Walsh Operators of Edge Detection for Gray-Scale Images

Machnev A.G., Selikhanovich A.M.
Institute of Engineering Cybernetics, National Academy of Sciences of Belarus
System Identification Laboratory
Surganova str. 6, 220012, Minsk, Belarus
sel@newman.basnet.minsk.by

Abstract

Walsh operators are proposed that may be used in image processing for edge detection. These operators based on discrete two-dimensional Walsh functions of appropriate dimensionality. The algorithms of a calculation of operators and the algorithm of edge detection are represented.

1: Introduction

Edge detection is an important process in low level image processing. The result of edge detection is initial data for further image processing. During this process pixels that belong to object borders are marked. There are numerous methods; to mention only a few: Prewitt, Kirsh and Sobel gradients, Haralick method, Laplacian of Gaussian, etc. [1-3]. It is difficult to estimate an effectiveness of the methods because of difficulties in determination of the best parameters, bound with each method, and also for lack of a uniform effectiveness criterion. [1, 4]. Therefore the different operators can be effective for various types of images. Below, the Walsh operators are submitted for edge detection on gray-scale images. The effectiveness of these operators is determined by presence of the fast algorithms for their computation. At the same time the edges are determined with the same quality that is obtained using known operators.

2: Walsh operators and their computation algorithms

The two-dimensional Walsh functions can applied for edge detection directly. The four such functions are illustrated in Fig.1 [5]. Thus, the values of coefficients C_{01}, C_{10}, C_{11} corresponding two-dimensional Walsh functions $wal(0,1,x,y)$, $wal(1,0,x,y)$, $wal(1,1,x,y)$ are calculated when direct transform is executed, and the coefficient C_{00} is assumed by zero. When the inverse transform is executed, only the value of coefficient C_{00} is calculated. The coefficients C_{01}, C_{10}, C_{11} can take either on modulo or their true values for computation the value of coefficient C_{00}.

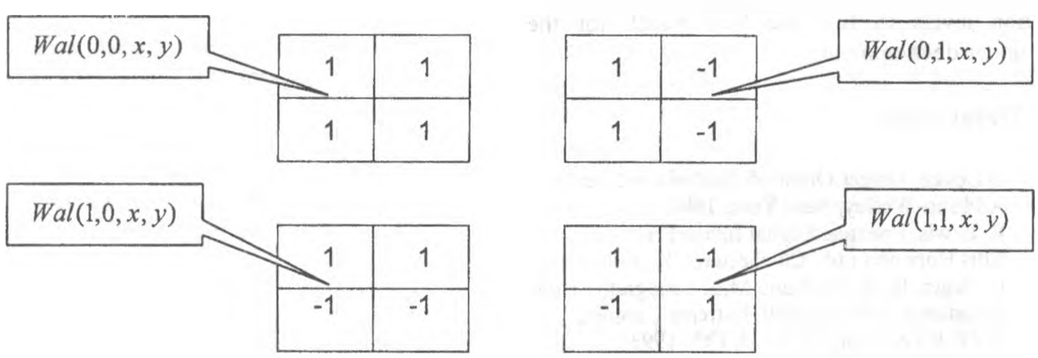

Fig. 1. Two-dimensional discrete Walsh functions.

The differences will consist in a distribution range of intensities of the image obtained after transformation. If the true values are used then the calculated coefficient C_{00} must taken on modulo. At usage of such algorithm the all image area is scanned by 2×2 window with a step equal 1. The value of coefficient C_{00} is assumed to the pixel that corresponds to this coefficient in operator window. A gray-scale image is obtained after applying this algorithm. Edge points are selected by thresholding the magnitude of the coefficient C_{00}.

Two matrix operators by dimensionality 3×3 pixels are usually used for edge detection [1,2]. The Walsh operators of such dimensionality can be obtained from two-dimensional discrete Walsh functions. To this end the line and column with the zero elements are inserted in two-dimensional discrete Walsh functions. The obtained operators are represented in Fig.2.

I

1	0	1
0	0	0
1	0	1

II

1	0	-1
0	0	0
1	0	-1

III

1	0	1
0	0	0
-1	0	-1

IV

1	0	-1
0	0	0
-1	0	1

Fig. 2. The Walsh operators.

The Walsh operators are used as well as the known operators. For example, the Sobel operator is applied as follows. The Sobel operator $S(m,n)$ [1,2] involves a nonlinear computation of pixel values over 3×3 window for transformation of the pixel at point (m,n) (see Fig.3). It is defined as either

$$S(m,n) = \sqrt{d^2_{x(m,n)} + d^2_{y(m,n)}} \tag{1}$$

or for computational efficiency,

$$S(m,n) = \left|d_{x(m,n)}\right| + \left|d_{y(m,n)}\right|, \tag{1a}$$

where

$$\begin{aligned} d_{y(m,n)} = {} & (f_{m+1,n-1} + 2f_{m+1,n} + f_{m+1,n+1}) \\ & - (f_{m-1,n-1} + 2f_{m-1,n} + f_{m-1,n+1}), \end{aligned} \tag{2}$$

$$\begin{aligned} d_{x(m,n)} = {} & (f_{m-1,n+1} + 2f_{m,n+1} + f_{m+1,n+1}) \\ & - (f_{m-1,n-1} + 2f_{m,n-1} + f_{m+1,n-1}). \end{aligned} \tag{3}$$

The operator is shifted exhaustively over the image area.

Two various combinations of operators represented in Fig. 2 can be used for edge detection with application of Walsh operators. The edges are determined with the best quality when the operators II and III are applied.

The value of the pixel at point (m,n) with application of operators II and III is calculated as follows:

$$W(m,n) = \sqrt{X^2 + Y^2}, \tag{4}$$

or for computational efficiency,

$$W(m,n) = |X| + |Y|, \tag{5}$$

where

$$X = (f_{m-1,n-1} + f_{m+1,n-1}) - (f_{m-1,n+1} + f_{m+1,n+1}),$$
$$Y = (f_{m-1,n-1} + f_{m-1,n+1}) - (f_{m+1,n+1} + f_{m+1,n-1}). \tag{6}$$

The fast computation algorithm can be used for a determination of values X и Y corresponding to Walsh operators II and III accordingly. This algorithm is represented in Fig.4 [6] for basis of two-dimensional Walsh functions (see Fig.1) and matrix $Z = \begin{bmatrix} z_1 & z_2 \\ z_3 & z_4 \end{bmatrix}$.

This algorithm determines the four coefficients of two-dimensional Walsh transform of matrix Z. The represented fast algorithm can be used for the operator window with dimension 3×3 pixels (see Fig.3). To this end the input data must be organized by appropriate way. The computation algorithm of Walsh operators II and III is shown in Fig. 5. At usage of these operators the all image area is scanned by 3×3 window with a step equal 1. A gray-scale image is obtained after applying operator. Edge points are selected by thresholding the magnitude of the $W(m,n)$. Fig. 6 shows the edge images obtained by applying Walsh and Sobel operators. The selection of the threshold level is very important to the final results. The discussion of the threshold selection may be found elsewhere [7]. Here, the threshold level has been selected in a heuristic way.

$f_{m-1,n-1}$	$f_{m-1,n}$	$f_{m-1,n+1}$
$f_{m,n-1}$	$f_{m,n}$	$f_{m,n+1}$
$f_{m+1,n-1}$	$f_{m+1,n}$	$f_{m+1,n+1}$

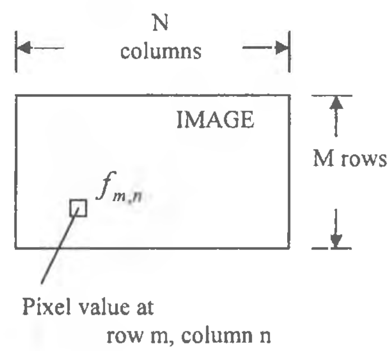

Fig. 3. Notation for an operator of edge detection.

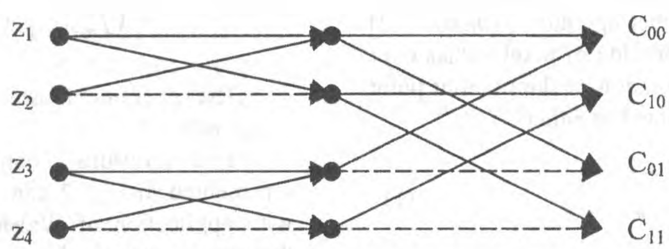

Fig. 4. Fast computation algorithm in basis of two-dimensional Walsh functions.

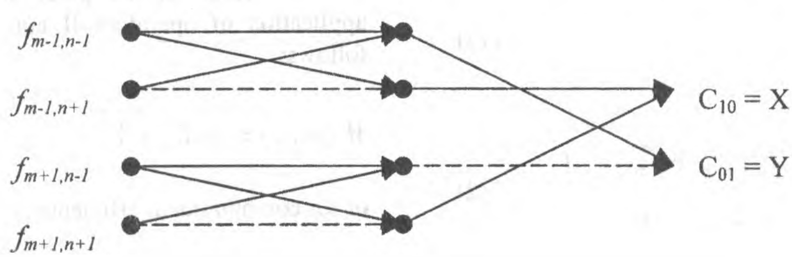

Fig. 5. Fast computation algorithm of Walsh operators.

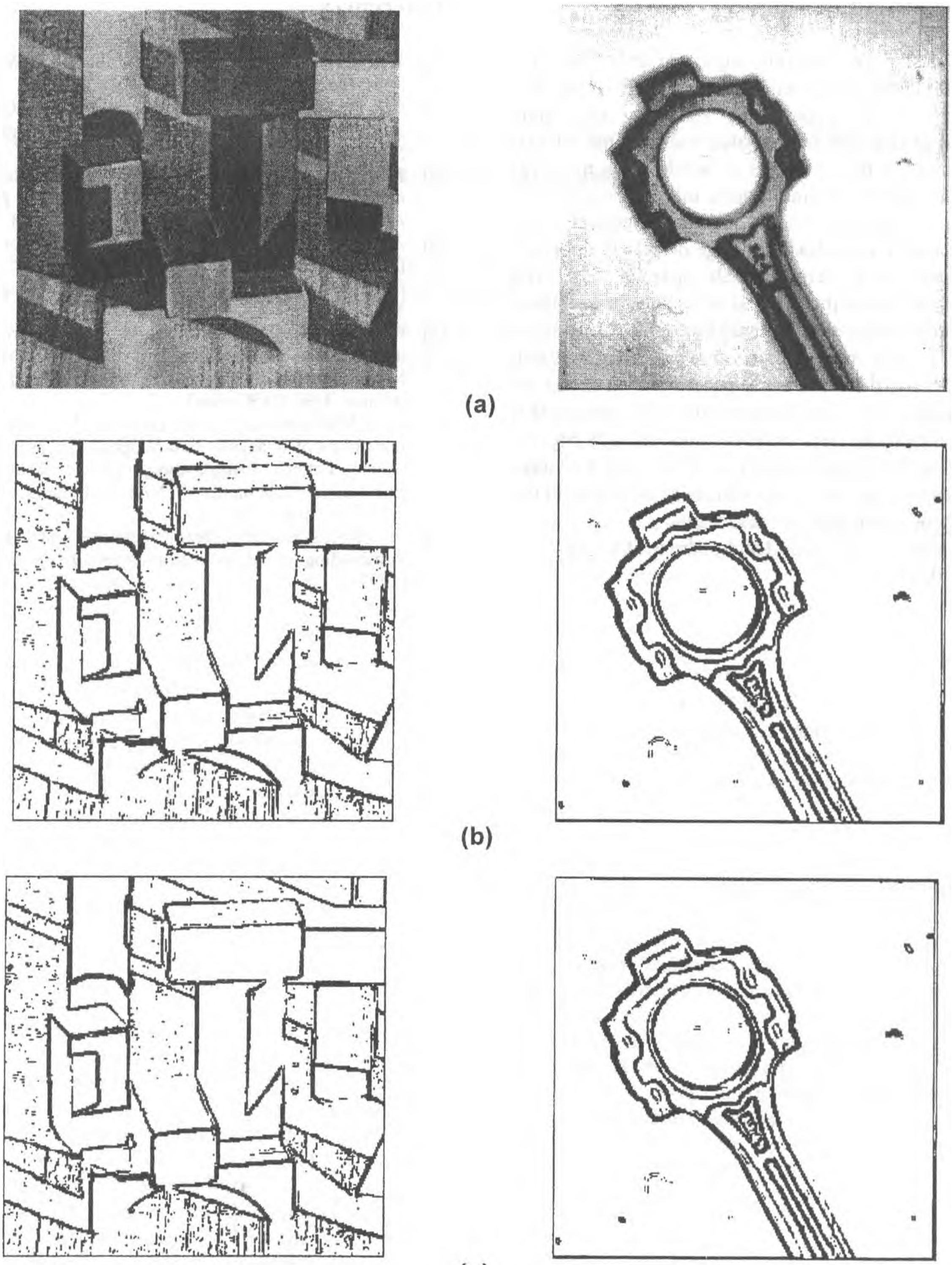

Fig. 6. Edge images obtained by different operators: (a) original gray-scale images, (b) Sobel operator, (c) Walsh operator.

3: Conclusion

A fast edge detection algorithm based on two-dimensional Walsh function has been developed and reported in this paper. The following two main features distinguish it from known algorithms. Firstly, processing an image by 2×2 window the proposed algorithm allows obtaining more thin contour lines of objects as against Sobel operator. Secondly, the computational complexity of edge detection algorithm is reduced with using Walsh operator. The fast computation algorithm is used advisable for execution direct and inverse Walsh transform. Only six addition operations are required in case of usage Walsh operators. At the same time, processing an image by 3*3 window our operator gives the edge images that identical to those ones by Sobel operator (see Fig. 6). Note, that the algorithm may be effectively hardware implemented and can be used for edge detection in the image processing systems of real time.

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