USING HOUGH TRANSFORM IN LINE EXTRACTION

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ABSTRACT

In close-range images, normally a large number of geometrical features is available. For photogrammetrists, the detection of shapes such as straight lines is very useful. These features are very helpful for further photogrammetric work, such as sensor calibration, image orientation, DTM generation etc. Hough Transform (HT), is such a powerful tool for detecting predefined shapes (i.e. lines, ellipses). HT has been used for more than three decades in the areas of image processing, pattern recognition and computer vision. However, in digital close range photogrammetry HT has only rarely been used. This paper is a contribution on how HT can be used as a powerful technique for line extraction in close range photogrammetric problems.

1. INTRODUCTION

In architectural photogrammetry where a large number of structures is available in the images, tools for detecting pre-assigned shapes such as straight lines are very useful. These features are very useful for further photogrammetric work, such as sensor calibration, image orientation, DTM generation etc. Hough Transform (HT), is such a tool for detecting predefined features (i.e. lines, ellipses) in images and has been used for more than three decades in the areas of image processing, pattern recognition and computer vision. However, in digital close range photogrammetry HT has only rarely been used.

In this paper HT focuses in problems of architectural photogrammetry. More specifically, HT is used for line extraction from close range images. An algorithm has been created and software in Microsoft Visual Basic has been developed.

It must be clear from the beginning that there are two ways in line extraction using the HT. It depends on the kind of work that the user wants to use the extracted lines. If the majority of lines is the subject of research then the whole image must be examined. This is a slow process and rather suffers from the disadvantage that both useful and useless data are simultaneously extracted from the image. On the other hand, if only specific lines are the subject of research then the algorithm is executed in a specific part of the image which is defined by the user. Surely in this case the process is much quicker.

The authors' approach aims to the second one, which means that HT is used as a tool to extract not all the lines from the image but only those that are useful for further process. The aim of this extraction process is the further use of lines such as in vanishing point computation, single photo resection and sensor calibration. Statistical tests are shown in real test images supporting the approach.

2. WHAT IS HOUGH TRANSFORM - HOW DOES IT WORKS

HT was first proposed and patented by Paul Hough in 1962 (Hough, 1962) as a technique for detecting curves in images. The classical HT is a technique for curve detection that can be described as a parametric curve (Ballard and Brown, 1982). Previously, HT has been expanded to detect arbitrary shapes (Ballard, 1981).

Using an edge detector to locate points that may consist an edge, the method examines whether the points are components of a specific type of parametric curve. For instance, such a curve may be a straight line or an ellipse.

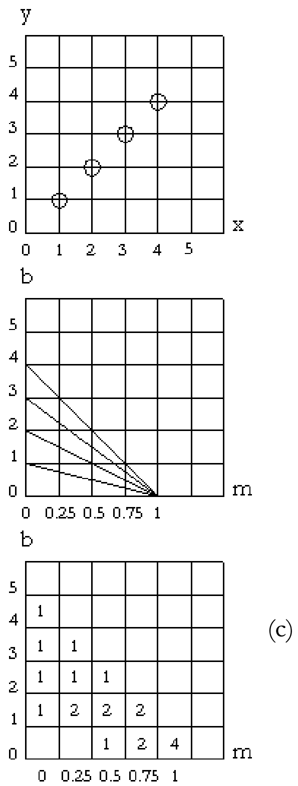

Figure 1. Image points (a), parameter lines (b), accumulator cells (c)

Each edge point is transformed from image space to parameter space by increasing the elements of an array called accumulator, using the line parameters as array indices. The cells of the array which have the largest values indicate the possible locations of lines in the image (Figure 1c). Initially accumulator is set to zero.

At first HT was used to detect straight lines presented by the slope-intercept form (Equation 1).

$$y = m x + b \tag{1}$$

For every edge point in the image plane (*xy* plane), the accumulator (*bm* plane, Figure 1c) is increased using values for the slope and y-intercept that satisfies the Equation 1 as indices:

$$A(m,b) = A(m,b) + 1 \tag{2}$$

Each edge point has an associated parameter line in the accumulator (Figure 1b). The existence and the position of collinear points are been indicated from the intersection of parameter lines. The higher the number of collinear points the greater the possibility that a line is been detected in the image.

HT complexity depends on the number of increments required for the slope. For instance, having *k* increments of *m*, there are *km* number of computations.

In 1972, Duda and Hart (Duda and Hart, 1972) proposed that the parameters for line would be better described by the length ρ and orientation θ (Equation 3) of a normal vector to the line from the origin of the image (Figure 2).

$$\rho = x \cos\theta + y \sin\theta \tag{3}$$

In the same way, following the steps of original HT, for every edge point in the image plane (*xy* plane), the accumulator ($\rho\theta$ plane) (initially set to zero) is increased using values for the angle θ and radius ρ that satisfy Equation 3 as indices:

$$A(\rho,\theta) = A(\rho,\theta) + 1 \tag{4}$$

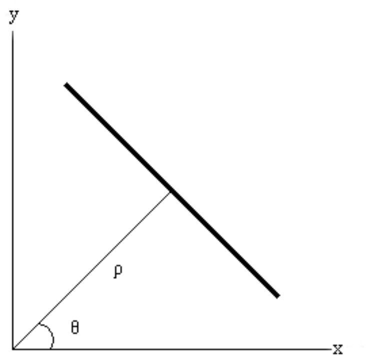

Figure 2. Normal representation of line

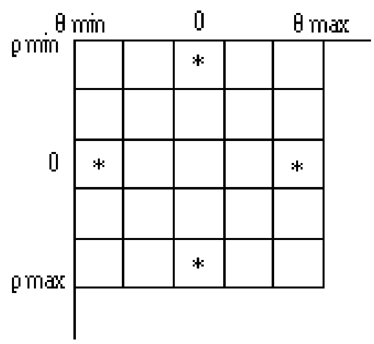

Figure 3. Parameter space ρθ

The accumulator cells with the greatest number of votes correspond to lines in image space. This way, the normal parameterization gives sinusoidal curves in the accumulator. The intersection of curves denote the possible locations of lines in the image and the number found at the intersection shows the number of collinear points in the line. The range of ρ is $-\sqrt{2}\ \mathrm{D}$ to $+\sqrt{2}\ \mathrm{D}$, where *D* is the diagonal size of the area searched in the image space. Additionally, the range of θ is between 0 and 200 grads.

3. GRADIENT IN HOUGH TRANSFORM

The aim is the detection of straight lines in close range images. In order to make the recognition of a line easier the most common way is the reduction of information which is included in the original image. To this end an edge operator is used, like the gradient operator, and thus a gradient image is generated by this process.

An image can be described as a function *f(x,y)*, where *x,y* are the space indicators and *f* the gray value for the specific image pixel. The gradient of *f* at position *(x,y)* is the vector given by

$$\bar{G}[f(x,y)] = \begin{bmatrix} \dfrac{\partial f}{\partial x} \\ \dfrac{\partial f}{\partial y} \end{bmatrix} = \begin{bmatrix} G_x \\ G_y \end{bmatrix} \qquad (5)$$

The magnitude of the gradient at position *(x,y)* is given by

$$G[f(x,y)] = \sqrt{G_x^2 + G_y^2} \qquad (6)$$

When using a 3x3 filter-mask such as

$$\begin{bmatrix} a_1 & a_2 & a_3 \\ a_4 & a_5 & a_6 \\ a_7 & a_8 & a_9 \end{bmatrix} \qquad (7)$$

the components G_x and G_y for the center pixel of the mask (7) are given by (Sobel filter)

$$\begin{aligned} G_x &= (a_7 + 2a_8 + a_9) - (a_1 + 2a_2 + a_3) \\ G_y &= (a_3 + 2a_6 + a_9) - (a_1 + 2a_4 + a_7) \end{aligned} \qquad (8)$$

Using formula (9)

$$G[f(x,y)] > T \qquad (9)$$

edge points are defined as these pixels that the magnitude of their gradient exceeds an initially defined threshold value T.

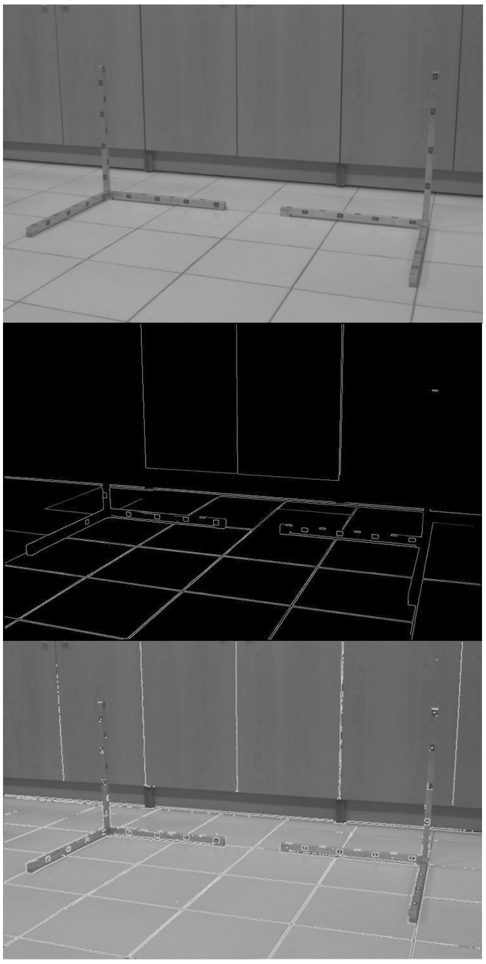

Figure 4. Original image (a), Canny edge detector (b) image, SUSAN image (c)

3.1 «Edge enhanced» images

The edge detection process is greatly eased if, instead the original images, «edge enhanced» ones are used. This inevitably leads to the use of some edge detector, like the ones presented next.

3.1.1 Canny edge detector. This is the work by John Canny for his Masters degree at MIT in 1983. He treated edge detection as signal processing problem and aimed to design the «optimal» edge detector. He formally specified an objective function to be optimized and used this to design the operator. The objective function was designed to achieve the following optimization constrains (Canny, 1986):

1. Maximize the signal to noise ratio in order to provide good detection.
2. Achieve good localization to accurately mark edges.
3. Minimize the number of responses to a single edge (non-edges are not marked).

3.1.2 SUSAN edge detector. SUSAN is an acronym for Smallest Univalue Segment Assimilating Nucleus. The SUSAN algorithms cover image noise filtering, edge finding and corner finding. The edge detection algorithm developed by Stephen M. Smith follows the usual method of taking an image and using a predetermined window (circular mask in this case – usual radius is 3.4 pixels giving a mask of 37 pixels) centered on each pixel in the image and applying a locally acting set of rules to give an edge response. This response is then processed to give as an output a set of edges. (http://www.fmrib.ox.ac.uk/~steve/susan/index.html)

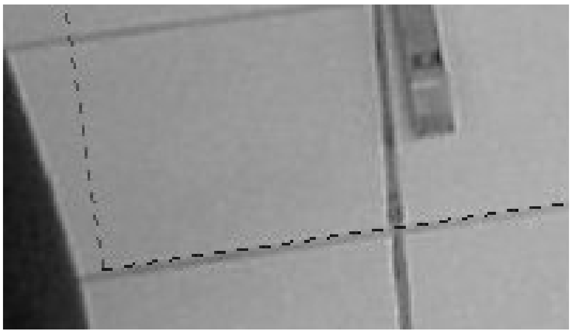

Figure 5. Final line is shown overlaid upon the «image» line

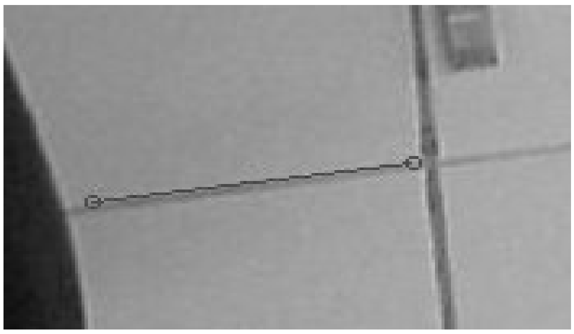

Figure 6. Final line alignment after best fitting process

4. IMPLEMENTATION - EXPERIMENTAL RESULTS

The HT experiment implemented through a software developed in Microsoft Visual Basic environment. The user has to select a search area for the algorithm to search, find and locate the possible line. The software responses, showing the line location (Figure 5). The extracted line is shown overlaid upon the «image» line so as the user can judge the effectiveness of the procedure. Additionally, all interesting pixels, that have a distance not greater than 1 pixel from the extracted line, are recorded.

Following a best fitting procedure for all the recorded interesting pixels, the best fitted line is calculated as well as its statistics (Figure 6). In this process line form of Equation 1 was used.

Figure 7. DCS 420

The experiment took place in an indoor image (Figure 8) acquired with Kodak DCS 420 still video camera with a super wide angle lens 17 mm (Figure 7). Four horizontal and four vertical lines have been extracted from the image and their statistics are shown in Table 1.

The results that presented in Table 1, are derived from the application of HT technique in the indoor image. Formerly, the original image was pre-processed with the SUSAN edge detector (Figure 4c).

A global reliability test took place, using the statistical test of variance weight unit. An one-sided F-test is defined as:

$$H_o : \sigma^2 = \sigma_o^2 \ / \ H_a : \sigma^2 < \sigma_o^2 \qquad (11)$$

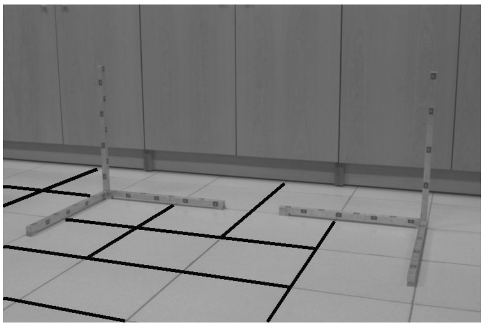
Figure 8. Extracted lines from the experimental test

In this case, the zero hypothesis H_o is being accepted if

$$\frac{\hat{\sigma}_o^2}{\sigma_o^2} \geq F_{f,\infty}^{1-\alpha} \qquad (12)$$

where f are the degrees of freedom and α is the significance level. In the experiment where σ_o was set equal to one pixel and $\hat{\sigma}_o$ calculated below unit (0.4 – 1.0) (Table 1), it is clear that the alternative hypothesis H_a is being accepted. These leads to the conclusion that measurements in the image were taken with an accuracy lower than one pixel.

Hough Transform Results in SUSAN Edge Image				
Line No.	No. of Points	$\hat{\sigma}_o$	$\hat{\sigma}_a$ (grad)	$\hat{\sigma}_b$ (pixels)
1 (H)	1107	**0.94**	0.02	0.05
2 (H)	1077	**0.99**	0.04	0.09
3 (H)	528	**0.89**	0.09	0.08
4 (H)	362	**0.74**	0.13	0.08
5 (V)	312	**0.90**	0.17	0.27
6 (V)	253	**0.89**	0.24	0.76
7 (V)	331	**0.75**	0.17	0.63
8 (V)	252	**0.37**	0.07	0.04

Table 1. Line statistics

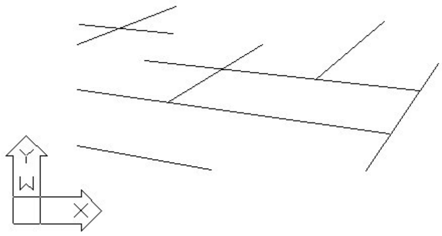

Figure 9. Extracted lines were plotted in Autocad environment using ActiveX technology

4.1 Model creation -ActiveX technology

During best fitting process, among the other parameters, line's endpoints coordinates are calculated and recorded as well. A very useful technique for data utilization has been developed using ActiveX technology in a CAD environment. AutoCad is such a CAD package that provides the ability to use this technology. Extracted lines from HT process were plotted in AutoCad environment (Figure 9). Through the software developed it is possible to use all possible AutoCad abilities.

5. CONCLUSIONS

HT is a technique for detecting arbitrary shapes and predefined shapes, such as lines, as well. Even if it is not widely used in close range applications, HT remains a powerful tool and must be used in line extraction. In this paper HT was examined from the point of view of line extraction.

Experimental results proved that using an edge image, quickly and accurately lines can be detected and located in close range images. More specifically, the value of a-posteriori variance of weight unit reached 0.4 pixel and lower than 1 pixel.

Finally, a new software module was created turning to advantage of ActiveX technology in a CAD environment. Using this technology in AutoCad environment, extracted lines where plotted, having as a result the image model creation. All AutoCad utilities and commands can now be accessed and used from the developed module.

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