AUTOMATIC HYSTERESIS OF CANNY EDGE DETECTOR FOR LINES DETECTION

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Abstract: The Canny edge detector is a very popular multi-stage algorithm for image edge detection and its output is frequently used as an input for the Hough transform algorithm for identification of lines. Its crucial step is the edge tracking by hysteresis, which selects the final edges by using two thresholds. The assessment of those two values in an unsupervised way is a difficult task, that is usually solved by application of statistical functions to the values of intensity of the input image converted to grayscale. This paper's objective is to experimentally prove, that it is more convenient not to use the input image, but instead the gradient image, which is the output of the Sobel gradient operator. The paper also revealed that with using the 2:1 ratio between the upper and lower threshold and the upper threshold to be set around 55 % of the maximum value of gradient image, the line detection reaches much better results.

Keywords: Canny, Hough, Hysteresis.

1 Introduction

The Canny edge detector is a very popular multi-stage algorithm for image edge detection, which has uses in many applications of computer vision, mainly in image data preprocessing. Its popularity is also indicated by the fact that, unless we don't count the simple gradient operators, it is the only implemented edge detector in the currently most used computer vision and image processing library – OpenCV.

The Canny edge detector algorithm consists of four steps: removing the noise with Gaussian filter, finding the intensity gradient with the Sobel gradient operator, non-maximum suppression and edge tracking by hysteresis (Canny, 1986). The last step, the edge tracking by hysteresis, is crucial, since selects the final edges by using two thresholds. The assessment of those two values in an unsupervised way is a difficult task that is yet to be solved in a satisfactory manner. Therefore, these values are usually set manually based on experiments (Medina-Carnicer et al., 2010).

The hysteresis divides all pixels of an image into three groups according to the three intervals set by the thresholds. If a pixel has a value higher than the upper threshold, it is considered an edge. Should its value be below the lower threshold, it is considered an inconsequential edge and it is discarded. And lastly, should the pixel's value be between both thresholds, the pixel is considered an edge only if it lay next to another pixel already considered an edge.

The Canny edge detector output, a binary image, is frequently used as an input for the Hough transform algorithm for identification of miscellaneous geometric shapes in the original image, most frequently lines. This papers's subject is the problematic of automatic determining of the thresholds for hysteresis used in the Canny edge detector. In contrast to the majority of papers dealing with this subject, its focus is not the detection of all the edges in an image, but the detection of those edges which allow to correctly detect lines using the Hough transform algorithm.

For this purpose, the determination of the thresholds, is usually recommended to be based on the results of statistical functions, such as the arithmetic mean or median, applied to the values of intensity of the input image converted to grayscale. Another way leading to the thresholds is to use the fractions of the output of Otsu's method algorithm for automatically performing thresholding of graylevel image (Fang et al., 2009). This paper's objective is to experimentally prove, that it is more convenient not to use the input image, but instead the map of the gradient at each point, which is the output of the Sobel gradient operator, thus pointing the direction for the ensuing research in this field.

2 Materials and Methods

All the programming for the purpose of this paper was done in programming language Python 2.7.8 using the NumPy fundamental package for scientific computing and the aforementioned computer vision library OpenCV in version 3.1.0. This implies that also the implementation of the Canny edge detector comes from the implementation used in this library.

The Gaussian blur with square matrix of order 5 is used for the image noise reduction. To find the gradient magnitudes we used the Sobel gradient operator size 3x3 (1) as a convolution kernel, namely twice, for horizontal (G_x) and vertical (G_y) first derivative approximations.

$$G_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} * A, G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{bmatrix} * A \quad (1)$$

The values of pixels G_x and G_y therefore may reach maximum of 1020 and a minimum of -1020. We can also derive that, if a pixel G_x has its maximum value 1020, pixel G_y highest value is 510 and vice versa, as shown in the examples of an image before the convolution (2), where X is the currently processed pixel. The highest possible sum of both values is therefore 1530.

$$\begin{aligned} &\begin{bmatrix} 0 & 0 & 255 \\ 0 & X & 255 \\ 0 & 255 & 255 \end{bmatrix} G_x = 1020, G_y = 510 \\ &\begin{bmatrix} 0 & 0 & 0 \\ 0 & X & 255 \\ 255 & 255 & 255 \end{bmatrix} G_x = 510, G_y = 1020 \end{aligned} \quad (2)$$

For the calculation of the edge gradient in the Canny edge detector from OpenCV in default settings, every pixel is processed by a function (3) using absolute values. A more correct and more accurate method would be to use an another function (4), which is, however, slower because of the use of powers and roots. With the first method, G values range between 0 and the highest possible sum of G_x and G_y, 1530; with the second, which we will be using, G values range between 0 and cca. 1140.395.

$$G = |G_x| + |G_y|, G \in < 0; 1530 > \quad (3)$$

$$G = \sqrt{G_x{}^2 + G_y{}^2}, G \in < 0; 1140.395 > \quad (4)$$

On this range, by testing all the options and subsequent evaluation by sensory observation, whereas the ratio between the upper and lower threshold will be tested in two variants: 3:1 and 2:1, we will be doing an experimental search for the best thresholds for the hysteresis. Sensory observation will be performed on the output of the Hough transform for line detection, which will follow directly after the edge detection. The Heath set of images (1997), which is still often used for the comparison of methods of edge detection, will be used as test images. The Hough transform will in all cases be statically set, with the resolution of one pixel and one degree and a minimum number of intersections equal to a hundred in Hough space to line detection.

3 Results

Table 1 shows information about the test images ordered by name in first column (Heath et al., 1997) and the results of the experiments. In columns „maximum", „mean" and „median" are the results of the corresponding functions applied to gradient values. Columns „3:1" and „2:1" contain the resulting intervals of the best upper threshold values.

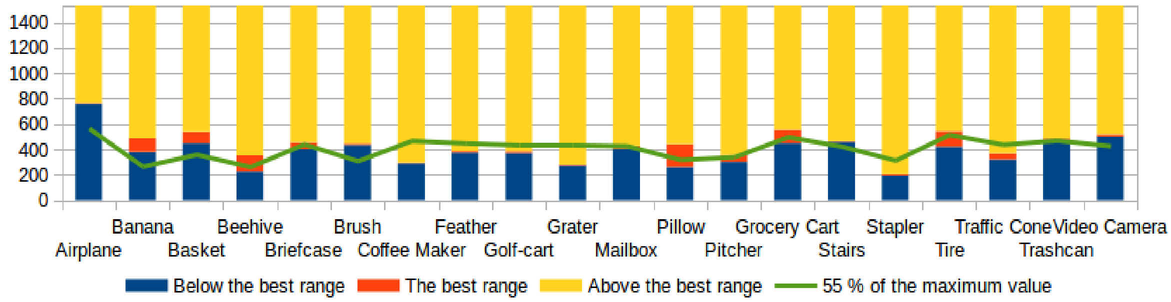

Figure 1: Results of the experiments with 2:1 ratio between the upper and lower threshold. Test images (x-axis) are described by intervals of the best upper thresholds to detect lines in range of possible gradient values (y-axis). Results (green line) are upper thresholds set to 55 % of the maximum value of gradient image.

We can argue that with a different setting of the Hough transform algorithm, the best setting of the Canny edge detector changes as well, but the experiments verified also, that even when the minimum number of intersections in Hough space for line detection is arbitrary, the range of intensity values is not always sufficient for the best result of line detection. The reduction of this minimum number of intersections in an image, where the edge detection was done inefficiently, often leads to poor identification of lines (Mukhopadhyay, Chaudhuri, 2015).

Table 1: Information about the test images and the results of the experiments

Image	Maximum	Mean	Median	3:1	2:1
Airplane	1034.2	61.3	28.0	836–838	756–762
Banana	487.2	25.1	11.7	408–487	380–487
Basket	659.5	100.2	81.0	558–562	448–538
Beehive	481.7	42.5	31.6	276–352	226–352
Briefcase	807.2	53.4	25.6	581–599	401–455
Brush	567.3	37.5	16.0	482–490	434–446
Coffee Maker	856.7	42.2	15.2	348–394	288–294
Feather	821.4	80.0	58.1	448–478	374–386
Golf-cart	792.9	62.9	40.5	528–550	370–384
Grater	786.5	39.4	15.6	324–358	272–278
Mailbox	782.3	84.4	61.1	522–526	404–426
Pillow	584.2	44.3	27.8	300–534	260–442
Pitcher	623.8	44.4	14.1	428–520	300–354
Grocery Cart	910.8	81.8	55.3	547–593	448–554
Stairs	775.5	79.6	48.8	622–634	459–463
Stapler	575.0	23.4	11.4	288–370	193–205
Tire	943.6	61.1	26.0	631–735	421–543
Traffic Cone	802.9	59.5	41.2	350–368	320–368
Trashcan	862.1	67.9	38.9	592–604	468–484
Video Camera	782.7	43.5	19.2	500–502	500–518

4 Discussion

As we can see, the best threshold values often go beyond the range of intensity values of the original image. So if we want to apply statistical functions to determine the threshold values, we should work with all the values of the gradient image.

The experiments also revealed that in some cases, the 2:1 ratio allowed a more accurate line detection and in most other cases, where the two tested ratios yielded comparable results, the 2:1 ratio had a greater interval, thus a higher probability of correctly determined hysteresis thresholds. Based on the table I would suggest for line detection to use the 2:1 ratio between the upper and lower threshold for hysteresis of the Canny edge detector. Then, the upper threshold to be set around 55 % of the maximum value of gradient image. With this setting, namely 52 - 56 %, the thresholds scored the best results in seven experiments and provided sufficiently good results in many others (as we can see in figure 1).

Similarly, we could also use the mean, where best results provided the upper threshold equal to approximately seven times the mean value of the gradient image, more precisely 691 - 696 %. I do not recommend, however, to use the median, because good results were quite scattered.

5 Conclusion

Based on the results of this paper, I believe that it is a bad practice to determine the Canny edge detector hysteresis threshold values solely on the basis of the intensity values of the input image. The values of the gradient image after performing the convolution with the Sobel operator and then consequentially calculating the gradient magnitude, provide much better results when used with detection lines using the Hough transform. There is no reason to believe that these values would not provide better results in other cases.

With the repetition of experiments on a larger set of test images, we could find the thresholds that give required results for many images, a sort of a starting point of setting for the Canny edge detector, which can be further modified according to the specific line detection problem.

Resolving this problem would simplify the line detection not only in OpenCV by the Canny edge detector, but also it would be possible to apply the results to other edge detectors based on the hysteresis, more of which appear in literature (Heath et al., 1997). It is likely that the results could also be used with a line detection algorithm other than the Hough transform, for example with the PClines method (Dubská et al., 2011).

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