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Research paper

Edge detection in medical images with quasi high-pass filter based on local statistics

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ABSTRACT

We developed a robust, quasi high-pass filter for edge detection in medical images. The kernel-based algorithm of our detector was similar to that of conventional edge detectors. The proposed edge detector has a mathematical form of local variance and is adaptive in nature. The mathematical formulation of the detector was exploited and re-expressed as a quadratic form of the Toeplitz matrix. The detector has a highly structured internal architecture with abundant spatial isotropic symmetricity. The proposed operator can greatly reduce problems frequently encountered in edge detection including fragmentation, position dislocation, and thinness loss. The detector is robust to noise and can efficiently extract crucial edge features. We named this new operator as the WL operator (Wang and Lin). The performance of the WL operator was compared to that of other edge detectors by using Pratt's figure of merits. In addition, the performance was confirmed with experts by using visual analog scale scores. The results obtained using the WL operator for different medical imaging modalities including X-ray, CT, and MRI are promising. Therefore, the WL operator warrants further investigation.

1. Introduction

Edge detection is a challenging task often encountered in image processing. Edge detection plays a crucial role in image segmentation and other preprocessing fields [1]. The success of subsequent high-level processing highly depends on these preprocessing tasks [2]. However, edge detection is often difficult in medical images such as X-rays, CT, and MRI. Medical images are often blurred because of intrinsic physical processes required for acquiring them. The management of blurred images by using traditional edge detection operators is difficult because of the Mach effect. Human eyes can identify most subtle parts of object boundaries even in the presence of blurring. In the case of a slowly changing blurred margin, the human vision often outperforms the computer vision. However, extraction of the correct margin in a severely blurred image is challenging [3]. The separation of a scene into an object and a background is an essential step in image interpretation. This process is effortlessly performed by the human visual system. However, when computer vision algorithms are designed to mimic this action, several problems can be encountered. Because of the presence of noise in an image, location of edge maps in the absence of real edges is possible. For similar reasons, it is also possible to completely miss existing edges. The degree of success of an edge detector depends on its ability to accurately locate true edges [4]. When interpreting medical images, human eyes can discern the blurred margin of most objects by adjusting detection scales effortlessly. By contrast, the scale adjustment always requires extra attention in the machine vision [5]. Moreover, human visual systems are robust to minor illumination and positional changes. However, combating the positional and illumination variation on the machine vision is of great concern [6].

Conventional edge detectors are usually sensitive to noise because of their high-frequency amplification property [7]. However, real medical images have high readout and photon noises. Traditional edge detectors are intrinsically high-pass filters; therefore, their noise power spectrum always tends to be exaggerated in the detection process. Accurate extraction of high-frequency components of image structures such as edges without amplification of undesired noise is crucial for the design of an edge detector [8]. Directional propensity is another disadvantage of the conventional kernel-based operator. Directional invariance should be the basic requirement of a robust edge detector [9]. In practice, this always requires manual adjustment by the performers themselves. Various solutions such as combining the horizontal and vertical Sobel's operator can be applied. However, different combination weights

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remain to be justified in this circumstance. As a result, many parameters in conventional kernel methods are quite arbitrary and not parsimonious in implementation. Thus, solving this issue of artificial parameter design is necessary [10]. In this paper, we proposed a new edge detection model that is free of arbitrary parameters. The proposed model can accurately locate the edge and is robust to noise. The characteristics of our proposed detector are discussed in the following sections.

The remaining paper is organized as follows. Some of the existing methods are described in Section 2, and the proposed method is described in Section 3. Some experiments based on our method are presented in Section 4, and the paper is concluded in Section 5.

2. Edge detection operators

2.1. Previous work

Over the years, many methods have been proposed for detecting edges in images. Some of the earlier methods, such as Sobel's and Prewitt's detectors, used local gradient operators that detected only edges having specific orientations and performed poorly when the edges were blurred and noisy [11,12]. Combining such directional operators to approximate the performance of a rotationally invariant operator is possible. Various algorithms that are immune to noise, non-directional, and can detect a more accurate location of the edge have been developed. A majority of these algorithms are linear operators that are derivatives of some types of smoothing filters. Torre and Poggio [13] suggested that edge detection is a problem in numerical differentiation and demonstrated that numerical differentiation of images is an ill-posed problem. Differentiation amplifies high-frequency components, thus exaggerating noise in the image data. However, differentiation is a mildly ill-posed problem that can be transformed into a well-posed problem by using several methods. Marr and Hildreth [14] proposed convolving the signal by using a rotationally symmetric Laplacian of Gaussian (LoG) mask and by locating zero crossings of the resulting output where the amount of smoothing is controlled by the variance of the Gaussian. The Gaussian filter is thus far the most widely used smoothing filter in edge detection [15]. This method is theoretically favorable because the localization properties of the Gaussian filter in both spatial and frequency domains makes it an optimal filter for edge detection [16]. Although the Gaussian filter reduces noise, it affects genuine and essential high-frequency edge features, and reduces edge localization accuracy in low-contrast images. Other methods such as multi-scale techniques can be used to address this problem [17]. However, selection of the appropriate step between scales and combining corresponding edge contours remains a major problem [18]. The edge location accuracy of the Canny edge detector is higher than that of the LoG-based approach, and the local extreme of the Canny edge detector's output may have desirable behaviors in the scale space [19]. However, the Canny detector is complex and time consuming, and there remains parameters to be determined in order to obtain optimal results [20].

2.2. The proposed edge detector

The WL operator was defined within a 3×3 neighborhood around a single center pixel $I(x, y)$ in I, where $I(x, y)$ is the input image of the size $W \times H$. The local intensity mean μ_l and local signal energy variation ε of the 3×3 neighborhood pixels were defined using the following expressions:

$$\mu_l(x, y) = \frac{1}{N}\sum_{i=-1}^{1}\sum_{j=-1}^{1} I(x+i, y+j) \quad (1)$$

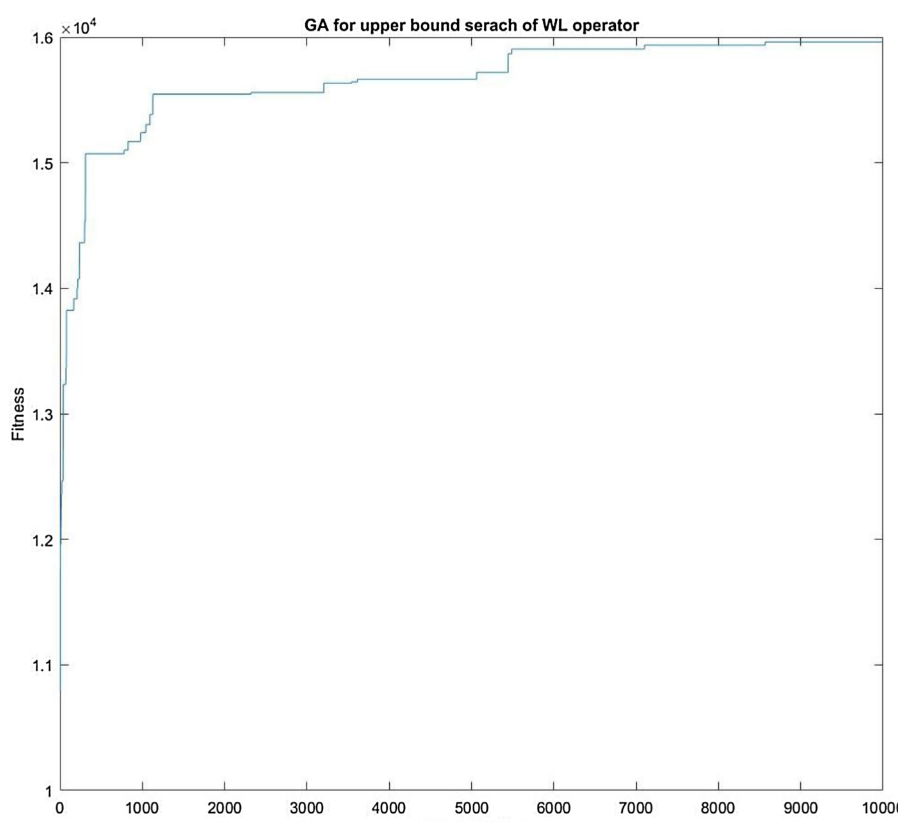

Fig. 1. Genetic algorithm evaluation for upper bound value of the WL operator.