AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303
REVIEW ARTICLE

Thermal imaging system and its real time applications: a survey

Mritunjay Rai[1], Tanmoy Maity[2], R.K.Yadav[3]

[1]Research Scholar, Indian Institute of Technology (ISM) Dhanbad
[2]Associate Professor, Department of Mining Machinery Engineering, IIT (ISM), Dhanbad.
[3]Professor, Department of Electronics and Communication, JRE Group of Institutions, Greater Noida.

Abstract: The IR radiations emitted by Thermal Imaging systems are captured by passive sensors for all the objects having temperature overhead the absolute zero. This method of detection was initially settled for surveillance and night vision device for military purposes, but are now economically more viable, hence there is a wider scope of application than ever. The illumination complications of normal Greyscale and RGB cameras are significantly reduced when this sensor is positioned in vision system. This paper produces real time application of thermal imaging system i.e. application in agriculture, medical diagnosis, detection, tracking and recognition of humans along with their facial expressions. Further, this paper explains the natural surroundings of thermal radiation and the imaging system technology.
Present paper has the following further sections: section 2 contains the definition of thermal radiation. Section 3 is about the machinery of thermal camera. Section 4 describes the application area and the survey of the work done so far. Section 5 contains brief summary and discussions regarding deployment of thermal cameras.

Keywords Thermal imaging system, IR radiation, Medical diagnosis, agriculture, Facial expression

1. Introduction

The human vision is extended by the use of thermal imaging to far IR region as it utilizes the light emitted by warm objects. The human eye lacks response in the absence of light in the 0.4μm to 0.7μm range, hence the device that can create the image by generating the dominant energy in low light conditions is needed. The photons emitted by the human body must be captured by the night eye as these dominate energy when solar radiations are absent. Moreover, the night eye should have spectral reaction where significant, emissivity, temperature and reflective differences exist in the scene. This is mandatory to make sure that the radiation pattern is sufficiently similar to the corresponding visual reflectivity ethics in order to make the visual interpretation of the converted scene possible. This spectral sensitivity must align with an atmospheric transmission window which doesn't overly absorb the desired radiation [1].
The complexity of generating the thermal image may be esteemed by taking into account the perfection of human eye because of which it generates the visible images. The human eye is a perfect sensor of visible light in three aspects. First, the spectral response of the human eye lies between 0.4 μm - 0.7 μm which coincides with the peak of solar spectral output. Around 38% of the solar radiant energy is concentrated in this band, and terrestrial objects tend to have a good reflectivity. Second, the retinal radiation detectors make the human eye an ideal quantum noise limited device as they have low noise at the quantum energy level in this band. Third, the retinal detector have negligible response to the photons emitted at the body temperature thus making this long wavelength unmask the response to desired wavelength. This optimization enables the human eye to do its

Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303

primary function that are the detection of reflectivity differences in objects illuminated between 0.4 µm to 0.7 µm radiations, to differentiate between patterns in this reflectivity differences and the association of these patterns with the abstractions derived from earlier visual and sensory experiences. As the parameters like intensity, direction and color balance change, the principal challenges are that of the dependency of images on the radiance. The figure 1 shows the images in both the spectrum i.e. visible and IR. The purpose of introducing other sensors in the vision system is to overcome some of the restraints mentioned above and acquire scene's images and corresponding information.

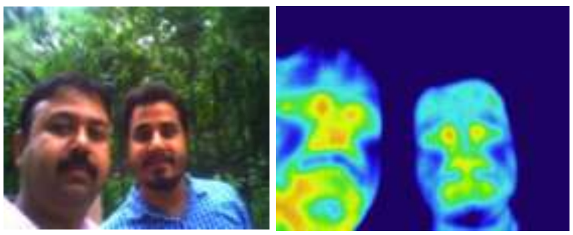

Figure 1 Visible and thermal image of same sight

2. Thermal Radiation

Radiations are released by every object having temperature overhead the absolute zero which is generally stated as thermal radiation. The features and source of these radiations will be discussed in this section.

2.1 Electromagnetic range

The same goes for radiation above 14 μ-m. The typical spectral range division for near-IR and thermal cameras is shown in table 2.The Infra-red radiations can be divided into a number of spectral regions depending on range, hence sandwiching the IR emission in between light and microwaves having wavelength spectrum of 0.7 μ-m – 1,000 μ-m displayed in Figure 2. Table 1 [2] depicts a regular scheme signifying non- identical scientific studies of diverse IRs. Several wavelengths present in the molecule are soaked up in the environment so that only radiations with notable wavelengths are emitted.
Most of the absorption of IR radiations [3] is due to CO_2 and H_2O. The variations in wavelengths with certain transmission of radiation (in %) is depicted in Figure 3. It also goes across molecule which is responsible for huge transmission gaps within it. As there is a hefty atmospheric transmission gap between 5 to 8 μ-m ranges, the cameras are insensitive here. Similar is the case for radiations above 14 μ-m. The typical spectral range division for near-IR and thermal cameras is shown in table 2.

2.2 Radiation and immersion of IR radiation

Planck's wavelength distribution function [4] describes the radiation caused by an object having temperature T by:

AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303
REVIEW ARTICLE

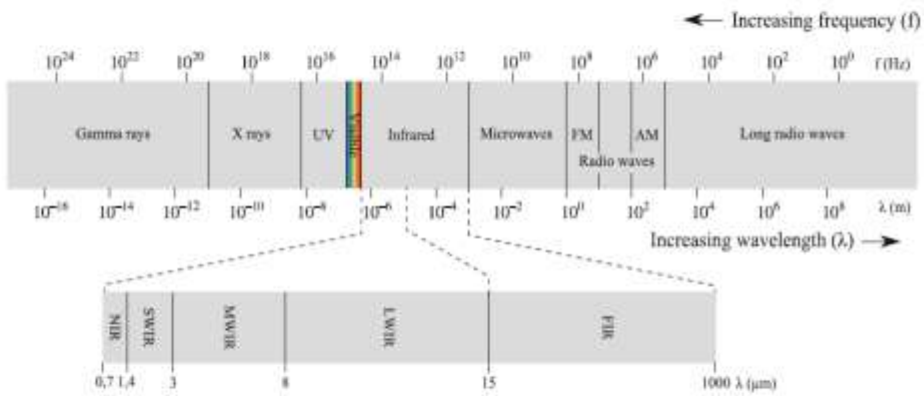

Figure 2 Electromagnetic range with sub divided IR range [66]

$$E(\lambda,T) = \frac{2\pi hc^2}{\lambda^5 (e^{hc/\lambda k_B T} - 1)} \qquad (1)$$

Where λ is the wavelength, h is the Planck's constant ($6.626\text{x}10^{-34}$ J-s), c is the speed of light ($2.99\text{x}10^{8}$ m/s) and k_B is the Boltzmann's constant ($1.3806 \text{ X } 10^{-23}$ J/K).

Table 1 IR Sub-division

IR Sub-Division	**Acronym**	**Wavelength (μm)**
Near-IR	NIR	0.7-1.4
Short-wavelength IR	SWIR	1.4-3
Mid-wavelength IR	MWIR	3-8
Long-wavelength IR	LWIR	8-15
Far-IR	FIR	15-1000

ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303
REVIEW ARTICLE

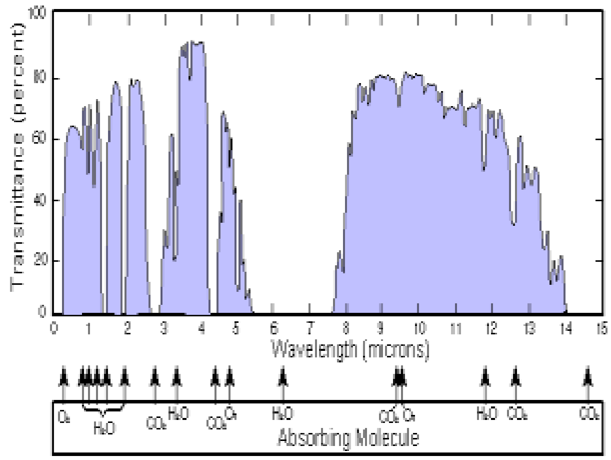

Figure 3 Atmospheric diffusion in part of the IR region [65]

Table 2 IR Sub-division for Thermal cameras

IR Sub-Division	**Acronym**	**Wavelength (μ m)**
Short-wavelength	SWIR	0.7-1.4
Mid-wavelength	MWIR	3-5
Long-wavelength	LWIR	8-14

It is evident from Figure 4 that intensity peak moves to shorter wavelengths with increase in temperature. The radiation extends to visible spectrum for extremely hot objects, e.g. an extremely hot iron-rod. The wavelength of the intensity peak is described by Wien's displacement law as [5]:

$$\lambda_{\max} = \frac{2.898X10^{-3}}{T} \qquad (2)$$

The radiations from a black body are described by Planck's wavelength distribution function (Eq. 1). The materials mostly studied for useful applications are assumed to be grey bodies which have a constant scale factor of radiation between 0 and 1, this factor is called emissivity. For e.g., polished silver has a low emissivity (0.02), human skin has an emissivity very close to 1 [6]. Gases are selective emitters having a specific absorption and emission bands in thermal IR spectrum [3].

AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303
REVIEW ARTICLE

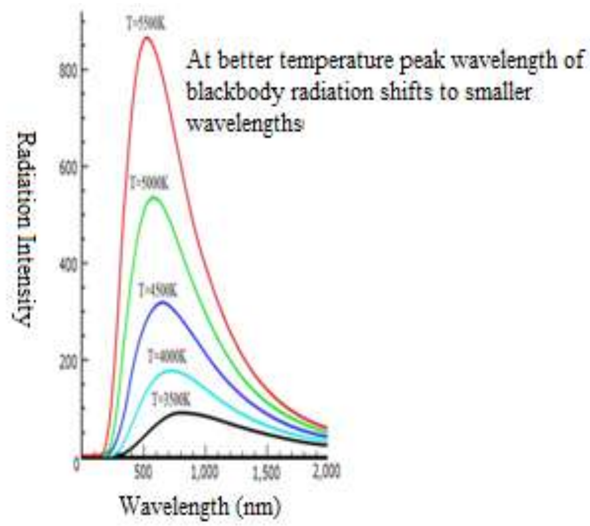

Figure 4 Intensity radiation of black body versus wavelength at different temperatures

3. Thermal cameras

The first commercial thermal imaging camera was sold in 1965 for high voltage power line inspections. Since then the utility of thermal imaging cameras for industrial applications has become a pivotal market segment for FLIR (Forward-looking IR) systems, a later name for high voltage power lines.

The thermal imaging technology has drastically evolved since then, and thermal imaging cameras have evolved to become compact in size and look like a digital photo camera. They are now easy to use and produce real time crisp high resolution images making them a widely important tool for industrial applications. They are able to detect anomalies that are generally invisible to the naked human eye, thus taking corrective preventing costly systems going for a total breakdown. Thermal imaging cameras are used to determine the maintenance requirements for electrical and mechanical installations as they tend to generate unusual heat before they fail. Preventive actions can be taken by discovering these hot-spots. A thermal imaging camera is a non-invasive instrument which scans and visualizes the temperature distribution of surfaces of a machine quickly and accurately, thus reducing cost and saving time across the world.

3.1 Camera types

IR cameras can be used as scanning devices or a 2-D IR focal plane array. When used as a scanning device they capture only a single point or row of an image at a time. When used as a 2-D IR focal plane array (IRFPA) all elements are captured simultaneously with each detector element in the array. Nowadays IRFPA is the dominant technology because it is faster, has better resolution and has no moving parts as compared to scanning devices [6].
There are 2 types of detectors used in thermal cameras: photon and thermal detectors. In Photon detectors, the absorbed EM radiations are directly converted into a change of electronic energy distribution in a semi-conductor

Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303

by variation of free charge carrier concentration. Whereas thermal detectors transform the absorbed EM radiations into thermal energy causing an increase in the temperature of the detector. The electrical output of the thermal sensor is then generated by a relative change in some of the physical properties of the object [3].
The photon detector operates in MWIR band where thermal contrast is high, which makes it very sensitive to minor differences in the scene temperature. The photon detector in recent technologies allow for a higher frame rate than the thermal counterpart. The drawback of these type of detector is they require cooling. To achieve reduction in thermal noise they need to be cooled below 77^{o}K. This was earlier achieved by using liquid Nitrogen but is now accomplished by cyro-coolers. As the cyro-coolers have moving parts and has helium seals, they need to be regularly serviced and replaced when required. The overall price (initial cost and maintenance) for a photon detector is therefore higher than thermal detector system. The radiation is measured in the LWIR band by a thermal detector. This band is used in various detector types, which will be described in the coming sections.

3.1.1 Thermal detector types

There are mainly 2 types of detectors used for developing uncooled thermal detectors: Ferroelectric and microbolometer. Ferroelectric detectors use the ferroelectric phase transition in particular dielectric materials. At this phase transition, small variations in temperature cause large changes in electrical polarization [8]. Barium Strontium Titanate (BST) is used as the material in ferroelectric detectors.
A microbolometer is a specific type of resistor. VOx (vanadium oxide) and amorphous silicon (a-Si) is used in microbolometer. The electrical resistance of a material is altered by IR radiations, which can be converted to electrical signals and processed into an image. Microbolometer has more advantages over the ferroelectric sensors and the VOx technology has gained the large market share. Microbolometer has greater sensitivity. The noise equivalent temperature difference (NETD), specifying the minimum detectable temperature difference, is 0.039^{o}K for VOx compared to 0.1^{o}K for BST detectors [7]. Microbolometer has smaller pixel size on the detector, allowing a greater spatial resolution. Also, BST detectors suffer from a halo effect, which is generally seen as a dark ring around a bright object, which wrongly indicates a lower temperature [7].

3.2 The lens

As glass has a low transmittance % (percentage) for thermal radiation, germanium is often used for this purpose. Germanium is a grey-white metalloid and is almost transparent to IR rays but is reflective to visible light. Since germanium has a high price, the size of the lens becomes even more significant. The *f* number of an optical system represents the ratio of focal length of its lens to the diameter of entrance pupil. So, a higher *f* number indicates that the price of lens is low but at the same time, a smaller amount of radiation reaches the detector. Uncooled cameras must have a low *f* number in order to maintain an acceptable sensitivity. A higher *f* number is acceptable for cooled cameras as we can increase exposure time to keep the same radiation throughput. This results in price of uncooled cameras to increase considerably with the focal length, while the price for cooled cameras only increases slightly with the focal length. In case of very large focal lengths, cooled cameras are cheaper than uncooled ones [8] as shown in Table 3.

Table 3 Evaluation between cooled and uncooled cameras

Features	Uncooled cameras	Cooled Cameras
f number	Lower	Higher
Price	Higher	Lower
sensitivity	Less sensitive	More sensitive
Cooling	Vanadium Oxide resistor	Cryocoolers

3.3 Camera output

The shape and size of modern thermal cameras make them similar to visual video cameras. Also the data transmission is done via USB, Ethernet, FireWire, or RS-232 interfaces. The greyscale is used to represent images with a depth of 8 to 16 bits per pixel. However, the images are generally visualized in pseudo colors for better visibility to the human eye. JPEG is used to compress Images whereas H264 or MPEG [9] is used to compress video. The analogue devices use NTSC or PAL standards [10]. Most of the larger cameras need an external power supply while some smaller handheld cameras are battery-driven. Uncooled cameras have thermal sensitivity of 40mK and the cooled cameras have thermal sensitivity of 20mK. The spatial resolution of commercial products varies from 160×120 pixels to 1280×1024 pixels, and the field of view varies from 1^o to 58^o [11, 12, 13, and 14].

4. Application areas

It is a great advantage to ‘see’ the temperature in various applications. The temperature can be used to detect specific objects and can also provide information about them. This section will discuss the applications of thermal imaging systems with 3 different categories of subjects: inanimate objects, and humans, animals and agriculture.

4.1 Surveillance

In many research fields pedestrian tracking plays a vital role, e.g. video surveillance, human-computer interaction and automatic driving assistance systems [15-17]. But the process of tracking becomes tedious because of the pedestrian’s appearance variability, especially in the outdoors [18]. The IR images have many unique advantages in contrast to the visible light images. The intensity of the target object is independent of illuminating conditions but is dependent on its temperature and radiant heat. So the tracking system can be used during day as well as night time. The influence of color, illumination and texture on the appearance variability of the target object is nullified by the IR images. Hence there is a latent development potential for pedestrian tracking in IR images. Earlier, the application of IR technology was primarily in the field of military applications because of its high cost. But now a days, the cost has dropped and developments in the field of IR technologies have made it possible to enable its application in the industrial and civil fields as well. Research is being carried out in the field of robust pedestrian tracking and detection using IR imagery [19-22].
The pedestrian body has unique discrimination features compared to non-pedestrian object in visible light images such as different skin colors which can be used to develop the pedestrian representation model. The surrounding

ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION
Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303
REVIEW ARTICLE

non pedestrian target objects' intensities are similar to pedestrian body's intensity in case of IR images. This makes it difficult to develop the pedestrian's representation model that is only dependent on its intensity. It is seen that though the IR images enable better segmentation, the performance of current tracking algorithm is poor [23]. An interactive system for detection and tracking for several people is presented by Darrel et al. [24]. Detection and tracking for pedestrians is done using IR systems by using the integration of information provided by three models: a face detector, a skin detector and the disparity map. The main drawback of the system is that it depends on a pre-defined color model when there is a significant difference in illumination conditions from the training samples [25], the tracking performance of the system deteriorates.

A dynamic skin color model is used to solve this issue in [26]. An interesting method is presented by Harville to track and locate multiple people in stereo images [27]. A sophisticated image analysis method [28] is used to build the environment model before the detection process begins. After that, based on merging information from two maps (including an occupancy map and a height map) the detection process is performed. Kalman filter is used to implement human tracking along with deformable templates. The main drawback of this system is that detection heuristics employed can lead to incorrectly taking people similar to human being as new objects in the scene.

A system comprising of fixed camera is used for detection and tracking of pedestrian. The proposed system requires the human's head to be at the center of the field view [19]. The system takes the earlier detected pedestrian's head as the template using the brighter property of the head in IR images. The system then tracks the pedestrian's head by a template match algorithm. Kalman filter and mean shift algorithm is used in F. L. Xu et al. to track human's head using the brightness of the head [22]. So the current algorithm can be used to track parts of the human being. The tracking algorithms for IR image sequences are devised solely on the characteristic of intensity and are applied for specific environments, so the application fields and performance of them are limited.

4.2 Human Emotions

Mostly, applications begin with face detection which includes face recognition, head pose analysis or even detection of the entire body. As the face of a person is not obstructed by clothes, a thermal camera can capture the skin temperature of the face directly. Head detection systems based on a combination of shape and temperature is proposed in Krotosky et al. [29] and Mekyska et al. [31]. The effects of illumination changes are eliminated when face recognition is done using thermal cameras. This also eases segmentation step. But it also brings in some difficulties due to different heat patterns of a subject, caused by different activity levels or emotions such as anxiety. One of the very early approaches is neural networks [31].

The comparison of use of thermal images in face recognition to visual images is done in Colin Sky and Selinger [32] and Wolff et al. [33] using appearance-based methods. The thermal images yield better results than visual images at this point. However, the effects of different activity levels of the subjects and extreme ambient temperature on recognition rate has not been tested yet. Using the techniques of polar transformation, Eigen space projection, and classification using a multilayer perceptron [34] a thermal face recognition algorithm has been developed. Gault et al. [35] tested the use of different parts of the face for facial recognition, and concluded that using the upper part of the face gives a better recognition rate than using the whole face. A face recognition system using characteristic and time-invariant physiological information as features has been proposed in Buddharaju et al. [36, 37].

Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303

Another task of importance is the recognition of common facial expressions. Neural networks have also been used as an early approach [38]. This system produces good results using a sparse dataset of 120 images showing four different expressions from one person. Jiang and Kang [39] proposed a system to recognize facial expressions by analyzing the geometry and local characteristics. In many vision systems facial orientations are of interest. A few researchers have proposed systems to estimate the head pose. Wu et al. [40] calculated the roll angle of frontal face images, while Yu et al. [41] proposed a system to estimate the yaw angle of the head.
A system for detecting driver's posture in a car is proposed in Kato et al. [42]. The face is detected at first thereafter classification of posture is done as rightward, leftward or frontward. The distribution of heat in the face gives information regarding the anxiety level [43], the emotion of car drivers [44], automatic blush detection [45]. The system should be able to follow the issue of interest in order to function automatically. A similar system is proposed in Zhou et al. [46] using a particle filter tracker. Akhloufi and Bendada [47] have proposed the use of thermal 'faceprints' for biomedical identification. The network of blood vessels represent the facial physiological features. The use of thermal face images for biometric identification is proposed in Guzman et al. [48, 49]. The exterior blood vessels are extracted from MWIR images with skeletonization.

4.3 Agriculture

Thermal imaging systems have a variety of applications in the food industry as well as agriculture. These systems are used in the food industry as they are portable, operate in real-time, and measure temperature without contact [50]. It is important to use a non-destructive way to minimize wastage in the quality management in food industry. The use of thermal imaging in the food and agriculture industry is reviewed in [50] and [51]. It includes both passive thermography and active thermography. Passive thermography deals with measurement of temperature of the scene while in active thermography thermal energy is added to the object. Then the temperature is measured.

To control temperature in food manufacturing passive thermography is used. The information regarding quality (damage and bruises in food items) is generated by active thermography. A normal and bruised tissue can be distinguished by observing their thermodynamic property. Fungal infections are also detected by thermal imaging [52] in wheat. Though the technique cannot differentiate between various fungal species, but can tell the difference between healthy and infected wheat grain. Classification between infected and healthy pistachio kernels is done in [53].

4.4 Medical

The details regarding physiological processes using skin temperature distributions is provided by thermal imaging systems. These distributions can be due to blood perfusion. High resolution cameras are used to observe minute variations in temperature in the medical field. The information of standard anatomical investigation is further enhanced by thermal imaging [54]. The medical applications of IR thermography are reviewed in Lahiri et al. [55] and Ring and Ammer [56]. This technique enables the detection of malignant tumors at a very early stage as described in [57].

Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303

Many other medical conditions can be studied from thermal imaging, e.g. the behavior of the ciliary muscle of eye [58], superficial temporal artery pulse [59], and facial vasculature [60]. Tissue related risks for diabetic patients [63] and sports persons can also be detected by thermal imaging. Thermal imaging can be used to invigilate and understand communication from people with motor impairment.

5. Discussion

The cost of thermal cameras is considerably more than that of comparable visual cameras, but the cost of hardware is decreasing continuously and the variety of cameras is becoming wider. Simple cheap sensors (pyroelectric IR sensor) are used in motion detectors for various applications, e.g. burglar alarm. This sensor cannot provide any image, but detects movement of humans and animals. The thermal cameras has IR array sensors which read temperature values in an image, which enables the system to analyze the movement, direction and speed of an object and are thus, used in entrance counting systems. The cost of these sensors is around $50 for 8x8 pixel arrays with 2.5°C temperature accuracy [65]. The cost increases with frame rate, resolution and accuracy from uncooled cameras to high-end specialized cooled cameras. The cost of the very high-end cameras with even higher frame rate and zoom can exceed $ 100,000. It is seen in this survey that there is a great scope of application of thermal cameras. Various research fields of thermal imaging system have specific need for resolution, sensitivity, price etc. It thus becomes imperative that variety of cameras will become larger in the coming years and will be user friendly. The analysis of known subjects and the possible detection of unknown subjects are solved by thermal imaging applications. In analysis of known subjects, the location of the subject is known in the image and its property is analyzed. This analysis can be of the condition, health and type of the material. This temperature of the subject is registered or even the images can be inspected manually. The computer based methods use simple algorithms such as thresholding and blob detection. The location or type of the object is known in the second type of problem. The analysis of this type begins with detection and classification of subjects. The objective is to design an automatic system which detects or tracks particular objects. Further advancement can be achieved by using advanced computer algorithms in order to design the automatic system. The thermal cameras make detection step a lot easier in applications where temperature of the subject is different than its surroundings.

The analysis of known subjects and detection of unknown subjects are witnessing a rapid expansion in methodologies due to reduction in price of thermal cameras. The thermal cameras can be seen as an alternative to non-contact thermometer in case of known subjects. In the other case, they can be considered as an alternate to visual camera and are therefore of greater interest from computing view point. However, the modern trend is inclined towards automation.

Considering the current trend, the automatic vision systems with replace manual and semi-automatic image analysis systems. The thermal sensors nullify the disadvantages of varying illumination and need of lighting in dark conditions. Thermal imaging systems don’t raise severe privacy concerns as compared to the visual systems. The scarcity of textural information is a disadvantage along with reflections of thermal radiations in thermal imaging systems. For thermal cameras to remain in demand, they must abide to reasonable cost, high resolution, high optical zoom and wider angle lens. Thermal images are combined with other image techniques in order to overcome so of these difficulties. However, there is still a dearth of a standardized method to calibrate thermal sensors with other sensor which must be solved to make these systems more practical. Some pre-calibrated thermal cameras exist today [13, 14] and it is expected they will grow in numbers in the future. With more and

Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303

more sensors becoming available, such as 3D, near-IR, and thermal, the usual choice of a visual camera is harder to justify.

It can be deducted from this survey that thermal sensors have benefits in a wide range of applications and the combination of various sensors can be used to get better results in some applications. A cautious choice of sensor will bring forward new applications and features for improvement in current applications in the future.

References

[1] J.M. Lloyd, Thermal Imaging System, Springer Science + Business media New York, October- (1982).
[2] J. Byrnes, “Unexploded Ordnance Detection and Mitigation”, Springer, Berlin (2009)
[3] M. Vollmer, K.P. Möllmann, , “IR Thermal Imaging—Fundamentals, Research and Applications”, Wiley-VCH, Weinheim (2010)
[4] R.A.Serway, andJ.W.Jewett, “Physics for Scientists and Engineers with Modern Physics”, 6th edn. Brooks/Cole–Thomson Learning (2004)
[5] J.D.Hardy, “The radiation of heat from the human body. III. the human skin as a black-body radiator”,Journal of Clinical Investigations, 13(4), 615–620 (1934)
[6] H.Kaplan, “Practical Applications of IR Thermal Sensing and Imaging Equipment”, 3rd edition SPIE Press (2007)
[7] FLIR: Uncooled detectors for thermal imaging cameras. Technical note (2011). FLIR Commercial Vision Systems B.V.
[8] FLIR: Cooled versus uncooled cameras for long range surveillance. Technical note (2011). FLIR Commercial Vision Systems B.V.
[9] AXIS Communications: Q1922 datasheet (2012). http://www.axis.com/files/datasheet/ds_q1922_q1922-e_46221_en_1207_lo.pdf
[10] FLIR Systems Inc.: FLIR SR-series (2012). http://www.flir.com/ cs/emea/en/view/?id=41864
[11] IR Integrated Systems Ltd: Thermal imaging cameras by Irisys (2012). http://www.irisys.co.uk/thermal-imaging/
[12] Fluke Corporation: IR cameras and thermal cameras by fluke (2012).http://www.fluke.com/Fluke/usen/products/category.htm?category=THG-BST&parent=THG
[13] AXIS Communications: AXIS Network Cameras (2012).http://www.axis.com/products/video/camera/index.htm
[14] FLIR Systems Inc.: FLIR product overview (2012).http://www.flir.com/cs/emea/en/view/?id=42100
[15] J.Zhou and J.Hoang, “Real time robust human detection and tracking system”, in Proceedings of the 2nd Joint IEEE International Workshop on Object Tracking and Classification in and Beyond the Visible Spectrum, San Diego,Calif,USA,June (2005).
[16] D.C. McFarlane, and K.A.Latorella, “The scope and importance of human interruption in human-computer interaction design”, Human-Computer Interaction, 17 (1), (2002), pp. 1-62.
[17] O. Tsimhoni and P. Green, “Time-sharing of a visual in-vehicle task while driving: effects of four key constructs”, Proceedings of the International Symposium on Automobile Lighting, Darmstadt, Germany.
[18] D. Ross, J. Lim, and M.-H. Yang, “Adaptive probabilistic visual tracking with incremental subspace update”, In Proceedings of the Eighth European Conference on Computer Vision, volume 2, (2004), pp. 470–482.

[19] M. Yasuno, N. Yasuda, M.Aoki, “Pedestrian detection and tracking in far IR images”, in Conference on Computer Vision and Pattern Recognition Workshop, 27-02 June (2004), pp. 125-131.
[20] C. Dai, Y. Zheng, X. Li, “Layered representation for pedestrian detection and tracking in IR imagery”, in 2nd Joint IEEE International Workshop on Object Tracking and Classification in and Beyond the Visible Spectrum, San Diego, CA,USA, June 20,(2005).
[21] M.G. Di Bono, G. Pieri and O. Salvetti, “Multimedia target tracking through feature detection and database retrieval”, in Proceeding of the 22nd International Conference on Machine Learning-Workshop on Machine Learning Techniques for Processing Multimedia Content(ICML2005), Bonn, Germany, 11th August (2005), pp. 19-22.
[22] F.L. Xu, X. Liu and K. Fujimura, “Pedestrian detection and tracking with night vision”, IEEE Transaction on Intelligent Transportation Systems, (2005), 6(1), pp: 63-71.
[23] E. Goubet, J. Katz and F. Porikli, “Pedestrian tracking using thermal IR imaging”, Mitsubishi Electric Research Laboratories, Technical Report, TR2005-126.
[24] T. Darrell,G.Gordon, and J. Woodfill, “Integrated person tracking using stereo, color, and pattern detection”, International Journal of Computer Vision, (2000), 37, pp: 175-185.
[25] B. Martinkauppi, M. Soriano and M. Pietikainen, “Detection of skin color under changing illumination: a comparative study”, in 12th International Conference on Image Analysis and Processing, (2003), pp. 652-657.
[26] L. Sigal, S.Sclaroff and V. Athitsos, “Skin color-basedvideo segmentation under time-varying illumination”, IEEETransactions on Pattern Analysis and Machine Intelligence, (2004), 26pp: 862-877.
[27] M. Harvile, “Stereo person tracking with adaptiveplan-view templates of height and occupancy statistics”,Image and Vision Computing, (2004), 2, pp: 127-142.
[28] M. Harville, G. Gordon and J.Woodfill, “Foregroundsegmentation using adaptive mixture models in color anddepth”, in IEEE Workshop on Detection and Recognition ofEvents in Video, (2001),pp. 3-11.
[29] S.Krotosky, S.Cheng, M. Trivedi,“Face detection and head tracking using stereo and thermal IR cameras for “smart” airbags: a comparative analysis”, In: The 7th International IEEE Conference on Intelligent Transportation Systems (2004)
[30] J. Mekyska et al., “Face segmentation: a comparison between visible and thermal images”, IEEE International Carnahan Conference on Security Technology (2010)
[31] Y.Yoshitomi, T. Miyaura, S.Tomita, S. Kimura,“Face identification using thermal image processing”, 6th IEEE International Workshop on Robot and Human Communication (1997)
[32] D.A.Socolinsky, L.B. Wolff, J.D.Neuheisel, C.K.Eveland,“Illumination invariant face recognition using thermal IR imagery”, IEEE Computer Society Conference on Computer Vision and Pattern Recognition (2001)
[33] L.Wolff, D. Socolinsky, C. Eveland,“Face recognition in the thermal IR”, Computer Vision beyond the Visible Spectrum, Advances in Pattern Recognition,. Springer, Berlin (2005), pp. 167–191
[34] M.K. Bhowmik, D. Bhattacharjee, M. Nasipuri,D.K.Basu,M. Kundu, “Classification of polar-thermal Eigen faces using multilayer perceptron for human face recognition”, IEEE Region 10 and the Third international Conference on Industrial and, Information Systems (2008)
[35] T. Gault, E. Mostafa,A. Farag,“Less is more: cropping to improve facial recognition with thermal images”, International Conference on Multimedia Technology (2011)

[36] P. Buddharaju,I.T.Pavlidis,P. Tsiamyrtzis,"Pose-invariant physiological face recognition in the thermal IR spectrum", Conference on Computer Vision and Pattern Recognition Workshop (2006)
[37] P. Buddharaju, I.T.Pavlidis, P. Tsiamyrtzis, M. Bazakos, "Physiology-based face recognition in the thermal IR spectrum", IEEE Trans. Pattern Anal. Mach. Intell. 29(4),(2007)pp: 613–626
[38] Y.Yoshitomi, N. Miyawaki, S. Tomita,S. Kimura,"Facial expression recognition using thermal image processing and neural network", 6th IEEE International Workshop on Robot and Human Communication (1997)
[39] G. Jiang, L. Kang,"Character analysis of facial expression thermal image", IEEE/ICME International Conference on Complex Medical Engineering (2007)
[40] S. Wu, L. Jiang, S. Xie, A.C.B. Yeo, "Arobust method for detecting facial orientation in IR images", Pattern Recognition,39(2),(2006)pp: 303–309
[41] X. Yu, W.K.Chua, L. Dong, K.E.Hoe,L. Li,"Head pose estimation in thermal images for human and robot interaction", 2nd International Conference on Industrial Mechatronics and Automation (2010)
[42] T. Kato, T. Fujii,M. Tanimoto,"Detection of driver's posture in the car by using far IR camera", IEEE Intelligent Vehicles Symposium (2004)
[43] I. Pavlidis,J. Levine, P. Baukol, "Thermal image analysis for anxiety detection", International Conference on Image Processing (2001)
[44] A. Kolli, A. Fasih, F. Al Machot, K. Kyamakya,"Non-intrusive car driver's emotion recognition using thermal camera", Joint 3rd InternationalWorkshop on Nonlinear Dynamics and Synchronization and 16th International Symposium on Theoretical, Electrical Engineering (2011)
[45] K. Harmer, S. Yue, K. Guo, K. Adams,A. Hunter,"Automatic blush detection in "concealed information" test using visual stimuli", International Conference of Soft Computing and Pattern Recognition (2010)
[46] Y.Zhou,P. Tsiamyrtzis,P. Lindner, I. Timofeyev,I. Pavlidis,"Spatiotemporal smoothing as a basis for facial tissue tracking in thermal imaging",IEEE Trans. Biomed. Eng. 60(5), pp: 1280–1289 (2013)
[47] M. Akhloufi, A. Bendada,"Thermal faceprint: a new thermal face signature extraction for IR face recognition", Canadian Conference on Computer and Robot Vision (2008)
[48] A. Guzman,M. Goryawala, M. Adjouadi,"Generating thermal facial signatures using thermal IR images", IEEE International Conference on Emerging Signal Processing Applications (2012)
[49] A.M. Guzman, M. Goryawala, J. Wang, A. Barreto, J. Andrian, N. Rishe, M. Adjouadi"Thermal imaging as a biometrics approach to facial signature authentication", IEEE J. Biomed. Health Inf. 17(1), pp: 214–222 (2013)
[50] A.A. Gowen, B.K. Tiwari, P.J. Cullen, K. McDonnell,C.P. O'Donnell"Applications of thermal imaging in food quality and safety assessment", Trends Food Sci. Technol. 21(4), (2010), pp:190–200
[51] R. Vadivambal, D. Jayas,"Applications of thermal imaging in agriculture and food industry—a review", Food Bioprocess Technol.4, (2011),pp: 186–199
[52] V. Chelladurai, D.S. Jayas, N.D.G.White,"Thermal imaging for detecting fungal infection in stored wheat", J. Stored Prod. Res. 46(3), (2010), pp: 174–179
[53] K. Kheiralipour, H. Ahmadi, A. Rajabipour, S. Rafiee, M. Javan- Nikkhah, D. Jayas,"Development of a new threshold based classification model for analyzing thermal imaging data to detect fungal infection of pistachio kernel", Agric. Res. 2(2), (2013), pp: 127–131
[54] B.F. Jones,P. Plassmann,"Digital IR thermal imaging of human skin", IEEE Eng. Med. Biol. Mag. 21(6), pp:41–48 (2002)

Journal of Engineering Technology (ISSN: 0747-9964)
Volume 6, Issue 2, July, 2017, PP.290-303

[55] B. Lahiri, S. Bagavathiappan,T. Jayakumar, J. Philip, "Medical applications of IR thermography: a review", IR Phys. Technol. 55(4), (2012),pp: 221–235
[56] E.F.J.Ring, K. Ammer,"IR thermal imaging in medicine:, Physiol. Meas. 33(3), R33 (2012)
[57] H. Qi,N.A. Diakides,"Thermal IR imaging in early breast cancer detection—a survey of recent research", 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (2003).
[58] B. Harangi, T. Csordás, A. Hajdu,"Detecting the excessive activation of the ciliaris muscle on thermal images", IEEE 9th International Symposium on Applied Machine Intelligence and Informatics (2011)
[59] S.Y. Chekmenev,A.A. Farag,E.A. Essock," Thermal imaging of the superficial temporal artery: an arterial pulse recovery model", IEEEConference on ComputerVision and Pattern Recognition (2007)
[60] T.R. Gault, A.A. Farag, "A fully automatic method to extract the heart rate from thermal video", IEEE Conference on Computer Vision and Pattern Recognition Workshops (2013)
[61] A. Mahmoud,A. EL-Barkouky, H. Farag, J. Graham, A. Farag,"A non-invasive method for measuring blood flow rate in superficial veins from a single thermal image", IEEE Conference on Computer Vision and Pattern Recognition Workshops (2013)
[62] K. Kondo, N. Kakuta, T. Chinzei, Y. Nasu, T. Suzuki, T. Saito, A. Wagatsuma, H. Ishigaki, K. Mabuchi, "Thermal rhythmography–topograms of the spectral analysis of fluctuations in skin temperature", 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (2001)
[63] H. Peregrina-Barreto, L. Morales-Hernandez, J. Rangel-Magdaleno,P. Vazquez-Rodriguez,"Thermal image processing for quantitative determination of temperature variations in plantar angiosomes", IEEE International Instrumentation and Measurement Technology Conference (2013)
[64] N. Memarian,T. Chau, A.N. Venetsanopoulos,"Application of IR thermal imaging in rehabilitation engineering: Preliminary results", IEEE Toronto International Conference Science and Technology for Humanity (2009)
[65] Panasonic: IR array sonsor: Grid-eye (2013).http://pewa.panasonic.com/components/built-in-sensors/IR-array-sensors/grid-eye/
[66] R. Gade, Moeslund, "Thermal Cameras and Applications: A Survey", Machine Vision & Applications, vol 25, no. 1, (2014), pp. 245-262.
[67] Wikipedia: Atmospheric transmittance (2006). http://en.wikipedia.org/wiki/File:Atmosfaerisk_spredning.gif