Observing Human Motion Using Far-Infrared (FLIR) Camera – Some Preliminary Studies

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Abstract

Far infrared imaging technology is becoming an interesting choice for many civilian uses. We explored the potential of using far infrared camera for human motion analysis, especially from the viewpoint of possible automated image and video analysis. In this article, we present the main characteristics of far infrared imagery that should be of interest to computer vision researchers and seek to eliminate some common misunderstandings about the far infrared imagery which may influence the choice of far infrared technology over other alternatives. We provide images that illustrate the problems and advances of using the far infrared imaging technology, especially for the purpose of observing humans.

1 Introduction

Developed for military use, far infrared cameras (sometimes also called *forward looking infrared* or FLIR cameras) are getting more and and more available for civilian use. They are already used in industry to detect serious faults in equipment, in process control, in quality control and in similar tasks. Decreasing prices of far infrared imaging technology make these cameras also a serious choice for civilian surveillance applications.

Unfortunately, this technology is not yet widely available, and many reasearchers lack the first-hand experience in acquiring far infrared (thermographic) images. As with conventional imaging systems (for example, CCD and CMOS cameras), the process of image formation is not simple, however, for the thermography images this knowledge is not as widespread as for more conventional imaging techniques. However, this knowledge is needed for successful planning and deployment of applications which would utilize far infrared sensors.

Adding to confusion are sometimes the descriptions of far infrared technology in scientific publications, which sometimes unintentionally reinforce the perception that far infrared imaging is a magic bullet that solves many difficult problems in computer vision, with the higher cost being the only drawback. For example, in [1] the authors say: *"Unfortunately, using color in outdoor imagery has proven more difficult, enough so that almost all existing military or remotesensing classification systems rely on nonvisual sensors (e.g. FLIR or LADAR). The main problem with (visible) color has been the unpredictability of an object's reflectance in daylight; the color shift between sunny and cloudy days (or between morning and afternoon) is simply not well modeled as Gaussian noise in RGB.“* We will later demonstrate that the thermographic images from FLIR sensors suffer from very similar problems, and therefore do not solve the problem as readily as authors imply.

2 Thermographic image formation

A very simple interpretation of thermographic images is that they depict the temperature of the observed scene, with different pixel intensities depicting different temperatures. This simple explanation does not reveal possible pitfalls of thermographic imaging, which are evident only with deeper understanding of the image formation process.

Far infrared sensors are built as arrays of *microbolometers*, which are in their function similar to thermocouples. When the far infrared radiation hits the microbolometer, its electrical properties change. The change is reflected in the change of electric signal, and this signal is represented as a brightness of a single pixel. The far infrared sensor array is the equivalent of CCD in the ordinary camera; the sensors with resolutions of 160×120 pixels are widely available, and their response time is sufficient to provide live thermographic video image at 25 frames per second, just as the ordinary video cameras.

Therefore, thermographic images do not depict *the temperature* of the observed object, they depict *the electromagnetic radiation of a object* in the far infrared range, which is $6 - 15\mu m$. There is no fundamental difference between the visible light (which occupies the range of $0.7 - 0.4\mu m$) and the far infrared radiation, since both behave according to the same physical laws [2]. Consequences of this behavior are interesting and will be described in the next section.

Usually, the object does not emit a radiation of a single wavelength. The distribution of wavelengths in radiation of a blackbody (the body which does not reflect any radiation) is definedy by the Planck's law. The peak wavelength λ can be obtained by the differentiating the Planck's formula, and is given by the Wien's formula, shown in Eq. 1 [2]:

$$\lambda = \frac{2898}{T} \left[\mu m \right], \tag{1}$$

where T represents the object temperature on a Kelvin scale. Our sun, at a temperature of approximately 6000 K, emits visible light with peak at $0.5 \mu m$. It is common knowledge that metal objects can be heated to the point of emitting the visible light, with the color that depends on the temperature of the object. It turns out that the objects at the room temperature (300 K) emit the wavelengths with the peak at $9.7 \mu m$, which is in the middle of far infrared range. This is the main motivation for the far infrared imaging: *in this range of electromagnetic radiation, objects at room temperature appear to "glow" without any external source of light.*

The thermographic image represents emitted energy from an object, and the relation between the temperature of an object and the emitted energy is given by the Stefan-Boltzmann formula, shown in Eq. 2 [2]:

$$W = \varepsilon \sigma T^4 \left[Watt/m^2 \right], \tag{2}$$

where T again represents temperature, W represents energy, σ represents Stefan-Boltzmann constant, and ε represents the object's spectral emissivity. Emissivity is the property of the material from which is the object made and varies with wavelength. Emissivity is in the range [0..1], and describes the percent of the radiation that the object emits with respect to the ideal blackbody (which has the $\varepsilon = 1$).

Thus, since the emissivity varies with the material, it is the important factor in thermographic image formation. For accurate measurements of temperature, it has to be provided to the camera manually to be included in temperature calculation. There are usually objects with highly different emissivities present on a single thermographic image, and therefore the function, which describes thermographic image, $I(x, y)$ has the form, described in Eq. 3:

$$I(x, y) = f(T(x, y), \varepsilon(x, y)), \tag{3}$$

where x and y are the coordinates of individual image pixels, $T(x, y)$ is the actual temperature of an object at image coordinates (x, y), and the $\varepsilon(x, y)$ is the emissivity at those coordinates[1]. Thermographic image is from the point of computer vision obviously the function of two images – the temperature image $I(x, y)$ and the emissivity image $\varepsilon(x, y)$. It is also obvious that with different materials on the scene it is possible to accurately measure only the temperature of the only one kind of material – the one for which the emissivity has been provided to the camera or used in the calculation of the temperature.

It is also obvious that contrast in thermographic images may be the result of either different temperatures of different objects on the scene or of different emissivities of different objects with same temperature – or both, which is the most frequent case. Camera will also underestimate the temperature of the objects with the lower emissivity and overestimate the temperature of the objects with higher emissivity.

3 Images and results

For the images, presented in this article, we used the Flir Systems E1 handheld far infrared camera. The emissivity was set to 1.0, regardless of the nature of the scene. Therefore, the temperatures measured do not represent accurate temperatures of the objects on the scene. All images, unless indicated otherwise, are scaled to depict temperature of 20 degrees Celsius as black, and temperature of 30 degrees Celsius as white. Higher temperature readings are therefore always depicted as brighter image pixels.

In this section, we present the images, grouped according to the properties of thermographic imaging which we decided to explore.

3.1 Reflection

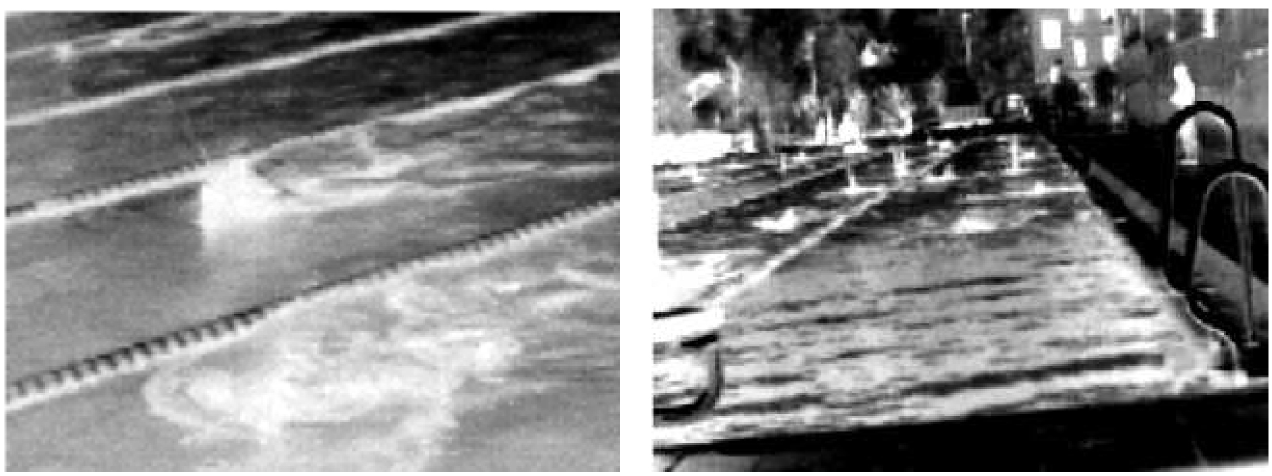
As noted before, far infrared radiation is subject to same laws of physics as the visible light. This may lead to some unexpected results when the straightforward relation between pixel intensity and object temperature is assumed. Far infrared radiation reflects off many surfaces, for example glass, polished ceramics, metals, polished parquet and stone, etc.

Fig. 1 shows some interesting results of this behaviour. In the Fig. 1(a) the people (bright silhouettes) reflecting on the polished wooden (parquet) floor can be seen. In Fig. 1(b) the piece of the metal on the side of the door (the lock) appears as extremely bright area, and the camera produced the reading of 31 degrees Celsius, in contrast to the surrounding wood, which should, according to the image, have the temperature of 23 degrees Celsius. This is nonsense – what is seen on the surface of the metal is essentially the reflection of the person behind the camera. Recall the Fig. 1(a) – humans literally "glow in the dark"

[1] There are more factors that influence the formation of image and can be included in the calculations, however we omit them for the sake of simplicity.

(a) (b)

Figure 1: Reflections in the far infrared spectrum. (a) Group of people on the wooden, polished parquet floor. (b) Metal part (door lock) reflecting radiation from a person behind a camera.



(a) (b)

Figure 2: People in water – swimming (outdoors). Images are scaled in the interval from 20 degrees C (black) and 25 degrees C (white). (a) It is impossible to see the outline of a person. (b) Strong reflections on a water surface.

in the near infrared spectrum due to our relatively high body temperature, much like a lightbulb in the visible spectrum. When a person enters the room, it *illuminates* the room with its radiation, and this radiation then reflects from every surface with high reflectivity. Based on our experience, there are plenty of such surfaces in typical human indoor environment and use of indoor thermal surveillance cameras will be probably hampered by this fact.

3.2 Water

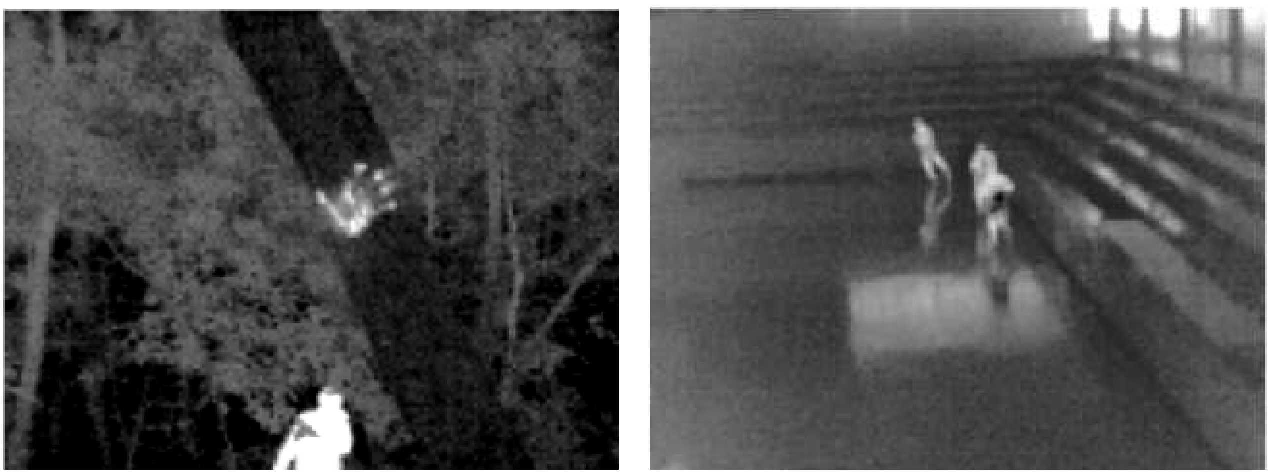
One of interesting applications is use of thermal camera for tracking and analysis of human motion in water, e.g. for performance analysis of swimmers, for surveillance (drowning detection) and similar. Fig. 2(a) shows two swimmers in water. Their silhouettes and their exact locations are not visible – the water around them glows due to dissipation of the radiation from their bodies. Fig. 2(b) shows water surface from another angle, where strong reflections from the surrounding are visible. The pictures were captured outside, on a sunny day.

3.3 Urban environment

Nowadays, surveillance of humans by use of thermographic cameras is usually employed in rural areas (forests, along borders, etc), where warm thermal image of human forms huge contrast with the natural environment. In urban environment, those contrasts may be far less apparent, as shown in Fig. 3. Urban surroundings is full of materials which also emit large amounts of far-infrared radiation and contrast may in some cases be not much better than with standard video equipment.

(a) (b)

Figure 3: People in urban environment. (a) During the night. (b) During the day.



(a) (b)

Figure 4: (a) Warm palmprint on a tree, 15 seconds after the person has left (this image is scaled to the range from 15 degrees C to 20 degrees C). (b) People running, same scaling as in other images.

3.4 Temperature as a feature

The fact that people have stable and much higher temperature than their surroundings is one of the arguments for thermography based surveillance. However, using the temperature as a feature is not a straightforward task. When people touch objects, they leave prints, which do not disappear quickly, as seen In Fig. 4(a). Also, people may exhibit different thermographic temperature in different circumstances – the group of running people in Fig. 4(b) exhibits slightly lower temperature than the group in Fig. 1(a).

4 Conclusion

Far infrared imaging comes with number of challenges that are either not apparent in visible light spectrum or not expected given the common knowledge about thermography. Nevertheless, it has at least two advantages over the visible light in observation of people. First, it is simple the different modality, and problems appear in different situations. For example, where color may be unstable feature, temperature may be more reliable, and vice versa. Second, thermal cameras operate at far greater bit depths (for example, 14 bits) than video cameras (usually 8 bits). This allows for more detailed segmentation of images than conventional video equipment.

References

[1] S. Buluswar and B. Draper. Non-parametric classification of pixels of varying outdoor illumination. In *ARPA Image Understanding Workshop*, pages 1619–1626, Monterey, CA, November 1994.

[2] *ThermaCam Reporter 2002: Operator's Manual.* Flir Systems AB, 2002.