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APPLICATION OF THE HOUGH TRANSFORM TO DIGITAL IMAGE ANALYSIS

ZASTOSOWANIE TRANSFORMACJI HOUGHA DO ANALIZY OBRAZÓW CYFROWYCH

A b s t r a c t

The main purpose of applying a transformation to the image is to achieve some information and make it more obvious and explicit, because, above all, the image must be understood, not just seen. In general the Hough transform allow to obtain the parameters of geometric shapes. The paper discusses how to use the Hough transform for the detection of regular curves such as lines, circles, ellipses, *etc.* The method is tolerant of gaps in feature boundary descriptions and is relatively unaffected by image noise, therefore, it works with the image analysis of low quality images.

Keywords: *Hough transform*, *curves detection*, *image analysis*

S t r e s z c z e n i e

Głównym celem stosowania transformacji obrazu jest pozyskiwanie informacji oraz przekształcenie w bardziej oczywistą i jednoznaczną formę, ponieważ obraz trzeba nie tylko widzieć, ale przede wszystkim rozumieć. Transformacja Hougha pozwala na pozyskanie geometrycznych parametrów kształtu obiektów. W artykule omówiono sposoby zastosowania transformaty Hougha do wykrywania krzywych, linii oraz okręgów na obrazach częściowo zniekształconych. Metoda ta jest mało wrażliwa na zakłócenia, zatem bardzo dobrze sprawdza się przy analizie obrazów słabej jakości.

Słowa kluczowe: *transformacja Hougha*, *detekcja krzywych*, *analiza obrazów*

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1. Introduction

Recognition the locations and orientations of certain types of features in a digital images are very important and not trivial tasks in digital images processing. Hough transformation gives satisfying results and can be used to isolate features of the particular shape within an image. It was first developed and patented by Paul Hough in 1962 [1] and is widely exploited from many years in image processing. It is most commonly used for the detection of regular curves such as lines, circles, ellipses, *etc.* on raster images but also can be employed in applications where a simple analytic description of a feature is not possible.

Hough transformation have been successfully employed to solve a variety of computer vision problems such as astronomical data analysis, spectroscopy, seismology, biomedicine. There are also some interesting work about mapping and localization for mobile robot [2] and recognition of human iris for biometric identification [3]. In the article will be discussed how to use the Hough transform to detect geometrical features of the object in low quality images.

2. Classical Hough transform for regular curves

Lines are used to described by the parametric representation in the picture plane. The simplest form of the Hough transform describes lines that match edges in a two dimensional image. It relies on the representation of the lines in the slope-intercept form $y_i = \alpha x_i + \beta$, where α is the slope of the line and β is the y-intercept. Now it is possible to construct a line parameters space (Hough space), but this method is not very stable, because for each image interest point, all possible lines are computed. On that case Duda and Hart [4] suggested using angle-radius rather than slope-intercept parameters. The extended Hough transform can be applied to any geometric shape that can be described by an equation in the normal representation (1), which is commonly referred as ρ-θ representation:

$$\rho = x\cos(\theta) + y\sin(\theta), \tag{1}$$

where:

(ρ, θ) – defines a vector from the origin to the nearest point on the line.

The parameters ρ and θ have a limited range considering the fact that an image has a limited size. If we plot the possible (ρ, θ) values defined by each (x_1, y_1), points in Cartesian image space map to curves in the polar Hough parameter space. This transformation is the Hough transformation for straight lines. When viewed in Hough parameter space, points which are collinear in the Cartesian image space become readily apparent as they yield curves which intersect at a common (ρ, θ) point. The main utility of the $\rho\theta$-Hough space is ease to handle vertical lines arising into the image space. Whereas, in the case of circles, the parametric equation (2) is as follow:

$$r^2 = (x - x_0)^2 + (y - y_0)^2 \tag{2}$$

where:

x_0, y_0 – defines the center coordinates of the circle,
r – defines the radius of the circle.

The main idea of the Hough transform can be extended to other shapes like ellipses, parabolas, etc. In all cases there are known the information of the objects shape. The aim is to find out data about location and orientation items in the image. The main advantage of parameterization is that values ρ and θ become bounded. There are used the accumulator arrays (known as *voting*) to find intersection of the parametric curves. Therefore there are used gradient information to reduce the computational load.

There is presented an example of applying the Hough transform to detect the 24 separate straight lines segments of the image (Fig. 1). In that way it can be identified the proper geometric structure of the objects in Fig. 1a. Using edge points as an input to the Hough transform, a curve is generated in ρθ-Hough space for each edge point in Cartesian space. This is the accumulation space and is viewed as an intensity image in Fig. 1b. After histogram equalization the image allows to see the patterns of information contained in the low intensity pixel values, which is shown in Fig. 1c.

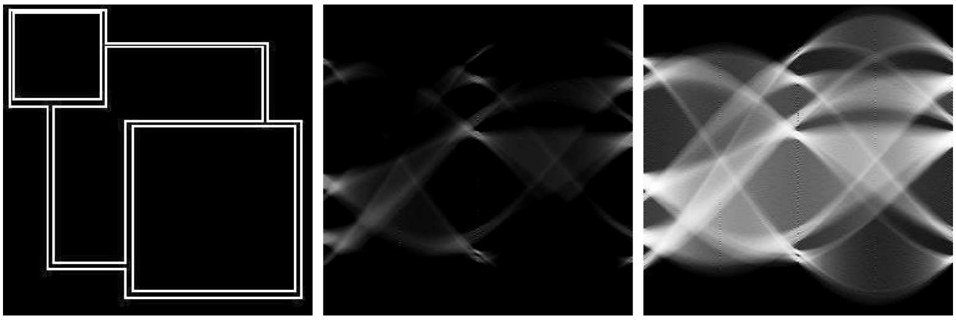
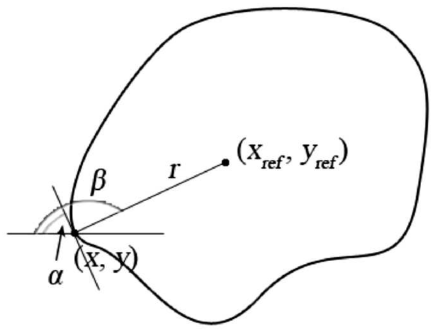


Fig. 1. Applying the Hough transform to separate straight lines segments in the image (1a – input image, 1b – ρθ-Hough space, 1c – ρθ-Hough space after histogram equalization)
Rys. 1. Zastosowanie transformacji Hougha do wyznaczenia linii prostych (1a – analizowany obraz, 1b –przestrzeń Hougha, 1c – przestrzeń Hougha po wyrównaniu histogramu)

3. Generalized Hough transform

In this paragraph the concept of the generalized Hough transform [5] will be showed. This transformation is engaged in applications where a simple analytic equation describing boundary of an object is not possible. To define the relationship between the boundary coordinates, orientation and the Hough parameters it can be used the look-up table instead of parametric equation of curve and this is the general idea of modified standard Hough transform. It is necessary to use a prototype shape during preliminary phase to compute look-up table values. The first step is to specify an arbitrary reference point (x_{ref}, y_{ref}) in the object, with known the shape and orientation, what is shown in Fig. 2. For all points of the boundary it was drawn a line to the reference point. The look-up table, so-called *R-table*, consists of distance and direction pairs, indexed by the particular known orientation α of the boundary.

The Hough transform space is defined in terms of the possible positions of the shape in the image. There are computed the possible reference points (x_{ref}, y_{ref}) from the coordinates of the boundary point, the distance r and the angle β, to be at {$x_{ref} = x + r\cos(\beta)$, $y_{ref} = y + r\sin(\beta)$}. The accumulator array cell is incremented while all the (r, β) pairs are read. This process is repeated for all edge points in the image. By identifying local maxima in the accumulator array, the presence of the shape is concluded. If the orientation of the shape is unknown, the procedure becomes complicated. The accumulator array must be extended by incorporating an extra parameter to take changes in orientation into consideration.



Rys. 2. Definicja komponentów *R-tablicy* uogólnionej transformaty Hougha
Fig. 2. Generalized Hough transform – definition of *R-table* components

Further there will be presented some examples of applying the Hough transform to detect circle and line shapes of the object. Due to the computational complexity of the generalized Hough algorithm, the main issue of this article will be the standard Hough transform.

4. Results

This paper was investigated feasibility of using the Hough transform to identify lines and circles in pictures. When object is placed on a plain background, the edges are easy to be picked up and the Hough transform is always success as shown in Fig. 3 and Fig. 4 (first row). In second row of Fig. 3 and Fig. 4 the original images were corrupted by salt and pepper to illustrate the Hough robustness to noise. There was presented the ρθ-Hough space in Fig. 3c and Fig. 4b (both rows) – lighter regions represents most probable places for finding lines or centers of circles what is also shown, for finding lines, as images with maximum points in Fig. 3b. The number of circles is entered by the user, which means that there will be choose the most lightest points in the Hough space. There was predefined number of circles with predefined radius (the algorithm tolerate a small error in the radius) and number of lines. Images with the detected lines and center of the circles marked are shown in Fig. 3d and Fig. 4c. The Hough transform detect correctly lines and circles in artificial images without noise and with salt and pepper noise respectively. The computational complexity depends on the number of edge pixel and the number of radius to be matched.

Further, it can be shown more examples of using the Hough transform to detect lines or circles from real object. To extract features of real object it is necessary to define proper criteria of selection. The original RGB images (shown in Fig. 5a and Fig. 6a) was converted to 8-bits. The Hough transform was applied for these images preceded by equalization,

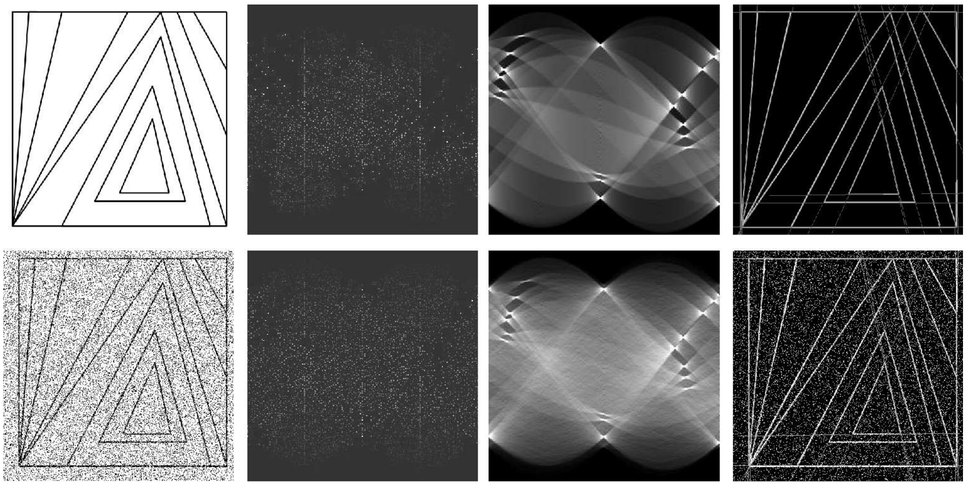


Fig. 3. Applying Hough transform to detect lines: 3a – input image, 3b – maximum points detection, 3c – ρθ-Hough space, 3d – detected lines (second row – applying Hough transform to noisy picture)

Rys. 3. Zastosowanie transformaty Hougha do wykrywania linii: 3a – analizowany obraz, 3b – detekcja maksimów, 3c – przestrzeń Hougha, 3d – wykryte linie w obrazie (w drugim rzędzie przedstawiono zastosowanie transformaty Hougha w obrazie zaszumionym)

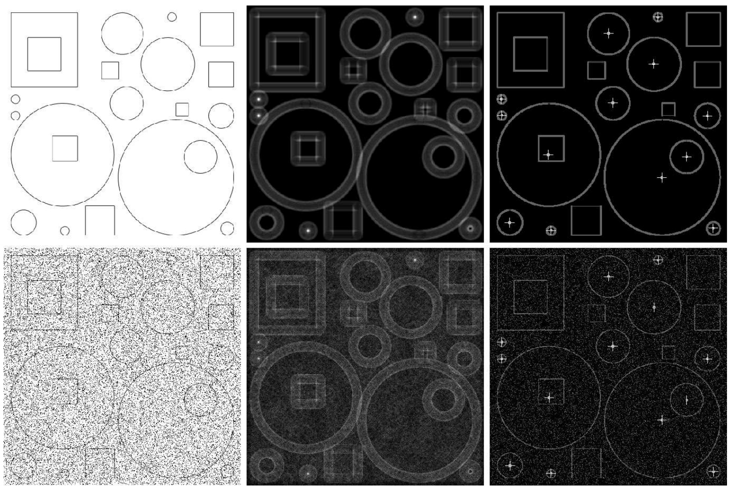


Fig. 4. Applying Hough transform to detect circles: 4a – input image, 4b – ρθ-Hough space for $r = 10$, 4c – center of the detected circles marked for $10 \leq r \leq 150$ (second row presents applying Hough transform to noisy picture)

Rys. 4. Zastosowanie transformaty Hougha do wykrywania okręgów: 4a – analizowany obraz, 4b – przestrzeń Hougha dla $r = 10$, 4c – zaznaczone środki wykrytych okręgów dla $10 \leq r \leq 150$ (w drugim rzędzie przedstawiono zastosowanie transformaty Hougha w obrazie zaszumionym) smooth, edge detection and threshold to perform better results. Good detection of lines and circles strongly depends on fine image preparation. Using the interactive program, after indication number of lines, circles and its radius, the proper lines and circles in object are automatically detected. In Figure 5b the results show 14 nuclei detected, which shape is close to circle with radius equal 16 px. Detection shown in Fig. 6b presents grid of 22 lines detected form the images, but there was a problem with peak points in the accumulator to locate in presence of noisy or lots of parallel edges.

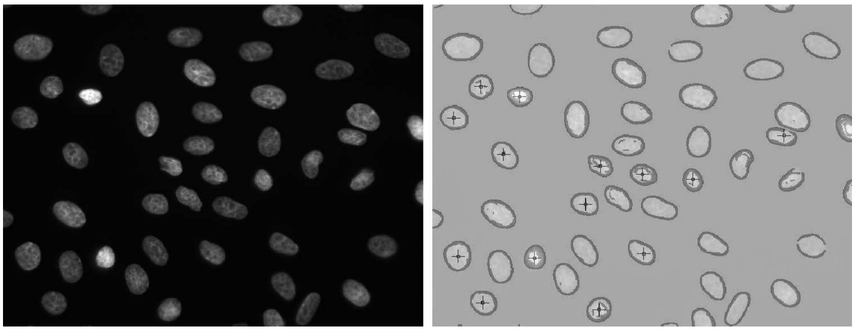


Fig. 5. Circle nuclei detected with Hough transform
Rys. 5. Wykrycie jąder o zaokrąglonym kształcie za pomocą transformacji Hougha

Fig. 6. Grid detected with Hough transform
Rys. 6. Detekcja siatki za pomocą transformacji Hougha

6. Conclusions

Hough transform is useful tool for recognition the locations and orientations of certain types of features in a digital images which gives satisfying results and can be used to isolate features of a particular shape within an image. If the shape or edges of objects is known, using Hough transform, edges can be detected and points can be linked together easily.

Correct detection of lines and circles strongly depends on fine image preparation. Equalization, smooth, edge detection and threshold was applied before Hough transform operation. Threshold is significant and determinant factor because of Hough transform dependency on the edge pixels and should be chosen carefully. Improper selection of threshold (too high value) and edge detection can cause elimination of correct edges and less number of edges that should be chosen. Furthermore, too low value of threshold might result in long execution time. These are the main limitation of the Hough transform method. There is also another problem with the calculation quantity, which is very large and increasing with image size. Efficiency of the algorithm decreases if image becomes too large. This involves that data become too large and the processing quantity is slower. To solve these problems, there was suggested some improvements [6] but this is associated with the cost of making certain assumptions or by expensing the degree of flexibility in the algorithm.

On the other hand, it can be concluded that the Hough transform is an effective tool for lines and circles detection even in the presence of noise. Hough transform can also detect deforming objects in poor quality pictures. And what's more, the main advantage of the Hough transform technique is tolerant of gaps in the edges and being relatively unaffected by image noise and occlusion in the image.

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