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THERMOVISION IN MEDICAL AND ENVIRONMENTAL APPLICATIONS

TERMOWIZJA W ZASTOSOWANIACH MEDYCZNYCH I INŻYNIERII ŚRODOWISKA

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Abstract

Thermovision offers a wide range of possible use in many areas of science. The paper presents applications of the thermovision technology with regard to healthcare and environmental issues. Apart from the literature review it also provides experimental results of the thermal image of the foot and surface temperature distributions as well as their analyses. The article lists common errors and limitations that need to be considered during infrared measurements to avoid significant mistakes at the stage of image analysis. The issue presented in the article is especially important because of reduced costs of the thermovision systems and their widespread availability to both private and institutional users.

Keywords: thermovision, IR applications, experimental uncertainties

Streszczenie

Termowizja oferuje szeroki zakres możliwych zastosowań w wielu dziedzinach nauki. W artykule przedstawiono zastosowania techniki termowizyjnej w aspekcie ochrony zdrowia i ochrony środowiska. Oprócz przeglądu literatury artykuł zawiera również wyniki badań eksperymentalnych rozkładów temperatury oraz ich analizę. W artykule wymieniono typowe błędy i ograniczenia, które należy wziąć pod uwagę podczas pomiarów w podczerwieni, aby uniknąć znaczących błędów na etapie analizy obrazu. Zagadnienie przedstawione w artykule jest szczególnie istotne ze względu na obniżone koszty systemów termowizyjnych oraz ich powszechną dostępność zarówno dla użytkowników prywatnych, jak i instytucjonalnych.

Słowa kluczowe: termowizja, pomiary w podczerwieni, niepewności pomiarowe

1. INTRODUCTION

Thermovision is one of the most rapidly developing measuring methods today. It is commonly applied in chemical industry, energy related applications, environmental engineering, medicine and machinery diagnostics [1]. It has been made possible mostly due to the reduced costs of production and improved design.

Infrared cameras and other IR devices (such as pyrometers) are more and more available. This technology has become cheaper which, together with growing opportunities of its use in clinical applications, should lead to a more common use of thermovision in hospitals (while pyrometers have been used for many years for temperature measurements) and well as monitoring the environment. There is

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already a significant number of applications in which this technique has proven itself to be a useful and powerful tool. However, attention has to be paid to measurements both at the stage of performing tests and also during result analyses. It stems from the fact that experimental errors might have an impact on forming diagnosis or conslusions basing on infrared test results.

It also needs to be noted that temperature measurement with infrared methods is easy, precise and fast – the results are actually available in real time if a camera if equipped with a display screen (which do not happen only for some stationary systems). Moreover, it is a safe diagnostics method. Computer software (often with enhanced graphical presentation possibilities) that enables the processing of the images generated by the cameras is an additional advantage of the system. It enables to connect thermographic devices to PC computes and analyze data, perform visualizations on the screen, which are useful for preparing reports.

2. MEDICAL AND ENVIRONMENTAL APPLICATIONS OF THERMOVISION

The infrared technology can be effectively used in medicine. It has been successfully applied in tests for breast cancer and cancers of other organs. This technique enables to detect warmer spots and abnormalities which could then be analysed in detail with other techniques.

The measurements using infrared cameras can be applied in surgery and orthopaedics in order to test osteomyelitis, posttraumatic, degeneration as well as cancerous states. It can also be applied to assist in wound and fracture healing [1]. Dental applications can cover, among others, investigations of temperature changes during polymerization of composites thorough measuring infrared emissions from surfaces of resin composite restoration during photocuring [2]. Thermovision method can also be used in skin diseases to detect abnormalities. It has been successfully applied, for example, in the infection caused by Clostridium perfringens in order to observe the complete extent of the viability of tissues [3]. Recently, Mačianskytė and Adaškevičius [4] experimentally analysed the use of infrared technique to discern the presence or absence of tumors located on orofacial and maxillofacial area in patients. The authors assessed the application of a special feature vector taken from face and mouth cavity thermograms and used it for classifying the images against the possible presence of tumors. While Baic et al. [5] performed tests on women after mastectomy to verify the changes regarding temperature distribution at 12 months after the end of radiotherapy. The described technique is regarded as a tool that can replace cranial computed tomography (CCT) for screening in testing of shunt function in hydrocephalic patients. The advantage here is the fact that infrared technique a safe tool, while CCT requires radiation [6].

Badža et al. [7] focused on the detection of the injury of muscle as well as changes of the temperature of the runner's feet exposed to low temperature. Considerable hypothermia of the feet was observed. Maksymowicz [8] discussed the use of thermovision in forensic medicine and medical-legal post-mortem diagnostics. Cholewka [9] compared the infrared temperature readings with experimental data from the equipment. It was proven that infrared technique can be applied in sports medicine with the view to be used in efficiency evaluation. In [10] sixty patients were invuestigated in order to determine the usefullness of infrared technology in assessing the effects of hyperbaric O_2 therapy to wounds healing. Ivanitsky [11] discussed the mechanisms of heat generation within a body, control methods as well as the impact of the surrounding environment. Gizińska et al. [12] analysed eighty one patients ill with rheumatoid arthritis and thirty nine healthy ones. Thermovision was used to determine the surface temperature of the dorsal side of the foot. The authors reported large differences in average temperatures between the healthy and unhealthy volunteers.

Environmental applications of thermography are also quite broad. Stokowiec et al. [13] analysed temperature distribution on the surfaces of chimneys of the heat and power plant in Kielce. A similar study, but focused on the determination of the impact of the physical condition of thermal insulation of the chimney on the spread of air pollutants from it has been done by Orzechowski and Orman [14]. The tests were done on the chimney of the cement plant, which is a significant source of environmental contamination. The results indicate that the heat losses as a result of poor thermal insulation (as evidenced by thermal images) leads to the reduction in the temperature of the exhaust gases and, consequently, the solid particles in the gases fall down closer to the chimney as opposed to the situation when they travel further if the insulation is in a better state. Żygadło et al. [15] conducted research focused on the landfill site in Ostrowiec Świętokrzyski. Due to the fact that at landfills biochemical processes occur at elevated temperatures, it is possible to use thermovision for monitoring activities. The tests in the paper indicate that there is a temperature difference between the freshly supplied household waste (which proved to be warmer) and the older one (reported to be cooler). Thermal imaging proved to be a useful tool, especially that the vast areas of landfills can be covered quickly. The concept of airborne measurements has also been used in [16], where the earth's temperature was recorded over a large area. These data can be useful for environmental assessments such as plant vegetation, evaporation rates, soil humidity determination as well as energy balances of the ecosystems. Similar studies can be made over the sea surface, as presented in [17]. It can be applied to the detection of anomalies in the marine environment and climate change issues. It has been shown that waters which are isolated and shallow undergo more extreme variations in temperature than those located deeper or the coastal ocean. An important area of thermovision use is the building industry. This technique can be applied to detect areas of intense heat losses (thermal bridges) and well as humid surfaces on the outside or the inside of buildings. Antczak et al. [18] analysed two buildings located in Leszczyny near Kielce. The measurements enabled to determine the areas of heat losses to the environments – typically windows and a balcony. In the case of the latter, significant heat fluxes were observed to be exchanged with the outside air, probably due to insufficient insulation. A thorough review of the application of the infrared technique in the studies of plant – environment interactions has been presented in [19]. The authors mentioned, among others, crop protection issues as well as stress detection and its management.

3. SELECTED MEASUREMENT LIMITATIONS AND UNCERTAINTIES – EXPERIMENTAL DATA

Determination of temperature of a given object with infrared methods is based on the radiation intensity measurement, which according to the Stefan-Boltzmann law is emitted by any body whose temperature exceeds 0 K. The radiation heat flux is proportional to temperature to the forth power, emissivity (a property of a surface from 0 to 1) and the Stefan-Boltzmann's constant. Because the thermovision camera detects and processes infrared radiation energy emitted from a body, its main element is a detector. The signal from the detector is magnified and transformed into a digital signal, which can then be used to calculate temperature of individual pixels of the image.

The measurement with infrared devices is not difficult in itself, however, proper analysis of the obtain thermal map is not easy and a lot of experience is needed to correctly determine temperature of the points in the thermograph. A good insight into measurement limitations for non – destructive testing is given in [20].

The interpretation of the thermal images can be challenging and the knowledge of the physics of thermal radiation phenomenon is necessary in order to properly conclude about the thermal state of the object. Thermal radiation is a wave and it is subject to the same laws as other waves. In analyzing thermographs it is especially vital to detect if a reflection of radiation has not occurred, which impact the readings. Figure 1 presents a bottle with a hot liquid located on the reflective floor. The phenomenon of reflection of radiation (generated by the hot liquid) can be easily seen. The floor and the reflective surface behind the bottle seems to be warm, but in fact they are not. The illusion is produced because radiation is reflected from the smooth surfaces and reaches the camera. Thus, creating the wrong illusion of the elevated temperature on the surfaces behind and below the hot object.

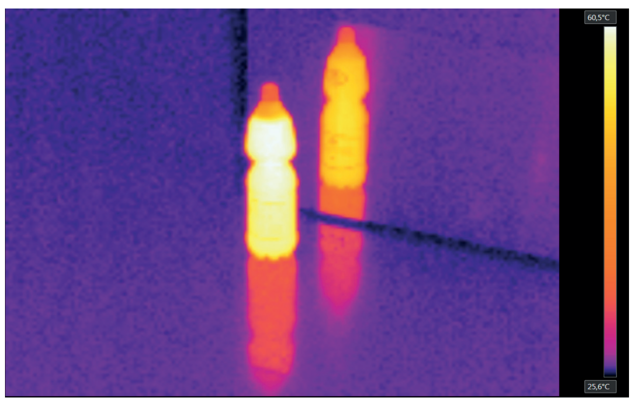

Fig. 1. Phenomenon of thermal radiation reflection – bottle filled with hot water and its reflections behind and below

Besides, it needs to be mentioned that thermal radiation travels through the medium (in our case: air) and some of it might be absorbed by carbon dioxide and water vapour which are present in the atmosphere. Thus, a reduction in the heat flux might occur (the temperature of the observed object might be lower).

One of the most important element in ensuring correct temperature testing is a precise determination

environment

of emissivity. If the incorrect value is input, then the obtained results might have a larger or smaller error. In order to deal with this problem, the contact methods of temperature measurement might be applied to calibrate the device and set the actual value of emissivity (although they might be find in literature, but those might also generate errors). However, in many applications it is usually not important to determine the temperature itself, but rather temperature differences between – for example parts of the body or cells. As an example a foot's thermal map presented (Fig. 2) with the background erased for clarity.

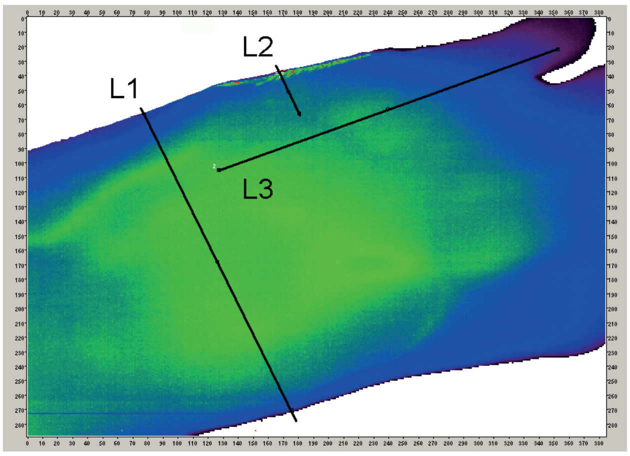

Fig. 2. Thermovision image of the foot (background was removed)

The example given above will serve as an illustration of most typical mistakes that can be made when analyzing medical infrared images. An operator who conducts thermovision tests should have in mind that the measurement of temperature on curved surfaces is governed by the Lambert law and the temperature reading might not be correct on curved surfaces, which has been shown in Figure 3 for line L1 (indicated on Fig. 2).

Analyzing Figure 3 it can be proven that temperature on the curved part just at the edge of the foot is much lower. It could be attributed to the fact that the camera can only receive part of the intensity of thermal radiation, which according to the Lambert law, changes with the angle of observation and is highest in the normal direction. Consequently, care is needed in such cases to prevent erroneous conclusions about the temperature values on the curvatures. The accuracy (errors) of the thermovision measurements are usually below 2% of the measuring range. In this case it would be maximally about 2°C, however, the proper calibration of the device enables to significantly reduce these errors.

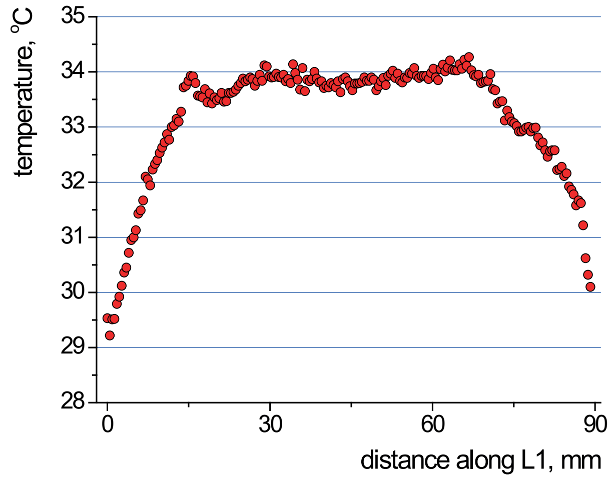

Fig. 3. Temperature distribution along line L1

Another very important limitation to be considered (partly mentioned before) is the reflection of radiation from heat sources located in the vicinity (e.g. central heating radiators). In such cases the thermovision camera receives more radiation for example from the patient's body than the body emits due to its temperature, because additional radiation is present in the signal. An example is line L2 (indicated in Fig. 2), since the radiation from the edge of the foot in this area is magnified by radiation from a nearby very hot element located about 50 cm away. Consequently, temperature distribution presented in Figure 4 has a peak, which seems much hotter than the rest of the foot. Naturally, real temperature of this area is lower.

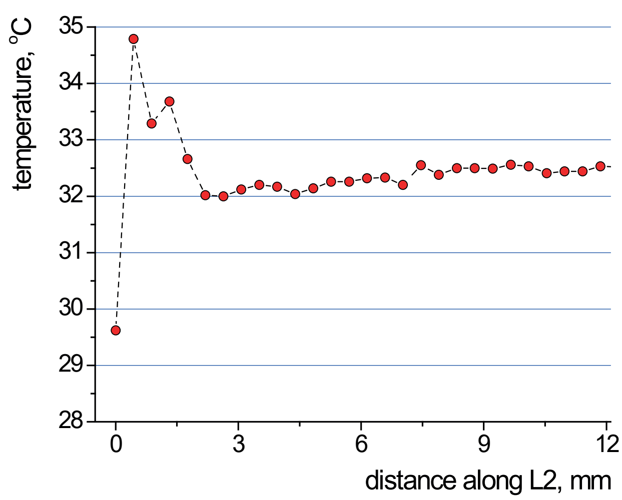

Fig. 4. Temperature distribution along line L2

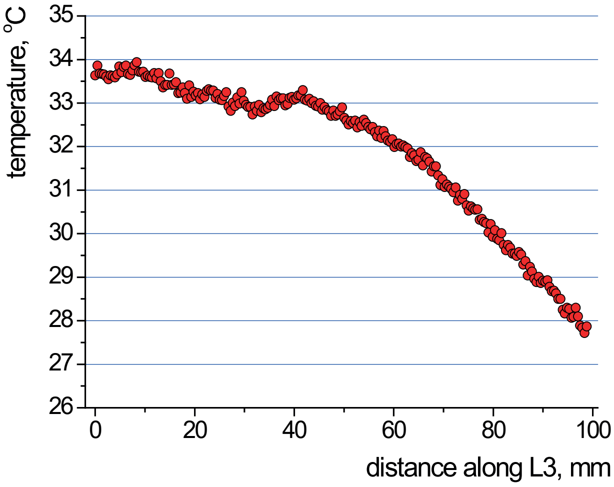

Fig. 5. Temperature distribution along line L3

It needs to be observed that Figure 2 also reveals that temperature of different parts of the body is not uniform. As can be seen below in Figure 5 toes are colder, which is undoubtedly related to the blood circulation in the body and good cooling conditions related to a high surface area subject to the colder environment of indoor air.

4. SUMMARY AND CONCLUSIONS

Precise infrared measurements require knowledge and experience. An operator needs to be aware of the reflection phenomenon, which might be a source of significant errors. Similarly an improper determination of emissivity might be a problem. Its value is always input into an infrared camera either before tests or during image analyses. An incorrect value will result in errors of temperature measurements. Thus, this value should be individually determined using contact temperature measuring methods, however, in medical and environmental applications it might be often neglected since it is the temperature difference rather than temperature value itself that is of interest during the testing.

Thermovision has many advantages over traditional methods of temperature measurement. It is non – invasive and tests results are available in real time. Its medical and environmental applications offer interesting opportunities and its use will undoubtedly increase, however, care and knowledge of experimental limitations and uncertainties are needed at the stage of analyzing thermographs in order to draw correct conclusions about the real surface temperature. Moreover, contact methods of temperature measurements might sometimes be necessary to verify the data obtained with the infrared technique.

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