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CHARACTERISTICS AND PROSPECTS OF MICROWAVE THERMOGRAPHY

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ABSTRACT

The microwave thermography is a non-invasive method of measuring internal tissue temperature through the detection of microwave radiation emitted from heated tissue. This noninvasive technique makes use of the human body emission in accordance to Planck radiation law. In microwave thermography, this feature is used for multiple purposes such as health indicator in medical applications. Scientific evidence suggests that thermography may only confirm the presence of a temperature difference, and other procedures are needed to reach a specific diagnosis. Microwave Thermography was possible because human tissues emit thermal radiation whose intensity at microwave frequency is proportional to tissue temperature. However, a potential advantage results if microwave and infrared thermography are used together for screening, and if mammography is used only for follow-up on those patients who were positive on either the microwave or the infrared thermograms. It is then possible to obtain true-positive and true-negative detection rates of 0.09 and 0.9, respectively, while only half the number of patients need be subjected to x-rays. The advantage of using microwaves are both avoiding ionization radiation and breast compression, using a fast method, specific and cheaper than MRI and has a fast Image processing. Microwave thermography system allows the detection of deep malignant structures because of the fact that microwaves have greater wave length as compared with the infrared radiation and less absorbed by the tissue on which it covers from the tumor to the surface. The most widely tested applications of Microwave thermography includes; Breast cancer detection, Treatment response monitoring of breast cancer patients, Preliminary studies of arthritic knee joints and Abnormalities of the spine. The paper presents various characteristics, prospects and medical application of microwave thermography.

KEYWORD: Thermography, Centimetric Wavelength, Non-invasive, Tissue, Temperature.

INTRODUCTION

Thermography is a technique for detecting and measuring variations in heat emitted by objects e.g., electrical and mechanical equipment, structures, the human body, etc. The need for measurement of heat radiation from the body tissues during cancer investigation is quite important at the pre-invasive stage. Thermology was first documented around 400BC by Hippocrates. In his time, Ancient physicians of the Golden Age were known to employ a primitive form of Thermology where they would apply thin mud slurry onto their patient's body. As the compound dried, patterns of hot and cold would emerge by different rates of drying (Schuster and Kolobrodov 2000).

Microwave thermography is the technique of observing the naturally emitted thermal radiation from body tissues at centimetric wavelength. It is the techniques for measuring temperature through the detection of microwave radiation emitted from heated tissue. The human body respects the same laws regarding electromagnetic emission as the environmental bodies, and can be considered as a grey body. The intensity of radiation depends on the temperature and the frequency (wavelength) of the electromagnetic radiation.

The first thermographic devices for non-military application available in the 1960s and 1970s with up to 3000 thermography clinics operating in the United States of America. Clinical thermography is the recording of heat distribution in order to form an image (a thermogram) of the temperature distribution on the surface of the body. Thermography was also introduced as a screening tool for breast cancer (Kennedy et al, 2009). Microwaves are electromagnetic waves that have a frequency range from 0.3 GHz to 300 GHz with corresponding wavelengths ranging from 1mm to 1m as shown in figure1.

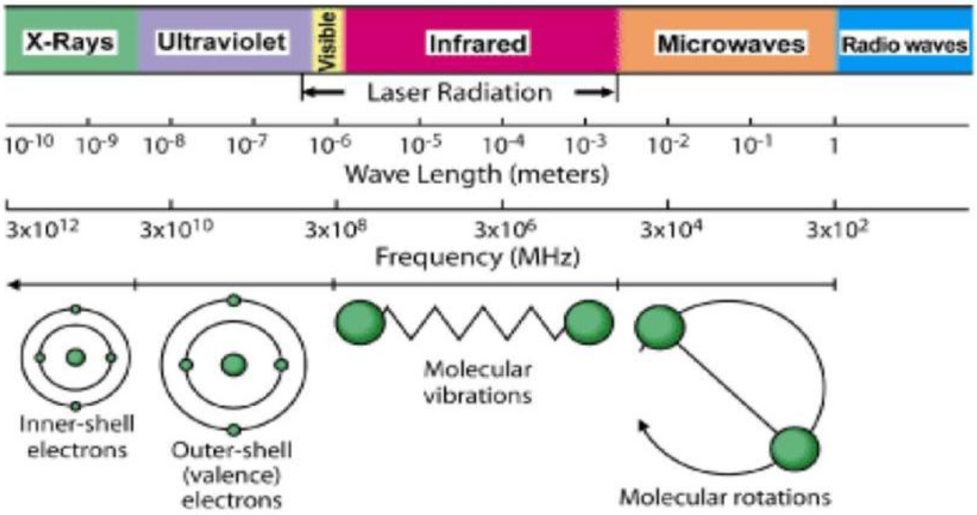

Figure 1: Electromagnetic Spectrum (Schuster and Kolobrodov, 2000).

MEDICAL THERMOGRAPHY

Medical Thermography (digital infrared thermal imaging - DITI) is used as a method of research for early pre-clinical diagnosis and control during treatment of homeostatic imbalances. The temperature variation over the human body reflects the effect of blood perfusion, metabolism and environmental temperature, therefore any disease which causes changes in the physiological properties of the human body also changes the measured microwave temperature and can be investigated using microwave thermography.

Microwave thermography usually has two parts: the microwave (Radio Frequency) camera and a standard PC or laptop computer. These systems have few controls and are relatively easy to use. The camera converts the Microwave non-ionizing radiation energy from the measured object into an electrical signal in the imaging sensor and displays a range of colors that correspond to temperature. The data are presented on the PC or laptop as either a still image or a video for analysis.

Utilizing high-speed computers and very accurate thermal imaging cameras, the heat from the body is processed and recorded in the computer into an image map which can then be analyzed on screen and printed out on-demand. Medical applications of microwave thermography are extensive, particularly in the fields of Rheumatology, Neurology, Oncology, Physiotherapy and sports medicine. Thermal imaging systems are an economical easy-to-use tool for examining and monitoring patients quickly and accurately. It is non-invasive, passive and does not cause distress to the patient.

Mammography and Thermography Compared

S/N	Description	
	Mmamography	**Thermography**
1	Uses X-rays to produce an image of the breast. Areas with abnormalities need to be dense enough to be seen. However, if too dense, interpretation may be difficult	Uses infrared imaging technology to detect heat and vascular activity. Heat is compiled into a computerized image for analysis
2	Focuses on structural imaging and has the ability to locate an area of suspicious tissue	Focuses on physiologic changes in temperatures and vascular activity that could indicate abnormal activity in an area of the breast
3	Early detection method, when breast tissue abnormality becomes evident	Early detection method, when abnormal vascular patterns and temperature changes are detected, generally much earlier than tissue
4	Cannot diagnose cancer. Can detect it at the pre-invasive stage	Cannot diagnose cancer. May provide signal that changes are occurring in the breast tissue
5	For most women with private insurance, annual mammography screenings are covered without copayments or deductibles, but it's important to contact the mammogram facility and the insurance carrier to confirm insurance coverage. Also, Medicare pays for annual screening for all female beneficiaries who are age 40 or above.	Generally not covered by health insurance plans. Some plans may offer some out-of-network coverage, but are should check with the plan administrator first. Thermography screenings are eligible expenses for health care flexible spending accounts and Health Saving Accounts. The cost of breast thermography screening averages \$150 - \$200

Source: Breast Thermography.com

Types of Thermography

Thermography is a tool that creates a high definition digital map of the body that illustrates temperature patterns — patterns that may detect some condition or abnormality. It uses a high definition infrared camera that measures the body's surface temperature, presenting the information as a digitized image (Jasem, 2017). These thermal images (thermograms) are analyzed for abnormalities that may be signs of disease in the body. Additionally, since the body is thermally symmetrical if normal, thermal asymmetries can indicate problems. The advantage to these new imaging devices are that they can provide a way for physicians to instantly capture large arrays (images) of quantitative thermographic or temperature information.

The following forms of thermography are probably the most widely used in clinical medicine:

1. Microwave Thermography
2. Infra-Red Thermography
3. Liquid Crystal Thermography

Microwave Thermography

Microwave thermography is the technique of observing the natural thermal radiation emitted from body tissues at centimetric wavelengths to obtain information about internal body temperatures. Even though there are microwave emissions from the skin surface, the intensity is very small when compared to Infra-red radiation intensity, (10 wavelength emission intensity is 108 times greater than 10 cm wavelength emission intensity). Using modern microwave radiometers one can detect temperature change of 0.1K, since body tissues are partially transparent to microwave radiations which originates from a tissue volume extending from the skin surface to a depth of several centimeters. Microwave radiometers consisting of matched antennae placed in contact with the skin surface for use at 1.3 G Hz and 3.3 G Hz have been used to sense subcutaneous temperature.

Infra-Red Thermography

Infra-red thermography detects the infra-red radiation being emitted from the skin and can be used to quantify changes in blood flow and inflammation in limbs and joints. This technique is also used to evaluate and monitor disease activity. Infrared thermography is the science of acquisition and analysis of thermal information by using non-contact thermal imaging devices. Human skin emits infrared radiation as an exponential function of its absolute temperature and the emissive properties of the skin temperature.

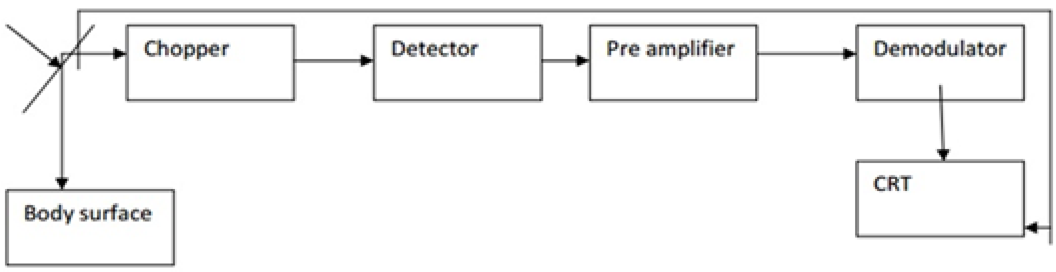

Figure 2: Block diagram of Infrared Thermography (IAMT, 2006).

Every thermographic equipment is provided with a special infrared camera that scales the object. The camera contains an optical system in the form of an oscillating plane mirror which scans the field of view at a very high speed horizontally and vertically and focuses the collected infrared radiations on to the chopper. The chopper disc interrupts the infrared beam so that A.C signals are produced. The signal is thereafter passed on to an infrared radiation detector. The detected output is amplified and led to phase sensitive.

$$P = KT\Delta F \qquad (1)$$

Where P is the power in watts, collected by the receiver from a tissue volume at uniform temperature T.

K = Boltzmann Coefficient ($1.38 * 10^{-23} * J * K^{-1}$)

ΔF = Receiver Bandwidth (Hz)

In practice, suboptimal coupling and tissue attenuation reduce the signal. Scanning is performed, as in infrared thermography and the microwave signal is digitized, processed and displayed as a colour image of temperature distribution.

Biomedical applications of microwave thermography include cancer distribution (Breast, Brain, Thyrod, etc.) and non-invasive control of hyperthermia.

$$P = \sigma A e T^4 \qquad (2)$$

Where P = Radiated power in Watts

σ = Stefan-Boltzmann Constant

= $5.670373*10^{-8} W/(m^2 k^4)$

A = Area of substance exposed, in m^2

e = emissivity of substance, which is a number Between 0 and 1 (no units).

T = Absolute temperature of the substance, in kelvin (K)

In the thermograms, temperatures are displayed in a spectrum of colors. The graphic in figures 2 and 3, illustrates the hierarchy of colors typically used to represent the relative temperature values of objects evaluated during an infrared inspection.

Figure 3: The hierarchical distribution of color relative to temperature. (Source: 2003 - 2017 Infra-red Analyzers, Inc.).

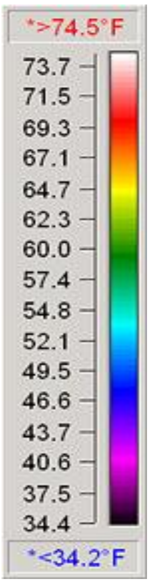

Figure 4: Documentation of Objects for Thermal Characteristics (Source: 2003 - 2017 Infra-red Analyzers, Inc.).

All thermal images feature extremely accurate embedded temperature measurement systems for fast, precise quantitative documentation of the object's thermal characteristics. The infrared energy emitted from an object is directly proportional to its temperature. Therefore temperatures are accurately measured by the infrared camera.

3.3 Liquid Crystal Thermography

Liquid crystals are a class of compounds which exhibit colour temperature sensitivity in the cholestric phase. Scattering effects with the material give rise to iridescent colours, the dominant wavelength being influenced by very small changes in temperature. The high temperature sensitivity makes cholesteric liquid crystals useful for thermal mapping. In this technique, the temperature sensitive plate consists of a blackened thin film support into which encapsulated liquid crystals cemented to a pseudo solid powder (with particle sizes between 10 to 30) have been incorporated.

Thermal contact between the skin surface and plate produces a color change in the encapsulated liquid crystals; red for relatively low temperatures through the visual spectrum to violet for high temperatures. But in infrared thermograms, the violet colour is used to identify the low temperature regions and the bright colour or red is used to identify the temperature regions. If we want to study a breast's temperature distribution, several different plates are necessary to cover a breast temperature range from 280C to360C. Each plate covers a range of temperature 30C. A record of the liquid crystal image may be obtained by colour photography. The response time varies according to the thickness of plate (ranges from 0.06mm to 0.3 mm) and is 20 to 40 seconds.

3.4 Properties of Microwave

1- Microwave is an electromagnetic radiation of short wavelength.

2- The frequencies of microwaves are those between 1GHz and 300GHz.

3- They are not reflected by ionosphere.

4- They can reflect by conducting surfaces just like optical waves

5- Microwaves are easily attenuated within short distances.

6- Microwave currents flow through a thin outer layer of an ordinary cable.

3.5 Radiation Laws of the Black Body

A blackbody refers to an opaque object that emits thermal radiation. A perfect blackbody is one that absorbs all incoming light and does not reflect any. At room temperature, such an object would appear to be perfectly black (hence the term blackbody). However, if heated to a high temperature, a blackbody will begin to glow with thermal radiation. The bodies occurring in real life show very diverse radiation properties. This model body is known in radiation physics as the "black body". It distinguishes itself by the fact that, of all bodies of equal temperature, it shows the largest possible emitted radiation. The energy emitted by a blackbody is called blackbody radiation. This takes the form of an electromagnetic field having an intensity-versus-wavelength relation whose graph looks like a skewed, bell-shaped statistical curve as shown in Figure 5.

The spectral spread of radiation emitted by a black body is described by Plank's radiation law:

$$M_\lambda = \frac{C_1}{\lambda^5 * [\exp\left(\frac{C_2}{\lambda T}\right) - 1]} \quad (3)$$

Where, $C_1 = 3.74*10^{-16} \mathrm{W}*m^2$

$C_2 = 1.44*10^{-2} \mathrm{K}*m$

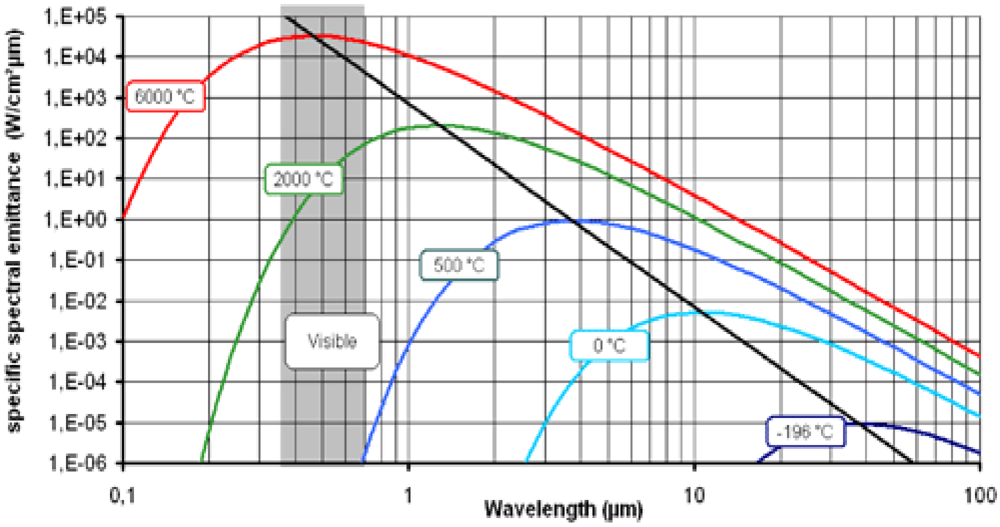

Figure 5: Variation of spectral composition with temperature (Schuster and Kolobrodov (2000).

This representation shows that the spectral composition varies with the object temperature. Furthermore, as postulated by Planck and others, as the temperature of a blackbody increases, the total amount of light emitted per second increases, and the wavelength of the spectrum's peak shifts to bluer colors (see Figure 6).

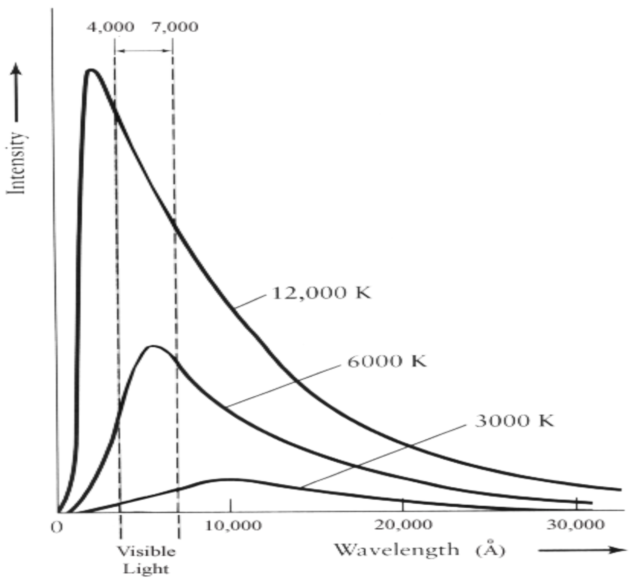

Figure 6: Variation of blackbody temperature with wavelength (Jasem (2017)).

4.0 Benefits of Microwave Thermography in Medicine

Microwave thermography can be used with great success in cancer investigation. The new methods for investigation present great advantages as compared with present medical techniques:

- The new investigation systems for breast cancer present a low risk for the health of the patient;
- The method could be used for detecting breast cancer in men (since we can't do a mamography for them);
- The structural modifications of tissues could be detected before those being detected with classical methods, ultrasounds and ionization radiations;
- The method is sensitive to all tumors and offers a specific contrast for malignancy;
- Breast cancer detection is made in a curable stage;
- Is a non-invasive method and easy to make;
- No risk for patient of any age;
- Cheap, faster and vastly used;
- Involves a minimum discomfort for patient, being easily accepted by women;
- Is easy to interpret and objective.

4.1 Advantages of Microwave Thermography in Medicine

The basic clinical advantages of medical thermography include:

a) Safe, easy, pain-free, and radiation-free.
b) Provides a color coded temperature "fingerprint"
c) No contact, compression, or pain.
d) Detects physiological changes of the body in real time imaging.
e) Identifies inflammatory conditions by temperature changes.
f) Identifies fibrocystic tissue disease and tumor inflammation within the body.
g) Effectively and safely screens dense breasts and women with implants.
h) Useful for evaluating chest wall size after breast surgery.
i) Effective for breasts of all sizes.
j) Creates opportunities for early intervention!

4.2 Limitations and Disadvantages of Thermography

a) Quality cameras are expensive and are easily damaged.
b) Images can be hard to interpret accurately even with experience.
c) Accurate temperature measurements are very hard to make because of emissivities. Most cameras have ±2% or worse accuracy (not as accurate as contact).
d) Training and staying proficient in IR scanning is time consuming Ability to only measure surface areas.

4.3 Application of Microwave Thermography in Medicine

Some of the common applications of Microwave thermography in medicine include:

- Breast pathologies
- Extra-Cranial Vessel Disease
- Neuro-Musculo-Skeletal
- Vertebrae (nerve problems/arthritis)
- Lower Extremity Vessel Disease
- Hormone Diseases
- Examination of Placenta Attachment
- Skin Grafts and Organ Transplantation
- Tumors
- Inflammation

CONCLUSION

Microwave thermography is a technique of measuring microwave emission from sites of inflammation. Microwaves have a wavelength of around 10 cm and are therefore able to penetrate clinically useful depths of up to 4 cm directly measuring tissue thermal radiation. Microwaves thermography, is a noninvasive and passive technique. It does not subject the patient to radiation, discomfort, stress and physical stress. The cancer detection is based on the contrast between the thermal images of the mammary normal and malign tissues respectively, obtained through radiometry, the last one having a higher temperature. In breast cancer diagnosis, this method presents incontestable advantages: low costs, repeatability (as often as necessary, even monthly), completely non-harmful. Microwave medical imaging is a completely noninvasive technique. The microwave technique also permits to show the difference between malign and a benign tumours, thus reducing the number of invasive and expensive biopsies. Mapping the spatial microwave emitting loci of the normal and malignant tissue we may early detect the areas with an increased biological activity. The real spatial malignant tissue positioning is limited by the breast normal shape and the physical dimensions of the antenna. The results obtained are more accurate if they are reinforced by the results given by other parallel non-invasive optic methods or thermography, influencing the expert’s opinion in the final decision.

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