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Easy rectification for infrared images

R. Usamentiaga

Department of Computer Engineering, University of Oviedo, Campus de Viesques, 33204 Gijón, Spain

HIGHLIGHTS

- A novel method is proposed to rectify infrared images without using calibration plates.
- The contour of objects in the image are extracted and compared with their reference dimensions.
- The fine estimation of projection parameters iteratively minimizes the distance from the extracted contour to the reference.
- The proposed method provides reliable geometric information about the objects in the scene with a single image.

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ABSTRACT

Most applications using infrared thermography only take advantage of one feature in the images: the intensity of the objects in the infrared images, which is mainly a function of its temperature. Many different applications use this feature as an indicator of health, early signs of malfunction or signs of hidden conditions. However, infrared images also contain relevant geometric information that can be used to measure objects or to locate areas of thermal contrast in the scene. The problem is that the extraction of geometric information requires a complex camera calibration procedure that depends upon calibration plates which are difficult to build. In this work, an easy rectification procedure for infrared images is proposed without using calibration plates. The proposed method uses a camera projection model not considering distortions, which greatly simplifies the estimation of the projection parameters while producing very good accuracy. The method estimates the projection parameters iteratively based on features from objects in the image and the knowledge about its geometric properties. The result is a method that provides reliable geometric information about the objects in the scene with a single image. A series of experiments are performed to validate the proposed method. Results show excellent performance, with sub-pixel accuracy.

1. Introduction

Infrared thermography has been established as an effective tool in many different applications [1]. Some of the main fields where infrared thermography is used include medicine [2], veterinary medicine [3], maintenance and process monitoring [4], building inspection [4], and non-destructive testing [5]. Infrared thermography has many advantages over other technologies [6]: it is a non-contact technology, it provides two-dimensional thermal images, it is real-time, it has no harmful radiation and it does not intrude upon the target.

The intensity of the infrared radiation emitted by objects is mainly a function of its temperature; the higher the temperature, the greater the intensity of the emitted infrared energy. Most applications using infrared thermography only take advantage of this feature. However, infrared images also contain relevant geometric information. This information could be used to calculate the size of a defect in non-destructive testing applications, or to accurately indicate the position of isolation failures in building inspection applications.

The reason why geometric information in infrared thermography is usually ignored is because it requires a complex camera calibration procedure [7]. Moreover, it requires specific calibration plates with features of known dimensions [8]. When calibration is applied to visible cameras, accurate calibration plates can be printed using off-the-shelf printers. However, in the case of infrared cameras, calibration patterns need distinguishing features in terms of infrared radiation. Therefore, standard calibration plates cannot be used and special devices need to be built.

An example of calibration plate for infrared cameras is proposed in [9]. It consists of a wooden plate, with a surface of 1 m^2, with 64 burning lamps specifically chosen because they are easily detected by the particular cameras used (long-wavelength infrared).

E-mail address: rusamentiaga@uniovi.es
URL: http://www.atc.uniovi.es/rusamentiaga

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A similar approach can be found in [10], where a wooden plate of 1000 mm × 1000 mm with 57 small lamps is used. This work indicates that the center of the targets lamps cannot be measured with precision. Thus, an alternative calibration plate based on differences in emissivity is proposed. Calibration plates that use light bulbs are also discouraged in [11]. It is indicated that these calibration plates are heavy, need an external power supply and present diffraction effects. Moreover, the marking process of the targets is manually performed. In [11] the calibration plate proposed is also based on differences in emissivity. In this case, the calibration plate consists of an aluminum sheet and a black card on top of the wooden plank. Targets are perforated in the card so that the aluminum sheet can only be seen in these regions. No information is given about how accurate is the perforation of the black card. A different approach is proposed in [12]. In this case, the calibration plate consists of scale bars with four reflective targets situated at the corners of the structure. Internally to the reflective material, a circular heater is placed to generate a circular heat pattern which can be measured by an infrared camera. This work estimates the projection parameters of the camera using only four points, and it does not take distortion parameters into account. In [13] a calibration plate is also used for the camera calibration and the pose is estimated based on the coordinates of 4 points in the inspected object.

This work proposes a method to estimate the projection parameters of an infrared camera which can be used to easily rectify the images. The result is a transformed image with a fronto-parallel projection where measurements in real world units (mm), and not pixels, can be carried out. The proposed procedure is influenced by the Iterative Closest Point (ICP) algorithm [14,15], which proposes a method to estimate correspondences between point clouds, and by the POSIT algorithm [16], which proposes a method to estimate the pose of a camera. Rather than using a specific calibration plate, the proposed method is based on geometric features from objects in the image. Moreover, it can be applied using a single image of a known object. In infrared images, it is difficult to extract specific features, such as corners or lines. In order to circumvent these issues, the information about the contour of the object is used in this work. It is not necessary to extract a complete contour, only some parts are necessary. The proposed work iteratively aligns the extracted contour with the information given about the shape of the object. The result of this process is an accurate estimation of the projection parameters which can be used to extract reliable geometric information from infrared images.

The proposed method does not require a calibration plate, and it does not apply a different procedure for the calibration of the intrinsic and extrinsic camera parameters. Moreover, it can be applied with a single image. All these aspects greatly simplify the estimation of the projection parameters that are used to rectify the images. Distortion parameters are not considered, which slightly reduces the accuracy of the rectification. However, this issue can be negligible in infrared thermography where generally lens with long focal length are used, and where extreme geometric accuracy is not commonly required.

The extraction of information about the contour of an object in the image is particularly easy in most infrared applications. This is because some objects can be easily distinguished in the image. For example, in non-destructive testing applications, the inspected object is heated using an external stimulus. That makes it very distinguishable in the image. In the case of building inspection, windows are easily identified due to the different infrared radiation. The information about the contour of these objects is the only reference required to estimate the projection parameters accurately.

The remainder of this paper is organized as follows. Section 2 introduces the fundamentals of camera projection; Section 3 presents the proposed approach; Section 4 discusses the results obtained with real data; and finally, Section 5 reports conclusions.

2. Camera projection

Camera projection is modeled in two steps: the transformation of points in world coordinates to camera coordinates, and the projection of points from camera coordinates into the image [17]. The model is illustrated in Fig. 1.

The transformation of world coordinates to camera coordinates is mathematically described using a rigid transformation in 3D [18]. Therefore, it consists of three translations (t_x, t_y, t_z), and three rotations (α, β, γ). These parameters are called the extrinsic parameters. They are generally given in a matrix, which can be expressed as (1).

$$\begin{pmatrix} x^c \\ y^c \\ z^c \\ 1 \end{pmatrix} = \begin{pmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^w \\ y^w \\ z^w \\ 1 \end{pmatrix} \tag{1}$$

The projection of points in camera coordinates into the image plane coordinate system is based on the pinhole model, which is calculated using (2).

$$\begin{pmatrix} u \\ v \end{pmatrix} = \frac{f}{z^c} \begin{pmatrix} x^c \\ y^c \end{pmatrix} \tag{2}$$

When no distortions are considered, the transformation from the image plane coordinate system into the pixel coordinate system is calculated using (3), where S_x and S_y typically represent the width and height of the pixels, and the point $(C_x, C_y)^T$ is the projection of the central pixel.

$$\begin{pmatrix} r \\ c \end{pmatrix} = \begin{pmatrix} \frac{v}{S_y} + C_y \\ \frac{u}{S_x} + C_x \end{pmatrix} \tag{3}$$

When high accuracy is required, a model for lens distortions is included in the mathematical description of the projection. The most common models are the polynomial and division models [19]. The most accurate is the polynomial model, which uses three parameters to model radial distortion (k_1, k_2, k_3), and two to model decentering distortion (p_1, p_2). Using this model, the total number of intrinsic parameters is 10 $(f, k_1, k_2, k_3, p_1, p_1, S_x, S_y, C_x, C_y)$.

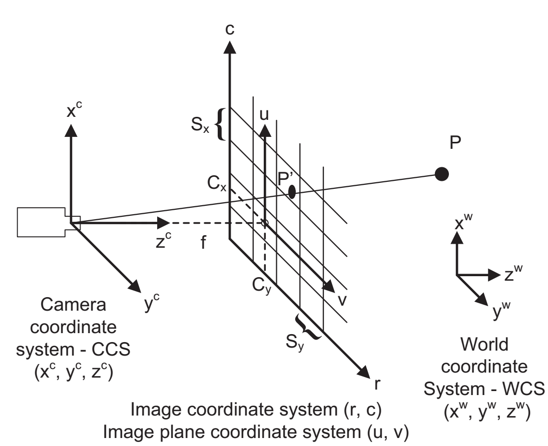

Fig. 1. Camera projection model.