An Evaluation of the Implications of Thermography within the Healthcare Setting

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Abstract: Thermography has developed rapidly over the past fifty years; it has been refined into a sophisticated tool to measure temperature that may be used anywhere owing to the reduction in size of the apparatus used. This technique has also been used industrially to ensure product quality. However, for over fifty years this technology has been employed in medical research studies as it is a non-invasive tool that can be used to study human skin temperature (Ring 2010). The body’s physiological mechanisms yield heat and temperature variations may indicate the presence of disease (Gatt et al. 2015). Thermography is not a tool that requires a skilled technician, nor is it a test that needs to be applied physically to the desired area. It is a simple test can be performed by a simple click of a button and the subject’s temperature readings can be uploading on the manufacturer’s software (Jones 1998). Repeatability of this test has been applied with successful results (Balbinot et al. 2013).

Over the past year, MCAST students in several faculties have observed first-hand the application of thermography as an indication of disease, making using the thermographic camera available on campus. Students from various disciplines could see how the heat-detecting camera being used for disease detection in addition to its applications in engineering, construction, and food technology. Using this research science and technology were linked to enhance the students’ learning experience and make them aware of a fresh approach on how humans can benefit from modern engineering in relation to health. The applications of thermography for disease detection and the understanding of its use is of the utmost importance for students following health-related courses, since thermography is a tool that may soon be available locally as research brings forth new beneficial practices in medicine. This paper appraises the importance of this tool within the health-care setting.

Keywords: Thermography; heat transfer; disease; identification.

The use of thermography in industrial manufacturing and quality control is well-known since it can easily detect heat variations; it is used within multiple fields, including building diagnosis to identify air leaks, electrical and mechanical engineering to detect insufficient insulating, marine electronics for navigation, and gas detection in the oil and gas industry (FLIR systems 2018), to name but a few. Thermography may detect defective materials in line operations, prevent outbreak of fires from stored flammable merchandise (Raytek 2010), and detect defects in printed circuit boards (PCB) in the initial stages (Spence et al. 1995).

However, thermography’s application in medicine shines a new light on disease diagnostics. Its use for medical applications involves the detection of emitted infra-red radiation from a body region of interest, typically the skin surface; different pathologies may cause inflammation and changes in the circulatory distribution,
thus changing the normal heat pattern of the body’s surface (Jones 1998). Modern thermographic equipment is extremely sensitive, designed to detect the smallest variations in infra-red emissions; still this technology is non-invasive and does not emit radiation which could harm the patient (Walker & Kaczor 2012). Since the development of thermometers in the 17th century, the need to assess temperature to identify disease has been recognized. Thermography was employed in the 1960s to study skin non-invasively although the equipment then available was bulky and noisy. The first study using thermography, conducted in the late 50s, was aimed to detect breast cancer before this was clinically obvious; however, the thermal camera used had a slow response and needed significant amount of space due to its bulkiness. Still thermography proved to be an effective tool for cancer detection (Bagavathiappan et al. 2009). Thermography has since come a long way in terms of reliability and modern thermographic imagers are smaller, have a greater resolution, and provide a speedy result that can be uploaded on a computer in seconds (Raytek 2010).

Having a reliable tool in the clinical area for identification of disease, further complications, or assessment of success following an intervention, increases the patient’s chances of survival. In cases of diabetes and poor circulation, this tool may be used to identify problems, such as the development of ulcers (Kanazawa et al. 2016) or identify conditions such as peripheral arterial disease (Gatt et al. 2018a).

Implementing such a tool that can determine whether an intervention is required through an accurate assessment of the perfusion to the areas of interest, most often the toes or the foot, ensures that patients who merit intervention achieve such intervention within time, while others are not subjected to the unnecessary risks of intervention.

Foot complications are common in patients with diabetes mellitus; staggering facts published by WHO (2015) state that diabetes will be the seventh leading cause of death in 2030 owing to its complications. The organization has also estimated that 1.5 million died owing to diabetic complications in 2012 and that 9% of the world’s population suffered from diabetes in 2014. Diabetic complications include blindness; kidney damage; cardiovascular disease and subsequently amputation of lower limbs; as well as ulcers that fail to heal, causing infection and gangrene and which may lead to minor or major amputations. Such consequences occurring because of the failure to foresee such complications cause increased hospital admissions and lengthy hospital stays (Comino et al. 2015) where diabetic foot disease is the leading cause of lower limb amputations and could be reduced by screening of the lower limbs and proper care (Bharara et al. 2010). Identification of poor perfusion may prevent people at risk, such as diabetics and patients with circulatory issues complications such as loss of function, immobility, or loss of limbs (Kaabouch et al. 2011). Recent publications have shown thermography to be a tool that can easily monitor peripheral temperature in the lower limbs to identify changes in disease (Gauci 2017); moreover thermal measurement has long been suggested as a way to identify foot problems in the health-care setting (Sun et al. 2005).

**Temperature-regulation Processes**

The human body regulates its core temperature by balancing the heat produced within the body with the heat lost, for the body to avoid hyperthermia or hypothermia; the body’s ability to regulate temperature by the central nervous system (CNS), depends on ambient conditions (Ammer & Ring 2000) and also in response to pathology (Greenwood et al. 2007). The body’s core temperature is regulated at 37 °C under...
normal conditions and is controlled by the autonomic nervous system by carrying signals to and from the CNS. Higher or lower temperatures may indicate disease or injury (Barriga et al. 2012) which could cause stress on the cardiovascular system (Frank et al. 1997).

Body heat is created in two ways: by digestion along with metabolism and heat produced by muscles, while the extremities gain heat by blood flowing through the cardiovascular system (Jones 1998). During metabolism, which comprises of anabolism and catabolism, heat is generated. During catabolism, large molecules divide into smaller molecules which is an exothermic process within the body. This process starts with digestion and ends within the cells where the energy is extracted for adenosine triphosphate (ATP) while further energy, which is more than half, is lost, aggravating the anabolic process that is vital in order to maintain a stable body temperature. This is kept constantly controlled by the hypothalamus that is part of the autonomic nervous system; specialized cells within the hypothalamus constantly adjust the body's temperature to maintain a set point of around 35.5ºC to 37.7º C, depending on factors such as gender and time of the day (Vainer 2005). As the heart pumps blood through the arteries, gaining heat from organs, heat is consequently lost to peripherals mainly the skin, the dermis layers of which are connected with a network of capillaries. These are visible through a microscope even from the epidermis that connect to vessels that regulate blood-flow through vasoconstriction or vasodilation, causing heat loss through the skin (Luk et al. 1986). When the hypothalamus detects a slight temperature rise within the body, this structure reduces the internal core temperature through activating heat loss through vasodilation within the vessels, causing sweating that may reduce metabolic rate (Jones 1998). In turn when the hypothalamus detects a decrease in body temperature owing to environmental changes, the body experiences involuntary muscle movement causing shivering which builds up kinetic energy resulting in heat (Luk et al. 1986).

**Temperature and Disease**

In disease, temperature variations may be clinical indicators of the presence of inflammation, tumours, reduced circulation, and ulceration, amongst other conditions (Diakides & Jenkins 1995). Keeping the body's temperature constant is part of the cellular levels preservation process, which is known as homeostasis; even slight changes in the body’s temperature indicate a disruption of this process (Jones 1998). Body temperature may increase or decrease, according to the particular cause. An elevated body temperature is usually caused by one of two processes: inflammation or carcinogenesis. Pathogen invasion could also lead to the innate immune system activating an acute inflammation, producing a higher peripheral temperature (Greenwood et al. 2007). Inflammation and venous flow alterations may result in a higher temperature of 0.7 to 1 (Bagavathiappan et al. 2009) presenting in poor circulation owing to disease, such as artery obstruction; this will manifest itself in temperature differences in affected areas, leading to lower peripheral temperature.

A common condition in Malta is diabetes mellitus which significantly increases risks of lower limb problems as a result of lack of circulation and which may result in limb loss (Malmstedt et al. 2008). The island has one of the highest prevalence of diabetes mellitus in Europe, where the incidence rate is increasing steadily (WHO 2016). Left uncontrolled, the disease can lead to foot complications and consequent lower-limb amputations (Vinik 2003). Monitoring circulation to the limbs can be done at local clinics, although the precision of tools to identify such conditions in diabetics because of hardened arteries, a common affiliation among diabetics, has been debated.
(Williams et al. 2005). A local study has investigated the tools currently used in the local general hospital and clinics to identify whether these devices efficiently identify circulation problems in a timely manner; it showed that these tools left many patients undetected (Formosa et al. 2013). Because of such unreliability, a local research group investigated infra-red thermography as a means to identify disease in the lower extremity. Thermography has already been used in several medical fields, including neurology, gynaecology, orthopaedics, dentistry, and vascular medicine. The local Diabetic Foot Research Group (DFRG) identified thermography as a valid screening tool to identify complications in the foot of diabetics (Gatt et al. 2018a,b).

**Thermography Use and Implications**

The first clinical thermometer was made over 200 years ago; its development helped clinical researchers discover knowledge that temperature changes in the body indicated progression of disease (Ring 2010). Thermal imaging is a non-contact measurement which detects infra-red thermal energy and converts that energy to an image to identify hot and cold spot variation (Raytek 2010). Thermography can capture real-time temperature as visual coloured thermal energy (Bharara et al. 2006). Skin temperature can be monitored using thermography as the blood vessels below the skin emit heat which the infra-red camera can detect. Thermography is now becoming a useful medical tool owing to lack of skin contact which minimizes the probability of cross-infection between patients and also because it is non-invasive; since patients experience no pain it increases client compliance (Bagavathiappan et al. 2009). Thermographic images are not user-dependent, as long as all settings are set well, because images can be analysed through user-friendly software and the equipment to read it is within the normal price range for medical equipment (Ring 2010). Also thermography can recognize the slightest change in temperature as this tool is sensitive to the body's biochemical processes (Deng & Liu 2004).

**Thermography Features**

Thermography can give valuable information and has been used for biomedicine for the past fifty years, although only currently has its application in medicine increased owing to thermography's sensitivity and repeatability, along with the fact that the patient is not exposed to any harm (Bharara et al. 2006). Thermography is a technology of radiation that ranges between 0.75µm to 1000µm within the range of human body emission. The traditional body infra-red rays range from 8µm to 12µm; however, a more common term used is thermal infra-red where medical infra-red measures the wavelength beyond 1.4µm, as within this wavelength indicates thermal radiation (Bagavathrappen et al. 2009). Thermography is based on the fundamental equation by Plank's, Stefan Boltzmann, and Wein’s Displacement Law that link the absolute temperature of an object with the radiation emitted by its intensity and wavelength. Stefan Boltzmann Law is based on the following equation, were ε=emissivity and T= absolute temperature: $W = \varepsilon \cdot T^4$.

The earlier infra-red cameras were inconvenient to use because of their large size; since they required liquid nitrogen cooling they could only be placed horizontally. Today’s cameras are smaller and do not need cooling; in fact, some cameras may even need to be warmed and they may be placed in any position making their application easier (Jones 1998). Current cameras are also cheaper; are manufactured using a technique of silicon wafer; have high temperatures ranges and spatial resolution; are electrically cooled, uncooled, or warmed; are small, portable, and compact; and may be used at any angle; and may be attached to a mobile device.
Thermography in Humans

Thermography can be used on humans as skin has an emissivity of 0.98, equivalent to a black body. The emissivity of a black body would show an emissivity value of \( \varepsilon = 1 \), while non-black body objects would have an emissivity lower than one. Since a true black body emits and absorbs all wavelength energy perfectly, emissivity represents the energy radiated from the object versus the energy returned from a black body having the same temperature (AAT 2015). Human skin can modify body temperature according to its surroundings, as human skin keeps the body’s temperature constant at 37°C; however, in hot environments, skin absorbs heat, making the body sweat as a cooling mechanism, whereas when the skin is in a cooler environment, the skin is cooled and emits heat, therefore being a black body (Bagavathiappan et al. 2009). The rate by which heat is exchanged in the surrounding environment is held constant; moreover as blood flows through the body’s vessels, heat is transported to the skin creating a thermal transfer. The body maintains a thermal balance by losing heat to the surrounding environment through multiple factors, such as natural or forced convections, exhaling carbon dioxide, thermal conduction or convection, and evaporating sweat (Jones 1998).

Infra-red used in medicine for diagnostic purposes is based on the measurement of physiological changes, mainly when vasodilation, hyperthermia, hyperperfusion, hypermetabolism, and hypervascularisation take place. These physiological changes are evident in conditions such as carcinogenesis, rheumatoid conditions, fractures, pathogenic infections, skin conditions, and vascular diseases (Herrick & Hutchinson 2004). Furthermore research suggests that skin colour, gender, or burns trauma cause no difference in emissivity (Vainer 2005).

Thermography Settings

Infra-red thermographic images need to be set according to the specific type of material studied; for human skin, emissivity needs to be set at 0.98, while the camera needs to be calibrated against a black body at an emissivity of 1.0, for each reading or patient, for best reliability. Temperature control is a crucial part of the test, where ambient temperature needs to be set at a constant temperature between 20–21°C, with no airflow directed on the subject’s skin. Lower ambient temperature may cause the patient to shiver, causing movement and vasoconstriction which would affect the outcome or impeding accurate measurements, whereas a higher temperature may cause the patient to sweat, which could interfere with skin temperature analysis and vasodilation. Therefore the room with the apparatus should preferably have matte-finished non-reflective walls and no mirrors in the camera view. The camera needs to be set at precision autofocus and may be set to take photographic images superimposed in one snap shot for reference (AAT 2015), as seen in Figure 1.

Thermal images need to be acquired after allowing the subjects’ peripheral temperature to adjust to the room temperature, with a minimum of 15 minutes allowed for the blood pressure and body temperature to settle (Ring et al. 2000) and using a contrast back-drop around the limb to avoid processing errors and to obtain the best image (Gatt et al. 2015). In this way human skin can be distinguished from the backdrop because of differences in temperature radiation. The thermography images can then be uploaded onto the computer and analysed by using software provided by the camera’s manufacturers which allows all recorded data to be reported by thermal imaging inspection and temperature plots to be analysed in detail. This software provides detailed functions and controls to report and analyse thermal images with
multiple anomalies, trends, and panorama images to give precise results. By using an automated segmentation algorithm, one can identify regions of interest, making the process much faster to analyse and reproduce (Gauci et al. 2017), allowing focus on the precise area to compare a patient’s image to a previous image, and identifying changes in the same subject. When collecting images of the sole of the foot, images need to be collected with the subject in a supine position and subsequently in a sitting position with the affected and unaffected feet exposed to ambient as shown in Figure 2.

![Figure 1. A diagram of a patient lying in the supine position with plantar surface area exposed for thermographic imaging](image1)

![Figure 2. Thermography set-up: An example of a subject in position for testing, with the camera set at a distance of 3-8 feet](image2)

**Conclusion**

Interest in the application of thermography in biomedicine has been gradually increasing (Nola et al. 2012) because abnormal temperature variations extracted from heat emitted by the body have been linked to disease (Armstrong et al. 2007; Ring 2010).

This tool shows promise in its application to improve the care of the diabetic foot since, due to the sensitivity of thermography (Nola et al. 2012), thermal imaging can pick up small body temperature variations. Thermography can also identify temperature changes which indicate the development of neuropathic ulcers (Gatt et al. 2018b), peripheral circulation obstruction (Ring 2010), and vascular reactivity (Wang & He 2010), which could all be applied to diagnostic medicine within the healthcare setting.
Temperature assessment promises to be a potentially useful addition to the currently available physiological tools and could, in particular clinical contexts, overcome the limitations of the other physiological tools. The major advantage of thermography is that its use requires little to no technical training, is acceptable to the patient, and does not involve patient contact; it is also quick to use and holds good potential for rapid screening uses and is particularly useful in busy clinical areas with a high turnover of patients. This tool could lead to a reduction in misdiagnosis of patients and could be used by all healthcare workers with minimum training, as the slight temperature variations could raise red flags indicating that further investigations are needed. Students in the healthcare sector need to be acquainted with this new technology as locally this tool is still being researched; however, its technology will soon be applied in actual practice.

References


