

Abstract Booklet of the 14th edition of the

International Workshop on Advanced Infrared Technology and Applications, AITA 2017

and of the 8th IWASPND E WORKSHOP

Sept. 27th - Sept 29th, 2017, Québec City (Canada)



Conference officially hosted by



Workshop organized by:

*Canada Research Chair on Multipolar Infrared Vision Infrarouge Multipolaire (MIVIM)
of the Electrical and Computer Engineering Department*

X.P.V. Maldague, Editor

publié par:

X. Maldague
É. du CAO
38, Chemin du Cap-aux-Oies
Les Éboulements (Québec)
CANADA
G0A 2M0

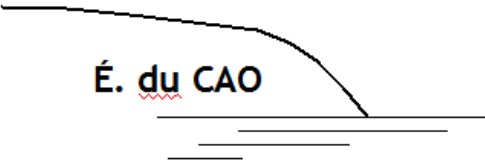
Copyright © 2017 par X. Maldague. Tous droits réservés. X. Maldague ne peut être tenu responsable pour l'authenticité, l'exactitude ou les conséquences éventuelles résultant de l'usage des renseignements publiés dans ce volume. Les opinions et affirmations publiées dans ce volume ne reflètent pas nécessairement l'opinion de X. Maldague. Les produits ou services publicisés ou mentionnés dans ce volume ne sont pas endossés par X. Maldague.

Copyright © 2017 by X. Maldague. All rights reserved. X. Maldague is not responsible for the authenticity, accuracy of information herein or for any outcomes resulting from reliance thereon, and published opinions and statements do not reflect necessarily the opinion of X. Maldague. Products or services that are advertised or mentioned do not carry the endorsement or recommendation of X. Maldague.

ISBN 978-2-9809199-5-4

Dépôt légal - Bibliothèque nationale du Québec, 2017
Dépôt légal - Bibliothèque et Archives Canada, 2017

Imprimé au Canada
Printed in Canada

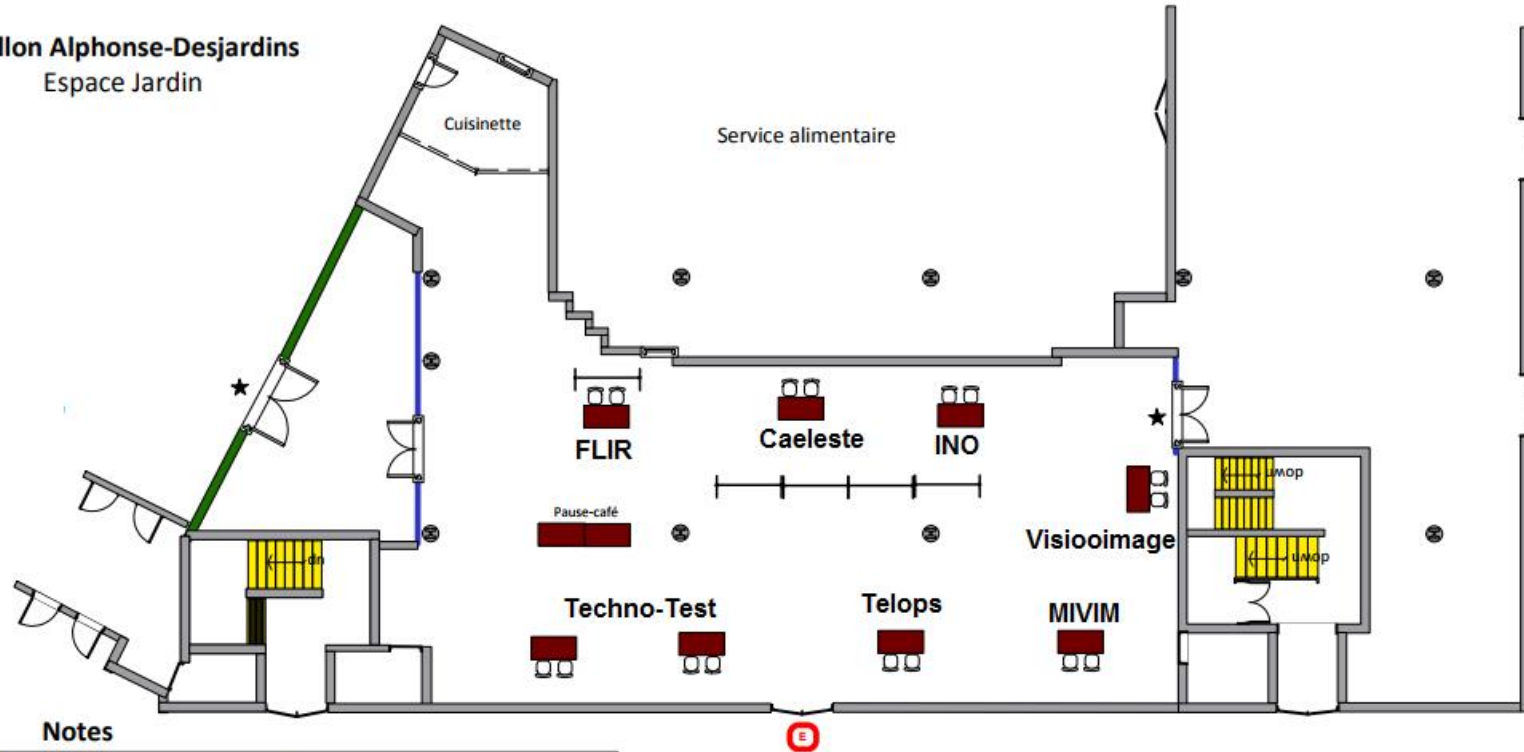


É. du CAO

à la frontière des connaissances
at the cutting edge of knowledge



Pavillon Alphonse-Desjardins
Espace Jardin



Notes

Caeleste
FLIR
InfraTec
INO
MIVIM
Techno-Test
Telops
Visioimage



Légende

- ★ Entrée / Sortie
In/Out
- ⓔ Sortie d'urgence
Emergency Exit
- ⊗ Colonne
Column

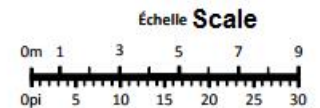


Table of contents

Keynotes

<i>Paolo Bison, Federico Cernuschi and Stefano Boldrini</i> IR thermography applied to assess thermophysical properties of Thermal Barrier Coatings	14
<i>Prof. Roman Maev and Dr. Dmitry Gavrilov</i> Cultural Heritage, an IR Perspective	18
<i>Prof. A. Mandelis</i> Principals and Non-Invasive Biomedical, Dental and Engineering Materials NDI Applications	19

Applications

<i>Magdi Mossoba</i> Application of Infrared Spectroscopy to Food Safety using Cryogenic Trapping, Chemical Imaging, and Portable Devices	21
<i>Hui Huang, Laura Liu and Michael Ngadi</i> Non-Destructive Evaluation of Fat Attributes of Pork Loin using NIR Images of Rib End	25
<i>Munetaka Ryu, Hidetoshi Sakamoto, Yoshifumi Ohbuchi, Tsuyoshi Yoshida and Yasunori Nakamura</i> Development of Furnace Wall Automatic Inspection.....	29
<i>A. Taram, C. Roquelet, Ph. Meilland, Th. Dupuy, C. Kaczynski, JL. Bodnar, Th. Duvaut</i> Induction Heating Thermography for Crack Detection in Spot Welds.....	33

Biothermophotonics Invited Session

<i>Boris Majaron, Nina Verdel, Ana Marin, Luka Vidovič and Matija Milanič</i> Quantitative Characterization of Human Skin by Combined Photothermal Radiometry and Optical Spectroscopy	35
<i>Nima Tabatabaei</i> Infrared Imaging Technologies for Early Detection of Dental Caries.....	39
<i>Perry Xiao, Xu Zhang and Christos Bontozoglou</i> Advances in Opto-Thermal Skin Measurements.....	40

Detectors

<i>Antoni Rogalski, Małgorzata Kopytko and Piotr Martyniuk</i> Performance prediction of p-i-n HgCdTe long wavelength infrared HOT photodiodes	42
<i>Yong-Gang Zhang, Yi Gu, Xing-You Chen, Ying-Jie Ma, Xue Li, Xiu-Mei Shao, Hai-Mei Gong and Jia-Xiong Fang</i> IGA-rule 17 for performance estimation of wavelength extending InGaAs photodetectors: validity and limitations	45
<i>Dr. Sven-A. Wode</i> Active spatial resolution enhancement for cooled IR cameras	49
<i>Ajit Kumar Kalgi, Dirk van Aken, Bart Dierickx, S. Veijalainen, K. Liekens, W. Verbruggen, P.Hargrave, R.Sudiwala, M.Haiml, H. Hoehnemann</i> Multiple shutter mode radiation hard IR detector ROIC	50

Environment

<i>Marija Strojnik, Beethoven Bravo-Medina, Guillermo Garcia-Torales and Michelle K. Scholl</i> Extra-solar planet detection: review of indirect and direct methods.....	57
--	----

<i>Bakhram Gaynullin, Maksym Bryzgalov, Christine Hummelgard, Claes Mattsson, Henrik Rodjegard and Goran Thungstrom</i> Pressure characterization and resolution limits' investigation of high accuracy NDIR Methane sensor for environmental applications.	61
<i>Moulay Akhloufi, Tom Toulouse, Lucile Rossi and Xavier Maldague</i> Three-dimensional infrared-visible framework for wildland fires	65
<i>Chan Park, Sungho Lee, J.S. Oh, I. Yuk, J.Lee, M.Chun, K.Kim, H.Oh, U.Jeong, N.Hwang, B. -H.Park, H.Lee, G.N.Mace, K.R. Sokal, L.Prato, D.T. Jaffe</i> IGRINS: Design, Performance and Plan for the Gemini Telescope	69
<i>Chao Ni, Yuanhao Wang, Yuting Lu, Fengzhi Tan and Yuan Li</i> Rapid and nondestructive quantitative determination of total flavonoids in Cyclocarya paliurus leaves by near-infrared reflectance spectroscopy	73
<i>Cinzia Lastri, Stefano Baronti, Giulio Coluccia, Donatella Guzzi, Demetrio Labate, Enrico Magli, Micael Miranda, Vanni Nardino, Lorenzo Palombi, Ivan Pippi, Alessandro Zuccaro Marchi and Valentina Raimondi</i> IR camera for NEO detection based on Compressive Sensing technologies.....	89
<i>Thibaud Toullier, Jean Dumoulin and Laurent Mevel</i> Comparison of Thermocouples Surface Measurements and Infrared Thermography for Transport Infrastructure Thermal Monitoring	93
<i>Bushra Jalil, Davide Moroni and Maria Antonietta Pascali</i> Power Lines Inspection via Thermal and Infrared Imaging	97
<i>Fernando López and Xavier Maldague</i> Determination of Energetic Parameters of Building Rooftops by Aerial Infrared Thermography.....	101
<i>Kazuhisa Nakasho , Carlos Cuadra , Hirokazu Madokoro , Nobuhiro Shimoi</i> Infrared Thermography Applied for Robust Image Processing to Examine Historical Wooden Buildings	104
<i>Guzzi Donatella, Stefano Baronti, Daniela Coltuc, Florin Garoi, Iuliana Iordache, Demetrio Labate, Cinzia Lastri, Vanni Nardino, Micael Miranda, Ivan Pippi, Alessandro Zuccaro Marchi and Valentina Raimondi</i> Compressive sensing and space applications in the SWIR-FIR spectral range	108

Image Processing

<i>Nobuhiro Shimoi, Carlos Cuadra, Kazuhisa Nakasho and Hirokazu Madokoro</i> Active Image Processing for Wooden Traditional Structure using IR Cameras	113
<i>Michal Švantner, Lukáš Muzika, Tomáš Chmelík and Jiří Skála</i> Quantitative evaluation of active thermography using contrast to noise ratio	117
<i>Jeroen Peeters, Bart Ribbens, Boris Bogaerts, Seppe Sels, Joris Dirckx and Gunther Steenackers</i> Optimized setup modification for automated active thermography	121
<i>Hossein Memarzadeh Sharifipour, Bardia Yousefi and Xavier P V Maldague</i> Skeletonization and Reconstruction Based on Graph Morphological Transformations.....	125
<i>Moulay Akhloufi and Axel-Christian Guei</i> DeepSIRF - Super-resolution infrared face images using Deep Convolutional Generative Adversarial Networks	129
<i>Julien Fleuret, Lei Lei, Changjian Shui, Clemente Ibarra-Castanedo, Xavier Maldague and Hai Zhang</i> An Improved Algorithm for Detection and Segmentation of Defects.....	133

Medical

<i>Mario D'Acunto</i> Near IR Biological Transparency Window and Theranostics Strategies	137
<i>Bardia Yousefi, Hossein Memarzadeh Sharifipour, Mana Eskandari, Clemente Ibarra Castanedo, Xavier P V Maldague and Denis Laurendeau</i> Incremental Low Rank Noise Reduction for Thermal Monitoring of Human Body Using Infrared Imagery	140
<i>Bushra Jalil, Valentina Hartwig, Ovidio Salvetti, Davide Moroni, Zunera Jalil, Antonio Benassi, Antonio L'abbate, Letizia Guiducci, Laura Pistoia, Tommaso Minutoli Tegrimi, Antonio Quinones-Galvan and Giorgio Iervasi</i> Near Infrared and Thermal Imaging of Normal and Obese Women During Oral Glucose Tolerance Test (OGTT)	144

NDT

<i>Marc Genest and Gang Li</i> Induction Thermography of Steel Coupons with Crack	149
<i>Frank Billy Djupkep Dizeu, Denis Laurendeau and Abdelhakim Bendada</i> Quantitative Nondestructive Testing Using Infrared Thermography: An Inverse Geometry Problem	153
<i>Matthew Bondy, Dmitry Gavrilov, Inna Seviaryna and Roman Maev</i> Practical Application of Acoustic and Thermographic Methods for Analysis of Impact Damage to Composite Avionic Parts	157
<i>Abdoulahad Thiam, Jean-Christophe Kneip, Eugen Cicala, Yannick Caulier and Jean-Marie Jouvard</i> Using numerical experimental design for crack detection by active thermography	161
<i>Alexandrine Huot, Frédérick Marcotte, Kamel Mouhoubi and Jean-Luc Bodnar</i> Using Active Infrared Thermography for Characterizing Types of Ballistic Impacts	165
<i>Takahide Sakagami, Daiki Shiozawa, Yu Nakamura, Shinichi Nonaka and Kenichi Hamada</i> Detection of Fatigue Damage in Short Carbon Fiber Reinforced Plastics Using Thermoelasticity	168
<i>Louis-Daniel Thérroux, Jacques Lewandowski, Benoit Masson, Jean-François Vandenrijt and Marc Georges</i> Practical simulation of delamination in composites for thermography NDT	172
<i>Hai Zhang, Stefano Sfarra, Ahmad Osman, Udo Netzelmann, Clemente Ibarra-Castanedo, Stefano Perilli, Fabrizio Sarasini and Xavier Maldague</i> Eddy Current Pulsed Thermography for Basalt-Carbon Hybrid Composites Subjected to Ballistic Impacts: A Numerical and Experimental Study	176
<i>Yui Izumi, Yoshiaki Mizokami, Akira Moriyama and Takahide Sakagami</i> Detection of back-surface crack based on temperature gap measurement using infrared thermography	179
<i>Daiki Shiozawa, Tsuyoshi Inagawa, Takaya Washio and Takahide Sakagami</i> Effect of mean stress on phase difference of dissipated energy	183
<i>Henrique Fernandes, Stefano Sfarra, Hai Zhang, Clemente Ibarra-Castanedo and Xavier Maldague</i> Fiber Orientation Detection on Fiber Reinforced Polymers Moulded with Randomly-Oriented Strands	187
<i>Marco Ricci, Giuseppe Silipigni, Stefano Laureti, Luca Senni, Riccardo Tomasello and Pietro Burrascano</i> Optimal Design of Chirp Excitations for Pulse Compression Thermography	191
<i>E.T. Delegou, M. Krokida, N.P. Avdelidis, A. Moropoulou</i> An Empirical mathematical Model Developed for Pulsed Thermography Analysis on Marble Surfaces	195

Techniques

<i>Ruben Usamentiaga, Daniel Garcia, C. Ibarra-Castanedo and Xavier Maldague</i> Metric Measurements on a Plane with an Infrared Camera	200
---	-----

Seol-Hee Yi, Ik-Hwan Kwon, Hyun-Chul Jung, Kyeong-Suk Kim and Chung-Ki Hong Measurement of three dimensional surface temperature distribution by hybrid digital holographic imaging system 204

Hector Torres-Ortega, Marija Strojnik, Guillermo Garcia-Torales and Michelle K. Scholl Thermal Chamber for DNA Amplification at Given Temperature (T=62 C): Preliminary Test Results 208

Hector Torres-Ortega, Marija Strojnik, Guillermo Garcia-Torales, Michelle K. Scholl Thermal Bed for DNA Amplification at given Temperature (test case T = 62 C) 212

Thermal Properties

Jonas Allegrini, Dominique Derome and Jan Carmeliet Wind Tunnel Measurements of Local Heat Transfer Coefficients and Local Air Temperatures in an Urban Street Canyon Using IR Thermography 217

Alexey Prosvetov, Christina Trautmann and Marilena Tomut In-plane and through-plane laser flash measurements of thermal diffusivity degradation induced by heavy ion irradiation in thin graphite samples..... 221

Suhyeon Park, Y.B. Ji and Srinath Ekkad Flame Infrared Radiation Measurement at a Model Gas Turbine Combustor 224

Francesco Montagner, Silvia Deambrosis, Enrico Miorin, Giovanni Ferrarini and Paolo Bison Optical temperature measurement of the rotating plate in PVD system 229

J. Robert Mahan, Vinh Q. Nguyen, Nazia B. Munir and Vinh X. Ho MonteCarlo Ray-Trace Diffraction Based On The Huygens-Fresnel Principle..... 232

Posters

Abbasali Saboktakin, Saeid Hedayatrasa, Hosein Moienkhah, Xavier Maldague and Guillermo Rus Carlborg Aircraft Fuselage Testing Using Vibrothermography Technique 237

Bryan García, Andrés-David Restrepo-Giron and Humberto Loaiza-Correa Detection of External Structures of Anti-personnel Mines by Means of Thermographic Inspection of Soil 241

Serge-Olivier Gnessougou, Clemente Ibarra, Xavier Maldague, Alain deChamplain Thermal Diffusivity Measurements with the Flash Method at Different Depths in a Burned Composite Material..... 245

Weike Dong, Zhenqing Song and Long Liu A Novel FPGA-based Data Reconstruction Method for Synchronized Real-time DMD Display with High Frame Rate 246

Mouhoubi Kamel, Taram Abdoulaye, Bodnar Jean-Luc Follow-up of Restoration of Works of Arts of the Patrimony by Infrared Thermography..... 254

Preface

It is our pleasure to welcome you here at Université Laval for the 14th edition of the International Workshop on *Advanced Infrared Technology and Applications*, AITA 2017!

AITA Workshops were born in Italy where most of the Editions took place. In 2007, AITA was hosted in León, Mexico by Prof. Marija Strojnik. Hence, to mark this 10th anniversary, the Program Committee decided to organize AITA 2017 once again in North America, but this time in Quebec City, Canada.

Interestingly 2017 marks also the 150 anniversary of the Canadian Confederation with all kind of celebrations all across the country so it is a unique opportunity to host AITA right here in Canada!

AITA is a forum that brings together researchers in the field of infrared science and technology to exchange knowledge and ideas. Interestingly, the VIIIth edition of the *International Workshop on Advances Signal Processing for NonDestructive Evaluation* (IWASPND, Quebec Workshops) will take place as a simultaneous event.

For the 2017 edition, sessions were divided as follows: Applications, Detectors, Environment, Image processing*, Medical, NonDestructive Testing*, Techniques, Thermal properties, and we also have an invited session organized by Prof. A. Mandelis: Biothermophotonics (*: joint sessions with *VIIIth IWASPND*).

The following invited Keynote Lectures are others program highlights:

- «IR thermography applied to assess thermophysical properties of Thermal Barrier Coatings», Dr. Paolo Bison, CNR - ITC, Italy;
- «Cultural Heritage, an IR Perspective», Dr. Roman Maev and Dr. Dmitry Gavrilov, University of Windsor, Canada;
- «Photothermal Coherence Tomography (PCT): «Principals and Non-Invasive Biomedical, Dental and Engineering Materials NDI Applications »
 Dr. Andreas Mandelis, University of Toronto, Canada.

The «Under 35 Paper Award» competition will take place during the Workshop. This Award is named after Ermanno Grinzato who passed away in 2012. Mr. Grinzato was AITA cochairman for a long time and was a very well-known scientist in the thermography community. Additional Workshop highlights are a Poster session, a Vendor Session, an Exhibit with the following Companies participating: Caeleste, FLIR, InfraTec, INO, TechnoTest, Telops, Visioo-Image.

The social program includes a Reception and a Visit, Cocktail and Banquet at «Aquarium de Québec». For this last event, we thank Telops for their generous support.

As usual, a selection of the received papers will be published in a peer-review journal: *OSA Applied Optics*.

Finally, the website: <http://aita2017.gel.ulaval.ca>
 will be maintained active for future references. The website includes the Workshop
 Booklet with all the abstracts in .PDF format. This way to proceed was found more
 convenient and environmentally friendly.

As partners in the success of this week, was the help of the Program Committee,
 Scientific Committee, Organizing Committee, Université Laval, including my own
 Electrical and Computing Engineering Department and staff. The participation of our
 exhibitors is also appreciated. I would like also to point out the dedicated work of all
 our student staff and particularly of our assistant, Mr. Patrick Deschênes Labrie.

I will conclude these remarks by wishing to all a fruitful Workshop, full with great talks,
 great discussions, meetings of old and new faces! I would like also to thank you all for
 your participation which is essential to the success of AITA 2017.

Enjoy AITA 2017, enjoy beautiful Québec City, Canada!

Xavier Maldague
 Chair, AITA 2017

Committees

Program Committee

General Chair

- L. Ronchi Abbozzo, Fondazione Giorgio Ronchi, Firenze, Italy

Cochairs

- X. Maldague, Electrical and Computing Engineering Dept., Quebec City, Canada
- P. Bison, CNR-ITC, Padova, Italy
- M. D'Acunto, CNR-ISM, Rome, Italy
- D. Moroni, CNR-ISTI, Pisa, Italy
- V. Raimondi, CNR-IFAC, Firenze, Italy
- A. Rogalski, Military University of Technology, Warsaw, Poland
- T. Sakagami, Kobe University, Kobe, Japan
- M. Strojnik, CIO, León, Guanajuato, Mexico

Scientific Committee

- D. Balageas, Onera, Chatillon, France
- C. Corsi, Alenia-Creo, L'Aquila, Italy
- E Derekiak, University of Arizona, Tucson, USA
- C.T. Elliott, Heriot-Watt University, Edinburgh, Scotland
- C. Maierhofer, BAM, Germany
- C. Meola, Univ. of Naples, Naples, Italy
- I. Pippi, CNR-IFAC, Firenze, Italy
- H.N. Rutt, Southampton University, Southampton, United Kingdom
- O. Salvetti, CNR-ISTI, Pisa, Italy
- J.L. Tissot, ULIS, Veurey Voroize, France
- V.P. Vavilov, Tomsk University, Tomsk, Russia
- H. Zogg, ETH, Zurich, Switzerland

Organizing Committee

- Xavier Maldague, chair, Université Laval, Canada
- Hakim Bendada, Université Laval, Canada
- Clemente Ibarra-Castanedo, Université Laval, Canada
- Marc Genest, National Research Council Canada, Canada
- Roman Maev, University of Windsor, Canada
- Andreas Mandelis, University of Toronto, Canada
- Stefano Sfarra, University of L'Aquila, Italy
- Nicolas P. Avdelidis, National Technical University of Athens, Greece

Technical Secretariat - AITA2017

- Mr. Patrick Deschênes Labrie
Department of Electrical and Computer Engineering
Université Laval, Québec, Canada, G1V 0A6
Phone : ++ 1 418 656-2962
Fax : ++ 1418 656-3159
Email : Quebec@gel.ulaval.ca

NEAR INFRARED AND THERMAL IMAGING OF NORMAL AND OBESE WOMEN DURING ORAL GLUCOSE TOLERANCE TEST (OGTT)

B. Jalil^a, V. Hartwig^b, D. Moroni^a, O. Salvetti^a, A. Benassi^a, Z. Jalil^e, L. Guiducci^b, L. Pistoia^c, T. Minutoli Tegrini^c, A. Quinones-Galvan^c, G. Iervasi^b, A. L'Abbate^{b,d}

^aIstituto di Scienza e Tecnologie dell'Informazione "Alessandro Faedo" CNR, Pisa, Italy

^bIstituto di Fisiologia Clinica CNR, Pisa, Italy

^cFondazione G. Monasterio CNR - Regione Toscana, Pisa, Italy

^dScuola Superiore Sant'Anna, Institute of Life Sciences, Pisa, Italy

^eDepartment of Computer science, Iqra University, Islamabad, Pakistan

Originally considered as an imbalance between energy intake and expenditure, obesity is studied in this paper by comparing body temperature of abdomen, neck and hand in obese subjects to lean ones with oral glucose tolerance test during thermos neutral and cold conditions. We studied obese and normal weight females with infrared thermal imaging (IRT) and near infrared spectroscopy (NIRS). We observed that a significantly reduced temperature was much more prevalent in the obese subjects around abdominal area and relatively higher temperature on the hand of obese subjects as compared to lean ones. However, we observe the higher oxygen saturation in obese females in both hand and abdomen.

Introduction

Obesity, now recognized as a major public health issue, is a condition associated with high body heat content. Several physiological changes that accompany the development of obesity tend to increase heat production. Obesity increasing with an alarming rate worldwide with the particular concern is the increase in health risk evidenced in younger persons and ultimately increases the risk of many serious conditions including hypertension, diabetics, coronary heart disease and many more. People with a body mass index (BMI) of 30 or higher are considered obese as it describe the health condition of significantly above ideal healthy weight [1, 2]. These negative health consequences of obesity attracted many researchers to study further and explore its effects on human health. Infrared thermography (IRT) has been used in the past few decades to study diseases in which skin temperature is an indicator of inflammation or blood flow changes. The use of IRT in the measurement of human skin temperature has the advantage to be completely noninvasive. A thermal camera makes use of infrared imaging to visualize and measure the thermal energy

emitted from objects in the environment. Thermal cameras are capable of discriminating temperature differences and used to assess the absolute temperature of specific points on the body, or alternatively to calculate average temperature of a specific region of the body as specified [3]. Savastano et al had studied human obesity in relation to the heat production using such cameras. They examined heat production and dissipation in obese adults as compared to normal weight adults [2]. Analysis of data indicated that obese participants demonstrated significantly lower abdominal thermal patterns than those of their normal weight counterparts. Similarly, Ludwing et al had studied maximal skin temperature at different region of interests [4]. Chudecks et al had drawn a thermal map of obese women and highlighted the body area where heat transfer is particularly impeded [5]. More recently, Gatidis et al had presented their extensive research on skin temperature using infrared thermography [6].

Assessment of oxygen saturation (StO₂) is important to study clinical condition and in monitoring several pathological changes. During the past few years, near infrared spectroscopy (NIRS) has been used to study

human adipose tissues to investigate obesity effects. NIRS is a method to non-invasively measure tissue oxygenation in vivo [7]. NIR spectroscopy has been largely used for measurement of changes in intravascular hemoglobin (Hb) and intramuscular myoglobin (Mb) for many applications *e.g.* Nirengi et al had evaluated the oxygenation in brown adipose tissues using near infrared spectroscopy in thermos neutral and cold conditions [8].

The aim of this study was to achieve a better understanding of the body temperature and oxygenation conditions on neck, hand and abdomen of normal and obese females during oral glucose tolerance tests. In the coming sections, we will first explain the methods, subjects and designed experimental protocols and then we will present our findings with discussion.

Subjects and Methods

We had performed 3-hours Oral Glucose Tolerance Test (OGTT) to find the difference of temperature and oxygenation in lean and obese subjects. The glucose tolerance test is a medical test in which glucose is given and blood samples are taken afterwards to determine how quickly it is cleared from the blood.

All the thermal images were acquired with Ti9Thermal Imagers (Fluke Corporation, Everett, WA) camera. The technique is based on the principle that the amount of energy radiated depends on the surface temperature of the object and the emissivity of the object's surface. The camera detects the infrared energy from an object and uses this information to estimate its temperature. Additionally, we acquired NIRS 2D images at the same time. The Kent imaging camera, used to take the NIRS images, is a non-invasive system for tissue oxygenation measurement based on near infrared light. The camera reports and approximates value of Hb + Mb StO₂ in superficial tissue. We have selected neck, abdomen and hand regions to study temperature and microcirculatory features in obese and lean subjects. Five healthy women (age 34.4±10.5)

with low body mass index (BMI= 19.6±2.3 kg/m²) and five overweight healthy women (age 39.8±11.0) (BMI= 27.5±1.8 kg/m²) were studied. Table 1 shows the characteristics of all subjects. The study was authorized by the local Ethical Committee. Each subject gave written informed consent.

Experimental Design

All subjects were selected from the Metabolic Unit of Fondazione G. Monasterio CNR – Regione Toscana, Pisa, Italy. Firstly, height and weight were measured and then BMI was calculated. Moreover, NIRS and thermographic baseline images were collected (after a 15-min acclimatization period).

	Sex	Age (years)	BMI (Kg/m ²)
<i>Subject 1</i>	<i>F</i>	27	20,4
<i>Subject 2</i>	<i>F</i>	33	19,0
Lean <i>Subject 3</i>	<i>F</i>	22	17,9
<i>Subject 4</i>	<i>F</i>	44	18,0
<i>Subject 5</i>	<i>F</i>	46	19,8
<i>Subject 6</i>	<i>F</i>	50	30,1
<i>Subject 7</i>	<i>F</i>	48	24,9
Obese <i>Subject 8</i>	<i>F</i>	43	33,4
<i>Subject 9</i>	<i>F</i>	23	27,2
<i>Subject 10</i>	<i>F</i>	35	25,0

Table 1. Participant characteristics.

A 3-h oral glucose tolerance test (OGTT) with the ingestion of 75 g of oral glucose was performed. NIRS and IRT images were taken every hour during 180 minutes. At the end of OGTT, a cold stimulation was performed by immersing the subject's left hand in ice-water for one minute. Finally, NIRS and IRT images were acquired immediately after the cold stimulus.

Results

Figure 1 (a) and (b) show respectively the thermal and StO₂ images of hand. Similarly, Figure 2 (a) and (b) represent abdomen temperature and StO₂ respectively and Figure 3 (a) and (b) show thermal and StO₂ images of the neck area.

Figures 4, 5 and 6 show the temperature averaged on five lean subjects and on five

overweight subjects for hand, neck and abdomen area during the entire experimental paradigm (3-h OGTT test and post ice stimulation). Figure 7, 8 and 9 show the mean StO_2 for both groups in hand, neck and abdomen respectively.

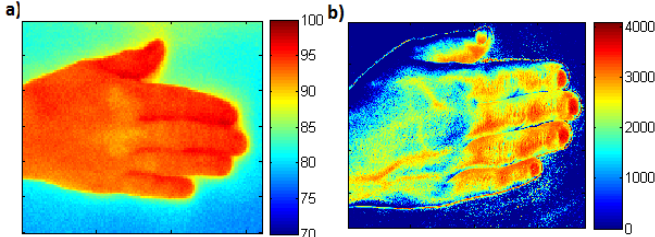


Fig1. a) Thermogram of hand. b) NIRS image of hand.

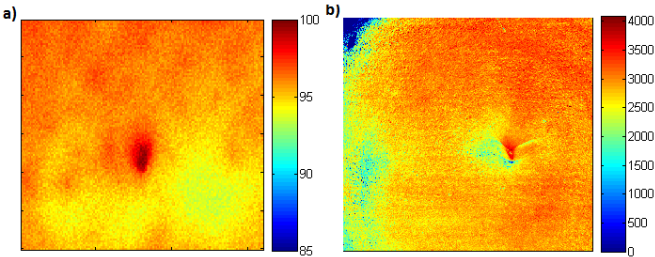


Fig2. a) Thermogram of abdomen. b) NIRS image of abdomen.

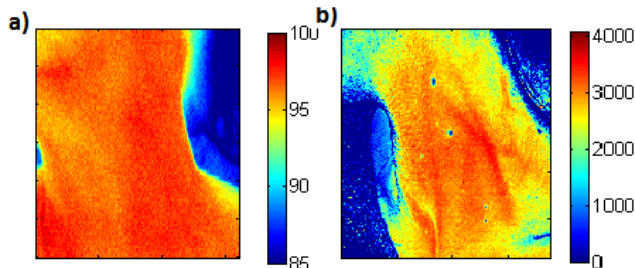


Fig3. a) Thermogram of neck. b) NIRS image of neck.

Discussion

The major finding of the present study is that we detected, both in lean and overweight subjects, a consistent, and highly localized, increase in local temperature of hand, neck and abdomen area induced by a glucose ingestion. We also observed that obese participants had lower abdominal skin temperature and higher in hand as compared to the lean subjects. This result, relative only to the baseline condition, is the same that is reported in [4]. It is even more interesting to note that the hand temperature in lean subjects continues to increase during the OGTT test while in the obese subjects the hand temperature remains more or less constant. Interestingly, abdomen temperature in obese

subject changes more during the first 2 hours of OGTT protocol respect to the temperature of the same area in lean subjects.

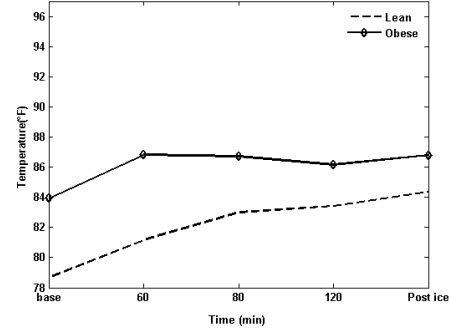


Fig 4. Mean hand temperatures in all subjects measured by infrared thermography.

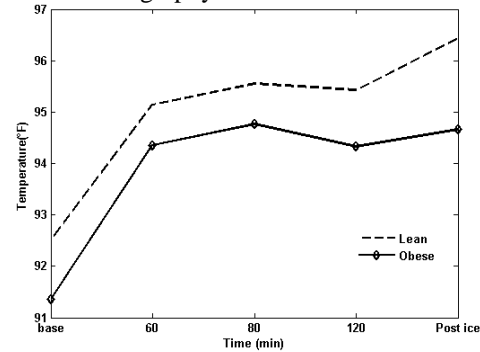


Fig 5. Mean neck temperatures in all subjects measured by infrared thermography.

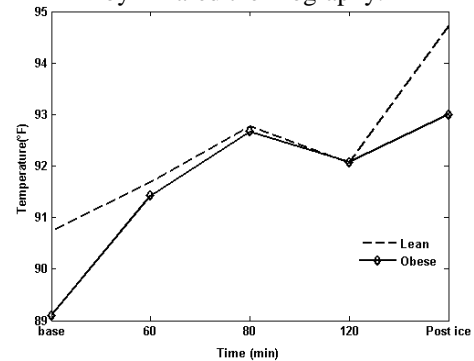


Fig 6. Mean abdominal temperatures in all subjects measured by infrared thermography.

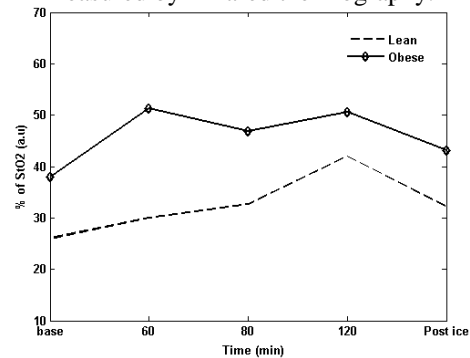


Fig 7. Mean hand StO_2 in all subjects measured by near infrared camera.

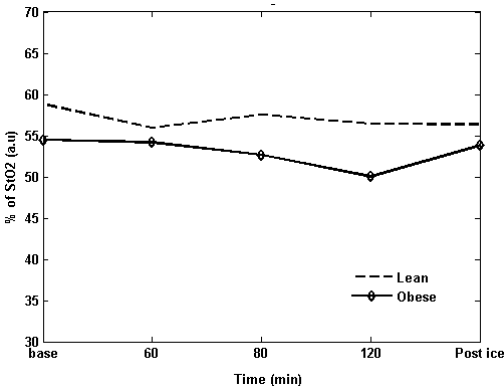


Fig 8. Mean neck StO₂ in all subjects measured by near infrared camera.

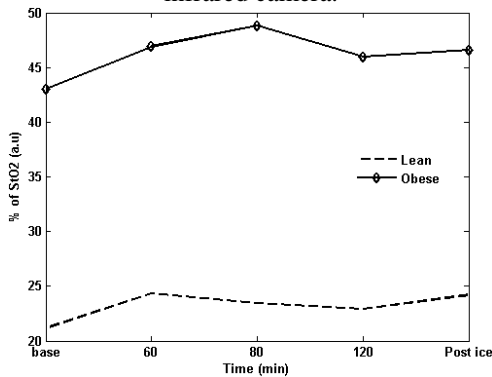


Fig 9. Mean abdominal StO₂ in all subjects measured by near infrared camera.

Temperature of the neck area have similar trends during the entire experimental paradigm for the both two groups.

We had also evaluated the differences in the oxygenation saturation of both lean and obese subjects in order to obtain information about the tissue perfusion. StO₂ has significant differences between lean and obese group only for hand and abdomen area but not for the neck. This difference is more pronounced in the abdomen area: oxygen saturation is higher in the abdomen area of obese subjects during the entire experimental paradigm. This could indicate a different distribution of vessel in superficial tissue of the abdomen. Otherwise this could be due to a very different depth of subcutaneous fat.

Conclusion

In this paper, we have applied non-invasive multimodal imaging techniques to monitor thermogenesis conditions in lean and obese females with different body mass index. We

observed relatively lower abdominal skin temperature and relatively higher temperature in hand in obese females as compared to the lean ones measured in both thermos neutral and cold conditions. As body core temperature represents a marker of energy expenditure, results from this study suggest that reduction of body core temperature plays a crucial role in favoring weight gain in obese subjects. At the same time, we observed higher oxygenation level in obese females. The difference is much higher in abdominal area as compared to the hand in obese females. In conclusion, IRT and NIRS methods are non-invasive, inexpensive and simple methods to investigate fatty tissues in human body. It is important to validate these finding further on large data set in different physical conditions and with obesity related diseases.

References

1. Martorell R et al, Obesity in women from developing countries. *European Journal of Clinical Nutrition* (2000) 54, 247-252.
2. Heubergerlet al, The relationship between thermal imaging and waist circumference in young adults, *Health*, Vol.4, No.12A, 1485-1491 (2012)
3. Chudecka M et al, Body surface temperature distribution in relation to body composition in obese women. *Journal of Thermal Biology*, 2014 Jul.
4. Savastano DM et al, Adiposity and human regional body temperature, *American Journal of Clinical Nutrition* 90(5):1124-31 · September 2009.
5. N. Ludwig et al, Skin temperature evaluation by infrared thermography: Comparison of image analysis methods, *Infrared Physics & Technology* Volume 62, January 2014, Pages 1–6.
6. Nirengi S et al, Human brown adipose tissue assessed by simple, noninvasive near-infrared time-resolved spectroscopy, *Obesity (Silver Spring)*. 2015 May 23(5):973-80. doi: 10.1002/oby.21012. Epub 2015 Apr 10.
7. Sergios Gatidis, Is It Possible to Detect Activated Brown Adipose Tissue in Humans Using Single-Time-Point Infrared Thermography under Thermoneutral Conditions? Impact of BMI and Subcutaneous Adipose Tissue Thickness, *PLoS One*. 2016; 11(3): e0151152.
8. Jalil et al, Near Infrared Image Processing to Quantitate and Visualize oxygen saturation during Vascular Occlusion, *Computer methods and programs in biomedicine*, Jan 2016.