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Pedestrians' detection in thermal bands – Critical survey

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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 have been introduced in literature. The research investigates specialized algorithms that would use the individual's heat signature for human detection, crowd counting and applications that take benefits of this new technology. 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.

Keywords: Thermography; Infrared bands; Near IR imaging; Thermal signature; Pedestrians detection; Crowd counting

1. Introduction

Pedestrian detection is an essential and significant task in any intelligent surveillance system, as it provides the fundamental information for semantic understanding of any scene. It has an obvious extension to automotive applications due to the potential for improving safety systems. Some obvious challenges facing pedestrians' detection like various styles of clothing in appearance, different possible articulations, the presence of occluding accessories, frequent occlusion between pedestrians, etc. have led to the replacement of visible bands by thermal ones in many recent researches. Once again the fast growth in computer vision research in the last decade has mostly been associated with visible-light sensors. Non-visible spectrum sensors have not been used as widely because, initially, low cost cameras had poor spatial resolution and a narrow dynamic range, and cameras with better image quality were prohibitively expensive for many researchers. However, sensor technology has nowadays advanced to a point that non-visible range sensors have regained researchers' attention in both academia and industry.

The remaining of this paper is organized as follows: In Section 2 a comparison between thermal bands and visible bands in the field of human detection is presented. In Section 3 a definition of the meaning of thermal imaging can

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be found. Section 4 reviews Infrared bands and thermal spectrum. Then in Section 5 an overview about how thermal imaging became a promising approach for such an application. Finally the paper is concluded in Section 6.

2. Comparison

Until very recent time, thermal imaging using infrared cameras has been mainly limited to military applications, helping operators to better see their environment and to detect humans and vehicles in very low light conditions. Driven by the emergence of new types of thermal cameras, more affordable, infrared imaging technology is starting to reach industrial, commercial, and consumer markets.

Current applications – for example surveillance systems used to detect human or vehicle intrusions – generally require the presence of a human operator for making decisions after viewing the infrared images on a monitor.

The visible (traditional) and IR images share several common characteristics. The appearance of objects changes with viewpoint in similar ways. However, visible images are highly sensitive to external illumination changes. Also, the texture pattern details, such as clothing worn by humans, are imaged in fine detail. In IR images, however, the fine texture details are lost as the human body temperature is relatively constant over the entire body though the measured intensity does depend on clothing to some extent. Not only are many details lost in the interiors of humans but also in the background. Thus, IR images have appearance that can be described as blob-like or “blobby”. Thus, it is expected that methods for pedestrian detection that emphasize silhouettes should function well for both classes of images though the importance of different features may be different for the two classes of images. But recent studies have proved that Compared with visible images, thermal images are represented with different intensity maps, and not sensitive to illumination change and complicated details. Besides, thermal images can provide an enhanced spectral range that is imperceptible to human beings and contribute to obvious contrast between objects of high temperature variance and the environment (Zin et al., 2011; Liu et al., 2013; Bertozzi et al., 2007; Fang et al., 2004; Li et al., 2010). Some examples are given in Fig. 1, where thermal images demonstrate their advantages over visible images in these scenarios. It is possible to detect pedestrians from thermal images with insufficient or over illumination. Moreover, the variability introduced by color, texture, and complex background becomes trivial (Bertozzi et al., 2007; Li et al., 2010; Olmeda et al., 2012).

3. Thermal imaging

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

Fig. 1. Sample visible (top) and thermal (bottom) images.

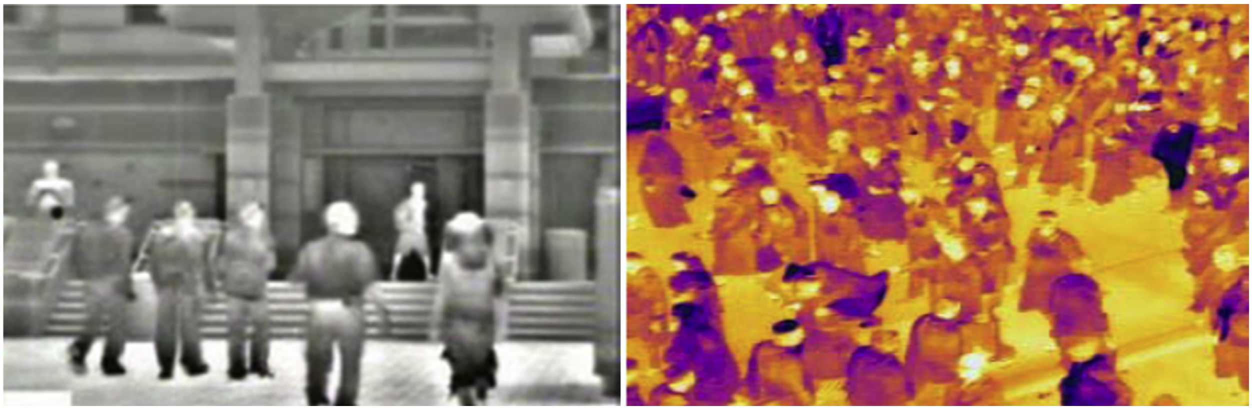

Fig. 2. Sample of gray level thermal image (left) and colored thermal image (right).

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 (see Fig. 2, left). Some thermal cameras, however, add color to images to help users identify objects at different temperatures (see Fig. 2, right). Nowadays this technology has contributed in many areas and in this paper an investigation about its contribution in the field of pedestrians' detection and crowd counting.

4. 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 μm, 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 (Bhowmik et al., 2012).

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 to 1400 nm (0.7–1.4 μm), IR-B that ranges from 1400 nm to 3000 nm (1.4–3 μm) and IR-C that ranges from 3000 nm to 1 mm (3–1000 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 13 μm. Water absorption increases significantly at 1450 nm. The 1530–1560 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

Table 1
Wavelength range for different spectrums.

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)	3–5 μm (micro meter/micron)
Long wave infrared (LWIR)	8–14 μm (micro meter/micron)
Very long wave infrared (VLWIR)	>14 μm (micro meter/micron)

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 14–1000 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.

5. Literature

There exist a fair number of approaches for detecting humans in thermal images in the literature. Bertozzi et al. (2003) introduced a pedestrian detection method as a part of a driver assistance system. The algorithm/method 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 (Fig. 3).

Davis and Keck presented a two-stage template-based method (Keck and Davis, 2005), which takes advantage of the invariance of edge information. In the first stage, human contours are obtained by creating Contour Saliency Map (CSM; Davis and Sharma, 2004) of thermal images. CSM represents the belief of each pixel belonging to an edge contour of a person. 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 (Fig. 4).

Arens and Jungling (2009) 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 (SpeedUp Robust Features; Tuytelaars et al., 2006) as features to describe these points. Then a codebook is created by clustering these features

Fig. 3. Sample results of pedestrians' detection (Bertozzi et al., 2003).

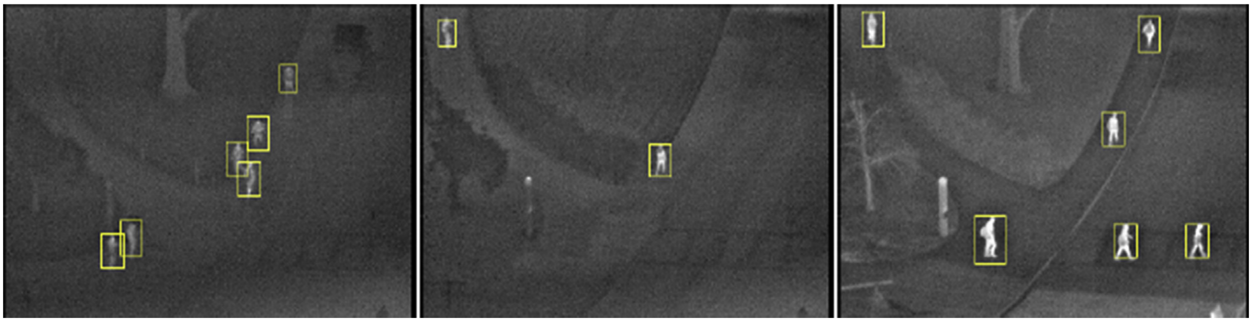

Fig. 4. Examples of detection results of Keck and Davis (2005).

Fig. 5. Sample result of successful detection of Arens and Jungling (2009).

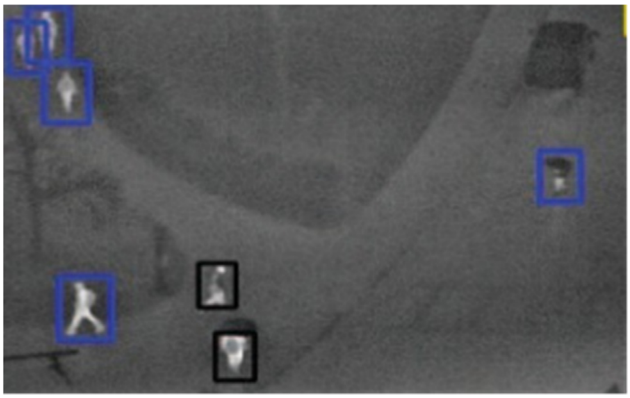

Fig. 6. Sample result of successful detection of Wang et al. (2010)

and building Implicit Shape Model (ISM) 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 (Fig. 5).

Wang et al. (2010) have 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 (Fig. 6).

In Li and Gong (2010), the authors went further to investigate real time pedestrian tracking thermal infrared imagery. It makes use of the characteristics of pedestrian body regions in infrared images, which is based on a particle filter framework. The method constructs the regions of interest's (ROI) histogram representation in an intensity-distance projection space model, so as to hurdle the disadvantage of insufficient information when only intensity feature is considered. In addition, the tracking algorithm which embeds the above mentioned representation model in the particle filter framework and update the sample's representation model automatically. The experimental results are gained by

Fig. 7. Tracking results for three different frames (Li and Gong, 2010).

using different infrared image sequences, which show that the proposed scheme achieves more robust and stable than the classical tracking method (Fig. 7).

In Qi et al. (2014) another advanced driver assistant system (ADAS) was developed but this time sparse representation was proposed for pedestrian detection in thermal images. Two types of dictionaries, i.e. a generic dictionary optimized by K-SVD and a naive dictionary with basis atoms being directly composed of training samples, were employed to represent image features. In the implementation, a boundary box shrinking scheme is applied to improve the accuracy of the detection through finding proper size for the boundary box. The experimental results demonstrate a comparable performance of the proposed approach (Fig. 8).

Zhang et al. (2007) investigated the methods derived from visible spectrum analysis for the task of human detection in infrared bands. Two feature classes (edgelets and HOG features) and two classification models (Ada-Boost and SVM cascade) were extended to IR images. They found out that it is possible to get detection performance in IR images that are comparable to state-of-the-art results for visible spectrum images. It is also shown that the two domains share many features, likely originating from the silhouettes, in spite of the starkly different appearances of the two modalities (Fig. 9).

Abuarafah et al. (2012) went further to introduce a novel technique for monitoring and estimating the density of crowd in real-time using infrared thermal video sequences. The research targets monitoring the crowd in Muslims' pilgrimage event (Hajj) while almost 3.0 million Muslims gather in Makkah to perform Hajj. During different Hajj phases the movement of the gathered Muslims is required at the same time from a place to another. Thus monitoring their crowd in real-time is crucial in order to take immediate decisions to prevent crowd disasters. A state of the art thermal camera has been acquired for the surveillance process. In addition, special software modules have been developed to analyze the captured thermo-graphic video sequences in real-time. The results show high accuracy of the estimation of the crowd density in real-time IR videos. However, the authors did not mention any automatic method for the determination of the range of humans' temperature. It is required to find a way for the automatic definition

Fig. 8. Detected human body in a small bounding box (Qi et al., 2014).

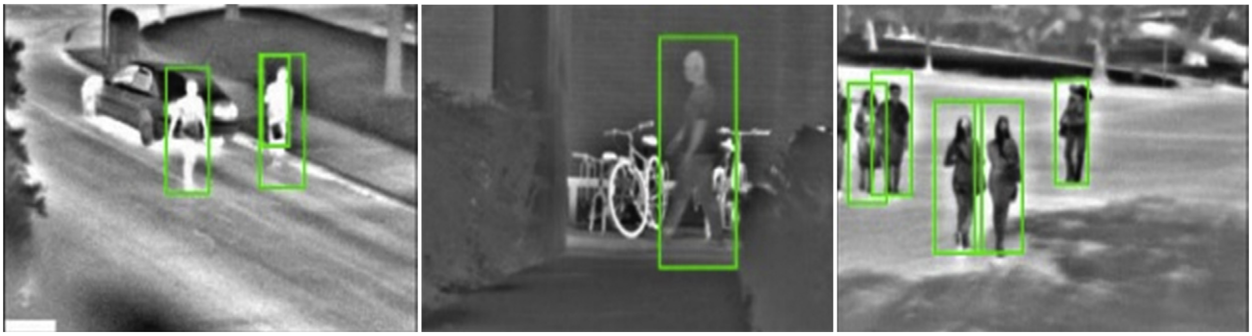

Fig. 9. Examples of detection results (Zhang et al., 2007).

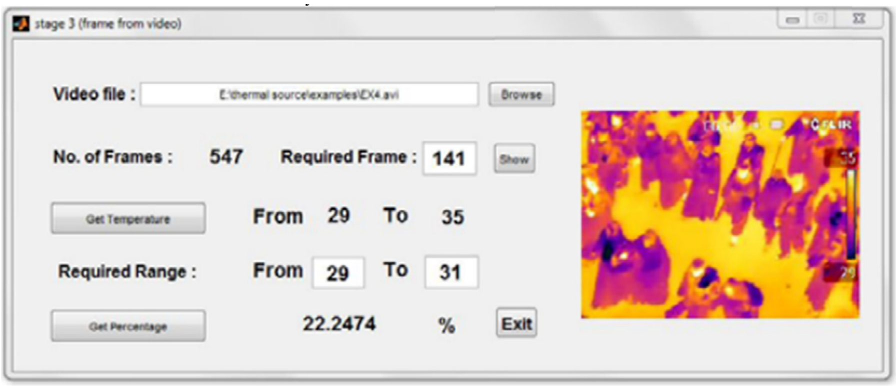

Fig. 10. Experimental results representing the success of estimating the crowd percentage in a thermal scene (Abuarafah et al., 2012).

of the pedestrians' temperature range as defining the human temperature range manually for every frame cannot be considered as a reliable solution for real-time systems as much as it cannot be accurate for all cases (Fig. 10).

In general it can be said that 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. It can also outperform the bad results obtained by visible images caused by occlusions or closing texture. It can be used where pedestrians' privacy respect cannot be violated.

6. Conclusion

From the previous discussion it is clear that dealing with thermal bands 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) Finding interest points and region of interests.
(5) Features matching.

Recent researches proved that thermal imaging has outperformed visible bands in the field of human detection plus that it allowed the presence of many applications that are needed in many different fields nowadays.

However, 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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