OUTLINE EXTRACTION OF A MOTORWAY FROM HELICOPTER IMAGE SEQUENCE

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ABSTRACT

Behavior analysis of each driver during congestion is still a problem in microscopic traffic analysis. To solve this problem, image sequences of traffic data are collected by helicopter. After detection and tracking of the vehicles, detailed data for microscopic traffic analysis result. To increase speed and reliability of vehicle detection and tracking, road detection is suggested. In this way, the search area for vehicle detection is limited to road boundaries while other moving objects such as vegetation or pedestrians are omitted. Road detection from aerial helicopter images is done by a line detection method based on edge detection and morphology operations. Unwanted lines and other errors introduced during the line detection are removed by a threshold method. These thresholds are based on gray value and connected component labeling. After this improvement process, some parts of road lines are still missing, due to physical obstacles and the previous operations. With a Hough transform method line fragments are connected to each other in order to form elongated road lines. The image sequence data are taken by a Basler A101f digital camera installed on a helicopter. Results show that most road lines are correctly detected and connected but still some minor parts of the lines are not completely connected.

Results can be improved by using a better technique for local maxima detection of the parameter space. The parameter space obviously shows number and positions of line that are completely correct are calculated.

KEYWORDS: road delineation, morphology, Hough transform, line detection, traffic data

1. INTRODUCTION

A new method is introduced for collection of data for calibration and parameter extraction of microscopic flow models of motorway traffic under congestion. It is based on image processing methods applied to aerial image sequences. Microscopic models differ from macroscopic ones in taking variability in driver's behavior into account. Microscopic models are governed by many parameters; the exact set of parameters is yet to be determined. Moreover, correct and reliable estimation of this large number of parameters is going to require very large amounts of data, acquired under very many different circumstances concerning road layout, traffic intensity, light and weather conditions etc.

Currently other traffic data collection systems are available, such as inductive loops, pneumatic tubes, video, etc. These are mainly used to facilitate real time surveillance, by providing input for dynamic speed limitation signs and for traffic information services via radio and the internet. To a limited extent these systems are capable to capture data for calibration and parameter extraction of macroscopic traffic flow models. One of the main limitations is caused by the inability of these systems to track individual cars from one measuring point to the next.

The overall objective of the research project is: to develop a data collection method to collect vehicle trajectories (longitudinal and lateral position of the center of the vehicle represented by a rectangle as a function of time) and individual vehicle characteristics (vehicle length and width) in particular during congested traffic flow conditions for a reasonable time period (15 minutes) and part of the roadway (500 m to 1 km).

The method must be applicable to many situations, but is in particular aimed at the application to motorways. These data are of great value for numerous practical and scientific purposes, such as the evaluation of different ITS applications, roadway designs. Within the framework of the present study, it is mainly used to answer fundamental research questions with respect to driving behavior in congestion.

The traffic data acquisition system being developed is based on recording of image sequences of selected motorway sections during elongated periods of time. A helicopter is used as a platform because of its capability to hover stationary above a section. A typical sequence concerns a section of 250-500m being recorded during 30-60 minutes. The camera records 10 frames per second with a spatial resolution of 1300 x 1030 pixels, the long axis being aligned with the motorway to be recorded. The spatial resolution is 25-50 cm. One of the problems concerns the relative instability of the camera platform caused by wind and (mostly) by turbulences induced by the helicopter itself while hovering at a constant position (Fig. 1). Therefore, image geo-referencing is a difficult task.

Because of the large number of images in a sequence, automation of processing of the data is important. The processing sequence consists of:
- camera calibration, lens correction (Fig. 1)
- geo-referencing

- radiometric correction (when lighting conditions are varying due to cloud cover above the helicopter)
- detection and tracking of vehicles

The overall result of the image analysis process consists of a set of *trajectories*, one for each car, describing the position of the car relative to an axis along the motorway section as a function of time. In addition, the position with respect to the axis perpendicular to the motorway (*i.e.* the lane) has to be recorded as function of time, as well as some fixed vehicle characteristics, such as the vehicle type (car, van, truck, trailer etc.) and its size.

To facilitate the automation of the above-mentioned process, automatic road delineation is an important step. In this paper, this step is applied using the lens-corrected images, but before performing the geo-referencing.

The image sequence under consideration contains a motorway section located in an urban surrounding. The challenge is therefore to extract only the motorway and not the numerous streets and other features in the surrounding, nor the objects on the motorway itself (*i.e.* vehicles and road markers).
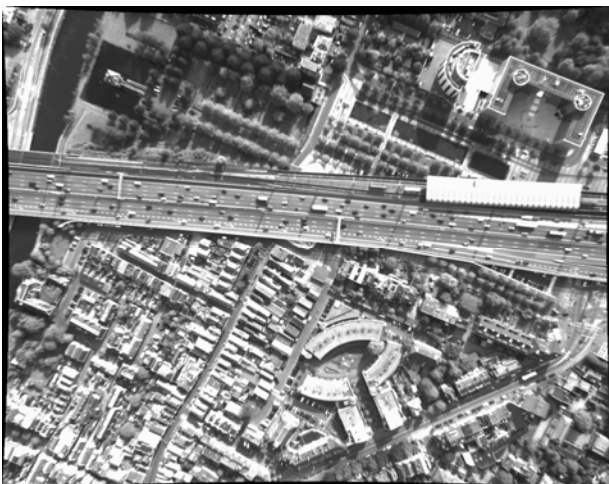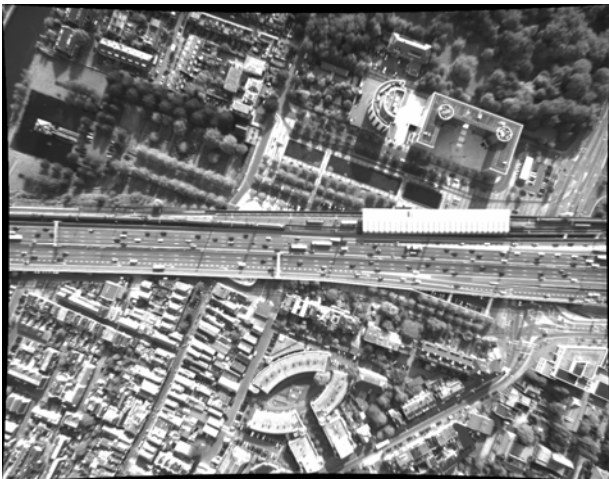

Figure 1: Two images from the sequence, after lens correction.

The purpose of road delineation is:

- to limit the search space while detecting moving objects in subsequent steps: only motorway traffic is to be detected, not vehicles moving around in the surrounding area (not to mention other moving objects like trees in the wind)
- to provide input for feature based matching during the geo-referencing step: this process would be greatly complicated by using urban landscape elements that typically occur at different heights above the terrain
- to obtain an initial reference coordinate system for detected vehicles (lateral positions and lanes).

The current dataset has following characteristics:

- Traffic data from helicopter platform
- Camera Basler A101f, grayscale, resolution 1300* 1030, camera with a 2/3" sensor chip. focal length is 16mm,
- Helicopter: Bell 206 JetRanger
- Measurement location and date: Dutch city of Den Haag at A12 motorway ;25th April 2002
- Ambient conditions:
  Wind (causes vibration and platform movement) instead of 280 meter of road only 200 meter is observed and loss of image quality due to the vibration of helicopter
  Clouds sometimes thin and sometimes thicker; therefore all of the images are not the same radiometrically.

Very many methods exist for automatic road detection; we need a fast method regarding the large number of images in our images to be processed.
Road detection methods are categorized according to the image resolution and also their sensor or platform:

1- low resolution such as satellite images
2- medium resolution such as aerial images
3- large scale such as traffic video images

The solutions of each category are different in process time, accuracy, methods and aim of road detection.

Dal Pos *et al* (Dal Pos, 2004) proposed a road extraction method based on geometrical knowledge of roads: a set of four road objects and another set of connection rules among road objects. According to the fragment, superimposition, parallelism and proximity, anti-parallelism, homogeneity and contrast rules, which are geometry knowledge of roads, are used for identification and building road objects. Road lines are extracted with geometrically construction of these objects. The method was applied on images taken in rural areas, where confusion between road outlines and other features was small. The value of the method is its ability to complete the outline reconstruction process, after initial detection was not too complicated. The method can be considered complementary to the results of the current paper: after we obtain an initial road outline model in our much more demanding urban environment, Dal Pos's method can be applied for further processing.

Koutaki and Kuchimura (Koutaki, 2004) proposed a method based on image segmentation for road detection, on using a road crossing model for detection of crossroads, and finally on a ribbon snake method for connection of road fragments. Also this can be considered a useful continuation, when applied to road outlines in our case, instead of to center lines.

2. METHODS

This paper focuses on delineation of the motorway in the image sequence under consideration. The challenge is to obtain a reliable and complete reconstruction of the outline of the motorway while omitting objects in the urban area around the motorway.

Inspection of the imagery revealed that at the current resolution, the outline of the motorway is marked by thin, bright *lines*, whereas the (unwanted) elements in the surroundings are mostly characterized by *edges*, *i.e.* boundaries between darker and lighter regions.

The lines that we are looking for can be characterized as:

- Thin, light lines
- Very long
- Almost straight

These characteristics govern the subsequent steps. These are:

1. Line detection
2. connected component labeling and selection (Gonzalez, 2002)
3. Hough transform (Gonzalez, 2002), (Castleman, 1996)

Finally, the results of the different steps are combined into the end result.

Line detection

Line detection is expected to be more useful than edge detection. Here three different methods are tested. In the following the methods are described and results are compared to each other.

1. **Line detection based on Sobel edge detector**: Edge detectors, such as Sobel (Gonzalez, 2002), detect double edges at either side of (thin) lines. If the interest concerns exactly those lines, morphological closing (Gonzalez, 2002) can be applied, *i.e.* dilation followed by erosion. The dilation step fills the space between the double edges, and the erosion restores the original width. By subtracting the original edge image from the closing result, the (filled) centerline between the two edges is obtained, corresponding to the line to be detected. All other (single) edges are not affected by morphological closing and will therefore have disappeared after the final subtraction step. (Fig. 2)

2. **Line detection based on Canny edge detector (Gonzalez, 2002) and closing morphology (see above).** The result is shown in Figure 3.

3. **Line detection based on morphological grayscale opening.** In this method grayscale erosion and then dilation (opening) is exerted on an image and then subtracted from the image. With morphological opening all image elements except thin lines are preserved, so by subtraction only these lines are detected. (Fig 4). Note that this procedure detects only bright lines, as required. To detect dark lines we would have to subtract the original image from the result of morphological grayscale *closing*. The width of the detected lines is controlled by the size of the structuring element. We were using a structuring element of size 3 x 3, yielding very thin lines only. Finally, a threshold has to be applied to select those pixels that are considered to be at lines of interest, i.e. the ones that have enough contrast with respect to the surrounding background. We used threshold value 20.

The third method gives better results than the other two, in terms of the ratio between detected road elements and other features. It will be used in the remaining process.
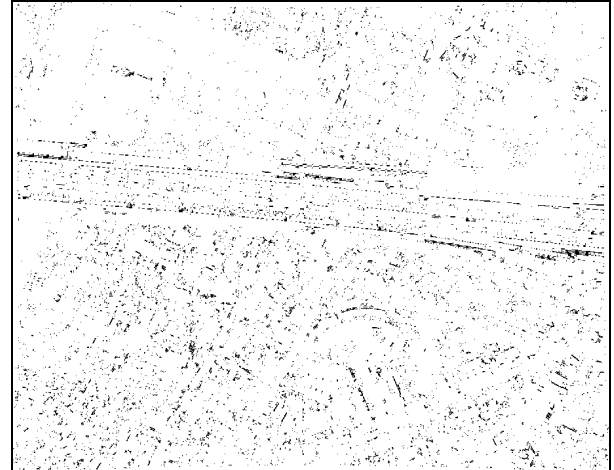

Fig. 2: Line extraction based on Sobel operator, morphological opening and image subtraction
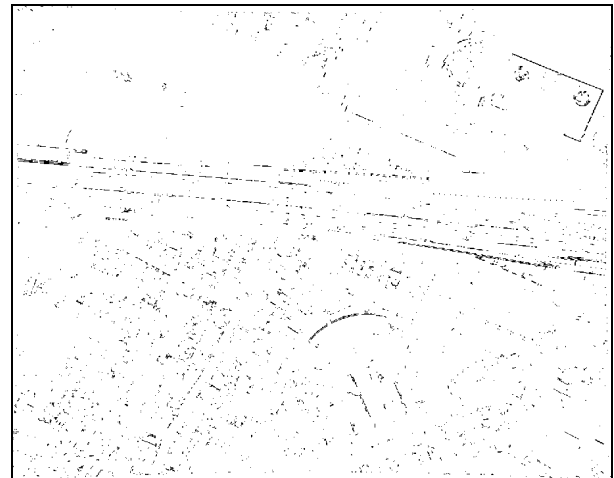

Fig. 3: Line extraction based on Canny operator, morphological opening and image subtraction

Connected component labelling

After line detection and thresholding, the lines of interest, i.e. those that are at the motorway boundary, appear as large linear segments. Many small lines are also detected that should be removed from the line image, such as small road line in the middle of main road and some part of bright vehicles, and very many features in the urban area surrounding the motorway.

Figure 4: Line detection by morphological opening and image subtraction.

The next step is connected component labeling of the object pixels using 8-connectivity. This algorithm numbers the objects in a binary image and assigns to each object pixel the number of the object that the pixel belongs to. The histogram of the result computes therefore the number of pixels in each object. It can be used to select objects based on their sizes. We selected objects of more than 50 pixels for the next step (Fig. 5). Many of the small lines are eliminated and most of the fragments of main road lines remain.

Figure 5: Lines with more than 50 pixels

Hough Transform

The result of the previous step is submitted to a Hough transform with parameters ρ and θ. For each selected pixel with coordinates (x, y) a curve is constructed in the (ρ, θ) parameter space satisfying

$$\rho = x \cos \theta + y \sin \theta .$$

Each point on this curve corresponds to a line passing through the point (x, y), so the entire curve represents the bundle of all lines passing through the point. With two different points (x_1, y_1) and (x_2, y_2) we obtain two curves (corresponding to two line bundles), and the point in the parameter space where the two curves intersect indicates the line that passes through both points. When transforming all the selected points of the object space (Fig. 5) to the parameters space, a set of curves appears as shown in Fig. 6.
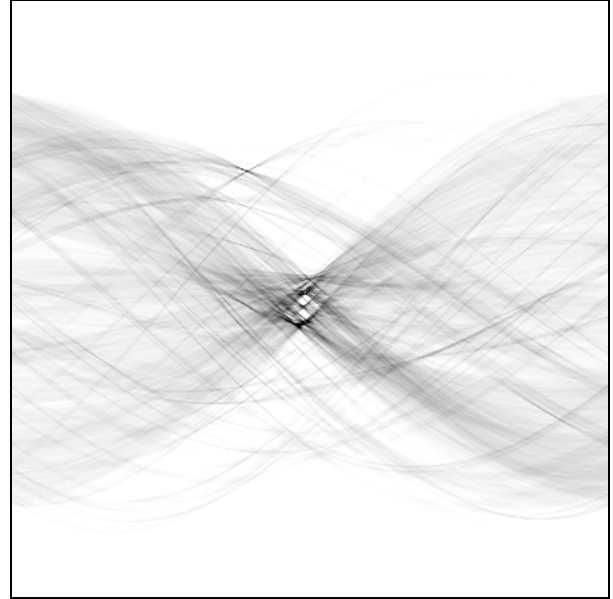

Figure 6: parameter space after Hough transform of Fig. 5

The points where many of these curves intersect in the parameter space (the darkest points in fig. 6), indicate lines that pass through many points in the object space. In the parameter space, these points are local maxima, which can be automatically selected (Fig. 7).
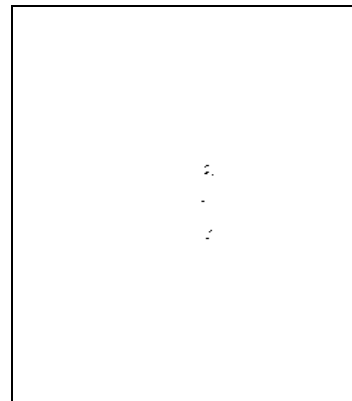

Figure 7: Local maxima in parameter space (fragment).

Now, inverse Hough transformation is a applied to obtain lines in the object space corresponding to the local maxima in the parameter space (Fig. 8). Note that to each point (ρ, θ) in the parameter space there is a corresponding parameterization of one line in the object space, for example expressed in slope and intersect. The beginning and ending coordinates in the object space, however, are unknown. Another problem is that, due to quantization effects in the discrete parameter space, artifacts occur in the object space after the inverse transformation.
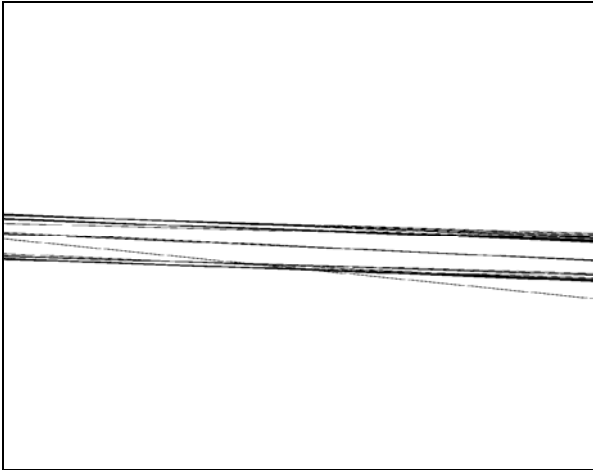
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Figure 8: Inverse Hough transforms of the local maxima in the parameter space (Fig. 6 and 7)

Therefore, we go back to the original line detection result, obtained by subtracting the result of morphological opening from the original image, and consider the inverse Hough transform result as *additional evidence* that point are located on (long) lines. This is implemented by multiplying the two data sets (Fig. 9), after which we can apply a threshold to make the final selection, visualized over the original image in Figure 10.

3. CONCLUSION

In this paper the outline of a motorway is extracted from images that are taken from a movie image sequences collected from helicopter at a height of around 500 meter by grayscale digital camera.

The method based on morphological operation, some neighboring operation and Hough transform

The results which are shown show the performance of the different methods is used in this paper. Lines are correctly detected and connected, after which the outline of the roads line result. Despite of the physical obstacles as well as the methodological weaknesses yielding a discontinuity in the line detection method, the outline of motorway are correctly extracted from aerial images.
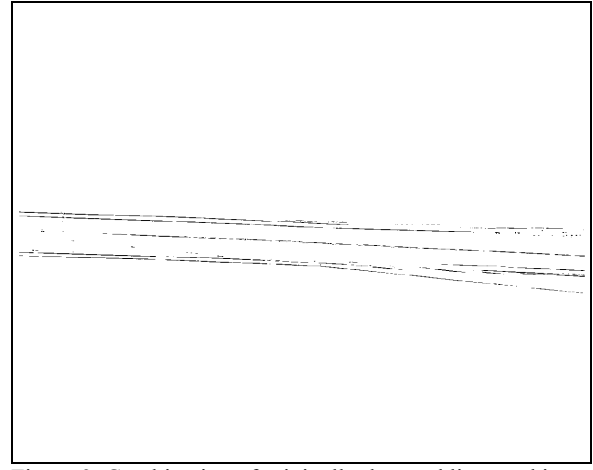

Figure 9: Combination of originally detected lines and inverted Hough transform

Future work

The aim of future work is to improve fragment connection by improving the local maxima method. Also a graph based method is suggested for connection of segments in addition to the Hough transform method for curved roads and for further improvement of results for straight roads.

Future work will focus on finding a data collection method for traffic data that allows for a detailed detection and tracking of each vehicle. The results will be used for a parameter estimation of a microscopic model of congested traffic flow. In the data collection part we have to find the best data collection system to observe congested traffic flow for longer time and larger distance, which will give us a better behavior analysis of the driver in the microscopic models. The next step is to use the result obtained in this paper for feature based matching during geo-referencing, and for providing a geometrical framework to which vehicle trajectories can be related, both along the road axis and perpendicular to it.

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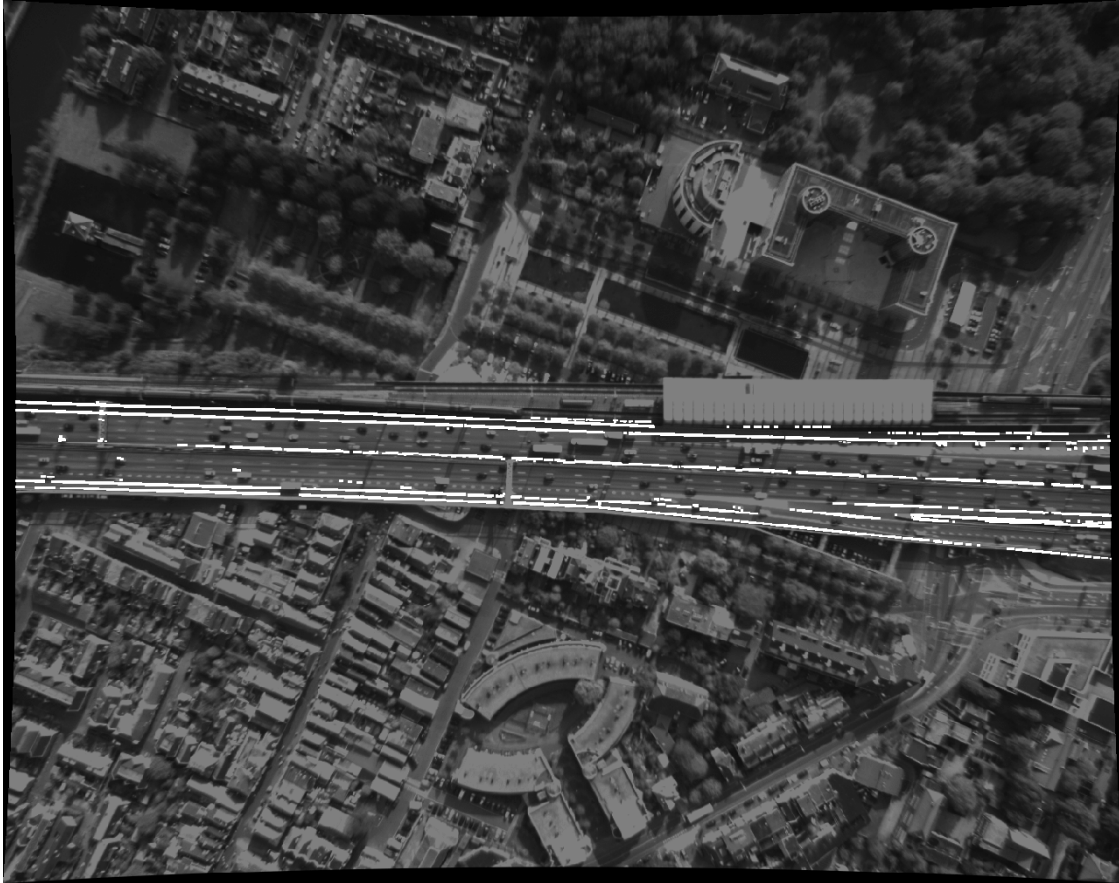Koutaki, G., Keiichi Uchimura, 2004, Automatic road extraction based on cross detection in suburb, proceedings of SPIE, electronic Imaging

Figure 10: Final result overlaid on original image.