ASSIGNING ELEVATIONS TO 2D ROAD NETWORKS BASED ON IFSAR-DERIVED DEMS

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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 discusses the challenges that we are facing in terms of assigning elevations to 2D road vector 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 our 3D road products are vertically accurate with an overall RMSE in the range of 1.0 to 2.0m depending on the complexity of the area.

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 (e.g., predictive adaptive front lighting, adaptive cruise control, and lane keeping assist) (Dobson, 2009), and Fuel Economy (e.g., predictive throttle control, predictive transmission control, and hybrid power cycle optimization) (Li, 2009; Zhang, 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 system has to physically drive 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, wide-area availability, resolution and accuracy are all factors in this type of approach. In this work, we take advantage 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 for most of Western Europe and the USA (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 elevation of objects - either natural objects such as vegetation or man-made objects such as buildings - located upon the terrain. DTMs represent the bare terrain and are derived from the DSMs.

For purposes described above, Intermap is in the process of collecting 2D road networks based on its ORIs with the 3rd dimension coming from the DEMs. The current process for 2D collection is mainly manual, while the elevation assignment to the 2D road vectors is highly automated.

This paper focuses on the elevation assignment part of 3D road extraction. An overview of our 3D road program is given in Section 2 followed by detailed methodologies in Section 3. Section 4 gives our validation results and finally Section 5 is our conclusions and future work.

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 will be also 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 is a picture of our 3D workstation and interface used in 3D road collection.

3. APPROACHES

Due to the nature of the IFSAR-derived DEM, extracting elevations for a road network is a complicated process that

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involves several major steps. 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.

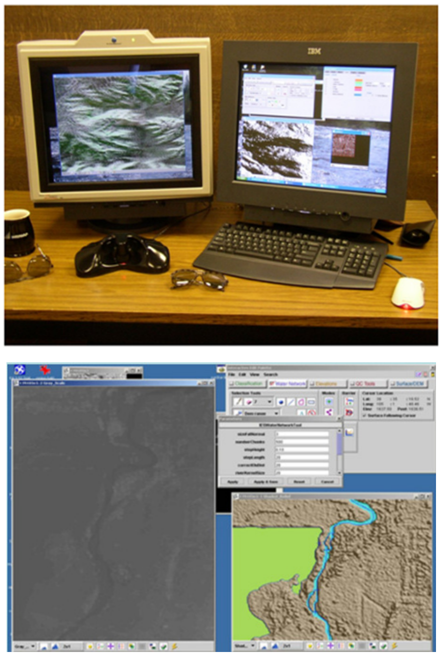

Figure 1. 3D Workstation (Top) and 3D Vector Collection Software (Bottom)

3.1 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.

3.2 Profile Smoothing

Profile smoothing takes in the elevations of road points and smoothes the elevation profile along the road direction. It works on the longest path that the program can find in the network.

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 that we have (e.g., DSM, DTM, ORI, correlation, etc.). In Figure 2, the cyan line is the smoothed version of the black line, i.e., the results from elevation sampling step.

3.3 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 will be checked and the elevation discrepancy will be removed by either averaging or tying one of the directions to the other.

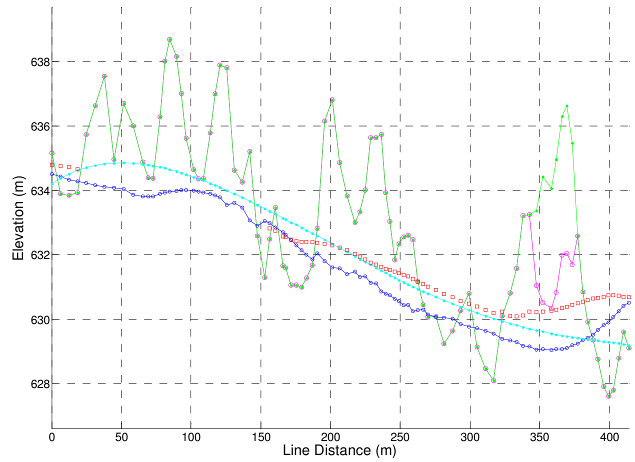

Figure 2. Elevation Sampling: elevation profiles showing DSM (green), DTM (blue), the sampled elevation (magenta), the smoothed profile (cyan), and the reference (red)

Figure 3 shows an example of matching elevations at road intersections. The three connecting lines meet at the road intersection shown as a white square with Line 1 and Line 2 as the master direction going from southwest to northeast. The third direction (northwest) joins the road intersection with about 1m elevation difference. This elevation difference has been removed by tying to the master direction's elevation. This process has also a component to make sure the elevation profile from one direction to another is smooth.

3.4 Quality Check

In our production chain, we have incorporated various quality check measures including an operator reviewing the results in a stereo environment and making corrections if necessary.

4. EVALUATION

In order to validate and evaluate our 3D road networks, we have acquired a number of reference datasets using a Lidar-based ground mobile mapping system. Figure 4 shows the histogram of elevation errors from one of our Italy datasets. The reference data was from a mobile mapping system with a scanning laser on-board, which gives an accurate road surface with typical vertical accuracy at 5cm RMSE. The dataset is from a mountainous area west of Assergi, Italy. The elevation values along the roads range from 600m to 1500m with various road categories and different obstruction levels. In total, about 150 km of road vectors were evaluated. The overall RMSE is about 1.0m.

Figure 5 shows an example of the 3D road vector that was successfully extracted by this approach. The extracted elevation profile follows the reference profile smoothly. The mean elevation error is about 0.18m with a standard deviation of 0.52m.

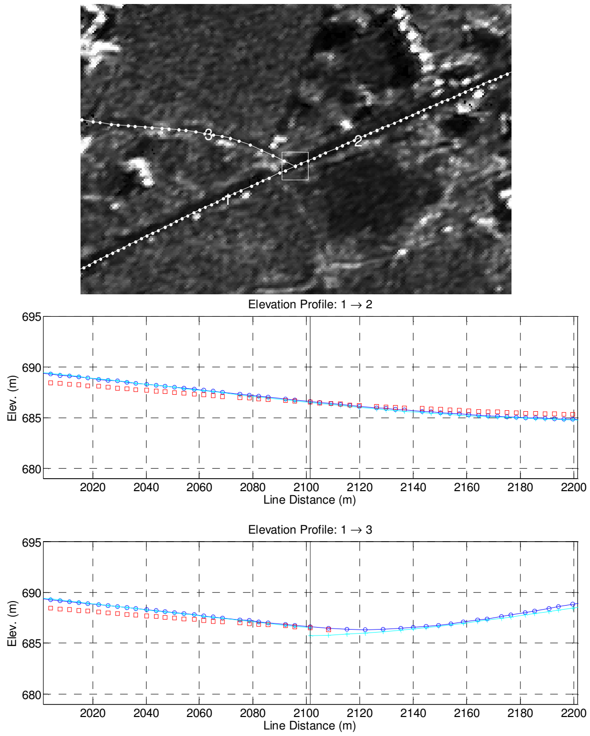

Figure 3. Matching elevations at road intersections: Top: Three connecting lines meet at road intersection. The underlying image is the input ORI. Middle and Bottom: Elevation profiles showing before matched (cyan) and after matched (blue) elevation with reference shown in red. The cyan lines in the bottom plot show about 1m elevation difference between two directions, which has been matched in the final output (the blue line).

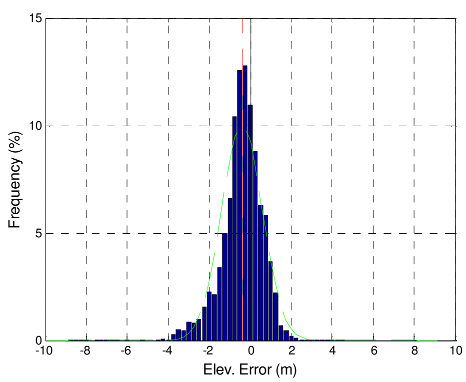

Figure 4. Elevation error histogram

Figure 6 is another example with more challenges. The road is about 750m long and is heavily obstructed by trees or buildings along the road sides in the eastern part of the road. Our extracted elevations are biased by about 1.5m in the middle of the obstruction and the mean elevation error is about 0.60m with a standard deviation of 0.86m.

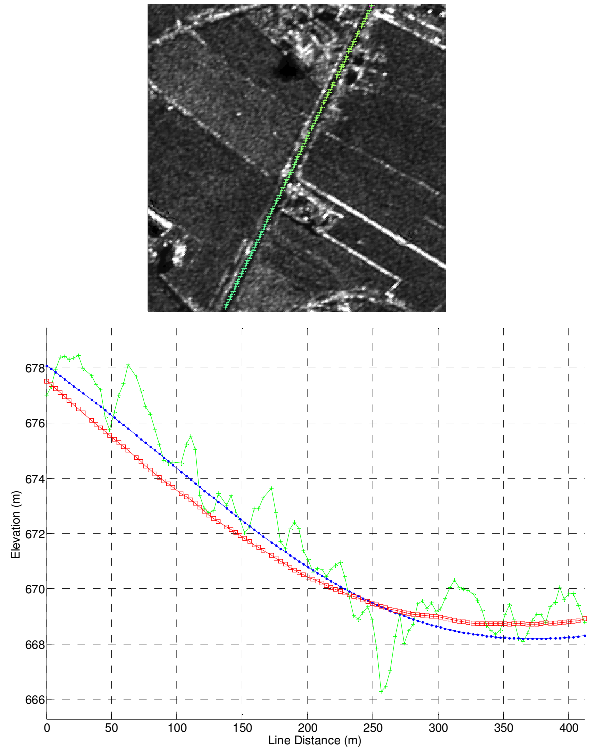

Figure 5. Elevation profile (Bottom): the green line is the DSM value, the blue line is the extracted elevations, and the red line is the reference. The top figure shows the road vector on ORI. The elevation profile is drawn from top to bottom.

Figure 7 shows one of our problematic examples. The road is about 650m long and is heavily obstructed by trees or buildings 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 1.29m with a standard deviation of 1.15m.

Based on our current evaluation results, our 3D road vectors show vertical accuracies in the range of 1-2 meters (RMSE) depending on the complexity of the area. Areas with continuous forest coverage have larger elevation errors.

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 data base consisting of DSM, DTM and ORI plus ancillary content. The results to-date are promising. In particular we have validated the performance at the 1-2 m (RMSE) level against a ground-based mobile lidar system.. We are currently working on various issues identified by the validation team to improve the vertical accuracy of our final 3D road product and to characterise the conditions under which accuracies may vary.

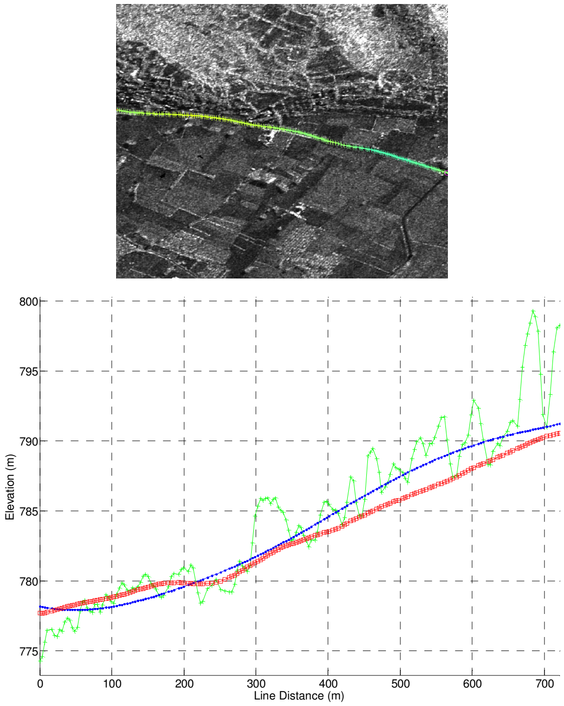

Figure 6. Elevation profile (Bottom): the green line is the DSM value, the blue line is the extracted elevations, and the red line is the reference. The top figure shows the road vector on ORI. The elevation profile is drawn from right to left.

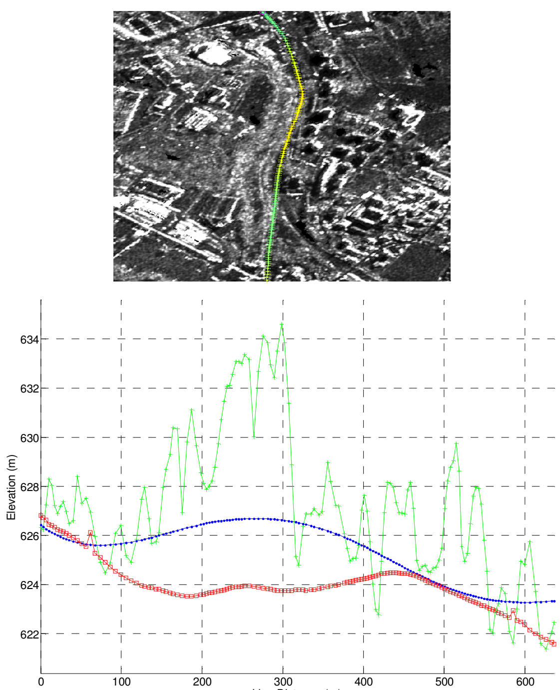

Figure 7. Elevation profile (Bottom): the green line is the DSM value, the blue line is the extracted elevations, and the red line is the reference. The top figure shows the road vector on ORI. The elevation profile is drawn from top to bottom.

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