Abstract  A new method for edge detection based on directional space is proposed. The principle is that: firstly, the directional differential space is set up in which the ridge edge pixels and valley edge pixels are abstracted with the help of the method of logical judgments along the direction of differential function, forming a directional roof edge map; secondly, step edge pixels are abstracted between the neighboring directional ridge edge and directional valley edge along the direction of differential function; finally, the ridge edge map, valley edge map and step edge map gained along different directions are combined into corresponding ridge edge map, valley edge map and step edge map. This method is different from classical algorithms in which the gray differential values of the mutual vertical direction are combined into one gradient value. The experiment of edge detection is made for the images of nature scenery, human body and accumulative raw material, whose result is compared with the one of classical algorithms and showing the robustness of the proposed method.

Keywords  Edge detection, Directional space, Roof edge, Step edge

1 Introduction

In computer vision, edge detection is a process which attempts to capture the significant properties of objects in the image. These properties include discontinuities in the photometrical and geometrical and physical characteristics of objects. Such information gives rise to variations in the grey level image. The most commonly used variations are discontinuities (step edges), local extremes (line edges) and 2-D features formed where at least two edges meet (junctions).

The purpose of edge detection is to localize these variations and to identify the physical phenomena which have produced them. Edge detection must be efficient and reliable for the validity, efficiency and possibility of the completion of subsequent processing stages to rely on it. To fulfill this requirement, edge detection should provide all significant information about the image. For this purpose, image derivatives are computed. However, differentiation of an image is an ill-posed problem that image derivatives are sensitive to various sources of noise, i.e., electronic, semantic, and discrimination/quantification effects. To regularize the differentiation, the image must be smoothed. However, there are undesirable effects associated with smoothing, i.e., loss of information and displacement of prominent structures in the image plane. Furthermore, the properties of commonly-used differentiation operators are different and therefore they generate different edges. It is difficult to design a general edge detection algorithm that performs well in many contexts and captures the requirements of subsequent processing stages. Consequently, over the history of digital image processing, a variety of edge detectors have been devised, which differ in their purpose (i.e., the photometrical and geometrical properties of edges which they are able to extract) and their mathematical and algorithmic properties.

The general method of the edge detection is that the edge intensity is calculated in a window, and then the thresholding of the edge intensity is decided in the whole intensity space, and the image is classed as the edge pixel and non-edge pixel by the edge intensity of every pixel point. Because the edge intensity is different in different regions, some edge pixels are lost, and some non-edge pixels are marked as the edge pixel after thresholding, and the continuity and reality of the result of the edge detection is not insured. On the other hand, the detected edge commonly has over-one-pixel width, and the detected edge width depends on the thresholding.

The early calculation for the edge intensity mainly
depends on differential calculation, which includes all kinds of gradient operators, e.g., Roberts, Sobel, Prewitt, Kirsch, Laplace operator, etc. All of these operators have higher sensitivity to the edge and the noise. Because they cannot strictly distinguish between the edge and the noise, their applications are limited. To restrain noise, in recent years, some mathematic methods, e.g., neural network, wavelet analysis, fuzzy set theory, surface-fitting, statistical classifier, co-occurrence matrix, etc., have been used to calculate edge intensity. However, they do not get rid of the restriction of the calculation of edge intensity in the window and the setting of thresholding, showing no outstanding improvement in the results of edge detection. Moreover, the calculation of edge intensity is becoming increasingly complicated.

This paper presents a new method of edge detection. It turns the three-dimensional gray image space into a combination of several two-dimensional directional gray image spaces, where the edge pixels are extracted and combined in the directional space to form the edge map. This method gets rid of the restriction of calculation of edge intensity and thresholding. In this way, the edge can be directly extracted by logic judgments. At the same time, roof edge and step edge can be obtained as well.

2 Basic concept of directional space

Suppose that the digital image is composed of $M \times M$ pixel matrix, the direction of the row and column pixels are indicated by $X$ and $Y$ respectively in Descartes coordinate system, the direction of each pixel’s gray level is indicated by $Z$, and the gray level of the pixel $(i, j)$ is indicated by $f(i, j)$. The set of gray level of all of the pixels in an image makes up the gray level curved surface called the gray level space. The distribution of gray level along the section of any direction of gray level space is a waved curve. The peak of the curve corresponds to the image’s ridge edge, and the valley to the valley edge.

Definition: The distribution of gray level along the section of any direction of gray level space is defined as directional gray level function $f_{dnm}(i, j)$, where the subscript $d$ indicates the direction of the directional gray level function, i.e., the included angle of the projection of the function to the axis $X$ in the Descartes coordinate. The subscript $n$ indicates the $n$th directional gray level function along $d$ direction in the gray level space. The subscript $m$ indicates the $m$th pixel of the $n$th directional gray level difference function along $d$ direction in the gray level space. The set of directional gray level function along $d$ direction makes up of the $d$ directional gray level space.

Hypothesis 1 The gray level space of the digital image can be denoted by the gray level space of any one (and only one) direction. When considering the position relation between pixels in gray level space, the direction of the directional gray level function can be realized more easily if they are taken as $0°$, $45°$, $90°$, and $135°$.

Therefore, the gray level space of the digital image can be expressed by the directional gray level function as follows:

$$F_d = \sum_{m=0}^{M-1} \sum_{n=0}^{M-1} f_{dnm}(i, j)$$

where, $m = 0, 1, \cdots, M-1$, $n = 0, 1, \cdots, M-1$, $d = 0°, 45°, 90°, 135°$.

It is worth noticing that, there is a one-one corresponding relation between the above sequential number $m$ and pixel position $(i, j)$ in the gray level space only at the two directional gray level function along direction $0°$ and $90°$. For example, for the directional gray level function along direction $0°$, the sequential number $m$ is equal to the pixel space position $j$. But for the directional gray level functions along direction $45°$ and $135°$, there is no one-one corresponding relation between sequential number and pixel space position. Therefore, in this paper, subscript $m$ is used to express the sequential number, and point $(i, j)$ is only used to indicate corresponding pixel.

Hypothesis 2 A differential level space of the digital image is formed by adding several directional differential level spaces.

Suppose $f'_{dnm}(i, j)$ expresses difference extreme value of the $m$th pixel in $n$th directional difference function along direction $d$, and the difference extreme of the pixel $(i, j)$ along direction $d$ is given by:

$$f'_{dnm}(i, j) = f_{dnm}(i, j) - f_{dnm(n-1)}(i, j)$$

The directional difference level space of direction $d$ is expressed as:

$$F'_d = \sum_{m=0}^{M-1} \sum_{n=0}^{M-1} f'_{dnm}(i, j)$$

Then the differential level space of the digital image can be expressed as:

$$F' = \sum_d F'_d , \quad d = 0°, 45°, 90°, 135°$$

Equation (4) only describes that the differential level space consists of four directional difference level spaces, giving no information about the relationship among difference extreme value of each point, which should be mentioned.

Hypothesis 3 At some point between the arbitrary adjacent directional valley edge point and directional ridge edge point of the directional gray level function, there is one and only one directional step edge point, which is supposed to be located at the point corresponding to direction difference extreme value between above two edges.

Hypothesis 4 The directional edges detected in directional space (including roof edge and step edge) may be added up to form a real edge corresponding to the original image.

3 Edge detection of directional space

In the difference level space along direction $d$, the following hypothesis is proposed: