AUTOMATIC 3D EXTRACTION OF RECTANGULAR ROADMARKS WITH CENTIMETER ACCURACY FROM STEREO-PAIRS OF A GROUND-BASED MOBILE MAPPING SYSTEM

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ABSTRACT:

The present paper is an extension of a previous work presented in Soheilian *et al.* (2006) in which an automatic algorithm of zebra-crossing reconstruction from stereo-pairs of a mobile mapping system was presented. The method has been adapted to reconstruct different kinds of rectangular roadmarks. The algorithm can be summarized in three main steps. First of all a 3D edge point reconstruction is performed by a dynamic programming optimization matching conjugate epipolar lines. Then during a detection step, dashed-line signature is recognized and sets of candidate line-segments are provided. A final modelling step optimally rebuilds each strip of the detected dashed-line. The method is evaluated on a set of 150 stereo-pairs. It provides promising results with a detection rate higher than 86%. Geometric accuracy of the method is about 2 cm for all of the reconstructed zebra-crossing and dashed-lines strips.

1 INTRODUCTION

Mobile mapping systems (El-Sheimy 1996) are more and more used in road database generation and update. A mobile mapping system (MMS) generally consists of a vehicle equipped with data acquisition systems such as Laser scanners and cameras. It is also equipped with georeferencing devices such as GPS (Global Positioning System) and INS (Inertial Navigation System). From data acquisition and positioning systems points of views, different kinds of MMS are used in road modelling.

In a real time system presented in Goulette *et al.* (2006), a laser scanner and direct localization sensors (GPS/INS) are used to acquire a 3D point cloud of the city. Within the scanned point cloud, the road points are segmented automatically and some useful information such as road borders, width and curvature are computed.

In the system proposed by Roncella and Forlani (2006) a stereoscopic image-based system is applied for countryside roads surveying. A semi-automatic image processing method is then used to measure lane width with 10 cm accuracy.

Another MMS that is generally used for road monitoring is presented in Barsi *et al.* (2006). The acquisition system is a combination of a pair of stereo-images and a set of laser projectors. The system provides the post-processing for the cross and longitudinal section extraction and crack detection.

In all of these mentioned applications, georeferencing is based only on direct positioning tools such as GPS and INS. However in dense urban areas the GPS signals are interrupted by high buildings which lead to the corruption of positioning process. In this case the absolute accuracy of positioning reach 1 m for long interruptions.

The aim of the project to which this work belongs is to generate automatically 3D road databases in urban areas with a centimetre accuracy. Nevertheless on the one hand, direct positioning does not provide sufficient accuracy, on the other hand road borders are always occluded by cars and could not be extracted. The roadmarks are useful features that are available on the majority of urban roads. Their size and shape are governed by strict specifications. The present work focuses on roadmark reconstruction for three following reasons:

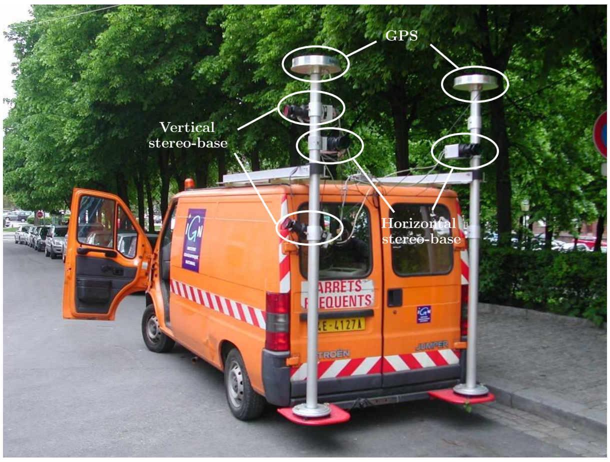
1. In our system, roadmarks are used to improve the positioning of system into a centimeter accuracy. It is performed by matching roadmarks reconstructed from terrestrial images of MMS with the same roadmarks reconstructed from calibrated aerial images (Tournaire *et al.* 2006).
2. After road borders, roadmarks are the only features that can specify a road with centimetric accuracy. Moreover they give useful information about the number of lanes and their width.
3. There is a growing need for roadmark databases in autonomous navigation projects and driver assistance systems.

This paper is an extension of our previous algorithm of zebra-crossing reconstruction (Soheilian *et al.* 2006) to rebuild different kinds of dashed-lines. Similar to the algorithm developed for zebra-crossings reconstruction the output is a set of 3D models for each strip. More evaluations are then presented on a set of 150 images.

2 THE STRATEGY

2.1 Available data

Our MMS called *Stereopolis* (Paparoditis *et al.* 2005) is developed at the MATIS laboratory of IGN (See Figure1(a)). It consists of three stereoscopic rigs of 4000×4000 CCD cameras. The vertical rigs take images of the facades. The horizontal stereo-base provides stereo-images of road. The six cameras are perfectly synchronized ($10\mu s$) and provide very high quality images (SNR = 300 and 12 bits dynamic range). The system is also equipped with 2 GPS antennas. The inputs of our roadmark reconstruction algorithm are the stereo-pairs provided by horizontal base of *Stereopolis* at their full resolution. (See Figure 1(b)). The interior calibration and relative orientation of the rig are *a priori* estimated and supposed to be rigid.



(a)

(b)

Figure 1: (a) *Stereopolis* MMS, (b) a stereo-pair captured by horizontal base.

2.2 Algorithm overview

As depicted in Figure 2, the algorithm consists of three main steps of 3D edge chain reconstruction, different roadmark detection and strip modelling. Compared to our previous work (Soheilian *et al.* 2006) the first step remains unchanged. The detection step is generalized to recognize dashed-lines and to provide a set of line-segments as hypothetical candidates for each strip. So in the modelling step, compared to the previous work carried out for the zebra-crossing modelling, only the strip size parameters are changed. The output is a set of 3D strips.

3 3D EDGE CHAINS RECONSTRUCTION

As explained in our previous work (Soheilian *et al.* 2006) the reconstruction step which is based on edge point matching between stereo-images can be summarized as follows:

- Edge detection in each image,
- Limitation of matching search area to an area around the road,
- Using correlation score to compute the initial matching cost,
- Final matching cost computed by taking into account the *figural* continuity,

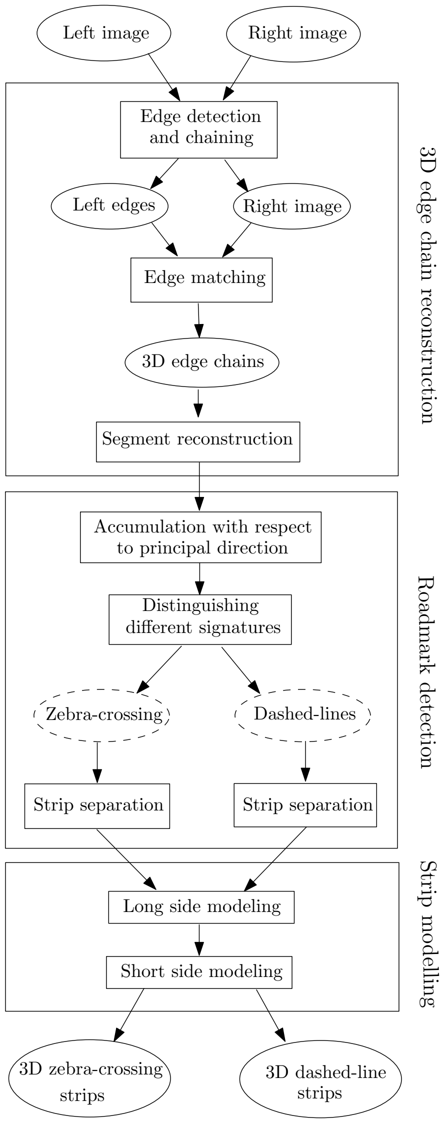


Figure 2: Our zebra-crossing and dashed-line strip reconstruction strategy.

- Matching by total cost minimization using dynamic programming.

The output of the matching step is a set of 3D edge chains. A set of line-segments is then estimated by polygonization. Figure 3 shows the reconstructed edge chains corresponding to the stereo-pair of Figure 1(b).

4 DASHED-LINE DETECTION

As zebra-crossing and dashed-line strips are parallelogram patterns, we try to detect the 4 corners of each strip. However the strip corners are often damaged and do not respect the theoretical pattern. Moreover even if an undamaged strip is partially occluded by cars or pedestrians, the corner detection will fail. This is the reason why corner detection algorithms are not suitable for strip detection. Our solution is to find each pair of parallel sides and to reconstruct the corners by intersecting edge sides. Regarding the results of reconstruction step the main difficulties of strip side detection are:

- The reconstructed set contains too many irrelevant objects such as cars, pedestrians, local textures, etc.

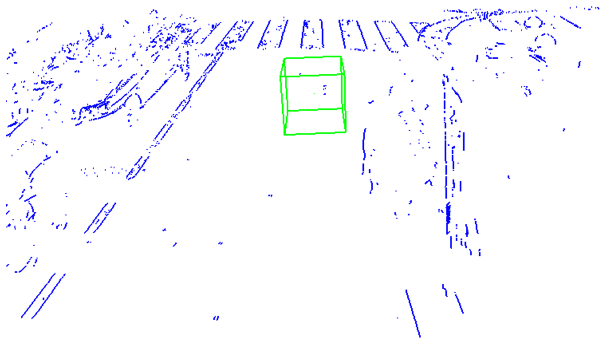


Figure 3: Reconstructed 3D edges.

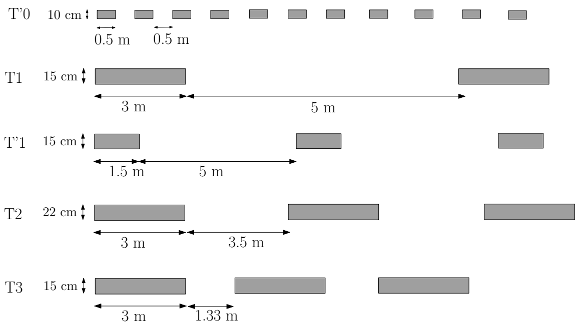


Figure 4: Specification of different kinds of dashed-lines.

- The chains are often fragmented due to edge detection and matching steps.
- The transversal sides of strips are not often correctly reconstructed due to the fact that they are aligned with epipolar lines.

In the detection step, the two long sides that are rarely parallel to epipolar lines are detected and the transversal sides are detected by searching around the extremities of the detected long sides. So only the first two difficulties must be handled.

The dashed-line strip detection algorithm is very similar to the detection of zebra-crossing strips. However because of their shorter length and their relative aligned position, different from zebra-crossing strips some changes have been made. In Section 4.1 the known specifications of dashed-lines are presented. Section 4.2 begins with a short summary of our previous detection method. Then the performed changes for dashed-line detections are explained.

4.1 Dashed-lines specifications

In France roadmarks are painted on the roads according to strict specifications (Transport Ministry and Interior Ministry 1988). For each kind of dashed-line, their strips' length, width and also their inter-distance are known (see Figure 4).

4.2 Dashed-line strip detection

In order to cut-down the complexity, all the reconstructed line-segments are projected on the road's approximate plane and the detection step is performed in this 2D space. This approximate plane is close enough to the road surface so that the deformation due to the projection is negligible. The initial 3D coordinates are saved in an appropriate data structure in order to refine the final modelling. Like zebra-crossing strips, dashed-line strips are always aligned with road main axis. Indeed road axis is the most occurring axis within the line-segments and can be estimated automatically. We define a one-dimensional accumulation space in the perpendicular axis to road axis. This accumulation space is discretized to cells with a step size that is proportional to the reconstruction accuracy (1 cm in our case). Each line-segment will vote with its length for the cell in which it is projected. So the line-segments that are perfectly parallel to road direction will vote by their total length for only one cell and the others will share their voting power between all the cells in which they are projected. Figure 5(a) depicts the initial line-segments and corresponding accumulation.

Two main signatures can be observed. The first one is a periodic high accumulation score in cells with a distance of 50 cm. The second signature us composed of two high scores with about 10 cm of distance. As seen in figures 5(b) and 5(c) these two signals can be extracted by thresholding with respect to known width and length of strip. However for dashed-lines thresholding is performed with lower values. Even if all dashed-line strips vote for the same cells and cause a high score, when only few strips are available the cells' score is very low. So the thresholding is performed with a lower value (the length of only one strip). As seen in the Figure 5(c) this causes some irrelevant segments to pass the filtering step. In order to cope with this problem and separate the strips of a dashed-line, a radiometric profile is computed along the dashed-line (see Figure 5(d)). This profile can then binarized with a threshold chosen as mean of maximum and minimum values. The outputs are sets of line-segments, candidates for each strip.

5 STRIP MODELLING

The set of line-segments for two long sides of a candidate strip is injected in the modelling step. As described in Soheilian *et al.* (2006) the modelling step consists of two main steps:

1. Modelling the two long sides of a parallelogram form strip if the candidates satisfy the known strip size.
2. Refining the model by searching for non-reconstructed transversal sides.

The figure 5(e) depicts the results of long side modelling of dashed-line strips. The extremities are not correctly reconstructed and lead to trapezoid forms. Our solution is to retrieve the transversal sides to model an optimal quasi-parallelogram. Figure 5(f) shows the final 3D reconstructed model of the running example and Figure 6 depicts their image projection.

Figure 6: The reconstructed zebra-crossing and dashed-line.

6 RESULTS AND EVALUATIONS

In order to evaluate the robustness and accuracy of our algorithm two kinds of evaluations are performed:

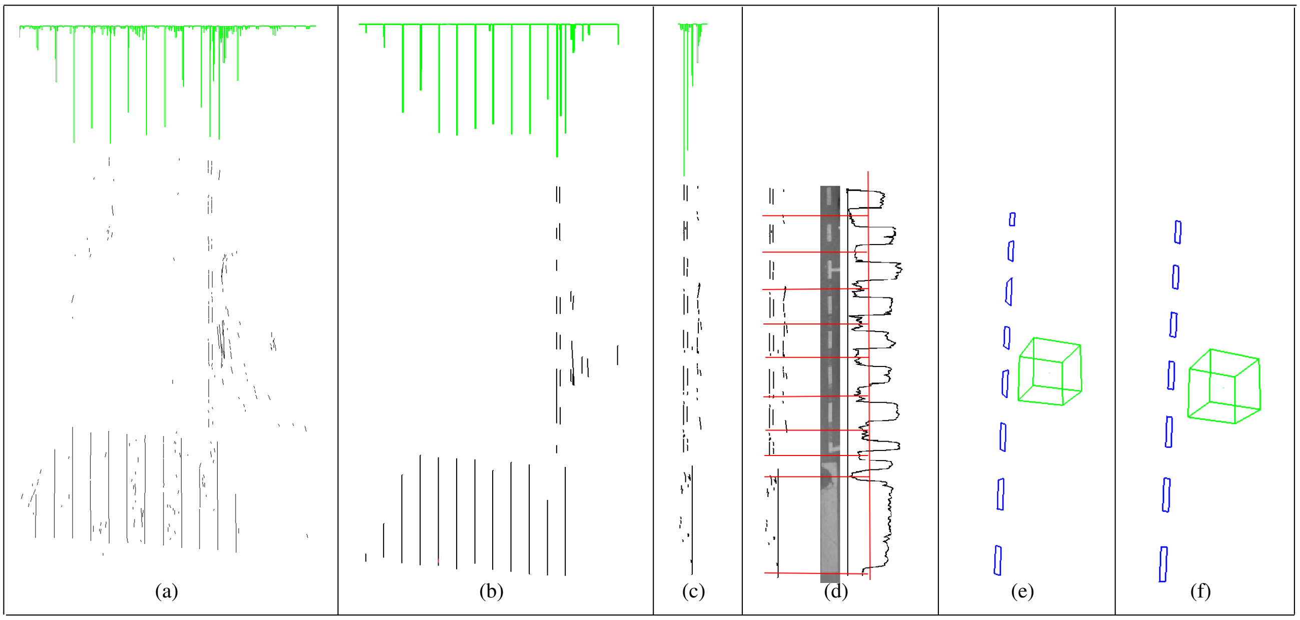


Figure 5: (a) Initial line-segments and corresponding accumulation, (b,c) zebra-crossing and dashed-line signature detection, (d) radiometric profile and strip candidates separation, (e) strips' long side modelling, (f) final strip modelling.

1. Geometric accuracy evaluation by computing RMS (Root Mean Square) value for reconstructed roadmarks coordinates.
2. Completeness evaluation by computing detection, quality and false alarm rates.

6.1 Geometric accuracy evaluation

In order to test the geometric quality of the reconstructed roadmarks, some reference zebra-crossings are measured by sub-centimeter surveying methods (total stations). The reconstructed zebra-crossings are compared to the surveying measures and RMS is calculated on all strip corners. We reach $2\ cm$ RMS accuracy which is relatively higher than our $5\ mm$ GSD (Ground Sample Distance) at the distance of object from stereo-base. This is due to differences between the theoretical model of the object and the real object itself (non planarity, etc.)

6.2 Completeness evaluation

In order to evaluate the completeness of our algorithm, it is applied to 150 successive stereo-pairs with 4000×4000 resolution that have been acquired in the city centre of Amiens in France. Figure 8 presents some of the obtained results. For each stereo-pair, the number of true-positives (TP_i), false-positives (FP_i) and strips that are visible in stereo which could be reconstructed (S_i) are counted. The following three performance measures are then computed for each type of dashed-lines and zebra-crossing.

- Detection rate: $\rho_d = \frac{\Sigma TP_i}{\Sigma S_i}$, $\rho_d \in [0, 1]$. (high values are better).
- Quality factor: $\rho_q = \frac{\Sigma TP_i}{\Sigma S_i + \Sigma FP_i}$, $\rho_q \in [0, 1]$. (high values are better).
- False alarm rate: $\rho_f = \frac{\Sigma FP_i}{\Sigma S_i}$, $\rho_f \in [0, \infty]$. (low values are better).

The results are presented in Table 1. Regarding ρ_q of $T2$ dashed-line, the quality rate is very low due to the large number of false-positives. It is often caused by non-roadmark objects that respect perfectly the dashed-line strips specifications. Figure 7 presents two false strips of $T2$ dashed-line type that are detected in the lighter border of road. This kind of FP can be filtered by a post-processing by considering stronger radiometric criterion.

Figure 7: An example of two false-positives for $T2$ dashed-line type.

7 CONCLUSION AND PERSPECTIVES

Our previous zebra-crossing reconstruction algorithm is extended to dashed-lines. The input of our algorithm is a calibrated stereo-pair of images. The algorithm is fully automatic and the output is a 3D model of roadmarks. The so called algorithm is tested on a large set of images and revealed robustness, accuracy and completeness for both zebra-crossings and dashed-lines. It is quite generic and can be applied to detect and reconstruct other planar parallelograms such as windows. It can be used to generate a complete roadmark database. This database can be applied in:

1. Accurate Georeferencing of the MMS (Tournaire *et al.* 2006),
2. Roadmark GIS and autonomous navigation projects (Soheilian *et al.* 2006).

The roadmarks are nowadays reconstructed independently in each stereo-pair. With high frame rates and thus highly overlapping images, the merging of independent results in object space will increase robustness and completeness. This is a work in progress.

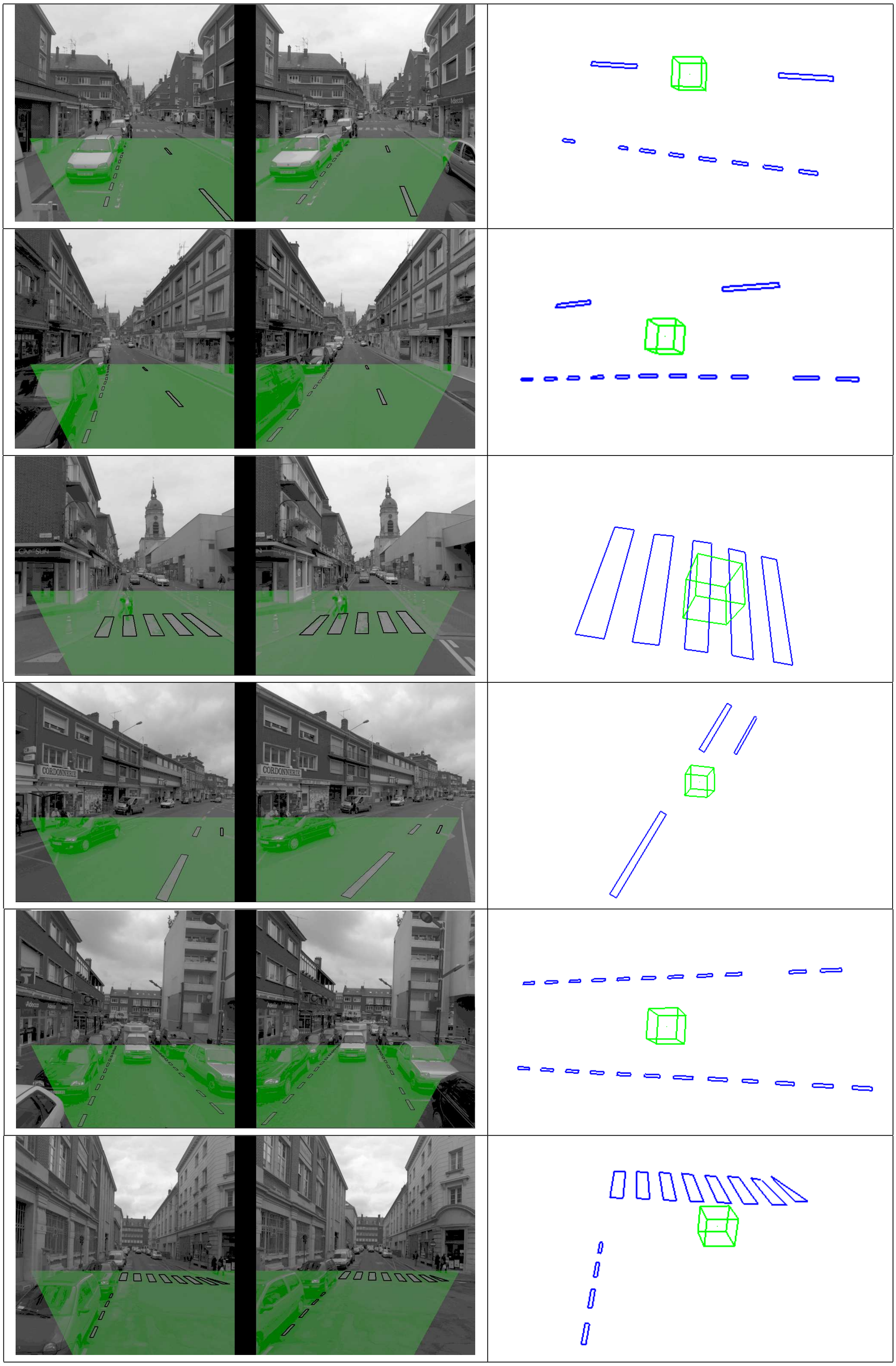


Figure 8: (Left) The stereo-image projection of reconstructed roadmarks – the overlapping region is highlighted –, (Right) 3D reconstructed roadmarks.

Type	Size (cm)	S	TP	FP	ρ_d	ρ_q	ρ_f
Dashed-lines							
T'0	10×50	485	416	20	86%	82%	4%
T'1	15×150	51	50	12	98%	79%	23%
T 3	15×300	30	30	2	100%	93%	7%
T 2	22×300	6	6	27	100%	18%	450%
Zebra-crossing							
—	$50 \times X$	359	329	8	92%	90 %	2%

Table 1: Completeness evaluation of roadmark reconstruction.

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