

# SEMI-AUTOMATIC ROAD EXTRACTION FROM DIGITAL AERIAL PHOTOGRAPHS

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## ABSTRACT:

By means of the progress in photogrammetry; it is now possible to produce the maps of huge areas more quickly and economically but the production steps are still expensive and time consuming. In recent years, parallel to the development in photogrammetry, more effective methods are researched to make available digitizing line features like roads full automatically or semi-automatically from digital aerial photographs. Because it is not still possible to designate the full automatic feature extraction methods clearly, the semi-automatic feature extraction methods, which combine experienced interpretation of an operator with the speed of a computer algorithm, are the best solutions. There are different semi-automatic approaches for digitizing features from digital aerial photographs. Nowadays, suitable methods for each specific mission are chosen in the literature, instead of one exact method which carries out all alternative algorithms. In this paper, roads are chosen as line features for digitizing from digital aerial photographs, because roads are the most time consuming features to digitize in photogrammetry. Two road extraction algorithms are applied to digitize roads from mono digital aerial photographs and the results are compared.

## 1. INTRODUCTION

By means of the progress in photogrammetry; it is now possible to produce the maps of huge areas more quickly and economically but the production steps are still expensive and time consuming. In recent years, parallel to the development in photogrammetry, more effective methods are researched to make available digitizing line features like roads full automatically or semi-automatically from digital aerial photographs. Because it is not still possible to designate the full automatic feature extraction methods clearly, the semi-automatic feature extraction methods, which combine experienced interpretation of an operator with the speed of a computer algorithm, are the best solutions.

In this paper, roads are chosen as line features for digitizing from digital aerial photographs, because roads are the most time consuming features to digitize in photogrammetry. There are several semi-automatic road extraction methods but two of them are chosen for the application. First one is based on edge and correlation analyses, developed by Aluir Porfirio Dal Poz. The other one is a road tracing algorithm by profile matching and Kalman filtering developed by George Vosselman and Jurrien de Knecht. In section 2 the road characteristics and the principles of two algorithms are described. Section 3 contains the experiments which are carried out by a software while conclusions are presented in section 4.

## 2. ALGORITHMS OF METHODS

In this section the algorithms of two methods are described but first of all the road characteristics have to be investigated because the algorithms are based on these characteristics.

### 2.1 Characteristics of the roads

The characteristics of the roads can be classified in five groups as below:

- Geometry
- Radiometry
- Topology
- Functionality
- Contextual

An operator uses these characteristics to recognize the roads during the evaluation and mapping processes from the imagery. Both of the two semi-automatic road extraction methods focus on radiometric and geometric characteristics because the other characteristics require more intelligence in order to exploit them automatically from the imagery so complex situations are left to the operator. Examples of these characteristics can be seen below:

- Roads are elongated (geometry)
- Roads have a maximum curvature (geometry)
- The road surface usually is homogeneous (radiometry)
- The road surface often has a good contrast with the adjacent areas (radiometry)
- Roads do not stop without a reason (topology)
- Roads intersect and build a network (topology)
- Roads connect cities (functional)
- Higher roads (fly-overs) may cast a shadow (contextual)
- Trees may occlude the road surface, but, on the other hand, an array of trees may also indicate a road (contextual) (Vosselman and Knecht, 1995).

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## 2.2 Road Tracing by Profile Matching and Kalman Filtering

An operator initializes the road tracer by measuring two points that indicate a short road segment. Between the two points gray value cross sections are computed at intervals of one pixel. The model road profile is taken as the average of these cross sections. This model profile is used as a template in the profile matching. Based on the indicated road segment an initial estimate is made of the parameters that describe the road's position and shape. This estimate is used to predict the position of the first road profile adjacent to the indicated segment. The profile at the predicted position is matched with the model profile. The result of this match is a shift between the two profiles. This shift is used by the Kalman filter to update the parameters that describe the road's position and shape. In the following iterations, the position of the next profile is predicted, the profile at this position is matched with the model profile, and the road parameters are updated. The road tracer continues until some break-off criterion is fulfilled (Vosselman and Knecht, 1995).

In this method least squares profile matching is used to overcome maximizing cross correlation because it can estimate the profile shift's precision which required as input for the Kalman filter. It is also possible to model the geometric and radiometric transformation between the two profiles by the help of least squares matching. Both of the road position and width can be estimated so good results can be obtained whether the road width is changing, when cross correlation fails.

The Kalman filter is a recursive procedure to estimate the parameters of a dynamic system and has found many applications in navigation (Kalman, 1960; Gelb, 1974). In the case of road tracing the parameters to be estimated are the parameters that describe the position and shape of the road. These parameters are called the state (Vosselman and Knecht, 1995).

If the state is not time-dependent, this method does not have a dynamic system but if the distance along the road is treated as if it were the time variable, then the recursive estimation procedure can be used. The Kalman filter consists of two steps:

- Time update
- Measurement update

In the time update an estimate of the state at time  $t+dt$  is made using all observations (i.e. profile matches) that have been made up to time  $t$ . Thus the time update predicts the state at the future epoch  $t+dt$ . In the measurement update the results of the profile match at time  $t+dt$  are combined with the prediction from the time update to obtain an optimal estimate for the state at time  $t+dt$  (Vosselman and Knecht, 1995).

The profile matching compares the model profile with the road profile at the position predicted by the time update. The differences between the two profiles are modeled by two geometric (shift and width) and two radiometric (brightness and contrast) parameters. These parameters are estimated by minimizing the square sum of the gray value differences between the profiles (Ackermann, 1983).

After determining the optimal transformation between the profiles the matching results are evaluated by three checks:

- The cross correlation coefficient between the gray values of the two profiles after the transformation is required to be higher than 0.8.
- The estimated values of the geometric and radiometric parameters should be reasonable. E.g., if the estimated contrast parameter has a high value, say 10, the match can not be accepted. A contrast value of 10 would mean that the gray value contrast in the model profile is 10 times the contrast in the profile at the predicted position. A high contrast value therefore indicates that the latter profile hardly contains any signal and most likely does not correspond to a part of the road.
- A match is only accepted if the estimated standard deviation of the estimated shift parameter is below 1 pixel.

If for one of the above reasons the result of the matching is not accepted, the Kalman filter will not perform a measurement update but instead continue with another time update. Several consecutive rejections of the profile matching can be used as an indication for a road junction or the end of the road (Vosselman and Knecht, 1995).

In this method a constant standard deviation of the profile shift of 0.3 pixel is used in the Kalman filter instead of obtaining by propagating the a posteriori standard deviation of the differences between the gray value profiles and based on the assumption that the gray value differences have a Gaussian distribution. For the Kalman filter processes and algorithms see (Vosselman and Knecht, 1995).

## 2.3 Semi-automatic Road Extraction Based on Edge and Correlation Analyses

This method works with two feedback loops controlling two basic steps and possible interventions of the operator. These basic steps are:

- Extrapolation
- Extraction

The inner loop monitors the failures in the extrapolation and extraction steps and decides whether the method can proceed itself or not. The built-in stopping criterion is based on the percentage of the failures in a pre-defined segment of road. Three situations may be considered concerning the outer loop. First, in the case of successful point extraction the process proceeds normally, i.e., a new loop is initialized. Second, the process may be automatically finished (e.g., the end of the road is detected). Third, the intervention of an operator may be required for finishing the extraction process or reentering the needed information to restart the process (Poz, 2001).

In the extrapolation process a parabola used as the road trajectory model (McKeown and Denlinger, 1988). The most recent points were used to fit the parabola. One characteristic of this solution is that only local extracted information is used to extrapolate the road trajectory. As a result, some weaknesses are expected whenever the method needs to handle a situation involving, for example, an obstacle on a curved road segment. To overcome this limitation, a more global solution is proposed; involving information located ahead the last extracted (Poz, 2001).

The computation of best direction of the road in the last extracted point is carried out by the template which is a matrix of  $m$  rows and  $n$  columns. For matching the template with the road:

- The shorter side of template  $m$  is chosen equally to the road width
- The longer side  $n$  is taken several times greater than  $m$ .

The points of the template, which is designed to rotate  $360^\circ$  around the last extracted point, are resampled from the original image by bilinear interpolation. The new extrapolated point and the best road direction are used by the edge-based extraction process to extract a new road center point. Whenever this process fails in finding a new point, the template is translated to the new extrapolated point and the computation of the best local direction and the piecewise linear extrapolation are repeated and so on (see more details and equations, Poz, 2001).

This method's extraction process is based on the edge-based model presented by Nevatia and Babu (Nevatia and Babu, 1980) and a little modified by McKeown and Denlinger (McKeown and Denlinger, 1988). First, a  $5 \times 5$  Sobel gradient operator is applied to the points along the line that is perpendicular to the best road direction at the extrapolated point. The Sobel values (direction and magnitude) for each point are used to compute a score based on the weighted sum of three component scores. Each of these components is a linear function varying in the interval  $[0; 1]$ . The component scores are the edge strength, the difference in orientation between the edge orientation and the road orientation, and the difference in orientation from each neighboring point (Poz, 2001).

In order to compute the component scores, the Sobel is first applied to every sampled points of cross-section of the extrapolated point and the point sequences whose magnitudes exceed a pre-defined minimum magnitude are detected. The point sequences are potential edge region, which are two for cases close to the ideal situation. The following values are then stored for all detected sequences:

- The point coordinates,
- Sobel magnitude and direction
- The difference in direction between neighboring points
- The maximum magnitude.

In order to allow sub-pixel precision, the selected distance between sampled points needs to be less than 1 pixel. The next step is to compute the component scores and the resulting score for each point of the detected sequences on both sides of the road (see more details and equations in Poz, 2001). Having computed the maximum scores on both sides of the road center, three cases can be identified:

- Two edge points are found on both sides of the road center;
- One edge point is found on one side of the road center
- No edge point is found

If first case occurs, it means that the road center is computed as the middle point between the two edge points. If second case occurs, the road center has to be computed based on the extracted edge point, the computed road width and the current cross-section orientation at the point. On the third case the

extrapolation process guesses ahead and another attempt is done to extract another point.

### 3. APPLICATIONS

These two approaches previously investigated are applied by the help of Borland C++ software.  $500 \times 500$  pixels (each pixel is 1 m) size black and white image is used for the tests. In both methods the same image is used.

Figure 1 shows the results of the road tracer by profile matching and Kalman filter. The traced road is shown in green (means good profile matching) and red (means bad profile matching). The red parts show that the road position is based on the time update only. It works quite good on most parts of the road. Especially at the region where the trees are and at the intersections where the profile matching fails, it works very efficiently and is able to correctly predict the road path. The experiment shows that this method has some problems at the big curvatures.

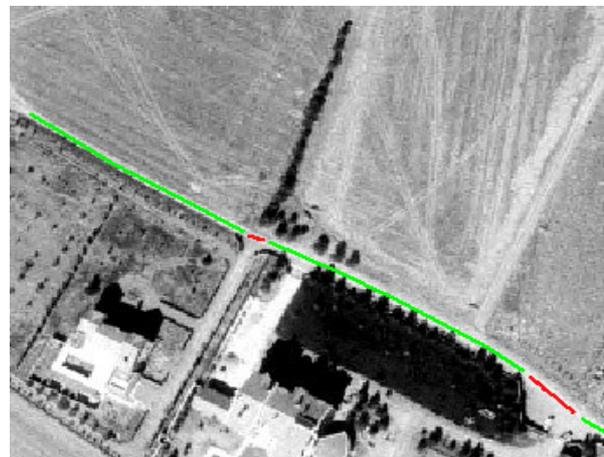


Figure 1. Road tracing by profile matching and Kalman filter

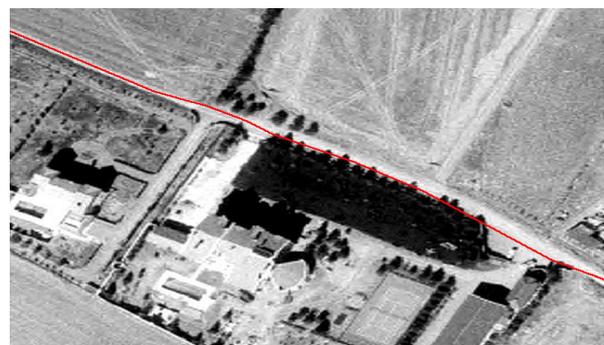


Figure 2. Road extraction based on edge and correlation analyses

Figure 2 shows the results of the road extraction based on edge and correlation analyses. The extracted road is shown in red. The visual interpretation of results reveals that the method works satisfactorily on most parts of the road. This method has some problems where the road width changes too much,

generating a sharp change of extracted road direction due to the temporally one-edge tracing. It has also problems at the region where the trees are (obstacles and shadows). In this field road segment coincides with one out of two road edges, instead of the road axis. It works quite good at the roads which have smooth curves, regular width and good contrast.

#### 4. CONCLUSIONS

In this paper, roads are chosen as line features for digitizing from digital aerial photographs, because roads are the most time consuming features to digitize in photogrammetry. Two road extraction algorithms are applied to digitize roads from mono digital aerial photographs and the results are compared.

Although they have some problems both of semi-automatic methods seems to be very advantageous for digitizing roads from digital aerial photographs because they can be much quicker than the fully human-based solution and the reliability and the precision can be also at a good level.

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