IAPR Workshop on CV - Special Hardware and Industrial Applications OCT.12-14, 1988, Tokyo

SURFACE IMAGE PROCESSING OPERATOR

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ABSTRACT

Presented is an operator that explicits surface relief by processing four images of the surface. It uses difference of images, captured under different illumination conditions. It is based on photometric stereo and local shading analysis. This operator eliminates image noise related with changes of surface albedo and explicits specific surface relief areas such as peaks and ridges or pits and valleys. We have theoretically proved, that for the surfaces with Lambertian reflectance, image obtained after processing only slightly differs from Laplacian of the function describing surface relief. Also presented are experimental results of operator testing.

INTRODUCTION

The segmentation of surfaces to planar, cylindrical, concave and convex fragments is frequently encountered in computer vision. The testing of the surface quality of series-produced objects, for example, may include location and explication of surface flaws such as steps, ravines, cracks, etc. Explication of such specific surface relief areas is often difficult for their obscurity. Additional obstacles (changes of surface albedo and matte reflection) make the use of traditional methods hardly effective. Therefore, special processing is necessary for their elimination in surface images and explication of least distinct surface relief.

A number of transformations are used to enhance slight changes in image brightness. One of them is the Laplacian operator and its several varieties widely used for detection of lines and contours (1). Its direct use in surface relief change intensification is, however, impossible as available are only images of surface, not the function describing the surface relief. It is, therefore, necessary to develop operators capable of obtaining Laplacian functions of surface relief description after surface image processing has been performed.

SURFACE IMAGE PROCESSING OPERATOR

These conditions considered, a new operator has been developed and tested. It is based on photometric stereo and local shading analysis (2,3,4). Four images obtained by sequential surface illumination with four lamps are used as input images. Illuminant directions

$$L_x=(l_x,\ 0,\ l_z),\ L_{-x}=(l_{-x},\ 0,\ l_z),$$
$$L_y=(0,\ l_y,\ l_z),\ L_{-y}=(0,\ l_{-y},\ l_z),$$
$$(l_x=l_{-x}=l_y=l_{-y}=l)$$

are symmetrical to the plane surface normal and the projections coincide with axes x, -x, y, -y (as it is shown in Fig.1a). The operator is defined by the formula

$$I_*(x,y)=I_v(x,y)+I_h(x,y)=$$
$$=\left(\frac{\partial I_x(x,y)}{\partial x}-\frac{\partial I_{-x}(x,y)}{\partial x}\right)+\left(\frac{\partial I_y(x,y)}{\partial y}-\frac{\partial I_{-y}(x,y)}{\partial y}\right),$$

where $I_x(x,y)$, $I_{-x}(x,y)$, $I_y(x,y)$, $I_{-y}(x,y)$ are input images obtained by sequential illumination of surface $z(x,y)$ with four illuminators(L_x, L_{-x}, L_y and L_{-y}), $I_*(x,y)$ represents the image with enhanced surface relief, $I_v(x,y)$ and $I_h(x,y)$ are the images with enhanced "vertical" and "horizontal" relief. By processing only two of input images it is possible to enhance surface relief along y or x axis ("vertical" or "horizontal").

Using a simple model of image formation widely used in shape-from-shading (2) it is possible to show that with doubly differentiable smooth surface function $z(x,y)$ the operator approximates the Laplacian operator:

$$I_*(x,y)=2\varrho l\,\frac{\frac{\partial^2 z}{\partial x^2}\left(1+\left(\frac{\partial z}{\partial y}\right)^2\right)+\frac{\partial^2 z}{\partial y^2}\left(1+\left(\frac{\partial z}{\partial x}\right)^2\right)-}{\left(1+\left(\frac{\partial z}{\partial x}\right)^2+\left(\frac{\partial z}{\partial y}\right)^2\right)^{3/2}}$$

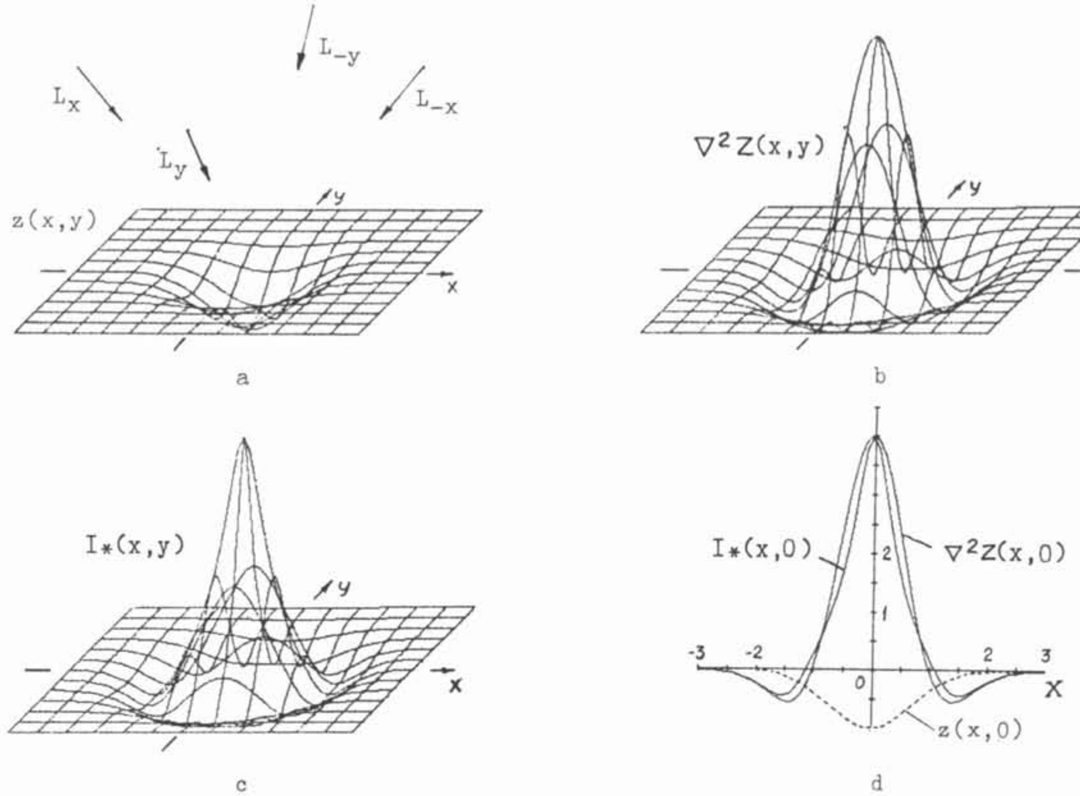


Fig.1

$$\frac{-2\frac{\partial z}{\partial x}\cdot\frac{\partial z}{\partial y}\cdot\frac{\partial^2 z}{\partial x\partial y}}{\qquad},$$

where ρ represents surface albedo and l is the coefficient dependent on direction of illumination. Accuracy of approximation depends on the $\partial z/\partial x$ and $\partial z/\partial y$ values. At the extreme points of the function $z(x,y)$,

$$\partial z/\partial x=0,\ \partial z/\partial y=0,$$

so $I_*(x,y)$ fully corresponds to the Laplacian

$$I_*(x,y)=2\rho l(\partial^2 z/\partial x^2+\partial^2 z/\partial y^2)=2\rho l\nabla^2 z(x,y)$$

Figure 1 illustrates a case of theoretical modelling of the operator and its comparison to the Laplacian operator, where 1a is the surface described by function

$$z(x,y)=-\exp(-x^2-y^2);$$

1b is the Laplacian of function $z(x,y)$; 1c, image $I_*(x,y)$; 1d, section of functions $I_*(x,y)$ and $\nabla^2 z(x,y)$ when y=0. This shows that $I_*(x,y)$ is a considerably accurate approximation of $\nabla^2 z(x,y)$.

Figure 2 illustrates an explication of "vertical" and "horizontal" surface relief. Fig.2a is the surface with round valley described by function

$$z(x,y)=-k\cdot\exp(-(x^2+y^2-4)^2),$$

where k=0.0625; 2b, image $I_v(x,y)$; 2c, image $I_h(x,y)$; 2d, image $I_*(x,y)$.

Discrete approximation of the operator is defined by the formula

$$I_*(x,y)=I_v(x,y)+I_h(x,y)=$$
$$=((I_x(x+d,y)-I_x(x-d,y))-(I_{-x}(x+d,y)-I_{-x}(x-d,y)))+$$
$$+((I_y(x,y+d)-I_y(x,y-d))-(I_{-y}(x,y+d)-I_{-y}(x,y-d))).$$

It has been theoretically proved that this operator is comparable with the Laplacian only in cases of surfaces with the Lambertian reflectance function, absence of shadows on image formation and constant surface albedo on convexities and concavities. Experimental testing showed this preprocessing algorithm efficient even when these limitations are ignored.

EXPERIMENTAL RESULTS

A universal image processing system "PERICOLOR-2000E" was used for experimental

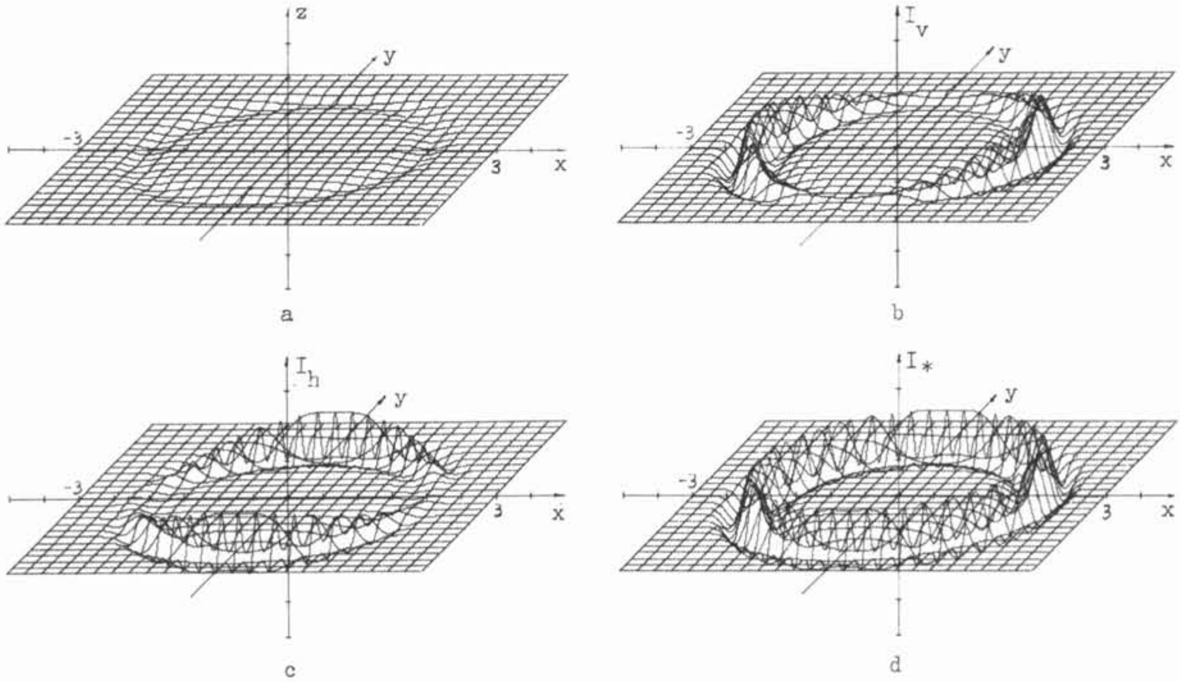


Fig.2

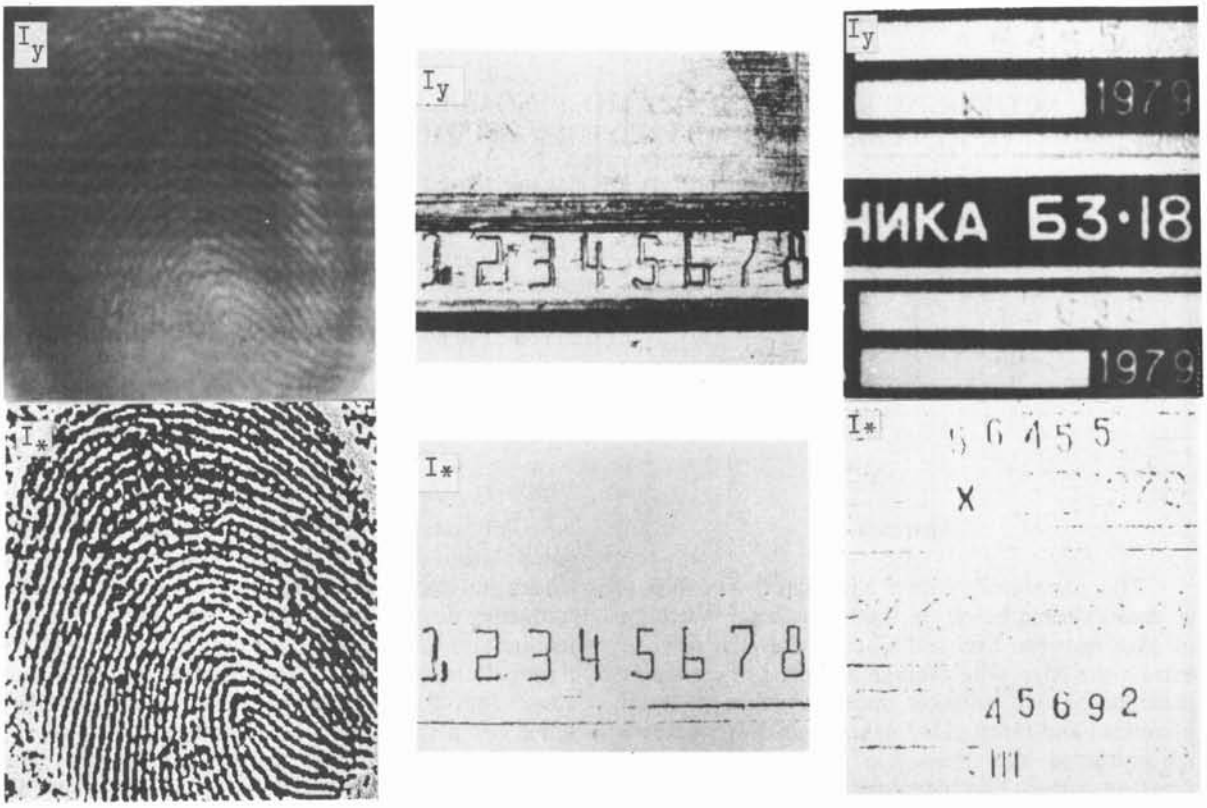
testing of the operator. A high quality TV camera was used as input device. Images were processed as 512*512 arrays with 256 shades of gray. Before processing images were smoothed. For experiments were used several surfaces with nearly specular and Lambertian reflectance: metallic badge with an old Lithuanian castle (Fig.3), fingerprint on a plasticine (Fig.4a), an aluminium plate with engraved numerals (Fig.4b), calculator label with stamped serial number and month of production (Fig.4c). There are shown one of the four input images of the above mentioned surfaces. All these input images are very noisy due to surface albedo changes, specular reflections and shadows. Also there are shown processed (output) images after binarization with explicit convex (concave) surface areas. It is possible to explicit concave surface areas by setting another level of binarization. Fig.3b illustrates possibility to explicit separatly "vertical" (lower left) and "horizontal" (upper right) surface convexities.

CONCLUSIONS

Proposed surface relief explication shows promising results. It allows to eliminate noises due to surface albedo changes, specular reflections and shadows. Image obtained after processing only slightly differs from Laplacian of the function describing surface relief. The operator detects convex and concave surface areas and can be used in computer vision.

a b c

Fig.3



a b c

Fig.4

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