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Human Biometrics: Moving Towards Thermal Imaging

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Abstract: Thermal imaging is simply the technique of using the heat given off by an object to produce an image of it or locate it. New thermal imaging frameworks for detection, segmentation and unique feature extraction and similarity measurements for human physiological biometrics recognition are reviewed. The research investigates specialized algorithms that would extract vasculature information, create a thermal signature that identify the individual. The highly accurate results obtained by the algorithms presented clearly demonstrate the ability of the thermal infrared systems to extend in application to other thermal imaging based systems.

Index Terms: Thermography, Infrared bands, Near IR imaging, Thermal signature, Pedestrians detection, Face detection, Ear detection, Iris recognition, Thermal spectrum, Hand vein patterns, Eye detection, Fingerprint discrimination.

I. INTRODUCTION

Thermal imaging can be seen as a method of improving visibility of objects in a dark environment by detecting the objects' infrared radiation and creating an image based on that information. Here's an explanation of how thermal imaging works: All objects emit infrared energy (heat) as a function of their temperature. The infrared energy emitted by an object is known as its heat signature. In general, the hotter an object is, the more radiation it emits. A thermal imager (also known as a thermal camera) is essentially a heat sensor that is capable of detecting tiny differences in temperature. The device collects the infrared radiation from objects in the scene and creates an electronic image based on information about the temperature differences. Because objects are rarely precisely the same temperature as other objects around them, a thermal camera can detect them and they will appear as distinct in a thermal image. Thermal images are normally grayscale in nature: black objects are cold, white objects are hot and the depth of gray indicates variations between the two. Some thermal cameras, however, add color to images to help users identify objects at different temperatures. Nowadays this technology has contributed in many areas and in this paper an investigation about its contribution in the field of physiological human biometrics as a new approach for detection, segmentation and feature extraction. The remaining of this paper is organized as follows: In section II a theoretical background of the most famous identification methods, human biometrics and the concept of Infrared imaging science. Section III reviews Infrared bands and thermal spectrum. Then in section IV an overview about how thermal imaging became a promising biometrics approach.

It also reviews some of the literature works done in the field of pedestrians' detection, face segmentation, hand geometry feature extraction, and ear detection. Finally, in section V we conclude the paper and discuss the possible future work.

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II. THEORITICAL BACKGROUND

A. Identification methods

Basically there are three different methods for verifying identity [1]:

1) Possessions, like cards, badges, keys.
2) Knowledge, like user id, password, Personal Identification Number.
3) Biometrics like fingerprint, face, ear.

B. Human biometrics

Biometrics is the science of identifying or verifying the identity of a person based on physiological or behavioral characteristics. Biometrics offer much higher accuracy than the traditional ones. Possession can be lost, forgotten or replicated easily. Knowledge can be forgotten. Both possessions and knowledge can be stolen or shared with other people. In biometrics these drawbacks do exist only in small scale. An ideal biometric is universal, unique, permanent *and collectable* [2].

There are several application areas where biometrics can be used. Basically there are two types of application scenarios:

1) *Identification (*also known as *recognition*, "Who I am?") and
2) *Verification* (also known as *authentication*, "Am I who I claim I am?"

In identification there is a database with biometrics and the just taken biometric.

Biometrics can be categorized into two main classes, the first class is based on the *behavioral* features of human actions and it identifies people by how they perform something. The most popular of such methods is voice verification. *Physiological (anatomical)* biometrics methods are based on the physiological features of humans thus they measure and compare features of specific parts of human body. So far the main interest is in the head and the hand with face and fingerprint features being the most important discriminates of human identity [3]. Both classes can be either *Passive* or *Active (Invasive)*. Facial recognition, for example is a Passive biometrics. It does not require user's active participation and can be successful without persons even knowing that they have been analyzed. But Active biometrics, fingerprint, retina scanning, signature recognition etc.

however, do require personal cooperation and will not work if one denies participation in the process [4]. There are a lot of biometric technologies that are commonly used like fingerprints, face, voice, iris, signature, and hand geometry. Ear biometrics is not commonly used, yet. Also keystroke dynamics, signature and voice as behavioral biometric technologies.

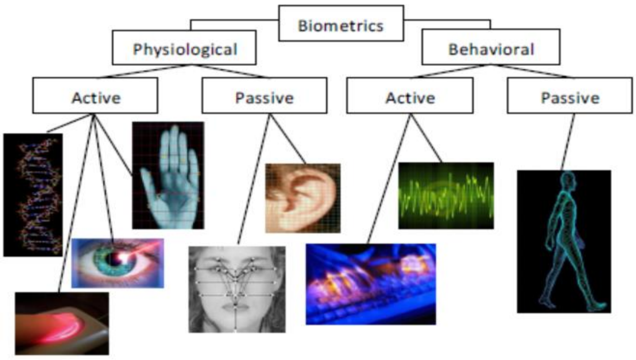

Fig.1. Human biometrics' classes and technologies [1].

C. Infrared imaging

Infrared thermography (IRT), thermal imaging, and thermal video are examples of infrared imaging science. Thermal imaging cameras detect radiation in the infrared range of the electromagnetic spectrum and produce images of that radiation, called thermograms. Since infrared radiation is emitted by all objects above absolute zero according to the black body radiation law, thermography makes it possible to see one's environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature; therefore, thermography allows one to see variations in temperature. When viewed through a thermal imaging camera, warm objects stand out well against cooler backgrounds; humans and other warm-blooded animals become easily visible against the environment, day or night. As a result, thermography is particularly useful to military and other users of surveillance cameras. Some other applications of thermography are Condition monitoring, Digital infrared thermal imaging in health care, Medical imaging, Infrared mammography, Night vision, UAV Surveillance[5],Stereo vision[6], Process control, Nondestructive testing, Surveillance in security, law enforcement and defense, Chemical imaging, Volcanology[7][8], Building[9]. Also recent researches have investigated thermal imaging as a human biometrics approach.

II. INFRARED BANDS AND THERMAL SPECTRUM

In Latin ‘infra’ means "below" and hence the name 'Infrared' means below red. ‘Red’ is the color of the longest wavelengths of visible light. Infrared light has a longer wavelength (and so a lower frequency) than that of red light visible to humans, hence the literal meaning of below red.
'Infrared' (IR) light is electromagnetic radiation with a wavelength between 0.7 and 300 micrometers, which equates to a frequency range between approximately 1 and 430 THz. IR wavelengths are longer than that of visible light, but shorter than that of terahertz radiation microwaves[10].
Objects generally emit infrared radiation across a spectrum of wavelengths, but only a specific region of the spectrum is of interest because sensors are usually designed only to collect radiation within a specific bandwidth. As a result, the infrared band is often subdivided into smaller sections.
The *International Commission on Illumination* (CIE) recommended the division of infrared radiation into three bands namely, IR-A that ranges from 700 nm–1400 nm (0.7 µm – 1.4µm), IR-B that ranges from 1400 nm–3000 nm (1.4 µm – 3 µm) and IR-C that ranges from 3000 nm–1 mm (3 µm – 1000 µm). A commonly used sub-division scheme can be given as follows: Near-infrared (NIR, IR-A DIN): This is of 0.7-1.0 µm in wavelength, defined by the water absorption, and commonly used in fiber optic telecommunication because of low attenuation losses in the SiO_2 glass (silica) medium. Image intensifiers are sensitive to this area of the spectrum. Examples include night vision devices such as night vision camera.
Short-wavelength infrared (SWIR, IR-B DIN): This is of 1 3 µm. Water absorption increases significantly at 1,450 nm. The 1,530 to 1,560 nm range is the dominant spectral region for long-distance telecommunications.
Mid-wavelength infrared (MWIR, IR-C DIN) or Intermediate Infrared (IIR): It is of 3-5 µm. In guided missile technology the 3-5 µm portion of this band is the atmospheric window in which the homing heads of passive IR 'heat seeking' missiles are designed to work, homing on to the IR signature of the target aircraft, typically the jet engine exhaust plume.
Long-wavelength infrared (LWIR, IR-C DIN): This infrared radiation band is of 8–14 µm. This is the "thermal imaging" region in which sensors can obtain a completely passive picture of the outside world based on thermal emissions only and require no external light or thermal source such as the sun, moon or infrared illuminator. Forward-looking infrared (FLIR) systems use this area of the spectrum. Sometimes it is also called "far infrared“.
Very Long-wave infrared (VLWIR): This is of 14 - 1,000 µm.
NIR and SWIR is sometimes called "reflected infrared" while MWIR and LWIR is sometimes referred to as "thermal infrared". Now, we can summarize the wavelength ranges of different infrared spectrums as in Table 1.

Table.1. Wavelength Range for Different Spectrums[9].

Spectrum	Wavelength range
Visible Spectrum 0.4	0.7 µm (micro meter / micron)
Near Infrared (NIR) 0.7	1.0 µm (micro meter / micron)
Short-wave Infrared (SWIR)	1-3 µm (micro meter / micron)
Mid wave Infrared (MWIR) 3	3-5 µm (micro meter / micron)
Long wave Infrared (LWIR) 8	8-14 µm (micro meter / micron)
Very Long wave Infrared (VLWIR)	> 14 µm (micro meter / micron)

III. THERMAL IMAGING AS A BIOMETRIC APPROACH

Thermal imaging and infrared bands have been recently used as a new approach for human biometrics. Detecting, segmenting, or even extracting the desired parts or features from thermal images can be more interesting than visual ones.

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Algorithms applied to thermal images can avoid some challenges that were facing algorithms applies to visual ones. Below are some of the most important technologies done in this area.

A. Pedestrians Detection

There exist a fair number of approaches for detecting humans in thermal images in the literature. Bertozzi [11] introduced a pedestrian detection method as a part of a driver assistance system. The algorithm is divided into three parts. (1) Candidate generation. The input thermal image is processed to locate warm symmetrical objects with a specific size and aspect ratio. (2) Candidates filtering. The candidates may contain poles, road signs and buildings, which also have symmetry characteristic. These false positive objects can be filtered by analyzing the shape of the vertical histogram in each search window. (3) Validation of candidates. Morphological characteristics of a human are extracted to form a model. Each filtered search window is compared with the model for validation. The weakness of this method is that human should be hotter than its background. Since human appearance can vary considerably in thermal images due to temperature variations, Davis and Keck presented a two-stage template-based method [12], which takes advantage of the invariance of edge information. In the first stage, human contours are obtained by creating Contour Saliency Map (CSM) [13] of thermal images. CSM represents the belief of each pixel belonging to an edge contour of a person [14]. Then a screening template is produced by averaging the human samples cropped from the CSM images. Last, a multi-resolution screening procedure is applied to obtain candidates. In the second stage, four Sobel filters with different angles are applied to the human samples to get four projected edge images. An Adaboost classifier is trained with the projected images and is applied to new input images. This method proves that edge is a robust feature for object detection in thermal images.
Recently Kai and Arens [15] proposed a local-feature based pedestrian detector on thermal data. In the training phase, they used a combination of multiple cues to find interest points in the images and use SURF (Speed Up Robust Features) [16] as features to describe these points. Then a codebook is created by clustering these features and building Implicit Shape Model (ISM) [17] to describe the spatial configuration of features relative to the object center. In the detection stage, SURF features are first located in each image. Then the matching between the features and the codebook is conducted to locate object center. The challenge of this detector is whether a high performance can be achieved when local features are not obvious, for example, in thermal images of poor quality.
[18] Presented a new method for detecting pedestrians in thermal images. The method is based on the Shape Context Descriptor (SCD) with the Adaboost cascade classifier framework.
Compared with standard optical images, thermal imaging cameras offer a clear advantage for night-time video surveillance. It is robust on the light changes in day-time.

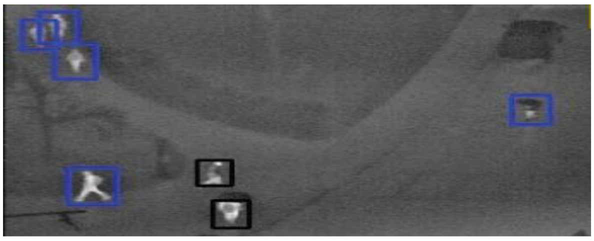

Fig.2. pedestrians' detection results [11].

B. Face Segmentation

The growing interest in robust methods (for example, for security applications) has driven the development of facial recognition exclusively in the infrared. Recognition in the LWIR is not affected by light variations.
A crucial step in the process of face recognition is the face segmentation. This is more demanding than simple face detection since it pinpoints not only the face's locations, but also must describe its shape. A robust segmentation system can improve recognition rates regardless of the recognition method. In contrast with the visible wavelength, where numerous methods have been proposed to accomplish this task (based on color, geometry, etc.), in the LWIR there is a lack of proposals to improve the current status.
Face segmentation, given that it is a preprocessing step for all recognition methods, will lead to their failure if it is not correctly performed. This is not a subject much discussed by the authors of recognition methods in the infrared. Some of the proposed approaches are based only on the creation of an elliptical mask that will be put over the image of the face [15], but these approaches will work only on frontal and centered faces. Siu-Yeung Cho et al. in [19] present a method for face segmentation in IR images based on the Sobel Edge detector and morphological operations. After the Sobel Edge detector, the largest contour is considered to be the one best describing the face. They apply the morphological operations to the area contained in this outline to connect open contours and remove small areas.
Pavlidis et al. in [20] describe a method for face segmentation using a Bayesian Approach. This method is based on the combination of two Normal Distributions per class, which are estimated using the Expectation-Maximization (EM) algorithm. This algorithm uses pixels from the skin(s) and background (b) for training. These are obtained from the training set images by selecting sub-regions that contain only pixels from each of these types.
Filipe and Alexandre [21] evaluated the methods of [15] and [20] and realized that it was possible to improve their results. Thier proposal is based on the method of [20]: after analyzing the results of it they concluded that its main problem is the removal clothing since the body warms it, clothes have temperatures similar to the skin. After this, they calculate the possible location of the center of the face with new signatures (horizontal and vertical). The center point is given by the maximum values of the signatures (when more than one maximum value exist in the horizontal or vertical signatures the average of these maximums is used). This possible center location of the face is used for the search for the largest contour. For contour extraction they used the canny edge detector. Only boundaries that have the center point inside are accepted.

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A possible drawback of this method occurs when the calculated center position of the face is not correct. This may cause the largest contour to be only partially over the actual face.

Fig.3. Sample result of face segmentation from thermal images [20].

C. Hand Geometry Feature Extraction

Stability and uniqueness of hand vein patterns have attracted the attention of researchers for its usage in personal identification. Lin and Fan [22] have presented a promising approach for the personal verification using palm dorsal images. They have systematically detailed the formation of thermal vein pattern images from the thermal IR camera operating in (3.4 – 5) µm range. The approach detailed in is fully automated and uses the combination of multi-resolution representations from the post processed thermal vein patterns. Wang and Leedham [23] present yet another approach for personal authentication using hand vein images acquired thermal imaging. They have employed Hausdorff distance to generate matching scores between the extracted line patterns and illustrated promising results. The near IR imaging of hand vein patterns has also been investigated in the literature with promising results. Cross and Smith [24] detailed the usage of near IR imaging for the extraction of hand vein patterns. Authors have demonstrated the two-fold matching of medial axis representation, after the vein skeleton extraction, for the authentication of 20 users. Im *et al*. [25][26] have presented the implementation for hand vein extractor, using FPGA in [25] and DSP processor in [26], but with little details on the matching strategy or on the size/nature of database employed for the performance evaluation. Tanaka and Kubo [27] also developed hand vein acquisition device using near IR imaging and employed FFT based phase correlation scheme for user verification. Kumar and Prathyusha [28] investigated a new approach for the automated hand vein authentication using the hand vein triangulation. The approach has been tailored to utilize the images acquired from the, low-cost, contactless, near IR imaging. In this research the image contours extracted from the acquired images are used for image normalization and region of interest (ROI) segmentation. Then an extraction of hand vein map from ROI images is done before the triangulation of minutiae points is used for reliable feature representation. Then hierarchal matching scheme for the minutiae triplets appears.

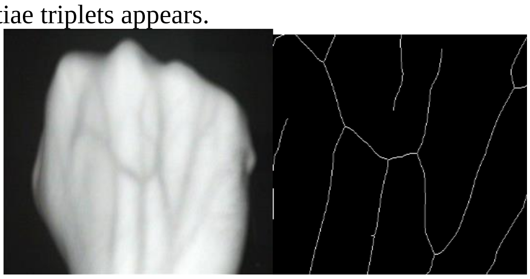

Fig.4. acquired hand images and extracted hand-vein topology [27].

D. Ear Detection

The problem of human ear detection in the thermal infrared (IR) spectrum was studied in [29] in order to illustrate the advantages and limitations of the most important steps of ear-based biometrics that can operate in day and night time environments. Their method was based on Haar features forming a cascaded AdaBoost classifier (their modified version of the original Viola-Jones approach [30] that was designed to be applied mainly in visible band images). The main advantage of the proposed method, applied on their profile face image data set collected in the thermal-band, is that it is designed to reduce the learning time required by the original Viola-Jones method from several weeks to several hours. They achieved a high detection accuracy that reaches ~ 91.5%.

Fig.5. Sample thermal (MWIR) profile images of multiple subjects where the ears are left and right 'detection results' [29].

E. Eye detection

The importance of using the MWIR band for detection and human recognition has been also discussed in [31] the authors studies the problem of eye detection in the Middle-Wave Infrared (MWIR) spectrum was studied. The main challenge was that in the MWIR domain limited features can be extracted from the eye region, mainly eyelashes and eyebrows, while features such as human irises, pupils, and superficial blood vessels of the conjunctiva are not clear. The main conclusion of the work was that human eyes on still frontal face images captured in the MWIR wavelength band can be detected with promising results.

Fig.6. Human eye in visible and thermal images [30].

F. Fingerprint recognition

A modified Gaussian high-pass filter was developed in [32], as a basic of a new finger recognition method. After the filtering procedure, three types of feature extraction methods—simple binarization, LBP, and LDP—were adopted and compared. Logically, an extracted binary pattern includes multimodal biometric features of finger veins and finger geometries.

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Authors of [33] went further to the discussion of distinguishing dummy (fake) fingers from real ones and used thermal imaging as a novel method for that purpose. Both researches proved thermal imaging to be simple, low-cost method, and effective.

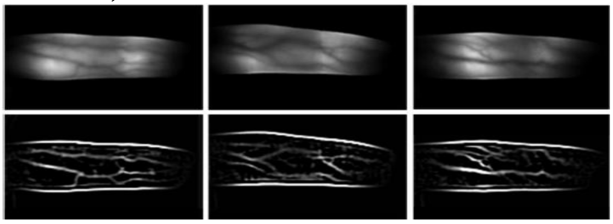

Fig.6. Finger thermal images and their filtered results [31].

IV. CONCLUSION

From the previous discussion it is clear that thermal images don't need any special techniques for processing:

1) Edge detectors: (Ex: Canny & Sobel filters).
2) Morphological operators.
3) Training classifiers: (Ex: Ada-boost & Bayesian).
4) Multi-resolution screening.
5) Finding interest points and centroids.
6) Features matching.

Recent researches proved that thermal imaging have outperformed visible bands in the field of human biometrics in many challenges. But there still a lake for researches that introduce a fair comparison between the two bands that may introduce challenges of this new approach.

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