Semi-automated Road Extraction Using Digital High-resolution Aerial and Satellite Images

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***Abstract*—Nowadays are widely used geospatial information-based software applications, among which navigation systems on vehicles, systems monitoring and management of traffic etc., requiring the use of accurate, complete and up-to-date roads, stored in different types of databases. There are many automated or semi-automated algorithms used for road extraction, but in this article is presented a new semi-automated algorithm for extracting roads from high resolution aerial and satellite images based on the weighted correlation of transverse profiles. The algorithm uses, as initial data, two starting points from which one obtains the path's orientation and template profile. Also, the operator must set threshold value of correlation coefficient between cross profiles, search distance, search angle, length of transverse profile and maximum number of rejections. Compared to other semi-automated road extraction algorithms, this algorithm is less sensitive to radiometric changes at the ends of the profile due to the assignment of higher weights to central pixels.**

***Index Terms*—semi-automated algorithm, correlation, road extraction, high resolution images, road databases.**

I. Introduction

The automated extraction of roads from aerial and satellite images has been an important direction of research in the field of photogrammetry in the last few decades.

Usually, there are three phases of the collection process [1, 2]: road identification, road tracking and road linking. The diversity of source images, in terms of space and radiometric resolution, has contributed to the development of several types of algorithms for road extraction from aerial or satellite images.

When human operators are involved in road identification, then the algorithm is semi-automated, otherwise the road extraction algorithm is fully automated.

Currently there are many semi-automated and automated algorithms used to extract roads from aerial and satellite images, and, an exhaustive classification of these is presented by Mena [3].

Semi-automated road collection algorithms use starting points and starting directions provided by human operator in road tracking process. The semi-automated method proposed by Vosselman and de Knecht [4] for road tracking is based on the similarity of road's cross profiles and Kalman filtering. Their method consists in calculating road positions comparing a template profile obtained by mediating the profiles of a reference road segment with profiles extracted from the image. Road parameters are estimated using a recursive Kalman filter. The predictive power of this filter allows the continuation of road tracking even if sometimes no profile similar to the template is found, until a completion criterion is met. McKeown and Denlinger [5] propose a method which uses the most recent road positions to determine a parabola and, further, extrapolates the next road position based on this parabola while Gruen and Li [6] applied a "snake" model and the least squares method to extract 3D roads from stereo models made up of aerial images.

The road collection methods are automated if the starting points are automatically determined, using different approaches, like gray values histogram [7].

In Baumgartner et al. [8], roads are modeled using a network of intersections and connections between these intersections, and determined by grouping processes. Amini, Lucas, Saradjian, Azizi and Sadeghian [9] use an object-based approach for automated extraction of major roads. In first stage, the source image is segmented and straight lines are extracted. Then, the spatial resolution of the source image is degraded and transformed into a binary image. The skeleton of road is then extracted from resulted binary image. Finally, the edges of roads are obtained combining the results of these two stages.

Generally, road tracking algorithms make the assumption that radiometric properties and direction of the road will not change suddenly, a satisfactory hypothesis for most sections of the road network.

This article proposes a new semi-automated extraction algorithm of roads from color aerial images with high resolution, less than 1 meter, which uses the weighted correlation between a template profile and transversal profiles along the road. In order to calculate the starting direction and the template profile, it is necessary that two consecutive starting points, as close as possible to the road axis be provided by an operator.

II. Presentation of Proposed Semi-automated Road Extraction Algorithm

The algorithm for semi–automated extraction of roads from very high-resolution aerial or satellite images in digital format consists of the steps highlighted in Fig. 1.

a) In the first stage the operator has to choose the starting points, minimum correlation threshold between transversal profiles r_{prag}, the transversal profile's length L of the road to be extracted, the length d of search distance, the maximum number of rejections m and search angle α.

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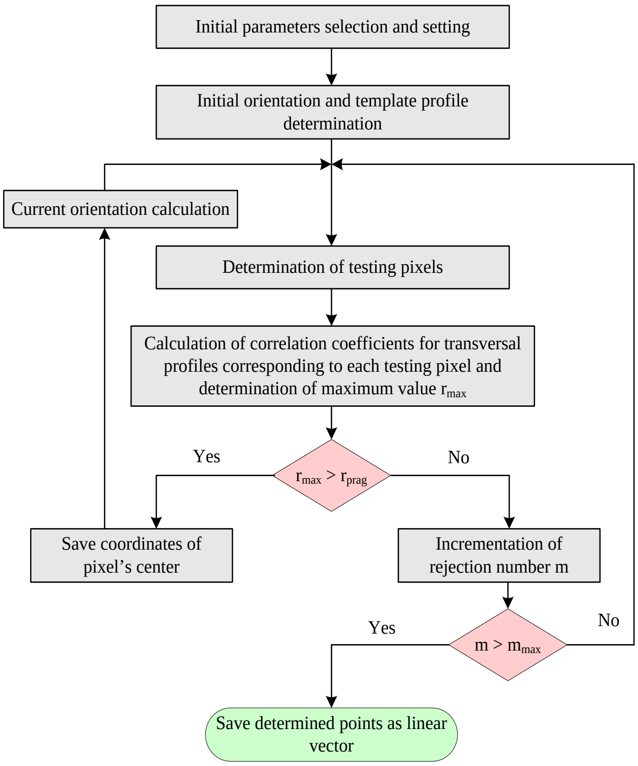

Figure 1. Semi-automated extraction algorithm using profiles correlation [10]

b) Initial orientation θ_2 is determined using the starting points followed by the extraction of two profiles perpendicular to the direction P_1P_2, in P_1 and P_2 points. These profiles are used to calculate the template profile which will be correlated with the search profiles, according to Fig. 2. Template profile is considered either the cross profile obtained in P_2 point or the average profile of cross profiles obtained in initial points. Orientation θ_2 is obtained using the following relation:

$$\theta_k = \operatorname{arctg}\frac{x_k - x_{k-1}}{y_k - y_{k-1}} \qquad (1)$$

where $k = 2$.

c) The coordinates of starting points, $A(x_A, y_A)$ and $B(x_B, y_B)$ are determined using the next formulae:

$$A:\begin{cases} x_A = x_{P_k} + d\sin\left(\theta_k - \alpha/2\right) \\ y_A = y_{P_k} + d\cos\left(\theta_k - \alpha/2\right) \end{cases} \qquad B:\begin{cases} x_B = x_{P_k} + d\sin\left(\theta_k + \alpha/2\right) \\ y_B = y_{P_k} + d\cos\left(\theta_k + \alpha/2\right) \end{cases} \qquad (2)$$

Geometric representation for $k = 2$ is presented in Fig. 2.

The number of pixels t along AB segment is determined based on spatial resolution of source image. Then, for each pixel along AB segment, the coordinates of the pixel's center are calculated.

In case of panchromatic images, for each pixel's center $S_i\left(x_{S_i}, y_{S_i}\right)$, $i = 1 \ldots t$ along AB segment, the orientation θ_{ki} of the segment P_kS_i ($k \geq 2$) is calculated, then the profile perpendicular to direction P_kS_i is extracted and the correlation coefficient between template profile and current profile is calculated, using the following relation:

$$r = \frac{\sum_{i=1}^{n} p_i^2 g_i q_i - \frac{1}{n}\left(\sum_{i=1}^{n} p_i g_i\right)\left(\sum_{i=1}^{n} p_i q_i\right)}{\sqrt{\left[\sum_{i=1}^{n}\left(p_i g_i\right)^2 - \frac{1}{n}\left(\sum_{i=1}^{n} p_i g_i\right)^2\right]\left[\sum_{i=1}^{n}\left(p_i q_i\right)^2 - \frac{1}{n}\left(\sum_{i=1}^{n} p_i q_i\right)^2\right]}} \qquad (3)$$

where n is the number of pixels in the template profile, g_i and q_i, $i = 1 \ldots n$ are gray pixel values of related profiles while p_i represents the weights assigned to each pixel from correlated profiles, and $\sum_{i=1}^{n} p_i = 1$.

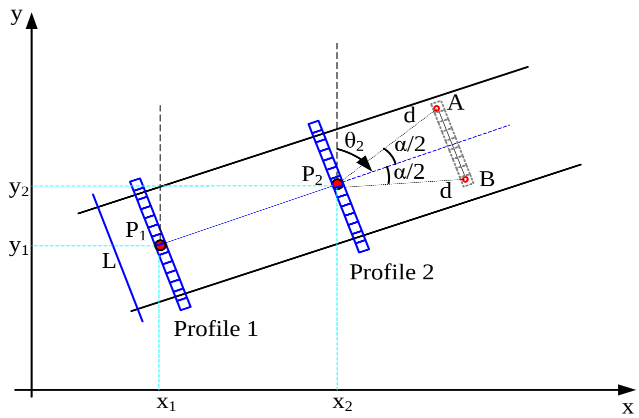

Figure 2. Geometric representation of initial data

If the number of pixels in analyzed profile is n, the scaling factor for the weights of marginal and central pixels is $b \geq 1$ (Fig. 3), then the weight of each pixel in transverse profile is calculated using the relations:

$$p_i = \begin{cases} p_0 + i \cdot u, \text{ for } i = 1 \ldots n_{med} \\ p_0 + (n - i) \cdot u, \text{ for } i = n_{med} \ldots n \end{cases} \qquad (4)$$

where $n_{med} = trunc\left(\frac{n}{2}\right)$, $p_0 = \frac{1}{b \cdot n}$, $u = \frac{b - 1}{b \cdot n_{med} \cdot \left(n_{med} + 1\right)}$.

The weight of central pixel is $p_{n_{med}} = p_0 + 2 \cdot u \cdot n_{med}$.

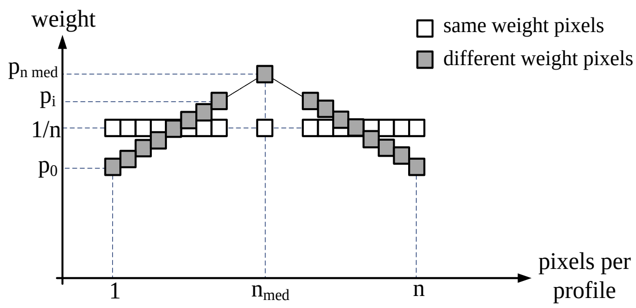

Figure 3. Assignment of pixels weights along a profile

In case of color images (for example, RGB), the final correlation coefficient will be considered the product of correlation coefficients calculated for each spectral band. The point S_i, where the value of the correlation coefficient between the profiles is the highest, will be saved (Fig. 4).

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d) If maximum correlation coefficient value is greater than or equal to threshold value of correlation coefficient set by operator, then the coordinates of S_i point, corresponding to the maximum value of the correlation coefficient, are saved. Further, the orientation θ_{ki} becomes the current orientation and the search process of the next point resumes from step c), and previously-determined point S_i becomes P_{k+1}. Otherwise, the number of rejections m is incremented and the point S_i is rejected.

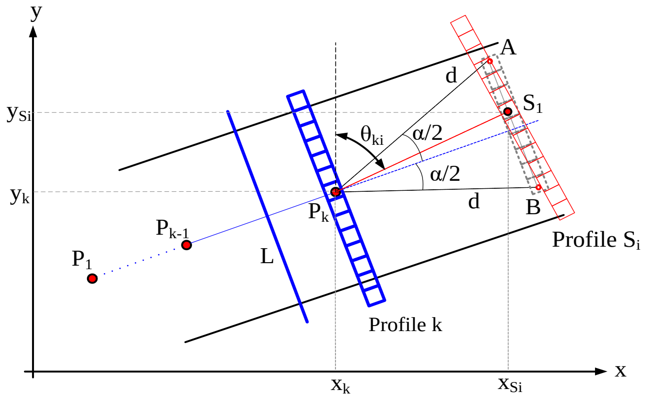

Figure 4. Identification of pixel for which correlation coefficient is the best

e) If m does not exceed the initially set maximum value, then ending point coordinates of a new $A'B'$ segment are calculated, according to Fig. 5. Thus, the segment $P_k P_j$ ($j = k + m$ has the length $m \cdot d$ and the coordinates of points A' and B' are determined using the next relations:

$$A': \begin{cases} x_A = x_{P_k} + m \cdot d \cdot \sin\theta_k + d \cdot \sin\left(\theta_k - \alpha/2\right) \\ y_A = y_{P_k} + m \cdot d \cdot \cos\theta_k + d \cdot \cos\left(\theta_k - \alpha/2\right) \end{cases}$$
$$B': \begin{cases} x_B = x_{P_k} + m \cdot d \cdot \sin\theta_k + d \cdot \sin\left(\theta_k + \alpha/2\right) \\ y_B = y_{P_k} + m \cdot d \cdot \cos\theta_k + d \cdot \cos\left(\theta_k + \alpha/2\right) \end{cases} \quad (5)$$

where m is the number of rejections.

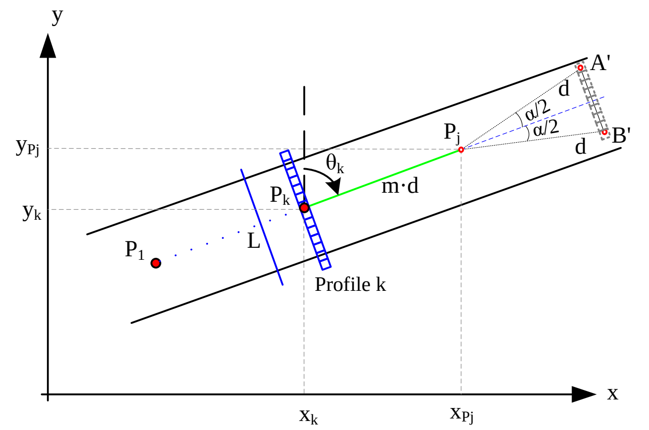

Figure 5. Determination of search pixels line $A'B'$ in case of successive rejections

In order to determine the correlation coefficients for the profiles along the $A'B'$ segment, the algorithm resumes from step c).

If m exceeds initially selected maximum value, then the extraction algorithm stops and saves the initial points and those determined by correlation as linear vector.

III. PRESENTATION OF *EXTRACTROADS* APPLICATION

The algorithm previously presented was implemented by the authors using Visual Basic .NET programming environment and ArcGIS SDK. The application, named **ExtractRoads**, is a dynamic linking library (DLL extension), and its interface is shown in Fig. 6. **ExtractRoads** application runs on computers with the Microsoft Windows operating systems and ArcGIS software package installed.

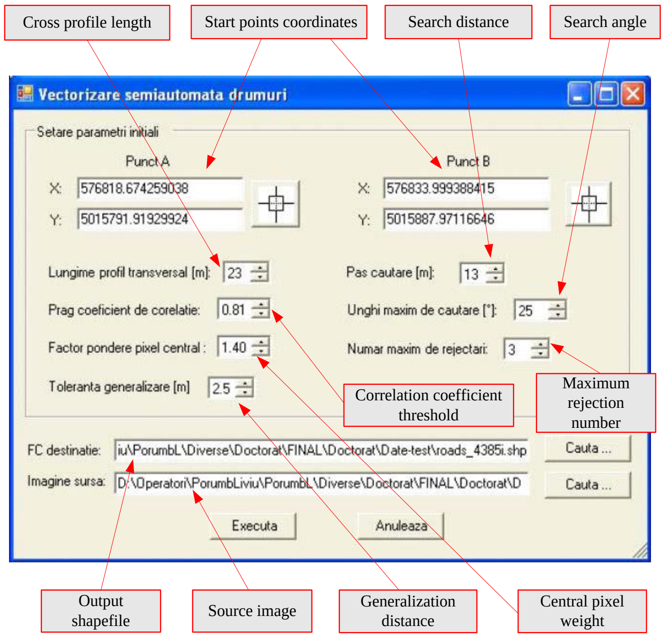

Figure 6. **ExtractRoads** application interface

After launching the application, the operator has to perform the following steps:

- provide the coordinates of the two starting points either by typing or by clicking points on the source digital image; it is necessary that these points be located as close as possible to the road axis in order to obtain a template cross profile that is as representative and accurate as possible;
- set the values of parameters required for semi-automated extraction algorithm: the cross-profile length of the road, maximum number of rejections, the threshold value of the correlation coefficient, search distance and search angle. It is recommended that the length of the profile be 1–2 meters longer than the road width in order to obtain a proper correlation. Search distance can be set between 1 and 30 meters and search angle can vary between 20° and 120°. The weight scaling factor actually determines the influence of central pixel in correlation coefficient determination and can range between 1 and 2. Maximum number of rejections parameter can take integer values from 1 to 3 and algorithm stops when this value is reached. Minimum value of correlation coefficient is 0.7, but it is recommended to use a value greater than 0.8 in order to obtain proper data. The resulted vectors can be generalized using Douglas-Peucker algorithm [11], setting the value of the vertex removal tolerance in the range of 1 to 4 meters;
- select the location and name of ESRI shapefile in which extracted roads will be saved as linear vectors. The coordinate system of resulted vectors will be the same as that of source image;
- select the file that contains the digital image of the area where the road extraction is executed.

Pressing the button **Executa**, the algorithm is initialized and road extraction process begins. Resulted points are saved as line vectors which are displayed on the screen symbolized with the red color.

IV. Practical Results

The application was used to test the proposed algorithm for extraction of seven road segments located in the western part of the city of Braila (Fig. 7). The source image, existing at Defense Geospatial Information Agency of Romanian Army, is a high-resolution rectified image, having 30 cm spatial resolution.

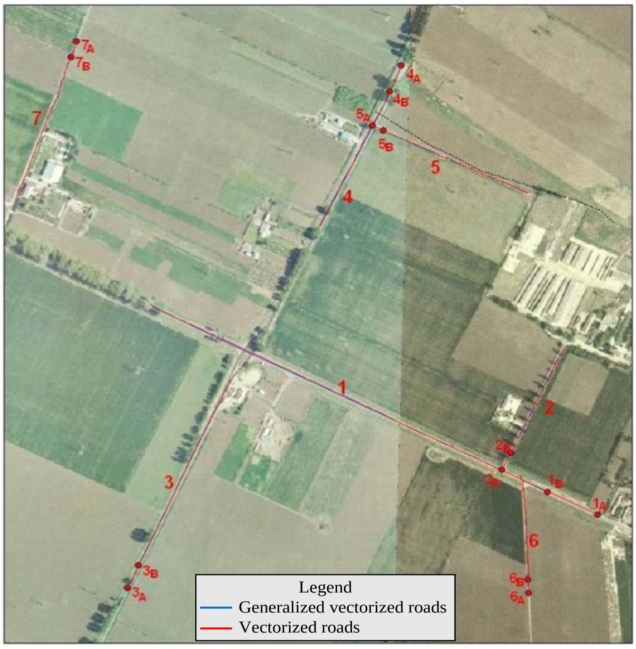

Figure 7. Semi-automated extracted roads in study area

In Table I are presented initial data for which optimal results were obtained by running the application, road extraction times and the maximum measured distance relative to the road axis.

TABLE I. Initial Parameters and Resulted Data after Extraction

Seg. no.	Initial parameters							Time [s]	Max dist. [m]
	L	d	r_{min}	θ	b	m_{max}	t_{gen}		
1	12	7	0.84	25	1.4	2	2	43	1.8[2]
2	10	7	0.84	25	1.5	2	1.5	12	1.6
3	13	7	0.82	30	1.6	3	2	32	1.9
4	13	7	0.84	30	1.4	3	2	20	1.2
5	8	4	0.89	25	1.4	2	1	21	1.3
6	8	5	0.89	25	1.4	2	1	9	1.6[2]
7	9	5	0.89	25	1.4	3	1	12	1.6

L – road cross profile length, in meters; d – search distance, in meters; r_{min} – minimum correlation coefficient; θ – search angle, in decimal degrees; b – weight scaling factor; m_{max} – maximum number of rejections; t_{gen} – generalization tolerance, in meters.

The influence of values set for input parameters is analyzed in the next paragraphs.

[2] The last vertex of the polyline determined by the algorithm was excluded from maximum deviation calculation

Thus, the length L of the transversal profiles along the road must be approximately 10–20% longer than the road width in order to ensure a better correlation and obtain vertices as close as possible to road axis. In case of setting values outside the range specified previously the algorithm could stop prematurely and generated vectors would have short lengths.

It was noticed that the extraction results are better when choosing a search distance value d greater than half of the profile length but smaller than profile length. Otherwise, the algorithm could retain points that are not situated on roads even cross profiles have similar spectral characteristics with template profile, for example in case of plowed areas along natural roads.

It is recommended that threshold value for correlation coefficient be higher than 0.8 in order to obtain geometrically and semantically properly vectors. For roads with hard surface (asphalt, concrete) the value of r_{min} should be chosen between 0.8 and 0.86 and for natural roads r_{min} has to be higher than 0.85.

The number of pixels in which test cross profiles are extracted (Fig. 4, *AB* segment) depends directly on the value of search angle.

Thus, if the value of search angle θ is high, the number of pixels used to extract cross test profiles will be higher. For smooth roads it is recommended to choose a value for θ less than 20–25°.

The weight scaling factor actually determines the influence of marginal pixels in correlated transverse profiles. It was noticed that values greater than 1.6 are not recommended due to the fact that weight of the marginal pixels decreases significantly while values lower than 1.2 lead to a considerable increase in their importance.

In the current implementation of the algorithm the maximum number of successive rejections allowed is 3, value that avoids erroneous collection of points that do not belong to the road to be extracted. The allowed minimum number of rejections is 1.

Due to the fact that extracted roads have a lot of vertices, one can generalize them using Douglas-Peucker algorithm. Generalization tolerance is chosen according to the road width and accurate roads could be obtained if, in case of natural roads is chosen a value lower than 2 meters and, for roads with hard surface, values higher than 2 meters are generally recommended (Fig. 8).

It was found that the length of the road to be digitized, as well as values chosen for search distance and search angle, have a significant influence on extraction time. Thus, for small values of search distance, there will be more points in which segments with testing pixels are generated, while for larger search angles, the number of pixels, in which perpendicular profiles to the direction formed by the last determined point and the current point are extracted, is bigger.

Regarding the measured values for maximum deviations of generalized vectors from the road axis, one can remark that they vary depending on length of road profiles and the road width. There are cases when the final vertex or more vertices are not on the road, as presented in Fig. 9.

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Figure 8. Generalized roads (blue) and non-generalized roads (red)

Figure 9. Final vertex of segment 6 position is out of road

This is mainly due to the mediation of the previous profile with the profile from the second starting point, a lower correlation coefficient threshold and similar radiometry along the profile. These minor shortcomings can be manually corrected. Except for these situations, such as the final vertices of segments 1 and 6, in which deviations at the end points were not measured for calculating overall accuracy, the other deviations do not exceed 2 meters. Based on these values, one can conclude that planimetric accuracy of analyzed extracted roads is very good.

Another factor that can be analyzed is the completeness of semi-automated roads collection from rectified images. It could be expressed as the ratio of semi-automated extracted road segment length and real road length. In practice one can notice that, generally, the completeness factor is smaller for roads with hard or loose-light surface and very good for natural roads [10].

The main explanation is the presence of various natural or artificial topographic details on the roadsides: trees (Fig. 10), parked or moving cars, constructions, etc. For example, in case of many trees along the road and theirs shadows, the algorithm stops. Further, if the value of the search step multiplied by the current number of rejections exceeds the size of an obstacle on the roads, the algorithm continues only if at next search a profile is found, similar to the template profile, and the current number of rejections does not exceed the initially set maximum value.

Generally, in case of simple intersections, the algorithm tends to continue road extraction in the direction which the orientation closest to the previous orientation. In case of more complicated intersections, where road's width changes or there is overpassing infrastructure or other buildings (Fig. 8), the algorithm stops.

In tested area there were no sinuous roads but the algorithm works well if their physical characteristics remain unchanged. Fig. 11 illustrates an example of sinuous road extraction.

Figure 10. Influence on road extraction of trees situated near the road

Because in practice the reflectivity of a road is not constant along its entire length and it varies depending on the surface material and other topographic details and nearby artificial elements, road's segments can be extracted successively by using the last vertex determined by the application and the second point chosen interactively.

Figure 11. Extraction of sinuous road

V. CONCLUSIONS

The algorithm proposed by authors could be integrated in software tools and used for semi-automated extraction of roads from high resolution aerial or satellite images with some limitations, mainly due to shadows of successive natural or artificial big objects situated close to roads.

This algorithm is more robust than other algorithms using correlation techniques due to the fact that it is less sensitive to the influence of pixels at the edges of roads and it can use more spectral bands. It tends to collect point situated close to road axis and it works well even the surface material changes or the illumination is varying along the road.

In order to improve the algorithm future work would take into consideration the use of a correlation window (rectangle, ellipse, etc.) rather than a single cross profile. To avoid rejections could be used supplementary processing. For example, the search distance could be gradually reduced, until a cross profile which matches the template one is found, or the last valid determined point can be retained and the orientation from the penultimate two valid points can be used further.

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