APARATURA
BADAWCZA I DYDAKTYCZNA

Advantages of active over passive thermography in terms of applying in medicine

AGNIESZKA WASILEWSKA

BIALYSTOK UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF MECHANICAL ENGINEERING

Keywords: joint temperature, active thermography, passive thermography, cooling conditions

ABSTRACT:

Introduction: Infrared thermography (IT) is a remote non-invasive technique of temperature distribution measurement and is widely applied in mechanics, electronics, metallurgy, medicine.
Experimental part: 11 healthy volunteers (36% of women), mean age (28.09 (4.46)) were recruited for the study. Firstly, according to passive thermography procedure, thermographic images of left and right hand were taken. Afterwards, active thermography procedure was performed. The protocol included immersing left and right hand in ice water, separately.
Results and discussion: Active thermography is to a lesser extent dependent on environmental, individual and technical factors of temperature measurement than passive thermography. Additionally, active thermography enables temperature distribution measurement over the course of time.
Conclusions: Active thermography is superior to passive method.

Zalety termografii aktywnej wobec pasywnej z punktu widzenia zastosowań w medycynie

Słowa kluczowe: temperatura stawu, termografia aktywna, termografia pasywna, warunki chłodzenia

STRESZCZENIE:

Wstęp: Termografia w podczerwieni (IT) jest bezdotykową, nieinwazyjną techniką pomiaru rozkładu temperatury i jest szeroko stosowana w mechanice, elektronice, metalurgii, medycynie i innych dziedzinach.
Część eksperymentalna: 11 zdrowych uczestników (36% kobiet), średni wiek (28,09 (4,46)) zostało zakwalifikowanych do badania. W pierwszej kolejności, zgodnie z procedurą termografii pasywnej, wykonano zdjęcia termowizyjne lewej i prawej dłoni. Następnie przeprowadzono procedurę termografii aktywnej. Protokół uwzględniał schłodzenie oddzielnie lewej i prawej dłoni w wodzie z lodem.
Wyniki i ich dyskusja: Termografia aktywna jest w mniejszym stopniu zależna od czynników środowiskowych, indywidualnych oraz technicznych pomiaru temperatury niż metoda pasywna. Dodatkowo termografia aktywna umożliwia pomiar rozkładu temperatury w czasie.

1. INTRODUCTION

Infrared thermography (IT) is a remote non--invasive technique of temperature distribution measurement and is widely applied in mechanics, electronics, metallurgy, medicine etc. In technical industry, infrared thermography is prevalently used for non-destructive testing of material strength. In medical diagnostics, due to its harmlessness, IT is widely considered as a new alternative to expensive medical imaging techniques, e.g. Radiography and Magnetic Resonance Imaging (MRI). Pauk et al. reported that thermovision should be considered as diagnostic tool for assessing bone erosions [1]. Few authors described the use of thermovision in muscle activity assessment [2, 3]. Two different methodologies have been predominantly presented in medical and research praxis: passive and active thermography. In passive thermography, detection of tissue abnormalities or material inhomogeneities is based on statistical analysis of temperature distribution in particular region of interest (e.g. joint). Active infrared thermography enables analysis of temperature alterations in particular time interval. In this imaging method temperature registration is followed by the application of external stimulus e.g. cooling or heating. Thereafter, thermal recovery to a baseline is observed [4-6]. The great advantage of active thermography over passive method is that it depends to a lesser extent on ambient conditions [7]. Thermography has been widely used in both research and clinical areas. The use of this imaging method has been previously presented in the area of building investigation [8]. In analysis of the inside of a building, delivered energy is absorbed by examined object and the following heat flux depends on material thermal properties and its topography. Dynamic temperature changes during cooling down process allows detection of measurable temperature differences over time, thus providing diagnosis of material defects. Active thermography was also proved to be effective in beverage industry. Aoyagi et al. performed water level observation in opaque containers for beverages. The surface of container was rapidly heated by light flash and thermographic changes of temperature distribution on can surface were observed afterwards. Differences in heat flux over time enabled detecting air presence in the examined portion of beverage. The authors confirmed applicability of the method in examined field. Similarly, infrared medical diagnosis is also determined by differences in heat flux in examined area. In human body, skin temperature distribution alterations arise from changes in metabolism and local blood flow. These processes reflect physiological functions and are a source of information about localization of pathological vascularization in variety of medical conditions including inflammation, tumor, vascular diseases etc. Medical applications of active infrared thermography has been widely presented in literature. Several authors [9-11] reported its applicability for monitoring the state of tissue structure during burns treatment. Kaczmarek et al. described the use of active infrared thermography for monitoring cardio-surgical interventions [12]. Despite the use of thermovision camera which is the evident mutual feature in presented studies, all of them vary in proposed methodology. Thus, the purpose of this study was the comparison of two available methods of infrared thermography: passive version based on thermal images and active method defined by the analysis of 3 minute-thermal recovery process of hand skin temperature in healthy subjects with the use of different cooling periods.

2. EXPERIMENT

11 healthy volunteers (36% of women), mean age (28.09 (4.46)) were recruited for the study. According to declaration of Helsinki, all volunteers signed informed consent for participation in the study. Procedures were approved by Bioethical Committee of Medical University of Bialystok. None of the participants had a health condition that would impact study outcome. Study procedure included two infrared thermography methods: passive and active IR. Total number of participants was assigned for both study procedures. Passive thermography measurement was based on thermal images acquisition before application of cold stimulus, dynamic procedure included registration of thermal recovery processes after immersing in ice water of less than 0°C. Efficacy of both applied procedures was compared. Thermovision camera FLIR E40 was used for skin temperature evaluation (FLIR, Estonia). The following joint temperatures were measured: trapeziometacarpal joints, thumb metacarpophalangeal joints, thumb interphalangeal

joints, metacarpophalangeal joints, proximal interphalangeal joints, distal interphalangeal joints. Firstly, according to passive thermography procedure, thermographic images of left and right hand were taken. Afterwards, active thermography procedure was performed. The protocol included immersing left and right hand in the ice water, separately. The procedure included 11 different immersion periods: 5 seconds, 10 seconds, 15 seconds, 20 seconds, 25 seconds, 30 seconds, 35 seconds, 40 seconds, 45 seconds, 50 seconds and 55 seconds. Finally, separate recordings of left and right hand temperature changes were performed for 3 minute periods in order to measure joint temperature distributions over the course of time. Thermograms and active thermography recordings were taken in participant's sitting position, ambient temperature 23°C. Camera was placed perpendicularly to the scanned surface. To minimize the influence of physiological factors on the measurement outcome, the participants were told to stay in seated position for 10 minutes in the examination room before the registration began. For registering thermal recordings and generating temporal plots FLIR ResearchIR Software was used.

3. RESULTS AND DISCUSSION

According to study procedure, before ice water immersion thermal image acquisition of all 44 extremities was performed (2 hands and 2 feet of 11 participants). Figure 1 pictures left hand of exemplary study participant with numbered tags that represent specific joints; trapeziometacarpal joint: 1; thumb metacarpophalangeal joint: 2; thumb interphalangeal joint: 3; metacarpophalangeal joints: 4, 5, 6, 7; proximal interphalangeal joints: 8, 9, 10, 11; distal interphalangeal joints: 12, 13, 14, 15. The scale on the right side of the image depicts temperature ranges that appear in the IT image. As can be seen, picture obtained with the use of passive thermography represents thermal distribution of one concrete moment of image acquisition which makes this method error-prone and vulnerable for individual factors, external measurement conditions and technical properties. Environmental agents include: room size, ambient temperature, relative humidity, atmospheric pressure, source radiation. Individual factors are divided into intrinsic and extrinsic agents. Intrinsic factors comprise: gender, age, anthropometry, circadian rhythm, hair density, skin emissivity, medical history, metabolic rate, skin blood flow, genetic and emotions. Extrinsic factors encompass: intake factors, applications, therapies, physical activity. Eventually, technical factors include: validity, reliability, protocol, camera features, region of interest (ROI) selection, software, statistical analysis [13]. For instance, Wasilewska observed that joint temperature distribution in rheumatoid arthritis patients vary among different age groups as well as disease duration and gender groups [14].

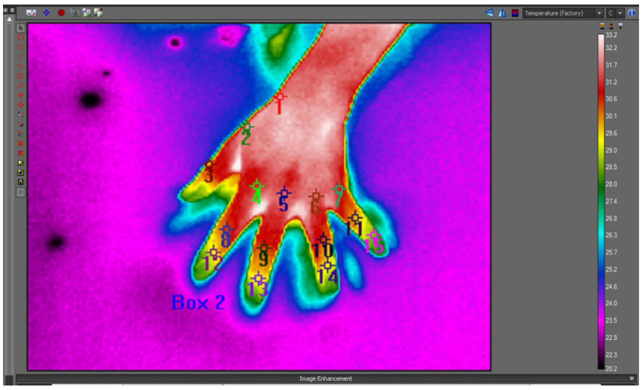

Figure 1 Thermal image of participant's left hand before 5 second cooling procedure

In the stage following ice water immersion, active thermography practice of all 44 recordings was implemented separately. Figure 2 presents hand thermal distribution of aforementioned subject for the same joints as marked in previous thermal image after 5 second cooling procedure.

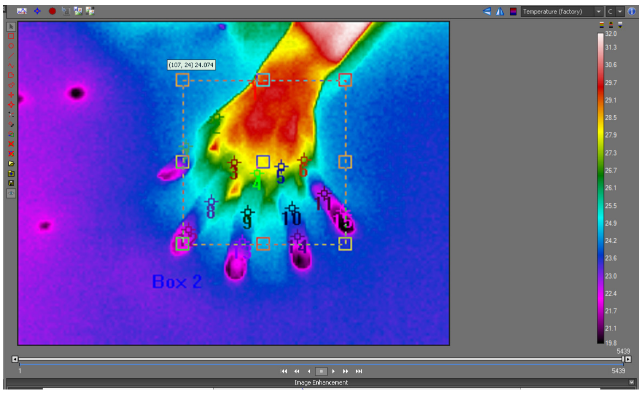

Figure 2 Thermal image of participant's left hand right after 5 second cooling procedure

Eventually, 44 recordings of 3-minute time courses for different cooling periods were obtained. On the basis of the recordings, with the use of FLIR Research IR Software, 44 plots presenting temperature evolution over 3-minute period were created. Figure 3 presents skin temperature changes of the same study participant after 5 second cooling period over 3-minute re-warming course. As seen in Figure 3, active thermography provides information on temperature evolution during the whole registration time. Thus, temperature differences between optional time points can be assessed. Moreover, thermal recovery to steady state after cold stress application can be observed. On the contrary, passive method provides temperature information about one particular time point only, with no possibility of external stimulus impact assessment. Active thermography presents a lot more advantages over passive thermography. Further to my previous comments, passive thermography provides only 2D thermal images with no time information. This problem could be solved by periodic thermal image acquisition. However, active thermography is superior to this method as it delivers information about the whole time course during temperature measurement, without the need of additional image procurement. On the basis of measured temperature alterations over a period of time, ResearchIR Software generates thermal recovery plots in a whole course of time (in current study 3-minute periods, Fig. 3). Referring to my previous argument, active thermography presents another great convenience over passive method. In current study, I analyze skin thermal return to initial state after cold stress. Due to the fact that temperature differences during thermal recovery to steady state are the main focus in active thermography, this method is to a lesser extent dependent on 3 main previously indicated factors affecting temperature measurement. All these features of active IT provide far more reliable results than passive IT.

Benefits of dynamic thermography have also been presented previously in literature. Li et al. [15] reported that dynamic thermal procedure improves breast cancer diagnosis due to its ability to amplify thermal contrast between tumor and normal tissue. Herman et al. [7] presented the role of dynamic infrared imaging in melanoma diagnosis. Author explained that heat generation of melanoma is too small to be detectable in passive method and proposed active thermography as an advantageous procedure of measuring temperature distribution in this condition. Similarly to Li, author referred that after cooling procedure thermal contrast between cancerous and healthy tissue was enhanced. In that paper, cold stimulus was introduced by blowing cold air or applying a cooling patch at 15-25°C for 1 minute. In my study I proposed alternative cooling conditions: immersion of hand up to wrist in ice water and additionally I performed wide range of cool-

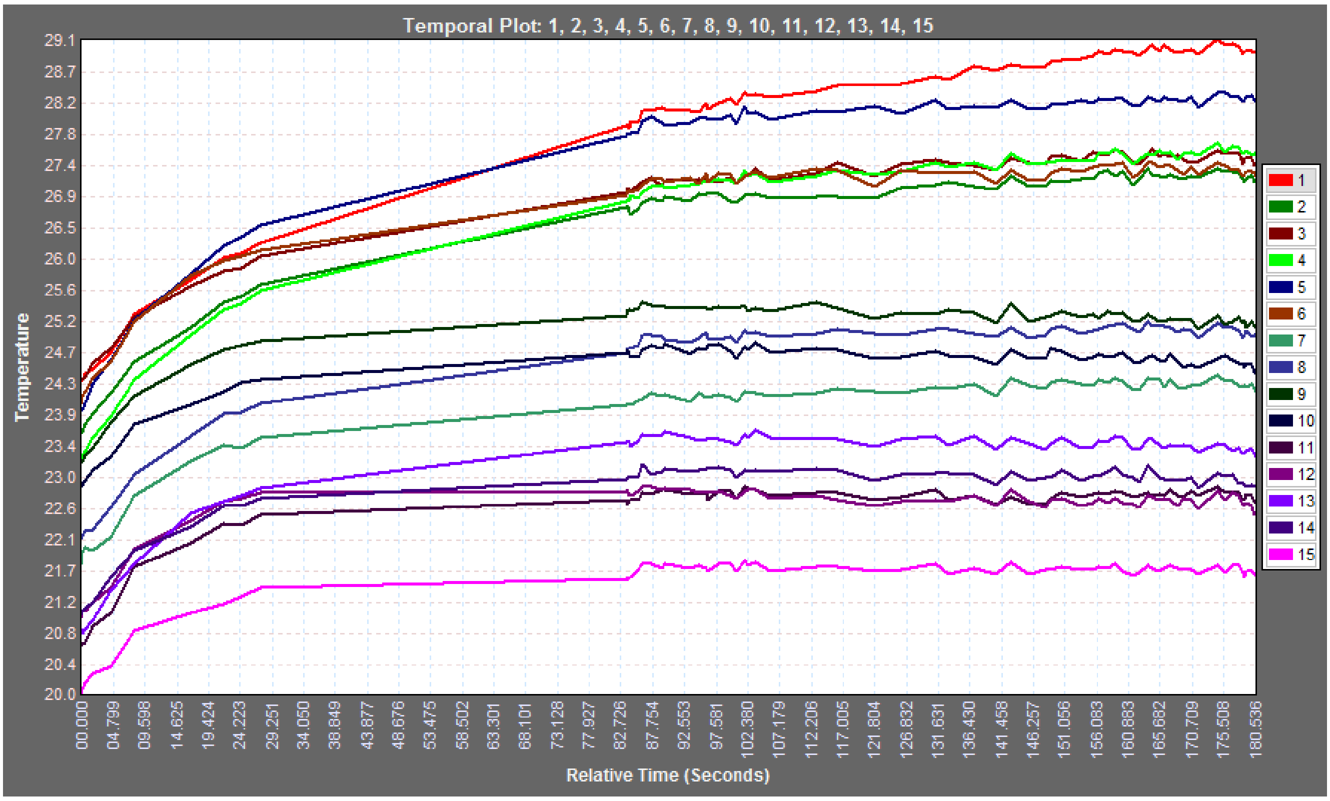

Figure 3 Temperature evolution of the skin after 5 second cooling period over 3-minute re-warming period

ing periods to adjust the most profitable and convenient for subject method. According to Lahiri et al., application of cold stimulant is desirable as it increases sensitivity of the image and exposes human veins [16]. Strzelecki et al. [17] suggested using active thermography as screening method in assessing disease activity and treatment monitoring in psoriasis. Authors compared 3 cooling methods to assess the most proper methodology of the study: cooling by gel, compressed air and putting metal blocks on skin for 6 seconds and registered thermal recovery for 5 minutes. Metal blocks appeared to be the most convenient cold stimulus. According to the results, differences between healthy and unhealthy subjects has been observed. This study conditions were comparable with conditions presented here, as in my study 5-second cooling time period was included. However, thermal recovery time proposed in my study was shorter (3 minutes). One of previous studies [18] evaluated applicability of ISO guidelines in dynamic infrared thermography in terms of diagnosis of vascular component of (Hand-arm vibration syndrome (HAVS). According to the paper, methodology was based on the analysis of 15 min of re-warming period after cold water immersion (12°C for 5 minutes). However, evaluated methodology did not perform properly as a diagnostic tool for vascular component of HAVS. These study conditions differed from conditions imposed in current study. Temperature of the water for extremity immersion was higher (12°C compared to temperature of less than 0°C in current study) and the re-warming period of registration was longer (15 minutes compared to 3 minutes). Other scientists [19] evaluated hand temperature changes among three groups of office workers in 10 minute-time period after 9 minute typing challenge. Two groups consisted of workers with diagnosed upper extremity musculoskeletal disorders; first with, second without cold hands after the use of keyboard. Last group was free from this disease. Authors found detectable differences among compared study groups. However, images were taken periodically during 10-minute period after typing: 0-2 min, 3-5 min, and 8-10 min. In our study, we performed continuous recording over a total 3-minute time period which delivered skin temperature data in arbitrary time point. Several authors [20] presented the use of dynamic IR in testing human skin reaction to inhalant allergens. Temperature of forearm was measured every 70 s from 0 up to 910 s after performing skin pricks. Authors confirmed that continuous registration of skin temperature in the area of allergen/histamine injection reflects skin reaction to administered substance. However, similarly to aforementioned scientist, due to periodic image acquisition, authors were only able to detect thermal changes in specific time point.

4. CONCLUSIONS

Although all cited studies present the use thermovision camera as a diagnostic tool in temperature distribution assessment, they vary in proposed methodologies. This diversity may arise from study purpose, examined material or medical condition and type of chosen stimulus. Additionally, among other factors that can impact final study results, endurance of stimulus application should be considered. However, the analysis terminates that due to additional time information and minimal dependency on external and host conditions, dynamic thermography presents certain advantages over static IT.

Acknowledgements:
This research was funded by scientific project: MB/WM/19/2016.

REFERENCES

[1] Pauk J., Wasilewska A., Chwiećko J., Domysławska I., Sierakowski S., Idźkowski A., Daunoravičienė K., Griškevičius J., Relation between treatment duration and temperature factors in rheumatoid arthritis; Proceedings of 11th International Conference BIOMDLORE'2016; 20-22 października 2016; 54-56.

[2] Rusowicz A., Piwnik J., Badania termowizyjne obciążonego stawu biodrowego; Aparatura Badawcza i Dydaktyczna; 1/2016; 2016; 50-53.

[3] Zuzda J., Pauk J., Latosiewicz R., Wasilewska A., Step aerobics training effect on the temperature of quadriceps femoris and biceps femoris muscles in undergraduate student, Biomechanics 2016, Biała Podlaska, 2016, 327-328.
[4] Francis J. E., Roggli R., Love T. J., Thermography as a means of blood perfusion measurements; J Biomech Eng 1979; 101: 246-249.
[5] Wilson S. B., Spence V. A., Dynamic thermographic imaging method for quantifying dermal perfusion: potential and limitations; Med Biol Eng Comput 1989; 27: 496-501.
[6] Boe Setså L., Mercer J. B., de Weerd L. & Elveness O.P. (2005), Dynamic Thermography as a reliable, non-invasive and easy method for monitoring perfusion in free flap surgery, preliminary results; Thermology International 15: 75.
[7] Herman C., The role of dynamic infrared imaging in melanoma diagnosis; Expert Rev Dermatol. 2013 April 1; 8(2): 177-184.
[8] Wiecek B., Poksinska M., Passive and Active Thermography Application for Architectural Monuments. Proc. in the 8th Conf. on Quantitative Infrared Thermography, June 28-30, Padova, Italy, 1-10 (2007).
[9] Nowakowski A., Kaczmarek M., Rumiński J., Hryciuk M., Renkielska A., Grudziński J., Siebert J., Jagielak D., Rogowski J., Roszak K., Stojek W., Medical applications of model based dynamic thermography, Proc. SPIE, v. 4360, p. 492-503, 2001.
[10] Kaczmarek M., Nowakowski A., Renkielska A., Rating Burn Wounds by Dynamic Thermography, Proc. QIRT Reims, p. 376-381, 2000.
[11] Kaczmarek M., Nowakowski A., Renkielska A., Grudziński J., Stojek W., Investigation of skin burns basing on active thermography, Proceedings of 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, CD-rom, Istanbul, 2001.
[12] Kaczmarek M., Nowakowski A., Suchowirski M., Siebert J., Stojek W., Active dynamic thermography in cardiosurgery; Quantitative InfraRed Thermography Journal; Volume 4, 2007 – Issue 1.
[13] Fernández-Cuevas I., Bouzas Marins J. C., Arnáiz Lastras J., Gómez Carmona P. M., Piñonosa Cano S., García-Concepción M. A., Sillero-Quintana M., Classification of factors influencing the use of infrared thermography in humans: A review; Infrared Physics & Technology 71 (2015) 28-55.
[14] Wasilewska A., Czynniki wpływające na pomiar w Reumatoidalnym Zapaleniu Stawów; Aktualne Problemy Biomechaniki; 2016; 10/2016; 81-84.
[15] Jiang L., Zhan W., Loew M. H., Modeling static and dynamic thermography of the human breast under elastic deformation; Physics in Medicine and Biology, Volume 56, Number 1.
[16] Lahiri B. B., Bagavathiappan S., Jayakumar T., Philip J., Medical applications of infrared thermography: A review; Infrared Physics & Technology; Volume 55, Issue 4, July 2012, 221-235.
[17] Strzelecki M., Strąkowska M., Kaszuba A., Novel methodology of medical screening using IR thermography; Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA), IEEE, 2014.
[18] House R., Holness L., Taraschuk I., Nisenbaum R., Infrared thermography in the hands and feet of hand-arm vibration syndrome (HAVS) cases and controls, International Journal of Industrial Ergonomics (2017) 1-7.
[19] Gold J. E., Cherniack M., Buchholz B., Infrared thermography for examination of skin temperature in the dorsal hand of office workers; Eur J Appl Physiol (2004) 93: 245-251.
[20] Rokita E., Rok T., Tatoń G., Evaluation of allergic response using dynamic thermography; Optoelectronics Review 23(1), 53-59.