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AUTOMATIC DETECTION OF GRAVEL BARS IN A RIVER CHANNEL FROM AIRBORNE LIDAR-DERIVED DTM

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Airborne Laser Scanning or LiDAR data are widely used nowadays in river valleys for topography and hydro-morphology. However, the large data sets of unprocessed 3D point clouds require some challenging treatment and end-users may prefer to deal with DTMs (Digital Terrain Models) derived from LiDAR surveys. Without any complementary data (such as field survey or photographs) detecting position and shape of gravel bars in a river is a demanding task, especially if done manually.

This paper presents a method for automatic segmentation of a river channel into distinct hydro- morphological entities: water, gravel bars, banks, ... This method is based on image processing algorithms (region growing segmentation combined with morphological closing and altitude thresholding) in order to separate water from other elements present in the channel, based on the altitude information. This method is applied to a reach of the Arc-en-Maurienne River, France, with alternate gravel bars. The only data source is the 0.25 m resolution DTM, derived from an airborne LiDAR survey.

Results show that the developed method succeeds in automatically delimiting the main channel and in detecting gravel bars. It is then possible to get global information on the gravel bars such as location along the river or emerged surface area and topography.

INTRODUCTION

River morphology is determined by water and sediment discharge as well as anthropic modifications of the river corridor, such as embankments. It has been observed that many straightened gravel bed rivers display the feature of alternate bars. The dynamics of these bars can give information about the river morphodynamics. Traditionally, morphological and morphodynamical studies of rivers implied extensive field work to gather topographic data. The emergence of remote sensing techniques has modified this situation, and new data sets may be available for morphological analysis of rivers.

In this paper, a method is presented, that automatically detects gravel bars from LiDAR-derived DTM (Digital Terrain Model) as only data source. The following of this paper is divided into three sections. First, a brief review of remote sensing application to river morphology is given. Second, the studied area is presented along with the input data. Third, the major steps of the proposed methodology are described and the results are presented and discussed.

REMOTE SENSING FOR RIVER MORPHOLOGY

As underlined in Marcus and Fonstad [10], remote sensing of rivers has been and is still a very active field of research with various data sources. Studies have been carried out with input data coming from optical sensors, such as Marcus and Fonstad [11] who show the feasibility of optical river mapping at fine resolutions and watershed extent or Feurer *et al.* [5] who propose a method for reconstructing bathymetry from stereoscopic images. Carbonneau *et al.* [1] also developed methods to produce bathymetric measurements from aerial images. Airborne LiDAR data source is also investigated by many authors. Charlton *et al.* [3] showed the potential of this data source to obtain high resolution topographic data. More recently, Cavalli *et al.* [2] show the effectiveness of LiDAR data in the recognition of channel-bed morphology in a headwater catchment. Bathymetric LiDAR is also a valuable data source for immersed topography, as stated by Hildale and Raff [6].

As noted above, very large data sets can be acquired to monitor a river corridor. Manual methods are not suitable anymore and automatic or at least semi-automatic methods have to be implemented. Furthermore, direct use of 3D data implies being able to manage and process them. In the present work, the input data is the DTM, interpolated from the 3D LiDAR data. We present a novel method to process this LiDAR-derived DTM and to segment the scene into morphological elements in the channel.

STUDY AREA AND DATASETS

Area of interest

The area of interest of this work is a reach of Arc en Maurienne river (see Fig. 1), belonging to the Arc-Isère study site. This is a collaborative study site of the ZABR (Zone Atelier Bassin du Rhône, a regional multidisciplinary observatory) and the OSR (Rhône Sediment Observatory). As presented in Jaballah *et al.* [8], the Arc en Maurienne river is located in the French Alps, and flows in a narrow valley equipped with hydroelectricity dams and dense transportation system. The dikes have affected the morphodynamics of the river, which led to alternate gravel bars. The studied reach is 800 m long and consists of a bar, which has been monitored since 2005 (see Jodeau *et al.* [9]). This bar is 500 m long and is located on the left side of the river. The mean local slope of the reach is about 0.6%, its width between the dikes is approximately 50 m. The bed is composed of gravels and fine sediments.

The Arc en Maurienne catchment area is 1957 km² large and delivers huge inputs of sediments to the river, which are partially stopped by the dams. The hydrological regime is nival, high flows generally occur in spring and summer during snow melt. However, once a year the dams are flushed and sediments are released into the river, associated with high discharge.

Data

LiDAR data were acquired in 2010 before and after a flush event by a laser scanner Riegl LMS-Q560 on board a helicopter, by the Sintegra company. The wavelength of the laser beam is 1064 nm. In uncovered areas, ground point density varies between 10 to 15 points/m², and drops to 1 to 4 points/m² under vegetation. The helicopter flights 600 m above the ground, and the swath width is approximately 300 m, which is larger than the river active channel. The theoretical precision of measurement is 0.25 m for planimetry, 0.07 m for altimetry.

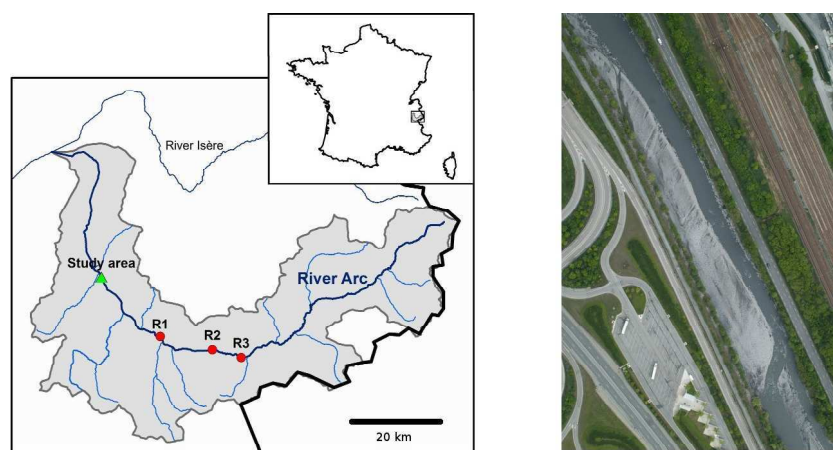


Figure 1. Area of interest: a reach of the Arc river, France. Left: location map ; right: orthophotography of the reach.

The data were processed with the Terrasolid softwares, including classification of ground points, removal of non-ground points, triangulation of the ground points and sampling of the altitude on a 0.25 m regular grid. The resulting DTM constitutes the input data of the present work and it can be seen in Fig. 3, top left.

LiDAR surveys are generally characterized by a low density of 3D points on water areas. This is due to reflection on the water surface when the sensor is not aligned with the water surface normal and to the absorption of the near infra-red wavelength by water. However, a preliminary analysis of the input DTM showed that there was evidence of dense data in river parts of the surveyed scene. This can be explained by two points: (1) the water surface is agitated in the case of this alpine river, and the incoming laser beam is reflected in multiple directions including that of the sensor and (2) the high sediment concentration in the whole stream flow implies a strong backscattering by the solid particles. This particularity is exploited by Tamari *et al.* [12]. Fig. 2 illustrates this phenomena: the intensity of the signal, which is absorbed by non running water, is high in the river area.

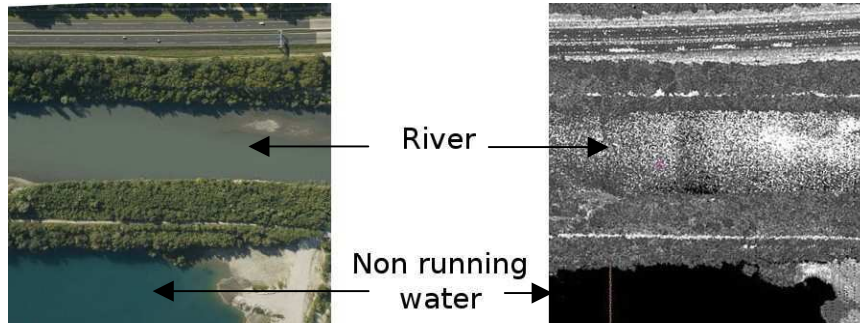


Figure 2. Loss of LiDAR signal on non-running water bodies. Left: image of a scene with running and non-running water ; right: intensity of the LiDAR signal (white: maximum intensity, black: intensity=0). Images courtesy of Sintegra.

METHODOLOGY AND RESULTS

Methods: state of the art

The goal of this work is to perform a segmentation of the scene to separate the main channel from banks, and inside the main channel bars from water. The only input data is the LiDAR-derived DTM.

Höfle *et al.* [7] have developed a similar method. They want to map water surface from airborne laser scanning and use signal intensity as well as elevation data. They note that the LiDAR point density in water bodies is very low, because this surface mainly behaves as reflective. Their water-land separation algorithm is based on characteristics of geometry and intensity of the laser echoes: low surface roughness, low intensities, dropouts and high relative variation of intensity. They implement a region growing algorithm and precise delineation of water-land boundary is performed, with good results on the data sets tested. Another study by Cobby *et al.* [4] shows that there are no LiDAR data in water bodies. The authors develop a special algorithm to distinguish holes in DTM due to regular sampling on the grid from holes due to water based on mathematical morphology.

Both methodologies (one based on 3D points, the other one on the interpolated DTM) succeed to separate water from land thanks to the lower LiDAR point density on water areas. As presented in the previous section, the LiDAR data used in the present work do not have a low density on water bodies. Thus the developed method has to base the segmentation on new criteria.

Developed method

The goal of this work is to segment the gravels bars in the river, thus to separate water and bar regions. In fact, water surface has specific properties: (1) locally approximately planar surface taking the effects of noise and water movements due to high flow discharge and (2) no slope breaks within a water area.

These two properties can be expressed on the DTM. Let DTM_{im} denote the DTM considered as an image. This image has one channel, containing the altitude value, and the

georeferencing information makes the link between image (c,l) and world (x,y) coordinates. The 5x5 neighborhood of a pixel (c,l) is denoted $V(c,l)$. The first selected criterion is the variance of the altitudes in the neighborhood of a pixel :

$$Var(c,l) = \overline{DTM_{im}(i,j) - \overline{DTM_{im}(i,j)}} \quad (i,j) \in V(c,l) \quad (1)$$

The second criterion is the difference of surface orientation of two adjacent pixels. The plane tangent to the surface of the DTM at a pixel (c,l) is estimated by the least squares method on the neighborhood $V(c,l)$ and the result is given Eq. (2).

$$z = \alpha x + \beta y + \gamma \quad (2)$$

Then the vector normal to the surface is defined by Eq. (3).

$$\vec{n}(c,l) = \frac{(-\alpha, -\beta, 1)}{\|(-\alpha, -\beta, 1)\|} \quad (3)$$

Region growing algorithm

A region growing approach is adopted, similar to the one implemented in Höfle *et al.* [7], but using attributes built on the DTM. The seed, starting point of the region growing, is automatically chosen at the point of the DTM with the lowest altitude, which is supposed to be in the river. During the growing step, according to the two selected criteria, a new pixel (c,l) adjacent to the current region is added to the current region if the conditions of Eq. (4) are fulfilled:

$$\begin{cases} Var(c,l) < T_{var} \\ angle(\vec{n}(c,l), \vec{n}(c',l')) < T_{ang} \end{cases} \quad (4)$$

with (c', l') the pixel adjacent to (c,l) in the current region.

Results

The region growing algorithm does not succeed in separating water from gravels bars, as shown in Fig. 3, top right. The two criteria fail to completely retrieve the bar contour. This is due to the absence of slope breaks and elevation difference at the two ends of the bar, upstream and downstream.

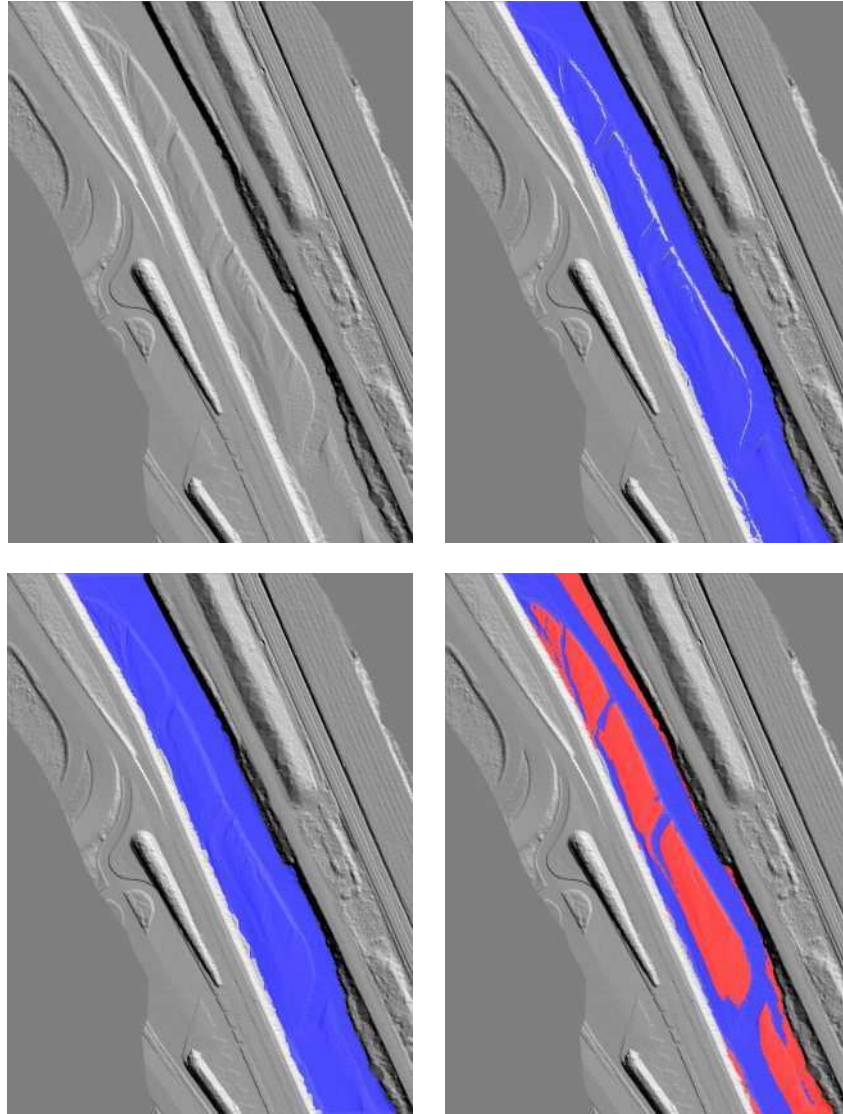


Figure 3. Results of the developed method. Top left: input DTM data ; top right: result of the region growing algorithm ; bottom left: result of morphological closing ; bottom right: final result.

However, the region obtained is closed to the river main channel (water and bars together). Thus a new workflow is adopted: first the segmentation algorithm automatically extracts the main channel, then a post-processing step is added to separate water from bars. The result of this first step, given in Fig. 3, top right, shows that small parts of the gravel bar are not aggregated with the region. To obtain a correct main channel region without holes, we perform a morphological closing of the region (dilatation followed by erosion),

with a large structural element. A size of 21 pixel has been chosen, representing about 5 meters. The result of this morphological closing step is displayed on Fig. 3, bottom left. The main channel region is correctly segmented, and the correct segmentation rate increases from 94% to 99% (the under-detection rate drops from 5% to 0.5%).

Final altitude thresholding

The final step aims at segmenting the main channel region into water and bar. There is no slope breaks between water and bar regions at the upstream and downstream ends of the bar. Thus, the choice is made to take directly altitude into account. The hypothesis that water is locally plane is extended to the whole. A plane is estimated with the least squares method on all the pixels of the main channel region. This plane is considered as representative of the water surface. The segmentation is obtained by a simple threshold by this plane translated by a vertical constant to take the noise into account. The final result can be seen in Fig. 3, bottom right.

CONCLUSIONS

In this paper a fully automatic method for segmenting a river channel into water, gravel bars and embankment classes has been presented. The only input data is a LiDAR-derived DTM. The results of the region growing algorithm show a very good separation of the main channel (water and bars) from the remaining part of the data. Water and gravel bars are segmented with a plane thresholding success.

Current work aims at extending this method on a longer river part, up to tens of kilometers. The main challenge is to cope with the large amount of data.

Future work will add aerial images in the workflow in order to overcome the limitations of altitude information and better determine the position of bar contours.

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REFERENCES

- [1] Carbonneau P. E., Lane S. N., and Bergeron N., "Feature based image processing methods applied to bathymetric measurements from airborne remote sensing in fluvial environments", *Earth Surface Processes and Landforms*, Vol. 31, No. 11, (2006), pp 1413-1423.
- [2] Cavalli M., Tarolli P., Marchi L., and Dalla Fontana G., "The effectiveness of airborne lidar data in the recognition of channel-bed morphology", *Catena*, Vol. 73, No 3, (2008), pp 249-260.

- [3] Charlton M.E., Large A.R.G., and Fuller I.C., "Application of airborne LiDAR in river environments: The river coquet, Northumberland, UK". *Earth Surface Processes and Landforms*, Vol. 28, No. 3, (2003), pp 299-306.
- [4] Cobby D. M., Mason D. C., and Davenport I. J., "Image processing of airborne scanning laser altimetry data for improved river flood modeling". *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 56, No. 2, (2001), pp 121-138.
- [5] Feurer D., Bailly J.-S., Puech C., Coarer Y. Le, and Viau A.A., "Very-high-resolution mapping of river- immersed topography by remote sensing". *Progress in Physical Geography*, Vol. 32, No. 4, (2008), pp 403-419.
- [6] Hilldale R. C. and Raff D., "Assessing the ability of airborne LiDAR to map river bathymetry". *Earth Surface Processes and Landforms*, Vol. 33, No. 5, (2008), pp 773-783.
- [7] Höfle B., Vetter M., Pfeifer N., Mandlbürger G., and Stötter J., "Water surface mapping from airborne laser scanning using signal intensity and elevation data". *Earth Surface Processes and Landforms*, Vol. 34, No. 12, (2009), pp 1635- 1649.
- [8] Jaballah M., Camenen B., Paquier A., and Jodeau M., "Field investigations on bar morphodynamics in an engineered alpine gravel-bed river: Arc en Maurienne, France". In Proceedings of *The 7th IAHR Symposium on River Coastal and Estuarine Morphodynamics*, Beijing, China, (2011).
- [9] Jodeau M. and Paquier A., "Analysis of water and sediment flows over an alternate bar in a gravel bed river". In Proceedings of the *International Conference on Fluvial Hydraulics - River Flow 2006*, Lisbon, Portugal, Vol. 2, (2006), pp 1251-1257.
- [10] Marcus W. A. and Fonstad M. A., "Remote sensing of rivers: The emergence of a subdiscipline in the river sciences". *Earth Surface Processes and Landforms*, Vol. 35, No. 15, (2010), pp 1867-1872
- [11] Marcus W.A. and Fonstad M.A., "Optical remote mapping of rivers at sub-meter resolutions and watershed extents". *Earth Surface Processes and Landforms*, Vol. 33, No. 1, (2008), pp 4-24.
- [12] Tamari S., Mory J., and Guerrero-Meza V., "Testing a near-infrared LiDAR mounted with a large incidence angle to monitor the water level of turbid reservoirs". *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 6, No. 6, (2011), pp 85-91.