EXTRACTION OF 3D ROAD GEOMETRY FROM AIRBORNE IFSAR DATA

Q. Zhang [a]*, L. Giovannini [b], M. Simantov [a], J. de Vries [a], M. Vuong [a], S. Griffiths [a], B. Mercer [a], X. Li [c]

[a] Intermap Technologies Corp., 500, 635 – 6th Ave SW, Calgary, Alberta, T2P 0T5 Canada - (qzhang, msimantov, jdevries, mvuong, sgriffiths, bmercer)@intermap.com
[b] Intermap Technologies GmbH, Heimeranstrasse 35, 80339, Munich, Germany - lgiovannini@intermap.com
[c] Intermap Technologies Corp., 200 - 2 Gurdwara Road, Ottawa, Ontario, K2E 1A2, Canada - xli@intermap.com

Commission III, WG III/4

KEY WORDS: Road extraction, 3D, DEM, InSAR, IFSAR

ABSTRACT:

Building an accurate 3D road database is important for many future advanced automotive applications. Intermap is in the process of collecting 2D road networks based on its orthorectified radar imagery and extracting elevations from its IFSAR-derived DEMs. The current 2D collection process is mainly manual, while the elevation assignment to the 2D road vectors is highly automated. This paper presents a semi-automated approach for 2D road extraction from radar imagery and discusses the challenges that we are facing in terms of assigning elevations and the approaches that we have been taking to building 3D road geometry based on IFSAR-derived DEMs. Validation results from various areas in Europe have shown that the 3D road vector products have overall vertical accuracy in the range of 0.5 to 2.0m RMSE, depending on the complexity of the area and the amount of road obstruction due to forest and buildings.

1. INTRODUCTION

Research has shown that 3D road geometry can play a significant role in a number of automotive applications such as Advanced Driver Assistance Systems (ADAS) (e.g., predictive adaptive front lighting, adaptive cruise control, and lane keeping assist) (Dobson, 2009), fuel economy (e.g., predictive throttle control, predictive transmission control, and hybrid power cycle optimization) (Li and Tennant, 2009; Zhang *et al.*, 2009), etc.

There have been a few different approaches to building a 3D road network. Using a land-based mobile mapping system is one of the most popular methods adopted by some major navigation data providers (Dobson, 2009; IDG Service, 2007). However, as the mobile mapping system has to be physically driven on the roads, this approach has been considered time consuming and viable for only highways or major roads, which accounts for less than 10% of all the driveable roads (NAVTEQ, 2006).

An alternative approach is to extract the road vector data from imagery – either optical or radar. Cost of source data, wide-area availability, resolution and accuracy are all factors in this type of approach. In this work, we take advantages of the relatively high-resolution orthorectified radar images (ORIs) and digital elevation models (DEMs) that have recently been created through the NEXTMap® Europe and NEXTMap® USA programs. These products have been created seamlessly using airborne interferometric SAR (IFSAR or InSAR) for most of Western Europe (~2.2 M km^2) and the USA (lower 48 states plus Hawaii ~8.0M km^2) (Mercer and Zhang, 2008) and have the spatial accuracy and spatial detail required for 3D road extraction in most areas. What is referred to generically as DEMs, is in fact represented by two elevation products: DSMs (Digital Surface Models) and DTMs (Digital Terrain Models). DSMs are created directly from the IFSAR and as the name implies, represent the apparent surfaces of terrain and objects upon it including natural surfaces such as that of vegetation or man-made objects such as buildings. DTMs represent the bare terrain and are derived from the DSMs. The ORI data have resolution of 1.25m over most of the NEXTMap Europe and USA data sets (0.625m for some) with absolute horizontal accuracy at the 2m RMSE level. DSM and DTM data are posted at 5m with 1m RMSE vertical specification (unobstructed, moderate sloped terrain).

For purposes described above, Intermap is in the process of collecting 2D road networks based on its ORIs with the third dimension coming from the DEMs. The current process for 2D collection is manual (using special-purpose workstations with Intermap proprietary software) and hence labour intensive. There is a need to integrate some automated algorithms to speed the collection process and also to ensure the quality of the extracted road vectors. This has led to some research and development on a new approach to semi-automated 2D road network extraction from Intermap's ORIs (Giovannini *et al.*, 2010). In this paper we will review the current performance of this approach.

The elevation assignment to the 2D road vectors based on DEMs is highly automated. In this paper, we will discuss the challenges and the approaches that we have been taking along with the results of validation studies.

An overview of our 3D road program is given in Section 2 followed by detailed methodologies and evaluation results in Section 3 and 4 for the semi-automated 2D road collection and the elevation assignment respectively. Section 5 is our conclusions and future work.

* Corresponding author.

2. OVERVIEW OF 3D ROAD PROGRAM

The main objective of our 3D road program is to provide an accurate and continent-wide homogeneous road network database with full road coverage. Such a database is strongly demanded by automotive ADAS and energy management applications.

In our program, road vectors are classified as: highways (Category 1), major Roads (Category 2), minor Roads (Category 3), and local Roads (Category 4). A feature code is used to determine whether a vector is a road, a bridge, or a tunnel. Currently we are focusing on the centrelines only. Further data can be derived such as, curve radius, beginning and end of curves, centerline slope, beginning and end of hills, and inflection points.

Figure 1 shows our 3D workstation and interface used in 3D road collection.

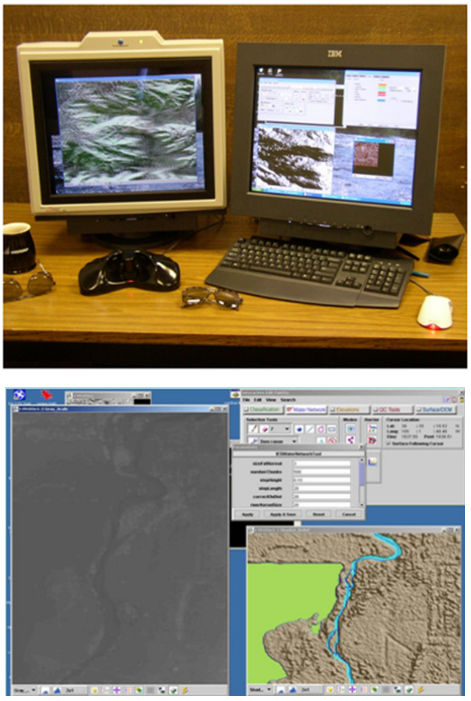

Figure 1. 3D Workstation (Top) and 3D Vector Collection Software (Bottom)

3. SEMI-AUTOMATED 2D ROAD EXTRACTION

Road extraction from orthorectified radar images has gained a lot of interest in the past decades with the increasing availability of high resolution spaceborne and airborne radar systems (Tupin *et al.*, 1998; Wessel *et al.*, 2002; Bentabet *et al.*, 2003). However, radar imagery is quite different from optical. It is considered less suitable for object extraction and its processing is more complicated (Baltsavias, 2004).

In the area of road extraction from remotely sensed imagery, the semi-automated methods are preferred by many researchers because of the on-the-fly editing capabilities they offer to the user (Doucette *et al.*, 2001). These types of algorithm ordinarily rely on user-provided clues e.g. seed points to identify approximate feature location and/or road direction (Baltsavias, 2004). In such a system, the focus is mainly to enhance user's productivity as the user supervision is ensuring the correctness, completeness, and accuracy of the extracted road network.

However, many semi-automated methods, developed at academic and research institutions, were not really conceived and designed from the beginning as such, and thus are not real, consistent semi-automated approaches and do not lead to systems that are relevant for practical use (Baltsavias, 2004). In this work, we adopted the idea of integrating automatic road-ahead prediction capability with standard manual collection at the system design stage. The basic manual collection tools are the baseline of this work and road-ahead prediction is offered to the operator without interfering with the current manual operation (Figure 2).

A novel road path finding approach has been designed to predict a road vector starting from the current road end-point. The road path finding is based on an optimization process that combines both radiometric information along the road path and road geometric modelling. Detailed descriptions of the road-ahead prediction and geometric modelling can be found in Giovannini *et al.* (2010).

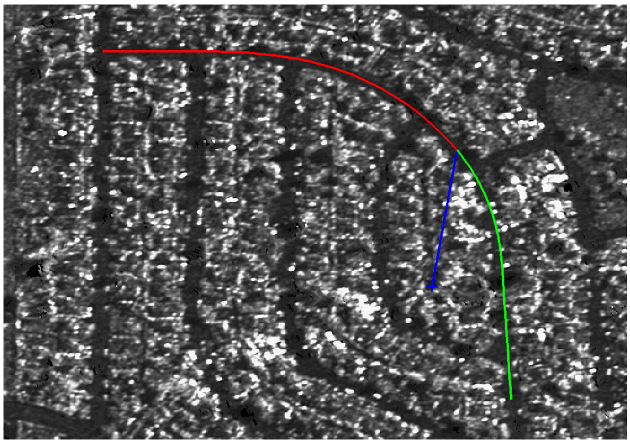

Figure 2. Road-ahead prediction: red line – previously accepted road vector; blue line – connecting line between current road end-point and cursor location; green line – road-ahead prediction.

The new semi-automated approach successfully addresses the need to increase road extraction speed, while guaranteeing compliance to high standards of accuracy. Figure 3 shows one of the extracted road networks overlaid on the input ORI. The area is a developed area in the southeast of Munich, Germany. The road network (or the street grid) is very dense and the input radar image is quite speckly, which makes the area not favourable for an automated road extraction approach. However, our semi-automated program worked successfully on about one third of the roads (red lines) for which the road-ahead prediction has been accepted.

It can be seen from Figure 3 that the overall road vectors are visually well-aligned with the input ORI and following road geometric rules. Tests are underway to determine precisely how much this approach speeds up the extraction and what improvement it brings to absolute and relative road accuracies.

Figure 3. Input ORI overlaid with the road network extracted using the proposed approach: The green lines are manually collected while the red lines are from automated extraction.

4. ELEVATION ASSIGNMENT

Elevations will be automatically assigned to the 2D road vectors from either manual or semi-automated collection based on our NEXTMap DEMs. Due to the nature of the IFSAR-derived DEM, extracting elevations for a 2D road network is a complicated process that involves several major steps (Figure 4). The first step is to sample the DEMs to determine the elevation values at road positions, point by point. The second one is to smooth the elevation profile along the road line. Finally, the elevation differences at road intersections from different directions are checked to ensure there are no elevation conflicts. We have also incorporated various quality check measures in our process including reviewing the results in a stereo environment. More detailed descriptions can be found in Zhang *et al.* (2010).

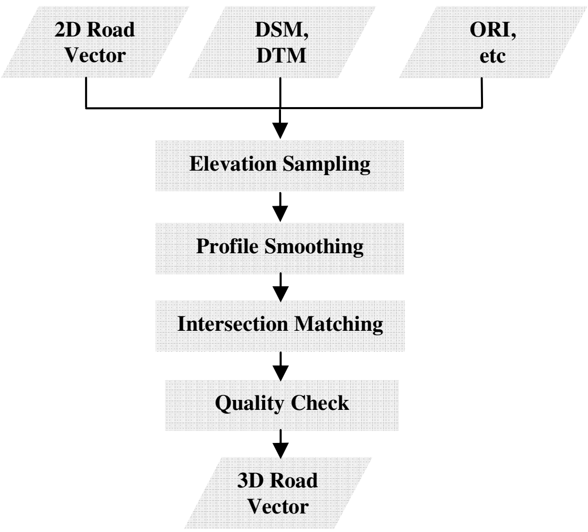

Figure 4. Flowchart of elevation assignment to a 2D vector

4.1 Elevation Sampling

This step is used to assign an elevation value for each road point. We classify the road points into three different obstruction categories: open area, transition area, and obstructed area based on an obstruction index derived from the differences between DSM and DTM in a moving window centered at the road location. In open areas, DSM values are used. In obstructed areas DTM values are used. In transition areas, a weighted average of the DTM values and the DSM values are used.

4.2 Profile Smoothing

Profile smoothing operates on the road point elevations and smoothes the elevation profile along the road direction. Our smoothing filter is a weighted version of polynomial fitting. The weighting is based on the characteristics of the input vectors and various other information sources (e.g., DSM, DTM, ORI, correlation map, etc.).

4.3 Elevation Matching at Road Intersections

As both elevation sampling and profile smoothing are direction dependent, elevations assigned to the same road intersection from different directions could be different. In this post-processing step, each road intersection is checked and the elevation discrepancy is removed by either averaging or tying one of the directions to the other.

4.4 Quality Check

In our production chain, we have incorporated various quality check measures including visual review by an operator in a stereo environment, making corrections as necessary.

4.5 Current Results

In order to validate and evaluate our 3D road networks, we have acquired a number of reference datasets in Europe. Table 1 shows the overall evaluation results from four test datasets in Germany and Italy. The reference data was from a mobile mapping system with a scanning laser on-board, which provides road centre-lines with typical vertical accuracy at 5cm RMSE. The German dataset is from a mountainous area south of Traunstein, Germany. The elevation values along the roads range from 500m to 1000m with various road categories and different obstruction levels. Italy Areas 1 and 2 are surrounding the City of Matera, Italy, while Italy Area 3 is in the mountainous area west of Assergi, Italy. The line kilometres evaluated for each area are shown in the second column of the table. The elevation errors of the extracted road profiles (relative to the ground laser data) were calculated directly from the outputs of our elevation assignment program without any manual editing. The elevation accuracy is in general expected to be higher with inputs from an editor in the quality check step.

Test Areas	Line Dist. (km)	Elev. Error (m)		
		Mean	Stdev	RMSE
Germany 1	51	-0.10	1.38	1.38
Italy 1	24	0.30	1.08	1.13
Italy 2	35	-0.19	0.59	0.62
Italy 3	68	0.32	1.47	1.51

Table 1. Evaluation Results

Table 1 indicates that our 3D road vectors have vertical accuracies in the range of 0.6-1.5 meters (RMSE) depending on the complexity of the area. Areas with continuous forest coverage or with buildings along the road sides have larger elevation errors.

Figure 5 shows an example of the 3D road vector set that was successfully extracted by this approach. The extracted elevation profile follows the reference profile smoothly. The mean elevation error is about 0.13m with a standard deviation of 0.54m.

Figure 6 is another example with more challenges. The road is heavily obstructed by trees along the road sides in the middle part of the road. Our extracted elevations are biased by about 2m in the middle of the obstruction and the mean elevation error is about 0.48m with a standard deviation of 0.91m.

Figure 7 depicts one of the problematic situations. The road is about 1000m long and is heavily obstructed by trees or buildings continuously along the road sides. Our extracted elevation is biased about 2.5m in the middle of the obstruction and the mean elevation error is about -0.14m with a standard deviation of 1.99m.

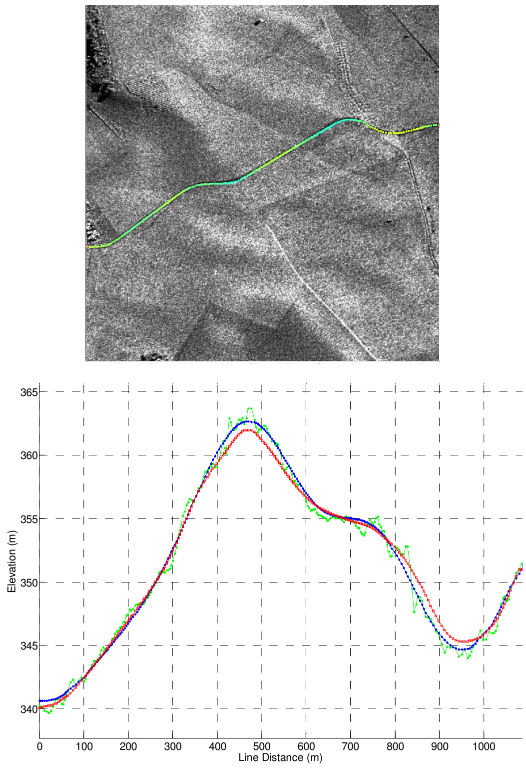

Figure 5. Elevation profile (Bottom): the green line is the DSM value, the blue line is the extracted elevations, and the red line is the reference. The top figure shows the road vector overlaid on the ORI. The elevation profile is drawn from left to right.

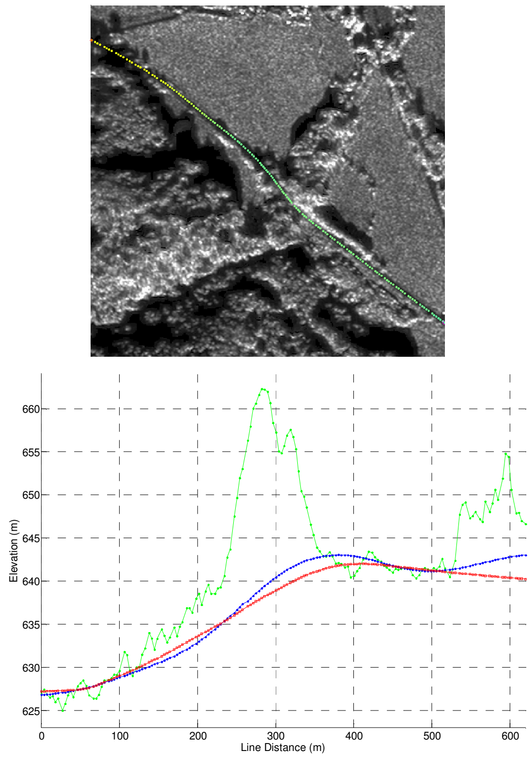

Figure 6. Elevation profile (Bottom): the green line is the DSM value, the blue line is the extracted elevations, and the red line is the reference. The top figure shows the road vector on ORI. The elevation profile is drawn from right to left.

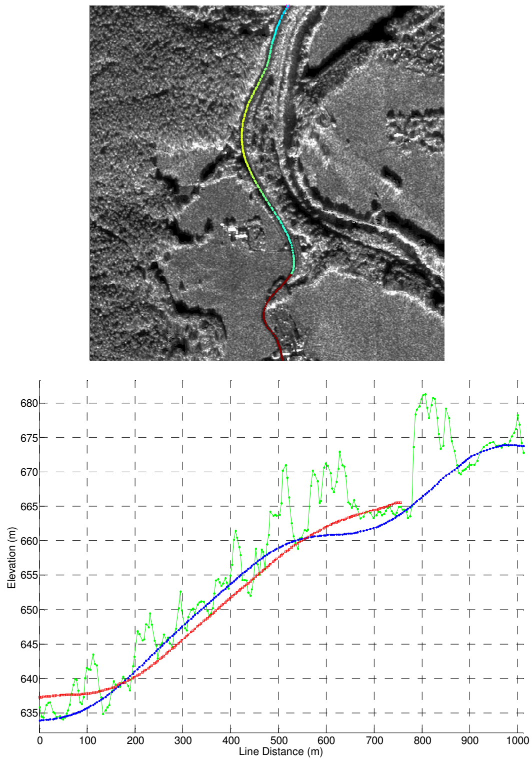

Figure 7. Elevation profile (Bottom): the green line is the DSM value, the blue line is the extracted elevations, and the red line is the reference (partially available). The top figure shows the road vector on ORI. The elevation profile is drawn from top to bottom.

5. CONCLUSIONS

Building a nation-wide 3D road network covering a range of highway and road types is a challenging task. The approach we have been taking is to extract the roads from the NEXTMap Europe, IFSAR-derived, data base consisting of DSM, DTM and ORI plus ancillary content. The 2D geometry of a road network is extracted from our high resolution ORI and the elevation of the road vectors is determined based on our DEMs.

A semi-automated approach has been developed for 2D road extraction from ORI. The proposed approach has three distinct features, namely the seamless integration between manual collection and road-ahead prediction, the optimized road path finding and the use of road geometric design rules. Preliminary tests have shown the new approach improves both user productivity and product quality. Our next step is to test the system more intensively and to put the system into a production environment after further improvements are made.

The elevation assignment to 2D road vectors is highly automated and has to work under a variety of road conditions. The major problem relates to obstructions by vegetation. The results to-date are, however, promising. In particular we have validated the vertical performance at the 0.5-2 m (RMSE) level against a ground-based mobile lidar system. We are currently working on various issues identified by an independent validation team, to improve both the horizontal accuracy and the vertical accuracy of our final 3D road product and to characterise the conditions under which accuracies may vary.

REFERENCE

Baltsavias, E.P., 2004. Objection extraction and revision by image analysis using existing geodata and knowledge: current status and steps towards operational systems. *ISPRS Journal of Photogrammetry & Remote Sensing*, Vol. 58, No. 3-4, pp.129-151.

Bentabet, L., Jodouin, S., Ziou, D., and Vaillancourt, J., 2003. Road vectors update using SAR imagery : a snake-based method. *IEEE Transactions on Geoscience and Remote Sensing*, 41(8), pp.1785-1803.

Dobson, M. W., 2009. ADAS and 3D-Road Map Databases, GeoInformatics, September, 2009, pp.28-33.

Doucette, P., Agouris, P., Stefanidis, A., Musavi, M., 2001. Self-Organised Clustering for Road Extraction in Classified Imagery. *ISPRS Journal of Photogrammetry & Remote Sensing*, Vol. 55, No. 5-6, pp.347-358.

Giovannini, L., Zhang, Q., Simantov, M., Griffiths, S., Mercer, B., 2010. A New Approach to Semi-automated Road Extraction from Orthorectified Radar Imagery. *Proceedings of 8th European Conference on Synthetic Aperture Radar* (*EuSAR 2010)*, June 07-10, 2010, Eurogress, Aachen, Germany.

IDG News Service, 2007. Tele Atlas speeding up 3D road map progress, http://www.roadsbridges.com/Tele-Atlas-speeding-up-3D-road-map-progress-NewsPiece13705 (accessed March 08, 2010).

Li, X., Tennant, K., 2009. Vehicle Energy Management Optimization Using Look-Ahead Three-Dimensional Digital Road Geometry, ITS World Congress, Sept. 21-25, 2009, Stockholm, Sweden.

Mercer, B. and Zhang, Q., 2008. Recent advances in airborne InSAR for 3D applications, In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVII (Part B1), Beijing, China, pp.141–146.

NAVTEQ, 2006. NAVTEQ Network for Developers™ Technical Support: Frequently Asked Questions, http://www.santa-eufemia.it/cms/data/pages/files/000033_resource2_orig.pdf (accessed March 10, 2010).

Tupin, F., Maitre, H., Mangin, J.-F., Nicolas, J.-M., and Pechersky, E., 1998. Detection of Linear Features in SAR Images: Application to Road Network Extraction, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 36, No. 2, pp.434-453.

Wessel, B., Wiedemann, C., Hellwich, O. and Arndt, W.-C., 2002. Evaluation of automatic road extraction results from SAR imagery. In: *International Archieves of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXIV(Part 4), Ottawa, Canada, pp. 786–791.

Zhang, C., Vahidi, A., Pisu, P., Li, X., Tennant, K., 2009. Utilizing Road Grade Preview for Increasing Fuel Economy of Hybrid Vehicles, 12th IFAC Symposium on Control in Transportation Systems, September 2 - 4, 2009, Redondo Beach, CA, USA.

Zhang, Q., Simantov, M., de Vries, J., Griffiths, S., 2010. Assigning Elevations to 2D Road Networks Based on IFSAR-Derived DEMs. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVIII (Part 1), Calgary, Canada, (on CD-ROM).