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APPLICATION OF THERMOGRAPHY IN UKRAINE



The review presents the results of applying the thermography to the diagnosis of tumors, vertebral pain of athletes, vascular lesions, joint trauma, maxillofacial pathology, the study of battery pathogenic effect mechanisms in biologically active environment, the study of heterogeneity of thermal fields in newborn incubators, and to the simulation of pollutant propagation in ecology. On the basis of Ukrainian R&D, the domestic industry has ensured the production of thermal imaging devices for military purposes. Wide application of thermal imaging thermography in Ukraine gives cause for anticipating a comprehensive development of this direction.

Keywords: thermography, thermal imaging, medicine, instrumentation, and military equipment.

Thermal radiation was discovered in 1800 by William Gershel, an English astronomer who dubbed it «*infrared radiation*» (IR), that is radiation which is outside the red margin of the visible spectrum. The first «thermal picture» was named «*thermogram*» and this term is also used in contemporary literature, too.

In the clinical practice, the thermographic method was first applied by a Canadian surgeon, Dr *Raw Lawson* back in 1956. He was also the one to apply the military night vision device to conduct early stage diagnostics of the malignant breast cancer in women which became a trigger to medical thermography. Probability to discover this pathology (especially in its early stages) was at about 60–70% at that time which, if the examinations were of mass character, justified the economic benefits of thermovision [1, 2].

From the moment the IR radiation was discovered by the scientific researchers, a great number of studies have been conducted into thermogra-

phy focusing on its nature from the surface of biological objects (BOs) and usage of these specifics to diagnose various pathologies [2–11].

In Ukraine, the first thermal imaging researches were conducted back in the 1970s by Professor *A.I. Pozmohov* of the Kyiv Scientific and Research X-Ray Imaging and Radiology Institute of the Academy of Medical Sciences of Ukraine on a thermal imaging device equipped with a Raduha type cooling system; in addition to this, a school of clinical thermal diagnostics existed up till mid-1990s, founded by the academicians, *O.F. Voizianov* and *L.H. Rosenfeld*.

There are also well-known theoretical researches and generalisations made by the authors' team based at the Department of Physics and Technology of Low Measuring Systems of the Lashkariov Institute for Semiconductor Physics of the National Academy of Sciences of Ukraine headed by Corresponding Member of the National Academy of Sciences of Ukraine, *F.F. Syzov*, working together with the specialists of the Vierkin Institute of Physics and Technology of Low Temperatures of the National Academy of Sciences of

Ukraine (city of Kharkiv). In 2003, thermal imaging studies were commenced for medical purposes that were using a range of photo recipient sensors [12–14], whereas subsequently, a matrix tomograph has been developed [15]. But subsequently, this team's researches have been reoriented to the studies in the THz-band of radiation [16].

An interesting development has been prepared by specialists from the Galkin Donetsk Institute of Physics and Technology of the National Academy of Sciences of Ukraine; it foresaw obtaining of a thermogram by way of resorting to a matrix scanner [17]. This work was introduced in medical facilities of Donetsk where it showed adequate efficiency in the course of diagnosing of tumours whereas the cost price of the subject device was dozens of times cheaper than that of a contactless thermal imaging device. Due to the War in Eastern Ukraine, this institution relocated to Kyiv. For reasons not depending upon the developers, further work on production and implementation of a contact thermograph was suspended.

Regardless of the large number of academic monographs, articles, and other published texts on medical IR thermal imaging and also notwithstanding the availability of the methods of thermal imaging diagnostics in medical protocols, there was no complete understanding and verification of the applicability of the subject method for biomedical assignments alongside the already existent methods of functional diagnostics so far.

This is largely due to the fact that first generation thermographs, imperfect as they were, have slowed down the development and implementation of thermal diagnostics as a clinical practice and have been sharply rejected by physicians who do not accept them today as well. The first devices were spacey and heavy and required special conditions for maintenance and storage; they also lacked the thermogram processing options almost entirely [18]. All of the above required the service personnel to possess additional knowledge and skills in the interpretation of the thermal images.

Methods of X-ray diagnostics that are widely used in contemporary biomedical researches are based upon the usage of electromagnetic radiation of the energetic spectrum on the basis of a single physical parameter. For example, in the course of X-ray imaging and magnetic resonance imaging is a coefficient of absorption of X-rays. One technique that has become widespread is ultrasound diagnostics influenced by echogenicity (ability to bounce an echo) of in matters. X-ray radiography, MRI and Ultrasound diagnostics are characterised by a range of benefits as well as defects and thus differ in terms of certain boundaries of diagnostic capacities: all of the above require external radiation sources to be applied which influence the biological object in a certain way.

The method of medical infrared thermography is a noninvasive and nonradioactive diagnostic instrument for control and analysis of physiological function of bioobjects. This unique technology is also being applied to detect and localise thermal anomalies. Almost at all pathological conditions, a change in temperature is the firstmost symptom emerging that points to a disruption in the organism. Temperature reactions, due to their universal nature, are emerging during all types of diseases: bacterial, virus, allergic, nervous, mental, and others [2, 19].

The present level of development of thermal imaging technology enables specialists to perform a broad range of diseases (up to 150 various forms) which is a cause for active implementation of thermal imaging as a clinical practice accepted by physicians worldwide: mammography, CT imaging, MRI, Ultrasound diagnostics [1, 3, 20].

As of the present day, the main reason for the fact that this method of diagnostics is not being implemented in practice is the fact that there is no corresponding equipment produced in Ukraine whereas foreign thermal imaging devices are too expensive. It should be noted, however, that in general terms, as far as nondestructive testing of the condition of technical equipment using thermal imaging diagnostics methods, Ukraine holds leading positions in Europe whereas with regard

to technical areas of application, our country is an active member of the European Federation for Non-Destructive Testing (EFNDT) and the International Committee for Non-Destructive Testing (ICNDT) [21]. One new direction in Ukrainian thermal imaging was a study into the influence of the temperature factor upon the errors of precise photoelectric devices [22–24].

In the long-term studies that have been conducted jointly within the framework of the agreement on scientific and technical co-operation signed between National Technical University of Ukraine *Kyiv Polytechnic Institute* (NTUU KPI) and the V.Ye. Lashkariov Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine (ISP of NASU), a thermal imaging database has been put together containing data on widespread human diseases.

The basic facility for joint scientific researches is the interchair scientific and training laboratory of noninvasive bioobject research methods at NTUU KPI where, using the IR thermal imaging method, over a thousand individuals of various age groups gave undergone testing and over five thousand thermograms of various pathological conditions have been obtained. In addition to the above, the aforementioned lab holds training and prediploma practical lessons for NTUU KPI students specialising in corresponding areas.

In the course of the studies, we have used IR thermal imaging devices with two spectral bands:

- 1) the thermal imaging device has been jointly produced by the ISP of NASU by a team led by *Ye.F. Venher*, principal executor – *O.H. Kollukh*), Institute for Single Crystals of the National Academy of Sciences of Ukraine (ISC of NASU) and the Elektron-Optronik company from Russia; the device had a cooling matrix, 320×280 elements on the basis of Schottky diodes with a temperature sensitivity at least $0.07\text{ }^{\circ}\text{C}$ (observation and supervision of thermal fields using this thermal imaging device were taking place in the range between $3\mu\text{m}$ to $5\mu\text{m}$);

- 2) the ThermaCAME300 thermal imaging device produced by FLIRSystems (USA) with an

unrefrigerated matrix from chromium-vanadium micro-bolometers, dimensions 320×240 and a temperature sensitivity at $0.1\text{ }^{\circ}\text{C}$ (used to conduct studies in the $8\text{ }\mu\text{m}$ – $14\text{ }\mu\text{m}$ range).

TUMOURS

As informed by the Institute of Oncology of the Academy of Medical Sciences of Ukraine [25], this pathology is the main mortality causes among women. The mortality per 100,000 women is 1.5 to 2 times higher in Ukraine than it is in developed countries and this tendency is not decreasing.

One of the possible ways to resolve this problem is to apply thermal imaging diagnostics. Being a noninvasive method, IR thermal imaging becomes extremely important during mass examinations with the purpose of early diagnostics of breast tumours. Thermal imaging ‘sees’ not the structures but the physical processes taking place in the body. This is why its application allows to detect the tumour process in its initial stages when the physical body of the tumour when the physical body of the tumour is extremely tiny [26] – this allows to draw the attention of the patient to the threat of tumour development sooner than is the case with ultrasound diagnostics.

VERTEBROGENIC PAIN IN SPORTSPERSONS

The most widespread complaint among sportspersons is the pain experienced in various sections of the vertebral column (the so-called *vertebrogenic pain* caused by osteochondrosis that are rapidly decreasing the activity, deteriorate the sports results and also, quite often, cause temporary disability [27, 28].

In addition to clinical or the so-called *objective method* of examination of patients suffering from vertebrogenic pain, the most available and widely applied method is still the *X-ray diagnostics*. Unfortunately, the only information it is able to provide is the condition of the bone component of the vertebral column. The CT imaging and MRI provide more extensive diagnostic possibilities by delivering information about the soft tissue

component as well. However, the increased dose of radiation at CT and the substantial cost of examination with the MRI method often precludes the application of both methods during the examination of the same patient. Our thermal imaging examinations of patients experiencing signs of pathology enabled us to detect such things as, for instance, acute thoracalgia and chronic lumbodinia at peak stages. The non-uniform distribution of temperature in corresponding areas amounted to 2 °C.

VASCULAR MALFORMATIONS

A thermogram of a patient with a varicose modified vena saphena magna of the left thigh (see arrow pointing) is shown at drawing *a*. The temperature difference versus the symmetrical area of the right thigh amounts to 3.2 °C [28–32].

The drawing *b*, shows a thermogram of lower extremities of a patient who had voiced no complaints but during his examination, a temperature reduction down to 28 °C has been detected (see arrows pointing) as compared to a relative standard value of 32.5 °C. In addition to this, oscillometry and microangiography of foot vessels has also been conducted which revealed functional deficiency of blood circulation to distal areas.

TRAUMAS TO JOINTS

The examinations have also been undergone by sportspersons who have suffered injuries in the course of training exercises [33, 34]. The margins of fluctuations that are rather blurred have been detected clinically: this made the process of extraction of a haematoma quite complicated. In the course of thermal imaging examination, a local area of temperature increase up to 38 °C has been detected with a temperature gradient of 4 °C: this substantially facilitated further therapeutic treatment activities. A positive result was also obtained owing to a thermogram of the female patient who voiced complaints peculiar to those during damages to the medial meniscus of the left joint. The temperature difference at the frontal surface of the knee joint amounted to 1.2 °C.

DENTO-FACIAL PATHOLOGIES

The IR imaging procedure can also be successfully used during the diagnostics of various diseases of the dentofacial area [35]. In a separate case, a female patient with a malignant pleomorphic adenoma of the right subauricular gland had a thermogram done which showed a hypothermal zone.

A pleomorphic adenoma of the subauricular gland, even if it is in its benign stage, has, just as any other tumour, an adjacent «infiltration area» having its own anomalous (hypothermic) field. As it transforms into a malignant tumour, the temperature and the dimensions of the «infiltration area» increase, as the process grows into the nearest lymph glands and so on. After the adenoma is removed, the anomalous thermal field of the adjacent regions undergoes changes whereby, following the surgical operation, the temperature of tissues adjacent to the suture may even exceed the temperature of the preoperative «infiltration area»; this temperature will gradually be decreasing as the suture is healing. After the surgical extraction of the adenoma, the gradient of the thermal asymmetry reduced from 1.9 °C to 1.2 °C and, during the subsequent observation (in the course of treatment measures taken) it continued to fall down.

During the thermal imaging examination of fifty individuals, ten of them have shown different temperatures of left and right eye pits. The temperature gradient was within the 0.7 °C to 1.7 °C range (in healthy individuals, this value usually does not exceed 0.2 °C to 0.4 °C) which urged the specialists to proceed with additional examinations in order to ascertain a precise diagnosis.

Thus, the examinations that have been conducted have shown that application of the cutting edge IR thermal imaging devices in health care widens the possibilities for diagnostics of various human diseases as well as preventive health care measures that may be taken. The IR thermal imaging procedure enables one to dynamically observe and control the efficiency of treatment, to oversee the healing of wounds at

various stages of morphogenesis and thus creates a possibility to prevent the development of further exacerbations.

STUDIES INTO THE MECHANISM OF PATHOGENIC IMPACT OF THE BATTERY

Another problem pending resolution in health care globally is the issue of electrochemical burn of the oesophagus in children as an exacerbation caused by the presence of a foreign body in its opening – that is, the power source; a round battery, \varnothing 20 mm to 30 mm [36].

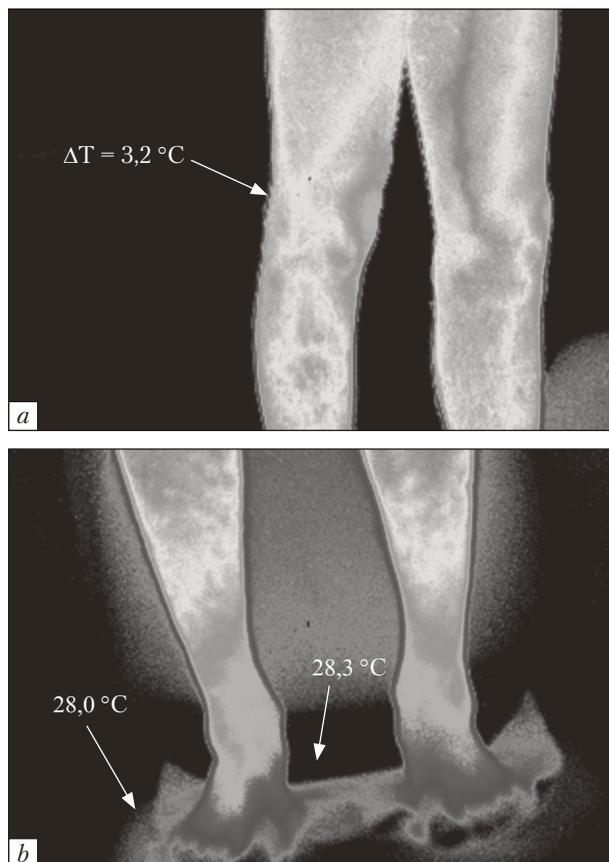
Considering the tendency towards rapid increase of such instances, the severe character of damage related to the peculiarities of distribution of electric currents in liquid conductive environment surrounding the power source, the authors have attended to a request made by the medical specialists [36] and conducted an analysis of the mechanism of pathogenic impact of the power source detected in the oesophagus with the IR procedure in order to be able to take technical decisions which would either minimise or totally eliminate the risk of electrochemical burns of oesophagi in children.

In order to obtain an experimental confirmation of theoretical calculations, an observation has been conducted with an IR thermal imaging device operating in the $8\ \mu\text{m}$ to $14\ \mu\text{m}$ range which has proven that a power source moistened with a diluted solution of hydrochloric acid (similar to the gastric acid), its temperature in the «critical area» increased by $3\ ^\circ\text{C}$ to $4\ ^\circ\text{C}$.

This study concluded with a statement that electrochemical burns are taking place in an area with increased chemical activity that is determined by the electrical field and constructive specifics of a power source.

STUDIES INTO NON-UNIFORM NATURE OF THERMAL FIELDS OF INFANT INCUBATORS

Jointly with the National Medical Academy of Postgraduate Education of the Ministry of Health of Ukraine, Lviv Danylo Halytskyi Natio-



Thermal images of patients having vascular diseases: *a* – varicosity of great saphenous vein of left hip; *b* – disorder of blood supply to the distal organs

nal Medical University and a private company, *N. Z. TEKHNO* (a Ukrainian representative office of *FISHER&PAYKEL*, an Austrian company, supplying intensive care equipment to Ukrainian locations), thermal imaging studies of thermal fields have been conducted in newborn infants with small and extremely small birth weight that are placed in infant incubators [37]. Such children tend to lose warmth to three times faster than the full-term newborns. In addition to this, a newborn loses warmth five to seven times faster than a grownup human being due to larger body area to mass ratio.

The above facts influence substantial warmth losses experienced by premature newborns residing in a closed type infant incubator.

The problem is that, in the intensive care and treatment of newborn infants, the medical personnel conducts various manipulations which necessitate opening of the incubator windows or its manipulation ports from time to time, and this causes sharp decreases of temperature inside the incubator. As a result of this, first and foremost, the infant body temperature decreases and the air humidity inside the incubator goes down, leading to body hypothermy and an increase in the need for O₂ for proper metabolism, and if the child receives oxygen therapy at the same time, the content of O₂ also goes down, leading to a loss of such a newborn.

With an IR thermography, an examination has been conducted of three types of incubators (due to the confidential nature of information, the producer will not be named) in order to compare temperatures indicated in the documentation for the user versus the actual operating temperatures.

Prior to the commencement of the studies, in order to maintain the experimental integrity, a temperature of 34.5 °C was set (specified). Then, using an IR thermograph operating in the range of 8µm to 14µm, in real time mode, thermal images of the mentioned incubators have been made and a custom software has been used to conduct thermal cross sections all along the upper and the lower parts respectively. A perfect outcome would have been if both the upper and the lower parts of the incubators would have shown the specified temperature, 34.5 °C – this would have testified to temperature uniformity of the internal environment.

A crucial aspect is the support of the thermal mode in the lower part of the incubator which is the actual location of the infant. In all models of incubators, the stream of heated air starts moving from the left part to the right and infants are placed with their head facing to the left, as stipulated by the instruction. If the incubator fails to maintain the specified (set) temperature, the newborn infant's head warms up faster and his legs warm up slower and cool down faster. The non-uniform warming up of the incubator sub-

stantially influences the general temperature of the newborn that is inside the chamber.

The results of temperature studies have enabled the specialists to ascertain which layout of an incubator is the best for uniform warming up. Following the results of the studies, corresponding recommendations have been provided to medical personnel to prevent cooling of premature infants by way of additional controls of the internal environment temperature which may or may not comply with the presets.

The materials of the studies have also been used in the protocols of in-patient departments of maternity clinics and special care nurseries at child health clinics.

THERMAL IMAGING STUDIES FOR SIMULATION OF THE DISSIPATION OF CONTAMINATIVE SUBSTANCES

In the process of studies into contamination of water reservoirs with industrial and household waste, its dynamics, particularly the stratification of the contaminated water and its movement, is a crucial issue. The contaminated components often have an increased temperature as compared to the temperature in the water reservoir. In this case, it is also necessary to solve the problem of heat exchange. We have conducted studies [38] into the distribution process of a 20% solution of NaCl that was heated up to the temperature of 60 °C whereby the closed-type water reservoir was contaminated by it. In order to conduct a simulation, an aquarium filled with freshwater was taken as a model for a closed-type water reservoir. The salt solution enabled the application of thermal imaging to study the process of distribution of the salt solution in the aquarium. The selection of the aforementioned salt was caused by the fact that in winter, it is the main component used by municipal services as they combat icing and snow coverage in the streets. This saline mix eventually gets into the water reservoirs. The urgent necessity of the results obtained is explained by the fact that water-soluble salts are used by municipal services in wintertime to com-

bat frost formation on the footways and the roads. These contaminations eventually get into the water reservoirs where, as our studies have revealed, they sedimentate on the bottom and block micro organisms that are cleaning the water reservoirs naturally. Thus, the researches have shown that it is necessary to use not the water soluble reagents but (if possible), tiny fraction gravel stones which may be collected next spring and recycled for usage in the subsequent wintertime.

THE THERMAL IMAGING DEVICES FOR THE MILITARY

The night vision devices are among the most important items of military equipment. Successful application of night vision equipment made war in night time a feasible option for the military. The image quality of night vision devices depends on the temperature contrast between the target and its background. In early 1980s, most of the Western armies began to introduce thermal imaging devices as part of their military equipment. As compared to the preceding generation of the night vision devices (observation and aiming devices), thermal imaging devices substantially increased the combat capacities of the equipment in night time; they also allowed to resolve the masking problem in the IR range of the radiation. The principal element of thermal imaging devices is an IR radiation received reacting to the thermal field of the object. If this field has non-uniform temperature, the radiation flux falling down onto the receiver undergoes changes and transforms into an electrical signal that is amplified and displayed as an image on the monitor screen [39–41]. Thus, thermal imaging devices enable to conduct observation of the mildly warmed up objects and discern them, thus the issue of masking and discerning of military equipment for protection of the said equipment from precision-guided weaponry is a pressing matter, albeit quite a challenge. First and foremost, both the optical and the thermal imagery substantially depend upon the angle of observation of the object. A reduction in the probability of detection of the military equipment that

needs to be defended is achieved by its masking that is reduced primarily to a modification of its silhouette and contours to match the surroundings (camouflage paint, masking with leaves, branches etc). For example, application of the «*barrier*» coating enables to reduce the thermal imaging contrast of the masked object [42].

Their high cost notwithstanding, thermal imaging devices have been widely accepted and received by the military as an observation device and a part of guidance systems. In Ukraine, technologies and optical materials required to produce night vision devices with electro-optical transducers and low-light TV cameras have been implemented and are produced by *Fotoprylad NVK* Research and Production Facility. One important step towards the increase of the range of operation in night time was the application of thermal imaging systems. Particularly widespread application has been enjoyed by thermal imaging systems operating in $3\mu\text{m}$ to $5\mu\text{m}$ and $8\mu\text{m}$ to $12\mu\text{m}$ spectral bands; this is due to the existence of the transparency windows in the atmosphere that exist within the aforementioned spectral ranges and also due to the availability of optical materials such as germanium, zinc selenide, leucosapphire, gallium arsenide, optical ceramics that are required for these spectral bands.

Night thermal imaging channels of the aiming devices using non-refrigerated microbolometric matrices of various formats (324×256 , 640×512 and oth.) have allowed to reach the distance of up to 2000 m – 2500 m with the accepted dimensions of optical devices. Substantial increase in the range capability was achieved owing to the application of cooled matrix photodetectors operating in the $3\mu\text{m}$ to $5\mu\text{m}$ and $8\mu\text{m}$ to $12\mu\text{m}$ spectral ranges.

Fotoprylad NVK Research and Production Facility, together with the V. Ye. Lashkariov Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine (ISP of NASU), have managed to resolve a set of issues including:

- ✦ development and commencement of production of optical germanium with enhanced optical characteristics;

- ✦ development of adhesive compositions with nano-admixtures;
- ✦ development and introduction of methods of processing of germanium optical details;
- ✦ development of optical surfaces that would allow to increase the light transmission factor of optical elements and increase in the resilience with regard to external impacts.

Thermal imaging aiming devices developed by *Fotoprylad NVK* Research and Production Facility: *Buran-Matis*, *Buran-Katrin* (PTT-2), *Skat-M*, *PNK-6*, *Spektr* allow to detect objects located as far away as 10 km, discern them from a distance of 5 km to 8 km, and identify them at a distance of up to 4 km; the devices are successfully used in the currently ongoing Anti-Terrorism Operation in Eastern Ukraine.

CONCLUSION

Widespread usage of thermal imaging in miscellaneous areas of activity in Ukraine allows one to come to a conclusion that in the nearest coming years thermal imaging will undergo a rapid development under the influence of cutting edge 21st century information technologies.

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ЗАСТОСУВАННЯ ТЕРМОГРАФІЇ В УКРАЇНІ

В огляді наведено результати застосування в Україні термографії для діагностування новоутворень, вертеброгенного болю у спортсменів, судинних патологій, травм суглобів, щелепно-лицьової патології, дослідження механізму патогенної дії елементу живлення у біологічно-активному середовищі, дослідження неоднорідності теплових полів інкубаторів для новонароджених, моделювання в екології процесів розповсюдження забруднюючих речовин. На основі власних розробок вітчизняна промисловість забезпечила виробництво тепловізійних приладів для вирішення військових задач. Численне й різноманітне застосування тепловізійної термографії в Україні дозволяє зробити висновок, що в найближчі роки теплобачення одержить всебічний розвиток.

Ключові слова: термографія, тепловізор, медицина, приладобудування, військова техніка.

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ПРИМЕНЕНИЕ ТЕРМОГРАФИИ В УКРАИНЕ

В обзоре приведены результаты применения термографии для диагностирования новообразований, вертеброгенных болей у спортсменов, сосудистых патологий, травм суставов, челюстно-лицевой патологии, исследования механизма патогенного действия элемента питания в биологически активной среде, исследования неоднородности тепловых полей инкубаторов для новорожденных, моделирования процессов распространения загрязняющих веществ в экологии. На основе собственных разработок отечественная промышленность обеспечила производство тепловизионных приборов для решения военных задач. Большое и разнообразное применение тепловизионной термографии в Украине позволяет сделать вывод, что в ближайшие годы тепловидение получит всеобщее развитие.

Ключевые слова: термография, тепловизор, медицина, приборостроение, военная техника.

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