



Medical 3D thermography system

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Abstract

Infrared (IR) thermography determines the surface temperature of an object or human body using thermal IR measurement camera. It is an imaging technology which is contactless and completely non-invasive. These properties make IR thermography a useful method of analysis that is used in various industrial applications to detect, monitor and predict irregularities in many fields from engineering to medical and biological observations. This paper presents a conceptual model of Medical 3D Thermography which introduces standardised 3D thermogram creation, representation and analysis concepts useful for variety of medical applications. The creation of 3D thermograms is possible through combining 3D scanning methods with thermal imaging. We describe development of a 3D thermography system integrating passive thermal imaging with 3D geometrical data from active 3D scanner. We outline the potential benefits of this system in medical applications. In particular, we emphasize the benefits of using this system for preventive detection of breast cancer.

INTRODUCTION

All bodies at temperatures greater than 0K emit electromagnetic (EM) radiation. The fundamental equations that link the absolute temperature of the body with the intensity and wavelength of the emitted radiation are given by the Planck, Stefan-Boltzmann, and Wein displacement law (1). A major amount of thermal radiation emitted by an object emitted radiation belongs to the thermal infrared range, in a wave length between 7 and 15 μm .

Infrared thermography is the technique of producing an image from infrared radiation, otherwise invisible to the human eye (1). Thermal cameras have sensors that capture the emitted or reflected thermal radiation from the objects. Thermal images generated by these cameras are referred as *thermograms* where each image pixel corresponds to a digital value, proportional to the amount of received energy. Infrared thermography is a non invasive (noncontact, non-destructive) imaging method. This makes infrared thermography a widely applicable technique, for fields such as building and electrical installation inspections and in industrial environments (2) but also in biology and medicine (3, 4).

Human body temperature distribution is influenced by many biological and physiological complex factors (e.g. the heat exchange processes between skin tissues, metabolic activity, vasculature, circadian rhythm, and the regulating of the sympathetic and parasympathetic activity for maintaining homeostasis) (1). Infrared thermography allows temperature distribution visualization of the human body and has been used in medical practice since the 1950s. The earliest medical applica-

tions of thermography was screening for sub epidermal tumour. Due to the drawback of less-sensitivity and low resolution, it was mainly used as an alternative method to detect breast tumour mass (5). Production of more sophisticated instruments, as well as increasing resolutions of cameras has allowed for more accurate tumour detection algorithms thus further establishing thermography as a viable alternative to standard tumour detection methods. Use of thermography in the field of medical oncology lies in the fact that tumours generally have increased temperature gradients compared to surrounding normal tissue. The reason for this is an increase in blood supply and angiogenesis, as well as an increased metabolic rate of tumour tissue (6).

Standard 2D thermograms are dependant on the distance and angle between the camera and the observed object. This means that it is very difficult to carry out quantitative and reproducible measurements or to correlate two different 2D thermograms of the same object. There is a need for standardising *thermograms* in order to solve this problem. Many studies and analyses have dealt with the problem of standardisation of *thermograms* (7).

Integrating 3D scanning techniques with *thermograms* can help creating standardised *thermograms* (7, 8) There are many 3D scanning techniques either active or passive (9). One of more suitable techniques is structured light 3D scanning technique (10). It is low cost because it uses standard widely available electronic devices: projector and digital camera and the process acquisition is fully automated. Using the 3D model data acquired by the 3D scanner it is possible to define spatial data that includes shape and temperature distribution information (11-15). Also correlating 3D *thermograms* is easier and can be performed automatically using 3D point registration algorithms.

This paper proposes a comprehensive conceptual model that enables combining 3D scanning methods with thermal imaging to produce standardised 3D *thermograms*, and integrating new approaches to temperature distribution data analysis and visual analytics based on 3D *thermograms*. Such a system provides a new base for medical applications based on non-invasive diagnostic methods.

3D THERMOGRAPHY SYSTEM ARCHITECTURE

System architecture defines system components and their synchronous operation. There are different approaches in creating 3D thermography systems, depending on system usage and demands. Operation of system components is described by system workflow.

3D thermography systems overview

3D thermography system is combining 3D scanning device and thermal camera to provide 3D thermal data which consists both spatial and temperature data representing 3D temperature distribution of desired objects.

Depending on the 3D acquisition method, 3D thermography systems can be passive or active.

Generally there are two different types of 3D thermography system approaches using passive 3D scanning methods. The first one is the system using two thermal cameras for objects temperature data acquisition (16). Captured thermal data of each camera is analyzed and feature point-pairs are extracted to calculate the 3D surface of the target object based on stereovision method. The second is the system using two digital cameras and one thermal camera (17). Similarly as the first approach, images captured by digital cameras are used for feature point-pairs extraction and to calculate the 3D surface data. Temperature data captured by thermal camera is then mapped as texture on the 3D surface data. These methods are largely dependent on the texture of the objects surface and cannot provide accurate high resolution 3D surface data.

Structure light, one of the most frequently used active scanning methods which does not rely on the texture of the surface, provides accurate 3D surface data. This system usually consist one projector, one or more digital cameras and one thermal camera. Three potential approaches for 3D thermography based on the structure light depending on their usage and demands can be determined. The first one is the usage of a standalone commercial structure light 3D scanner for obtaining spatial data as black-box unit and thermal camera; the second is based on Microsoft Kinect as 3D scanner with thermal camera; and the third one is custom system which consist NIR DLP projector, two NIR cameras and thermal camera. Overview of these three approaches is shown in Table 1.

Commercial 3D scanner is closed system with user software whose implementation cannot be manipulated. This makes thermal camera integration more difficult than in other systems. There can be noticeable disadvantages in usage of commercial structure light based 3D scanner. Those 3D scanners are usually composed of video projector that emits high density visible light that can be unpleasant for the patient during scanning process. Additionally, their acquisition process takes certain amount of time making them not suitable for capturing moving objects. The system based on Microsoft Kinect is more comfortable for the patient because Microsoft Kinect uses IR light projector which is not visible for human eye. Because Microsoft Kinect is designed to capture depth images in real-time it is possible to create 3D thermal model of moving object. The problem is that this system has low resolution and accuracy and to overcome these drawbacks custom system, which consists of NIR DLP projector, two NIR cameras and thermal camera can be used. This system is fast enough to collect data in real time and have high resolution and accuracy. This method is also comfortable for the patient because it uses NIR light projector.

System workflow includes processes for combining spatial data and surface temperature distribution useful

TABLE 1

Overview of three possible approaches for 3D thermography system based on structure light 3D scanning.

	3D thermography system (commercial 3D scanner)	3D thermography system (Microsoft Kinect)	Custom 3D thermography system (NIR DLP projector, two NIR cameras)
Acquisition speed (s)	> 1	< 0.05	< 0.1
Distance form object (m)	0.7–4.5	1.3–4.5	Adjustable depending on the lens
Resolution (mm)	~ 0.5/3	~ 0.5/22	Estimated high resolution in the application with high resolution NIR DLP projector and NIR cameras
Accuracy (mm)	~ 0.1	~ 30	Estimated high accuracy, depending on the focus and the resolution of the projector and cameras

in various medical applications. There are three processes that form the workflow: calibration, acquisition and medical application as shown in

System components

System we propose combines two different multidimensional data sources: 3D scanner and thermal camera, and a 3D visualization display into a comprehensive multispectral visualisation tool suitable for medical applications. This allows the system to obtain spatial data and surface temperature distribution. Medical 3D thermography system is shown on

The 3D scanner used with the system uses a Digital Light Processing (DLP) video projector and a digital firewire camera. A video projector is used to project structured light patterns on the object to be scanned. The digital camera is used to acquire images of the object under structured lighting. Both devices are driven by a software tool running on a standard PC, which produces the series of patterns, projected by the emitter and synchronizes the camera capture process.

The thermal camera is used to capture *thermograms* – images showing surface temperature distribution. Based on the surface temperature distribution it is possible to isolate areas of interest for different medical conditions. *Thermograms* captured using the thermal camera are two dimensional and are later associated to the three dimensional spatial data gathered by the 3D scanner.

The 3D scanner and the thermal camera are controlled by software components installed on standard PC for driving system workflow processes. Result of system workflow is displayed on special 3D visualization display.

System workflow

System workflow includes processes for combining spatial data and surface temperature distribution useful in various medical applications. There are three processes that form the workflow: calibration, acquisition and medical application as shown in

Calibration process is used to obtain system parameters that describe spatial relations and physical properties of system components. These parameters are based on

various calibration methods. System parameters obtained during this process are used in the acquisition process.

Acquisition process combines spatial data gathered through 3D scanning acquisition and captured by the thermal camera into *3D thermograms* using system parameters. These *thermograms* can be analysed and visualised for various medical applications.

Medical applications include scientific approach for *3D thermogram* data analysis and visualization for diagnostic purposes of various illnesses that manifest through temperature deviations. Collecting standardized *3D thermograms* provide a solid base for building diagnostic and predictive physiological models.

CALIBRATION PROCESS

Calibration process includes both calibration of the 3D scanner and the thermal camera. The calibration is used to compute optic extrinsic and intrinsic parameters of the system components.

The intrinsic parameters are modelling the optic imaging process. These include the focal length of the objective and parameters defining optical distortion of the objectives. For the determination of these intrinsic parameters, a method based on analysing images of geometrically well known pass points (checkerboard pattern)

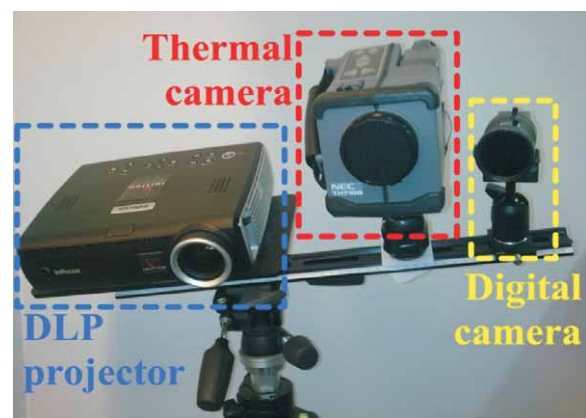


Figure 1. System components.

was used. There are two distinct intrinsic parameters groups. Parameters defining camera matrix based on the pinhole camera model and parameters defining radial and tangential camera distortions caused by physical properties of lenses (18).

Extrinsic parameters describe spatial relations of system components. These parameters include position and orientations of components in regards to each other. Extrinsic parameters of each component are contained in translation vector and rotation matrix. Translation vector describes the translation of reference points between two components and the rotation matrix defines rotations of reference axes between two components (18). To determine extrinsic parameters, intrinsic parameters have to be known.

3D scanner calibration

To compute intrinsic and extrinsic parameters of the projector and the camera a green-purple checkerboard panel is used. The green-purple checkerboard panel is simultaneously captured by the camera and the projector from multiple orientations. The camera used is monochrome so it is almost equally sensitive to green and purple colours. To capture the camera pattern – the checkerboard pattern printed on the calibration panel – the projector illuminated the panel with green light to increase the contrast between the two colours making the pattern easier to segment. For capturing the projector pattern – the checkerboard pattern projected by the projector onto the calibration panel – the projector projected a black and white checkerboard pattern that was not hindered by the underlying checkerboard pattern printed on the calibration panel because of the monochrome camera. The captured images of corresponding camera and projector patterns were used in the calibration method.

Thermal camera calibration

To compute intrinsic and extrinsic parameters of the thermal camera a black and white checkerboard panel is used. The thermal camera, although it captures thermal radiation, is able to detect the calibration pattern due to the fact that black and white coloured objects have very different emissivity factors. This means that a black ob-

ject emits more thermal radiation than a white object if both are illuminated using white light, even though the both objects are at the same temperature. depicts *thermogram* of a black and white checkerboard pattern. The temperature radiation values on pixels marked by the black line are also shown. These two figures show the difference in captured thermal radiation between black and white fields of the pattern. In order to determine the extrinsic parameters of the thermal camera, captured thermal images of the pattern are used along with images captured by the camera from the 3D scanner.

ACQUISITION PROCESS

In order to construct the *3D thermogram*, the object 3D scanned mesh and temperature map have to be acquired. The acquired temperature map is then mapped onto the 3D model given by the 3D scanner using computed system parameters.

3D object acquisition

To obtain spatial data structured light 3D scanner was used. Spatial data acquisition process is carried out by projecting a sequence of vertical light stripes pattern onto the object using the DLP projector. Each vertical line in pattern is gray coded through subsequent projected patterns (14). The camera captures greyscale images of deformed projected stripe patterns. Using the system parameters calculated during the calibration process (angle between the projector and the camera of the 3D scanner) spatial coordinates of each pixel captured by the camera is computed. The (a) shows 3D surface model acquired by the 3D scanner.

Temperature map acquisition

Temperature map acquisition process is used to acquire the object *thermograms* consisting temperature distribution of object's surface. These *thermograms* are later applied over the surface of the 3D object obtained by 3D scanner. The (b) shows temperature map captured by the thermo camera.

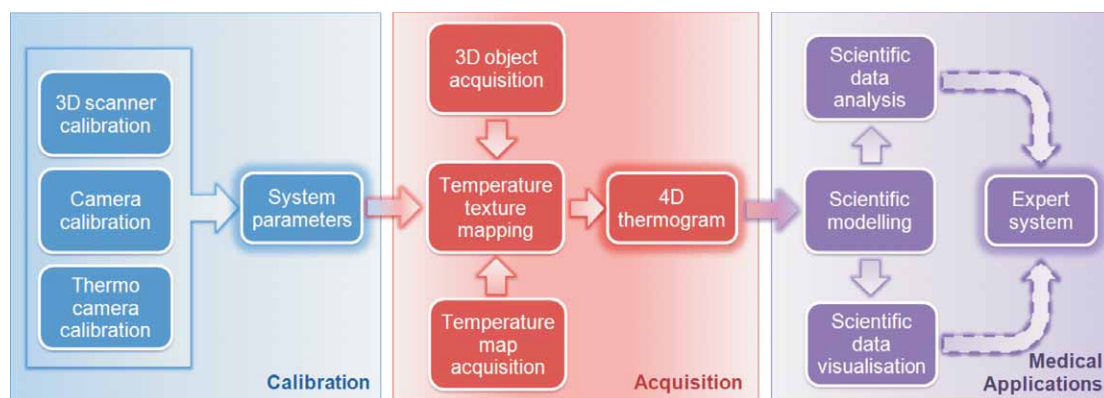


Figure 2. *D thermography system workflow.*

Temperature texture mapping

System parameters allow *thermograms* captured by the thermo camera to be reprojected to the 3D space of the object captured by the 3D scanner. This is possible because the camera from the 3D scanner and the thermo camera are calibrated together. This means that it is possible to translate and rotate points captured by the thermo camera into space defined by the 3D scanner.

MEDICAL APPLICATIONS

Various medical applications are based on analysis and/or visualisation of data relevant for processes happening in the human body. The temperature distribution is connected to biological and physiological processes that can normally occur or are the result of an illness.

3D *thermograms* allow modelling different models and processes based on scientific studies of medicine and biomedicine (e.g. breast cancer temperature dissipation). This means new data analysis methods have to be invented and new method of visualisation can be applied to enable medical professionals setting up a more reliable and comprehensive diagnosis.

Scientific modeling

Scientific modelling represents different use cases for the 3D thermography. 3D *thermograms* provide a more insightful view of the temperature distributions in the human body. Inflammatory processes are manifested on *thermograms* as temperature hotspots due the increased blow flow and cellular metabolic rate. Focused inflammation is a symptom of many diseases such as cancer. How close the inflammation hot spot is near the surface of the skin effects the impact on the temperature distribution on the skin surface. Many studies have shown that breast cancer can be detected in thermograms because of the surrounding tissues and close proximity to the skin.

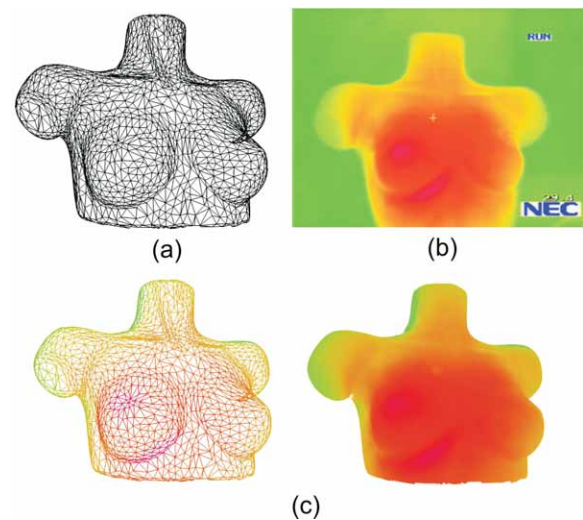


Figure 4. (a) 3D mesh constructed by 3D object acquisition process, (b) thermogram captured by the thermo camera, (c) 3D thermogram.

Scientific data analysis

Standardisation of *thermograms* is a viable possibility using the 3D thermograms. Also 3D thermograms allow analysis not only based on temperature distribution but also based on shape and how temperature distribution changes with time (dynamic thermography) (4). This is especially important when monitoring certain medical states (e.g. recovery progress). One of many possible medical applications is estimation of size and depth of cancer inflicted tissue for persons diagnosed with breast cancer (19).

Scientific data visualisation

Modern technology allows new and exciting methods of visualisation that enables viewers a more in-depth approach to the observed object. 3D *thermograms* visualised on 3D monitors provide a more realistic view on the tem-

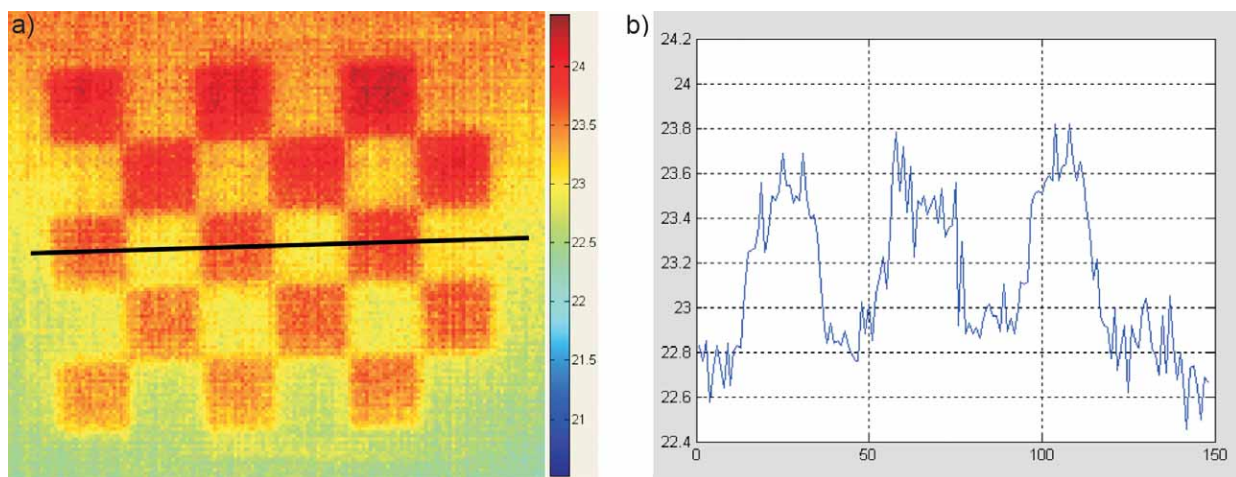


Figure 3. (a) thermogram of black and white checkerboard pattern, (b) the temperature radiation values on pixels marked by the black line.

perature distribution than standard 2D *thermograms*. Using data derived from scientific data analysis can complement such visualisation with added details of the problem (e.g. visualizing breast tumour computed using data analysis). On the other hand visual analysis can steer data analysis into new directions and can expose the problem in a more apprehensible way.

CONCLUSION

In this paper, the development of 3D thermography system integrating active scanning system and passive thermography system has been presented. The integration of structured light based 3D scanner and thermal camera enables acquisition and modelling of 3D *thermogram*. 3D *thermogram* is a spatial model of observed object that contains surface shape and temperature distribution data. Thus it can be a valuable data model for current and future applications for modeling and simulating biological and physiological processes of the human body.

This concept is defined by 3D thermography system workflow presented with three conceptual processes, calibration, acquisition and medical applications. These processes provide novel framework for development of new 3D human physiological models and techniques for their analysis and visualization.

Future work is oriented towards analysis and improvements in all three conceptual processes. Novel methods for calibration and acquisition processes will be studied to enhance acquisition of 3D *thermograms* in real-time. This will bring novel opportunities for different medical applications. Different ways of data analysis and data visualization will be also explored for developing 3D *thermogram* analysis (statistical, spatial), visual-analysis and visualization tools used in different medical applications.

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