Current Trends in the Application of Thermal Imaging in Medical Condition Analysis

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Abstract**: *Long Wave IR imaging is one of the imaging modalities that have been used to study medical conditions of a human body by means of body surface temperature measurement. The thermal image obtained from a thermal imager can be better described as the heat map of the captured ROI (Region of Interest). These thermal markers could be potential indicators of existing medical condition and can give further insights about the illnesses. While the literature review reports of extensive study of thermal imaging as subordinate tool for disease diagnosis, it cannot be denied that there still is dearth of standard thermal image databases of human body with medical conditions characterized by elevated temperatures in affected body parts which could be a useful research aid. This could be attributed to the highly expensive Thermal Imagers commercially available. Therefore attempts to design and develop a reliable and cost-effective thermal sensor could be a pragmatic step towards widespread availability of thermal imaging device for use in medical applications. In this Paper, we have attempted to review the research works which has reported application of thermal imaging for medical purposes. We have also summarized the thermal imagers used and the temperature range and resolution of thermal sensors utilized in their reported works.***

Index Terms**: *Heat mapping, IR imaging, Medical thermography, Thermal imagers.***

I. INTRODUCTION

Thermal imaging is the method of detecting Long IR range of electromagnetic spectrum which is invisible to the human eye by means of special and sophisticated cameras called as Infrared Imagers. The Long-Wave IR falls between 8µm - 15 µm and provides thermal data or heat map of the captured scene in quantified form representing temperature data of the same. Thermal imaging does not need ambient light to capture thermal image as its working principle is based solely on detecting thermal emissions of the scene to be imaged. The temperature map thus obtained is represented through application of pseudo color palette for visualization purposes which is done by software application in the form of firmware inside the infrared imager or on an application in a computer system. Fig. 1 shows a pseudo colored thermal image of hand. The detector technology, IR Optics used, combined with the software functions are parameters that decide the cost of the thermal imaging system. Uncooled silicon microbolometer based Imagers have been predominantly used for various applications like research, military, commerce, etc. due to comparatively lesser costs as compared to the cryogenic Imagers which are very expensive and used in military and industrial applications [1]. Nevertheless, thermal imagers still remain beyond affordability for groups with modest budgets.

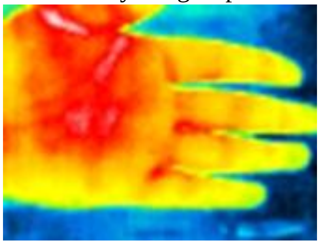

Fig 1: A pseudo colored thermal image of hand

II. MEDICAL USES OF THERMAL IMAGING

Thermography finds its way not only in military and surveillance applications, but has been widely applied in R & D of non-invasive diagnosis of several medical conditions. Preservation of homeostasis requires a steady body temperature in accordance to external environmental conditions such that the body fluids and body tissues maintain their composition and perform their functions. Fluctuation in the body temperature is a strong indication of some sort of physical dysfunction. And if these fluctuations cross a certain range may cause obstruction in some vital chemical processes [2]. A range of medical conditions exist that are marked by changes in body temperature that can be detected through changes in body surface temperature. The easiest and most common means of fever detection in daily life is by merely touching the body. But the quantification of fever is vital for understanding the severity of the illness. From clinical mercury-based thermometer to non-contact thermal imagers with advanced detectors and IR optics, the advancement in thermal quantification has come a long way. Carl Wunderlich in 1868 developed the thermometer, which is still being used in clinical practice. It has a limited scale with a typical range of 35 °C to 42 °C or 90 °F to 110 °F which is around the range of internal body temperature [3]. But medical conditions such as hypothermia and hypothermia are characterized by extreme alterations in body temperature which can be life-threatening [4]. The change in body surface temperature occurs due to changes in blood perfusion rate at the peripheral site of the body on account of an illness. In most of the cases, even before clinical symptoms appear, temperature change is preceded, this can be essentially used for early diagnosis and prognosis [5]. Illnesses such as fever,

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hypothermia, hyperthermia, diabetes, breast carcinoma, peripheral vascular disorders, dermal problems induce characteristic changes in body temperature that can be detected through measurement of body surface temperature. In the following sections we present a small review of the recently reported thermography applications on four most commonly studied medical conditions.

A. Hypothermia/Hyperthermia/fever

Fever can be a vital sign for presence of various infections from which, some could be contagious. Thermal imaging has proved to be effective in mass screening of fever which could be especially useful to monitor crowded places which is illustrated in Fig. 2 [6]. Outbreaks of pandemics like Ebola and SARS could be monitored effectively in people present in public places like malls, airports and other travelling junctions through means of thermal imaging systems installed at such places [7]. The hypo thermic and hyper thermic body regions can be identified during surgical procedures for observing temperature fluctuations in the organ. By use of thermal imaging system, Danilova et. al attempted to control heart temperature and successfully detected hypothermia by imaging the myocardium [8].

Fig 2: Fever screening using IR Imaging

B. Diabetes

Thermography has also been proven effective in imaging diabetic foot caused due to vascular problems. Diabetic neuropathy is marked by changes in body surface temperature especially which can be observed in the limbs. This is caused due issues in blood circulation. Worsening of the foot problems is most commonly faced by patients suffering with diabetes mellitus [9]. Fig. 3 illustrates the thermal image of plantar angiosome on the left side foot [10]. A study by Sun, P. C. et al. [11] concluded that normal subjects had lower mean foot temperature as compared to the pre-diabetic subjects. IR screening can also be useful in ulcer monitoring in diabetic subjects and examining the effectiveness of treatment related to blood circulation issues in the limbs [12]. IR imaging can be used as an auxiliary technique to study diabetic foot characterized by higher temperatures and loss of sensation [13].

Fig 3: Thermal image of plantar angiosome on the left side foot

C. Skin Cancer

Works in the direction of cancer detection techniques have studied skin cancer with the help of dynamic thermal imaging technique. Though thermography is not an established method of cancer detection, the implementation of dynamic thermal imaging has been giving promising results in the study and behavior of malignant skin tumors under certain stimuli. A standard and acceptable imaging protocol has yet not been established [14]. Attempts were made to identify the thermal signatures of melanoma compared to other skin cancer types and it was found that melanoma had higher thermal profile (Fig. 4) as compared to basal cell carcinoma and squamous cell carcinoma [15]. Image processing on skin cancer thermal images for ROI extraction and segmentation for lesion boundary detection have been attempted where it was observed that the lesion boundary of skin cancer tumor could be detected by means of various edge detection algorithms [16]. Extensive works by Pirtini Cetingul et. al [17] report of early diagnosis of melanoma using dynamic thermal imaging that involves providing thermal stimulus to the area that is examined followed by imaging the skin recovery process in periodic time intervals.

Fig 4: Visible light image and thermal image of right foot with melanoma lesion

D. Breast Cancer/Carcinoma

Breast Carcinoma is prominent type of cancer in females. The tumor formation in the breast can be examined through thermal imaging of the breast vascularity. As the heat build-up in tumors in higher as compared to the surrounding healthy region owing to surged metabolic activity [18], thermal imaging can be effective means of monitoring this change. Bezerra L.A. et al. [19] applied a novel approach for assessment of thermal properties in breast, using sequential quadratic technique. This was a significant contribution establishing the potentials of thermal imaging in characterization of breast thermophysical properties. Though IR imaging has been declared as an adjunctive tool for breast cancer detection [20], extensive research based on studying thermal properties and image processing approaches has been done to explore its usefulness in detection of breast carcinoma. In their comparative review, Kennedy, D. A. et al. [21] concluded that rates of specificity along with sensitivity of thermal images classification can be combined with the existing diagnostic approaches like clinical assessment, mammography and ultrasound for breast cancer screening. A study [22] reported effectiveness of thermal imaging as an auxiliary means for breast cancer diagnosis in 60 subjects with a 97%, 44%, and 82% sensitivity,

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specificity, and negative predictive value respectively. From one of the works in breast research [23], the temperature profiles of healthy and non-healthy breast can be seen in Fig. 5.

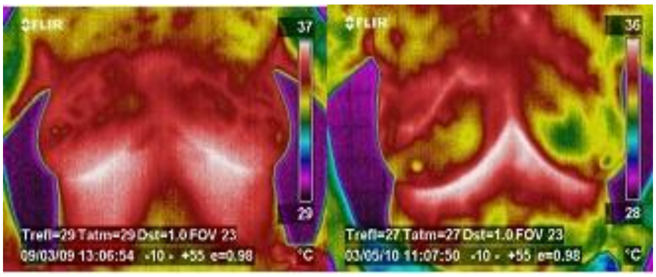

Fig 5: Healthy temperature profile and non-healthy temperature profile of breast

III. THERMAL IMAGERS

Whether it is a fire fighters thermal camera or a medical diagnostic purpose thermal imager all IR-based thermal cameras are mainly composed of five major constituents namely an optical system or sensor, an thermal emission detector, some amplifiers, a signal processing unit and a suitable display. Table 1 enlists some works where thermal imaging systems were used to study the diseases in light of changes in body surface temperatures during the period of illness. The works selected are recent so as to bring to notice the preferred thermal imaging systems used along with their important specifications that are parameters in selection of the thermal imagers. From fever screening to cancer detection, the most preferred IR imagers are the Longwave IR cameras whose spectral range is 7~14μm. In almost all studies, the ideal IR resolution is 320 x 240 pixels. A 320 x 240 Thermal image has 76800 pixels each of which represent a temperature value of the captured target which is quite suitable for obtaining detailed temperature information of the ROI to be examined. The same IR resolution was found suitable for study of cancerous lesions like melanoma that can be quite small sized [31]. The selection of thermal imager with IR resolution of less than 320x240 pixels may not be the ideal choice for study of certain illnesses like melanoma i.e. a category of skin cancerous lesions where finer details hold vital thermal cues of the ROI that is imaged. From this study, it is also observed that FLIR is one of the most reliable and preferred thermal imagers in medical research and studies. Thermal cameras are comparatively much higher priced compared to the visible cameras that are commonly used at present, which can be attributed mainly to the expensive lens material used like germanium, the coolers included in the system to help reduce thermally-induced noise in captured data, the detector resolution, etc. Also, the demand for such special cameras is comparatively on the lower side, hence they aren't mass produced. Further, thermal imagers with higher resolutions can escalate the imager costings in multitudes as compared to the ones with lower resolutions. The difficulty in procurement of such high costing IR systems in itself is a deterrent to many small study groups who find it beyond their affordability to buy these cameras. Where, generating one's own standard databases due to the above-mentioned reasons could be an impediment in research work, a suitable alternative is the open access to existing standard databases of medical thermal images. Most of the research works mentioned, have generated own databases through affiliation with hospitals or organizations that are equipped with the standard thermal imaging equipment lack details regarding access to these databases for reasons like patient privacy and hence, these databases are inaccessible. It is also of interest to scrutinize the availability of open access medical thermal images datasets and research works that report of having used these datasets to work towards medical diagnosis of health conditions of interest.

IV. THERMAL IMAGE DATABASES FOR ANALYSIS

As availability of standard medical datasets is a valuable aid in research activity, attempts were made to search for access to the freely available medical thermal image datasets over the web. A collective effort from several centers resulted in the reference database which was solely designed and developed for standardization of thermal imaging for cross verification and reference of thermal measurements of clinical significance [33]. To the best of our knowledge, there are quite few of such repositories with free access to their datasets. One of the most accessed and cited database repositories is that of breast thermal images by Visual Lab [39] containing a total of 3534 thermal images captured using FLIR SC620 in 640 x 480 IR pixel resolution. Additionally, the database comes with supportive information in the form of segmented images, diagnostic information and help links. In the recent years, studies for examination of breast tumors in light of thermal imaging have gained momentum and such a well-established repository is a valuable aid. The Thermal Focus Image Database [34] hosts a freely available database of 960 thermal images containing face and hand thermal images among others categories including non-biological entities. From the information provided by the providers, the database is not a dedicated medical repository of human thermographs. Gonzáleza, J. R.vet. al [35] reported to have analysed the dataset of neck thermograms for thyroid nodules of 25 subjects provided by Visual Lab [24] and proposed a novel ROI extraction method. Thermal IR images of the hands of 100 subjects are provided by the Faundez-Zanuy, M. et al. [36]. The paucity of datasets available can be attributed to the exceptionally higher costs associated with the good resolution thermal imagers and lack of consent for public access by the subjects imaged.

V. CONCLUSION

The paper presented a precise review of some currently reported applications of thermal imaging on four commonly studied medical conditions where thermography seems to show potential in visual study and heat analysis. The paper also attempted to summarize some recently used IR-based thermal cameras. While working on this paper it was felt that there is dearth of standard thermal image databases and some efforts are needed to put in towards generation of standard thermal image

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databases for research and development purposes towards understanding the critical thermal ranges that would aid in early detection or serve as an adjunct diagnostic procedure.

Some of the major medical conditions where thermography is extensively used are skin cancer, diabetic neuropathy, and breast cancer. It was also noticed that FLIR is one of the most reliable and preferred thermal imagers in medical research and studies and the ideal IR resolution is 320 x 240 pixels for medical condition analysis.It was strongly felt that user friendly, cost effective and reliable thermal imagers are needed for research community and laboratories, and practicing clinicians. Availability of such imagers would boost research in thermal imaging especially for medical applications. The paucity of datasets available can be attributed to the exceptionally higher costs associated with the good resolution thermal imagers and lack of consent for public access by the subjects imaged. In light of the above discussion, studies conducted for setting universal standards for thermal image acquisition setup and generation of such reliable referential thermal image databases in light of the established acquisition protocols could pragmatically change the shortage of standard thermal image databases and bring to light some quality research work.

Table. 1 Summary of studies carried out using thermal imaging systems for medical applications

Pathology	Researchers	Year of work	Thermal Imager for Medical Application	Spectral Range	IR Pixels of Camera
Fever screening	Eddie Y.K. Ng[24]	2004	FLIR IR ThermaCAM S60	7.5~13µm	320X240
	Chiu, W. T. et. al [7]	2005	Telesis Spectrum 9000MB DITI system	7~14µm	320X240
	Ring E. F. J.[25]	2008	FLIR T400 FLIR 620	7.5~13µm 7.5~14µm	320X240 640 X480
	Nishiura, H. et. al[26]	2011	TVS-500EX	8 to 14µm	320X240
Diabetes	Sivanandam, S. et. al [27]	2012	FLIR T400	7.5~13µm	320X240
	Balbinot, L. F. et.al. [28]	2012	PV320T Electrophysics IRISYS IRI 4010 FLIR T400	2~14µm 8 to 14µm 7.5~13µm	320 x240 160X120 320X240
	van Netten, J. J.et.al[29]	2013	FLIR SC305	7.5~13µm	320X240
	Peregrina-Barreto, H. et. al[10]	2014	FLIR A300	7.5~13µm	320X240
Skin Cancer	Santa Cruz, G. A. et. al.[30]	2009	Raytheon PalmIR 250	7–14mm	320X240
	Pirtini Cetingul M et. al[26]	2010	Merlin midwave	3~5µm	320X256
	Herman, C. et. al.[31]	2011	Merlin midwave	3~5µm	320X256
	González, F. J. et. al[15]	2012	FLIR T400	7.5~13µm	320X240
Breast Cancer	Bezerra, L. A.[19]	2013	FLIR ThermaCAM^{TM}S45	7.5~13µm	320X240
	Zadeh, H. G.[32]	2015	NFREC R500 Model	8 to 14µm	640 X480
Hypothermia	Danilova et. al[8]	2015	FLIR i7	8µm - 15 µm	320X240

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