Write data to file
fid2 = fopen('C:\Temp\d4temperature.txt','w');
dlmwrite('C:\Temp\d4temperature.txt', T4D, 'delimiter', '\t', ...
         'precision', 6)
fclose(fid2);
```

APPENDIX B

Using modern thermal imaging for medical applications