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A subpixel edge detection method based on an arctangent edge model

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ABSTRACT

The sub-pixel edge detection method is widely applied in image processing to improve accuracy of measurement and recognition. Detection methods often encounter difficulties with low computational efficiency or poor robustness. To address such difficulties, a new least-squared-error-based method is proposed in this paper. First, a one-dimensional solution is derived by means of an arctangent edge model. In the two-dimensional situation, the Sobel operator and the cubic surface fitting method are used to determine the normal direction of edge. Then, two-dimensional edge detection can be transformed into a one-dimensional problem that can be solved with a one-dimensional solution. Because there is no complicated surface fitting in this least-squared-error-based method, it will provide an opportunity to ascertain quickly the accurate location of an edge. The experiment is described at the end of the paper, comparing three edge detection methods. The results indicate that the new detection approach has robustness equal to the traditional least-squared-error-based methods, while run time is much faster and very close to the moment-based methods. The above advantages indicate this approach is very suitable for on-line accurate detection.

1. Introduction

Edge detection is a fundamental task in many image processing applications such as motion analysis [1,2], image segmentation [3], pattern recognition [4–6], vision measurement [7–12], remote sensing and medicine [13–16], etc. Many pixel-level edge detection algorithms have been proposed, e.g., Sobel, Roberts, Prewitt and Canny Operators, which are widely studied in the literature [17]. Usually, the accuracy of these algorithms is inadequate for applications where precise and fine edges are required. Therefore, traditional pixel-level detection algorithms have been developed for sub-pixel detection; these attempt to obtain the location and orientation of the edge within a pixel. Currently, edge detection algorithms at the sub-pixel level fall into three main categories: moment-based, interpolation-based and least-squared-error-based.

In the moment-based algorithms, a closed-form solution is derived using the moment integral operator to detect edge location and orientation; these require no interpolation or iteration. As previously described in detail [18], the first moment-based work was proposed by Tabatabai and Mitchell [19]. In this work, edge parameters (location, orientation, contrast and background) are solved from four gray moments by means of an ideal step edge model. Subsequently, a method proposed

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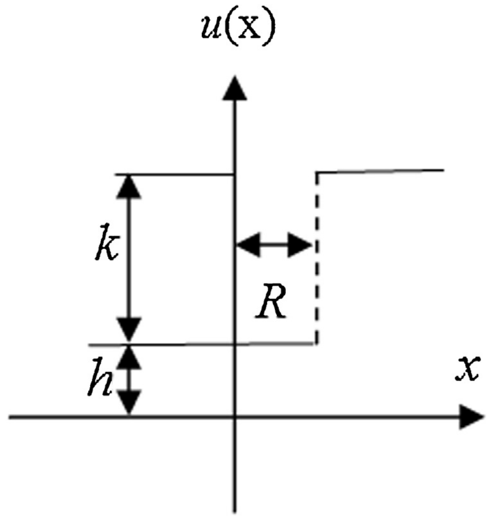

Fig. 1. Step model.

in the literature [20] instead uses spatial moments for edge detection; six masks are given to calculate geometric moments, which in turn are used to determine four parameters of the step edge. Currently, other moment-based studies are proposed such as Zernike moment [21] and Fourier–Mellin moment [22]. In the moment-based methods, the number of moment templates used in convolutions is not less than three; therefore, they may be computationally expensive when the image window is large. Additionally, the calculation of edge orientation sometimes is very sensitive to noise in the moment-based methods.

The interpolation-based algorithms attempt to achieve subpixel edge accuracy by interpolating the gray values of an image or their derivatives. A method is proposed in Ref. [23] to extract edges and lines by Steger, in which a second-order polynomial is used to interpolate the data of a gradient image. Subsequently, a work presented in Ref. [24] first uses a Canny detector and then applies Hermite interpolation to estimate the areas of the edges. Recently, some new methods are proposed in this category of edge detection algorithms, e.g., Ref. [25,26]. All these methods are computationally efficient, but the performance may be poor in noisy images.

The least-squared-error-based methods attempt to obtain the subpixel edge location by fitting the gray values of the image with an assumed edge model. Nalwa and Binford [27] proposed a least squared-error method using the hyperbolic tangent function as the edge model. In Ref. [28], a method is proposed where a local energy function is used to help determine the parameters of the edge. In the method, three types of edge (step, ramp, and roof) can be detected based on their responses to the convolution. To improve computational efficiency, a quadratic polynomial gradient is used for least squares fitting in the studies [29]. A recent work has been presented by Ye et al. [30], who proposes a high-precision detection algorithm based on a Gaussian edge model. Another recent work based on deformable models has been carried out by Bouchara and Ramdani [31]. In general, these methods are effective and reliable in noisy image processing, but are computationally expensive.

In this paper, a new subpixel edge-detection algorithm is proposed to improve robustness and computational efficiency. In the algorithm, a new blurred-edge model is given; the model is called an arctangent model. A least-squared-error solution is derived for both one- and two-dimensional situations. An evaluation of the proposed algorithm's performance is also included using a comparison with the methods proposed in Refs. [20,30]. The paper is organized as follows. A blurred arctangent edge model is given in Section 2. Sections 3 and 4 derive the solution for the one- and two-dimensional situations, respectively. Experimental studies are given in Section 5. The paper ends with conclusions.

2. Arctangent edge model

As shown in Fig. 1, an ideal edge can be modeled as a step function for the one-dimensional situation without considering the blurring effect:

$$u(x) = \begin{cases} h & x \le R \\ h+k & x > R \end{cases} \tag{1}$$

where $u(x)$ is light intensity at x, R is the subpixel location of the edge, and h and k are the intensity of background and contrast, respectively.

With understanding of the image formation process [32], the blurring effect of the camera system should be taken into account. Therefore, an assumed blurred-edge model is used in the least-squared-error-based algorithms such as the Gaussian edge model as shown in Fig. 2. This model is obtained by convolving $u(x)$ in Eq. (1) with the Gaussian kernel as the impulse