ANALYZING ROAD JUNCTIONS BY GEOMETRIC TRANSFORMATIONS

Z.Tóth - A. Barsi

Department of Photogrammetry and Geoinformatics
Budapest University of Technology and Economics,
H-1111 Budapest, Muegyetem rkp. 3.
Hungary
{toth.zoltan,barsi.arpad}@fmt.bme.hu

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ABSTRACT:

Hough-transformation is a widely used method for analyzing lines in different images. One of the advantages of the technique is the rotation and scale invariant representation. Roads and their junctions are built of image edges, which can be detected by a wide spectrum of operators. High-pass filters (e.g. Sobel) or special operators (e.g. Canny) are the right tools marking pixels, where the intensities are significantly changing in form of intensity steps. The resulted line segments must be grouped into higher level objects, for example to get road segments. Road junctions are complex objects built up from these edges and their interrelations. Since the junction geometry and topology, as well as its orientation are very diverse, their description is difficult. The Hough- and the similar radon-representation of lines are helpful to manage smaller uncertainty of the derived line directions. The paper focuses on the geometrical analyses, performed by the Hough- and radon-transformation. Different types of junctions (mainly three and four-arm junctions) are studied in several orientations with the goal to find rules. The junction samples are cut from black and white digital orthophotos and high-resolution satellite images. The preliminary tests have proved that these line representations can be alternative tools in generalization of image edges indicating roads. By the selection of the main directions and their crossings, the basic junction description can be executed or existing database content can be checked.

1. GEOMETRIC TRANSFORMATIONS

1.1 Hough-transformation

Hough transformation is widely used in various fields of image processing. In this study we present the possible applications in the automatic recognition of crossings. The original algorithm – which was published by P.V.C. Hough quite a long time ago in 1959 – was the analytical detection of parameterized geometrical primitives (lines, circles, ellipses, etc.) in binary images. The procedure is based on the transformation of the original image pixel-by-pixel into the Hough-space adequate to the actual parameterization. In this paper we are concerned with the detection of straight lines describing the road elements. In such cases the algorithm is the following:
Consider the equation of the straight line parameterized in the following way (Equation 1):

$$\rho = x\cos\Theta + y\sin\Theta$$

where:

ρ is the distance of the line from the origin of the coordinate system, and

Θ is the azimuth angle of the normal vector of the line

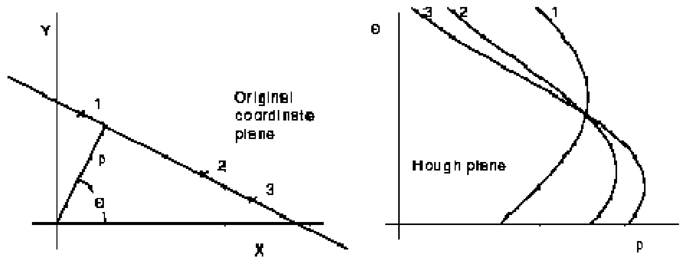


Figure 1: The coordinate system of the original image and the Hough-space [1]

In case of *N* given points, all the possible straight lines connecting them by defined *N* curves in the $\rho - \Theta$ parameter space, also called Hough-space. For collinear points, the mutual intersection unambiguously defines the parameters of the straight line passing through the points and – in general – *N* curves can have N*(N-1)/2 intersections.

With this aspect, the task is now directed to finding points of intersections. In order to reduce calculations, in practice – according to demands of accuracy – the resolution of the parameters are defined in advance, then a block with a corresponding size and a dimension considering the number of parameters is initialized, out of which – in the simplest case – we can find the straight lines with the selection of elements higher than a certain threshold. The connection between the Hough- and the image space is usually summarized like this (for lines) [1]:

- A curve corresponds to every point of the image space in the Hough-space
- A point in the Hough-space is equivalent to a straight in the image space
- The collinear points in the image space are curves with mutual intersections in the parameter space
- Points on curves in the Hough-space – deriving from the above mentioned arguments – are straight lines with a mutual intersection in the image space.

1.2 Radon-transformation

The Radon-transformation closely related to the above presented Hough-transformation is widely used for detecting straight lines in digital images. The process calculates the projections with given origin and rotation ($\Theta = 0 - 180^\circ$) of the $f(x, y)$ image matrix.

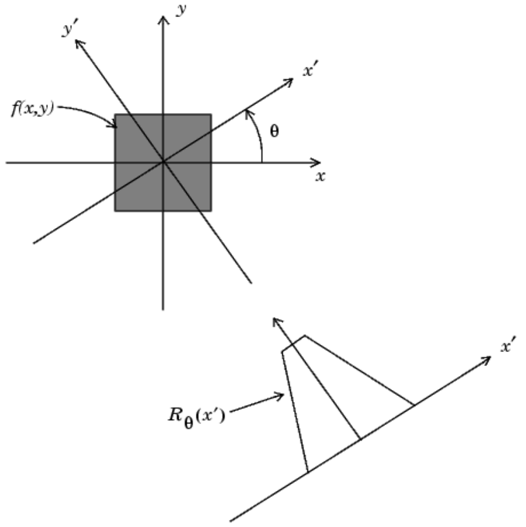


Figure 2: The original image and its projection [4]

The integral of the $f(x, y)$ image matrix can be calculated as

$$R_\Theta(x') = \int_{-\infty}^{\infty} f(x'\cos\Theta - y'\sin\Theta, x'\sin\Theta + y'\cos\Theta)\,dy'$$

where:

Θ stands for the rotation angle.

The rotation in matrix form is:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\Theta & \sin\Theta \\ -\sin\Theta & \cos\Theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

2. IMAGE ANALYSIS

2.1 Automatic road recognition process

One of the main interests of today's photogrammetric research is the development of automatic and semi-automatic mapping technologies and algorithms. Two major research areas can be distinguished: the mapping of roads and that of the buildings. Within the mapping of roads the different fields of development can be summarized as follows:

- Snake algorithms
- Kalman filtering procedures
- Neural networks
- Special image operators
- Hough-transformation

A perfectly automatic scale-independent procedure is not yet known; the combination of various procedures seems practical. Previously, we developed an application for the intersection point recognition based on neural networks (Junction Extraction by Artifical Neural Network – JEANS) [2,3]. In this study, we show a process for this application independently from JEANS. The algorithm is based on the Hough-transformation of a certain size environment of the area recognized as an intersection. The algorithm is:

- Defining the area of interest (AOI) around the intersection
- Smoothing
- Edge detection
- Hough-transformation
- Analysis

2.2 Data collection

For our experiments we cut out square, 101 × 101 pixel size areas of intersection from black and white digital orthophotos. As we would like to derive general rules for both Radon- and Hough-transformations by examining a great deal of intersections, we developed applications by which can make such cuts efficiently manually or as well as from the intersection detections of JEANS. Every single cut can be visualized, interpreted and even the accuracy of the recognition can be checked automatically not only in the original orthophotos, but also in geographic information systems.

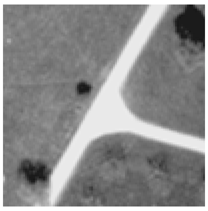


Figure 3: Cut-off of a digital orthophoto (~ 60 × 60 m)

In our studies, we primarily focused on rural roads and their intersections. The developments were performed by using OpenCV, Intel's open-source computer vision library and Matlab.

2.3 Edge detection

In aerial images roads have different intensity from their environment. With edge detection algorithms even road edges can be extracted. However, it makes difficulties, that in high-resolution aerial images the road has not a completely homogeneous surface. The inhomogeneities are caused by the cars, the plants partly covering the roads, the road signs and the asphalt flaws. These inhomogeneities appear as noise by finding the edges. In order to eliminate them, a median filtering can be run on the investigated area or adequate parameterized edge detection can be applied. The edge detection process was preformed by several well-known methods: Sobel high-pass filter, and Canny-operator.

2.4 Hough-transformation

As a results of the edge detection process, we get the pixels detected as edges in the binary images sometimes with a quite high noise. From this discrete set of points the characteristic lines can be detected by either the Hough- or the Radon-transformation. The function library that we used contains several solutions. As an initial approach we employed the function of the classical Hough-transformation. As parameters, the function needs the input binary image, the resolution of the two parameters and a threshold. The result is the parameters of the detected straight lines. The input parameter for the resolution and the threshold can be estimated from the aspect ratio and the size of the cut-off window, respectively.

From the resulting straight lines we need to highlight those straight lines that potentially belong to road edges. The method is the following. First, the straight lines have to be grouped according to their angle of tilt neglecting their direction.

From these grouped straight lines those ones that have similar parameters mean the potential road edges since not necessarily one single straight line represents a given road edge. Knowing the resolution of the original image, we can estimate the width of a road with a given rank in pixels. In this way, straight lines parallel to each other can be selected from the detected ones, i.e., straight lines with a tilt angle of 1-2 degrees, the distance from each other almost coincides with the assumed road width. These straight lines represent the two edges of a road segment with high probability. These are shown in blue and red in Figure 4. With this method, e.g. straight lines that appear at the border of different agricultural cultivation areas can be filtered out (Figure 4 yellow marks).

The road axis can be determined from the road edges selected previously by elemental path averaging. The intersection of two road axes defines the possible origin of a junction. A further possibility to avoid false identification is to accept an intersection of two road axes as a junction only if the angle between them ranges from 70 to 110 degrees.

The results of a run for a four- and a three-arm junction are shown in Figure 5 and Figure 6.

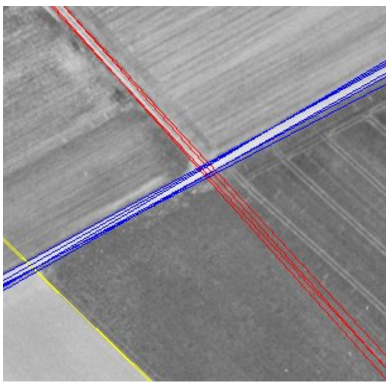
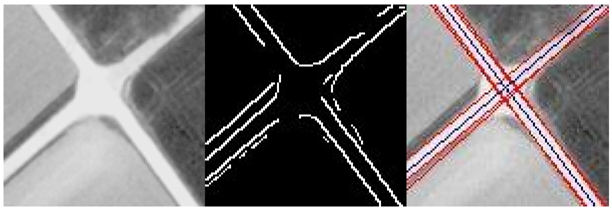
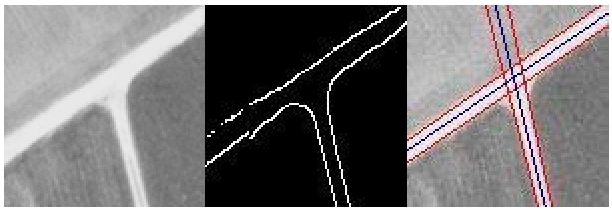


Figure 4: Grouped road edges.



a b c

Figure 5: Four-arm junction: a) original image, b) edges, c) detected straight lines (red) and the computed centerline (blue)



a b c

Figure 6: Three-arm junction: a) original image, b) edges, c) detected straight lines (red) and the computed centerline (blue)

2.5 Radon-transformation

The Radon-transformation for the junctions of the experiment was also performed. A common advantage of the Hough- and the Radon-transformation is that they are rotation invariant. Analyzing this, we have prepared the Radon-transformation of the intersection and that of the image of the intersection rotated by 90 and 180 degrees. The result is illustrated for four- and three-arm junctions in the following figure.

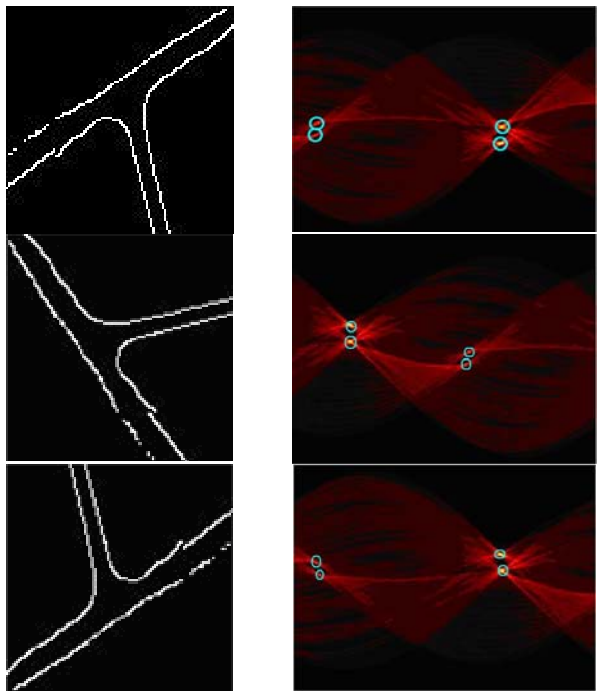


Figure 7: Rotated (0° - 90° - 180°) road edges and the Radon-space.

It is clearly seen that the image of the Radon space of the rotated junctions is also rotated or mirrored, however topologically, the intersections, i.e., the parameters of the detected straight lines appear and remain the same. This test has proved that the Radon-transformation is topology preserving. From the Radon-space the locations of the intersection can be derived by the generalization of the road edges. The result is shown in Figure 8.

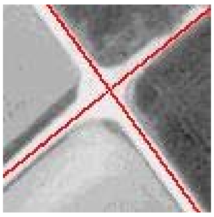


Figure 8: Road centerlines from the Radon-space

3. CONCLUSION

The present paper summarizes the application of the Hough- and Radon-transformation for the detection of road junctions. We have studied the results of the transformation of junctions cut from certain environments and deduced general rules for the selection of characteristic parameters of intersections.

We mentioned that both transformations share the common advantage of rotation and scale invariance that was illustrated. In the future the most interesting task is to increase the robust feature of the system. Furthermore, we would like to develop the existing system in order to use it as a kind of running window method and to integrate it into the JEANS system based on neural network.

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