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Focusing in thermal imagery using morphological gradient operator

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ABSTRACT

This paper presents focusing on an object of interest in thermal infrared (IR) imagery using the morphological gradient operator. Most existing focus metrics measure the degree of sharpness on the edge of an object in the field of view, often based on the local gradient operators of pixel brightness intensity. However, such focus measures may fail to find the optimal focusing distance to the object in thermal IR images, where strong edge components of an object do not exist. In particular, when the end goal of image acquisition is object recognition, focusing on an object must retain prominent features of the object for recognition. In this paper, the performances of various focus measures are evaluated in terms of sharpness as well as recognition accuracies for face recognition in thermal IR images. Experiment results show that the morphological gradient operator outperforms conventional gradient operators in terms of autofocusing resolution metric as well as face recognition accuracy.

1. Introduction

In an image acquisition process, an object of interest within the field of view of a camera must be well-focused to obtain its full details for visual evaluation or computerized processing. An optical camera can be focused on an object in the scene at a lens position that gives the sharpest image of the object formed on the image plane. The distance from the lens to the principal focus is called the focal length, where the lights from a point on the object converge. A focus measure finds the sharpness of an image at different lens positions. When the end goal of image acquisition is object recognition, a focused object of interest in a scene must retain the visual features that are critical in object recognition. Most existing focus measures, however, compute the degree of sharpness on the edge of an object, rather than the features of the object. Therefore a focus measure that delivers an in-focus image of an object must preserve the details for object recognition as well as for visual evaluation.

Thermal infrared (IR) spectrum comprising mid-wave IR (MWIR) in the spectral range of 3–5 μm and long-wave IR (LWIR) of 8–14 μm has been suggested as an alternative source of information for object recognition. Thermal IR imaging sensors measure the heat energy radiated, not reflected, from the object. IR energy can be viewed in any light conditions and is less subject to scattering and absorption by smoke or dust than the visible light. Face recognition using different imaging modalities, particularly IR imaging sensors, has become an area of growing interest (Kong et al., 2005; Chen et al., 2005). The use of thermal IR imagery has demonstrated performance improvements of face recognition in uncontrolled illumination conditions, including low illumination or even in darkness.

Focusing on a face object in a thermal scene is often challenging due to a significant amount of diffraction blur in thermal imaging since the refractive index decreases as the wavelength increases. In thermal IR imaging, it is challenging to visually find an in-focus object in the scene due to lack of strong edge components. In visible imaging, chromatic distortion caused by the defocusing problem can be easily dealt since the wavelength is relatively short. The defocusing problem in thermal imaging of longer wavelength can be 5–10 times more significant than in the visible imaging. Therefore, it is important to develop robust and objective criteria to evaluate whether a given thermal IR image is in-focus. It is relatively recent to study focusing in thermal IR imagery than in the visible spectrum (Pertuz et al., 2013). Various focus measures in thermal IR imaging were discussed in Faundez-Zanuy et al. (2011) along with a thermographic image database, suitable for the analysis of automatic focusing measures. Among their 10 different databases, a thermal face image database consisting of a set of human facial images was used to test autofocusing. However, there were no quantitative comparisons among the five existing focus measures. Since they manually selected in-focus (optimal) thermal face images, a proper evaluation of focus measures in terms of face recognition was not performed. Face recognition performance can be significantly influenced by the image quality (Sang et al., 2009). According to International Standard ISO/IEC 29794-5, out-of-focus,

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non-frontal posture and side lighting are regarded as primary elements responsible for poor face image quality.

This paper investigates the performances of various local gradient operators on focusing in thermal imagery for qualitative as well as quantitative analysis including face recognition accuracy. We evaluate and compare several existing focus measures with a new focus measure using the morphological gradient operator in thermal imaging. Thermal imagery often shows a narrow dynamic range in gray level intensity with small bright and dark artifacts. Therefore, we adopt the morphological gradient operator which highlights the gray-level transition and reduces small bright and dark artifacts. Morphological dilation operation locally brightens the image according to the geometry of structuring element, while the erosion can locally darken the image. The morphological gradient operator, which finds the difference between the dilated image and eroded image, highlights the gray-level transition. With a proper selection of the threshold value, the dilation and erosion process removes small bright and dark artifacts. Autofocus resolution metric (ARM) has been used to quantify the shape of the focus measure curve (Xie et al., 2006). We used the Faundez-Zanuy database to evaluate the usefulness of five popular focus measures for the purpose of determining the optimal focus position. Experiment results on face recognition in thermal IR imaging show that the focus measure with the morphological gradient operator outperforms other focus metrics including the popular focus measures investigated in Faundez-Zanuy et al. (2011) in terms of low ARM, monotonicity, and the zero offset properties.

2. Focus measures and performance metrics

2.1. Existing focus measures

A number of focus measures have been investigated in the acquisition of various types of images including microscopic images and thermal IR images. A desirable focus measure is expected to satisfy some of common requirements (Faundez-Zanuy et al., 2011; Huang and Jing, 2007):

- unimodal distribution of focusing performance with a unique maximum at the in-focus position;
- monotonicity of focusing performance outside the in-focus position;
- a steep slope with respect to the degree of blurring;
- minimal computational complexity.

In addition to such requirements, the following requirements are considered for focusing on the face in thermal images:

- consistent focusing position in enrollment and verification processes;
- a maximum focus value at the position resulting highest recognition accuracy.

Faundez-Zanuy et al. (2011) evaluated five focus measures to compare their focusing performances with thermal IR images: Energy of Image Gradient, Tenengrad, Energy of Laplacian, Sum-modified Laplacian, and the measure proposed by Crete et al. (2007). Energy of image gradient (EOG) finds the sum of squared directional gradients

$$\text{EOG} = \sum_{x=1}^{M-1}\sum_{y=1}^{N-1}\left[I_x(x,y)^2 + I_y(x,y)^2\right] \tag{1}$$

where $I_x(x,y) = I(x+1,y) - I(x,y)$ and $I_y(x,y) = I(x,y+1) - I(x,y)$.

Tenengrad computes the sum of squared Sobel gradient magnitudes that exceed a discrimination threshold T:

$$\text{Tenengrad} = \sum_{x=2}^{M-1}\sum_{y=2}^{N-1}\left[I_x(x,y)^2 + I_y(x,y)^2\right],\ \sqrt{I_x(x,y)^2 + I_y(x,y)^2} > T \tag{2}$$

where the gradient magnitude value is given by the Sobel operators such as

$$\begin{aligned} I_x(x,y) = &-I(x-1,y-1) - 2I(x-1,y) - I(x-1,y+1) \\ &+ I(x+1,y-1) + 2I(x+1,y) + I(x+1,y+1) \end{aligned} \tag{3}$$

$$\begin{aligned} I_y(x,y) = &-I(x-1,y-1) - 2I(x,y-1) - I(x+1,y-1) \\ &+ I(x-1,y+1) + 2I(x,y+1) + I(x+1,y+1) \end{aligned} \tag{4}$$

Energy of Laplacian (EOL) of an image is defined based on the second derivatives such as

$$\text{EOL} = \sum_{x=2}^{M-1}\sum_{y=2}^{N-1}\left(\nabla_x^2 I(x,y) + \nabla_y^2 I(x,y)\right)^2 \tag{5}$$

where

$$\begin{aligned} \nabla_x^2 I(x,y) + \nabla_y^2 I(x,y) = &\ I(x+1,y) + I(x-1,y) + I(x,y+1) \\ &+ I(x,y-1) - 4I(x,y) \end{aligned} \tag{6}$$

Sum-modified Laplacian (SML) was proposed from the observation that the Laplacian second derivatives in the x and y directions can have opposite signs canceling each other.

$$\text{SML} = \sum_{x=2}^{M-1}\sum_{y=2}^{N-1}\nabla_{ML}^2 I(x,y) \text{ for } \nabla_{ML}^2 I(x,y) > T \tag{7}$$

where

$$\begin{aligned} \nabla_{ML}^2 I(x,y) = &\ |2I(x,y) - I(x-1,y) - I(x+1,y)| \\ &+ |2I(x,y) - I(x,y-1) - I(x,y+1)| \end{aligned} \tag{8}$$

Crete et al. (2007) proposed a focus measure, based on the discrimination between different levels of blur perceptible in the image rather than transient characteristics in the same image. This measure calculates the degree of blurring, so the sharpness can be obtained as

$$\text{Crete} = 1 - \max(Bi_v, Bi_h) \tag{9}$$

where Bi_v and Bi_h denote vertical and horizontal blur values that range from 0 to 1.

In addition to those five focus measures mentioned above, we also tested other popular focus measures for focusing in thermal imagery: Normalized variance, Cross sum-modified Laplacian, Histogram-based Entropy, and Steerable Filters-based measure. The variance represents the variations in gray level of image pixels. The normalized variance (NVAR) measure refers to the variance divided by the average μ (Santos et al., 1997):

$$\text{NVAR} = \frac{1}{\mu MN}\sum_{x=1}^{M}\sum_{y=1}^{N}[I(x,y) - \mu]^2 \tag{10}$$

Cross sum-modified Laplacian (XSML) extends the sum of modified Laplacian with the diagonal terms (Thelen et al., 2009):

$$\text{XSML} = \sum_{x=2}^{M-1}\sum_{y=1}^{N-1}\nabla_{XSML}^2 I(x,y) \tag{11}$$