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Visualisation of urban airborne laser scanning data with occlusion images

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ABSTRACT

Airborne Laser Scanning (ALS) was introduced to provide rapid, high resolution scans of landforms for computational processing. More recently, ALS has been adapted for scanning urban areas. The greater complexity of urban scenes necessitates the development of novel methods to exploit urban ALS to best advantage. This paper presents occlusion images: a novel technique that exploits the geometric complexity of the urban environment to improve visualisation of small details for better feature recognition. The algorithm is based on an inversion of traditional occlusion techniques.

1. Introduction

In recent decades Airborne Laser Scanning (ALS) has emerged as an effective tool for acquiring accurate point data over large areas. As a form of Light Detection And Ranging (LiDAR), ALS uses an aircraft-mounted laser that reflects pulses of light from the ground and then computes the spatial positions from which pulses are reflected. The resulting point data can then be used in fields such as hydrology (Hollaus et al., 2005), forestry (Hollaus et al., 2006; Yu et al., 2011), disaster management (Laefer and Pradhan, 2006; Corbane et al., 2011) and glaciology (Geist et al., 2003; Arnold et al., 2006).

ALS has also been applied to urban modelling, in which the goal is to create models of buildings across an entire city either for visual reconstruction or for computational modelling. Urban ALS has thus been used to identify buildings and other permanent man-made structures (Dorninger and Pfeifer, 2008; Tournaire et al., 2010; Huang et al., 2013) as well as road networks (Clode and Rottensteiner, 2007; Elberink, 2010), power lines (Melzer and Briese, 2004), and urban vegetation (Rutzinger et al., 2008).

In order to minimise time and cost, several highly automated building extraction methods have been introduced, in particular for loosely spaced and fairly uniform suburban buildings (Rottensteiner et al., 2005; Matikainen et al., 2007; Awrangjeb et al., 2010). For dense urban centres, however, where buildings abut each other and a greater variety of buildings occur, extraction methods still rely heavily on human intervention, and, therefore, on visualisation of the point data. Additionally, even highly automated building extraction methods require some form of visualisation to evaluate the success rates and to allow for manual correction of the results.

While orthophotos and other resources, such as ground plans, are sometimes useful in building extraction (e.g. (Haala et al., 1998)), they cannot be used to visualise errors that happen in the acquisition process. Moreover, such resources are often outdated making them difficult to use in many scenarios. As such, there appears to be an increasing trend to use methods that are data driven. Common examples of these types of methods used to visualise ALS point data and to prepare them for segmentation include the following: (1) elevation images, (2) intensity images, and (3) colour images. Elevation images are created by mapping ALS points to pixels and assigning grey-scale values proportional to the highest elevation in the mapped points appearing in each pixel. This approach enables visualising ALS data as grey-scale images, which has the effect of emphasizing the building outlines. In contrast, in intensity images the pixel values are assigned from the intensities of the return laser pulses recorded for each point. Finally, colour

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images can be directly generated from the ALS data, as some ALS systems (e.g. FLI-MAP400) are equipped with a line scan camera fitted to the laser scanner, which is used to generate a type of colour values for each laser return. However, for dense urban areas, none of these visualisation processes are individually robust due to geometric complexities, small features, closely abutting buildings, intermingled vegetation, and the presence of large volumes of traffic within the urban context.

To address these existing deficits an alternative method is proposed to visualise urban ALS point data. This method is entitled occlusion images and employs the differential visibility of walls, roofs, and small building features when sampled from multiple directions. In particular, the similarity between this problem and an existing technique in computer graphics – ambient occlusion (Zhukov et al., 1998) is exploited (and basically inverted) to better visually articulate architecturally significant features.

2. Urban ALS acquisition and visualisation

2.1. Acquisition

For the purposes of this paper, it is assumed that high-quality ALS data have been acquired for an urban centre using redundant overlapping strips to cover the area of interest. For details see (Hinks et al., 2009); as well as the survey papers by (Baltsavias, 1999a,b,c,d) for an overview of the ALS acquisition process. In order to understand the use of occlusion, however, some key characteristics of how the data acquired are introduced (Fig. 1).

The aircraft typically flies above the area of interest in straight flight tracks. Points recorded during a flight track are collectively referred to as a flight strip (Fig. 1). In this paper, it is assumed that points are acquired in roughly parallel scan lines. Other scan patterns exist, as described in (Baltsavias, 1999b). As the aircraft moves forward, laser pulses are emitted sideways by rotating a mirror that deflects the laser before it exits the aircraft (Latypov, 2005). Each scan line is acquired by emitting pulses at regular angular intervals in the direction perpendicular to the flight direction, as shown in Fig. 1. Typically, the scan rate is compared to the speed of the aircraft and, therefore, the aircraft is often considered to be stationary during the acquisition of a single scan line. An additional complication is that some pulses may not return a detectable signal, but this can be remedied by interpolating additional points (Hofle, 2007).

The aircraft typically flies above the area of interest in multiple flight tracks. While it is technically feasible to have curved flight tracks, the best quality data generally results from a straight and level flight, as illustrated in Fig. 2. Related work (Hinks et al., 2009) has shown that urban details can be captured more consistently using heavily overlapped flight strips, a low aircraft altitude, and flight tracks that are oriented in two diagonal directions. Based on this study, an ideal flight path would include flight tracks offset from each other at a distance of 1/3 of the total scan width (Fig. 2, left). In other words, the overlap between flight strips is about 67%, plus a slight increase to avoid in the data.

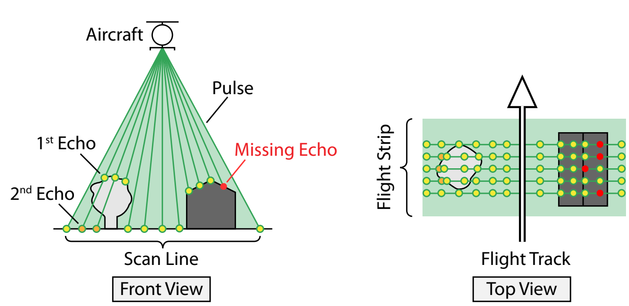

Fig. 1. *Left*: Pulses are emitted at regular, angular intervals in scan lines. For each pulse a number of echoes may be detected. If no echoes are detected, no points are recorded for that particular pulse. Consecutive scan lines are parallel and fairly regularly spaced in the flight track direction.

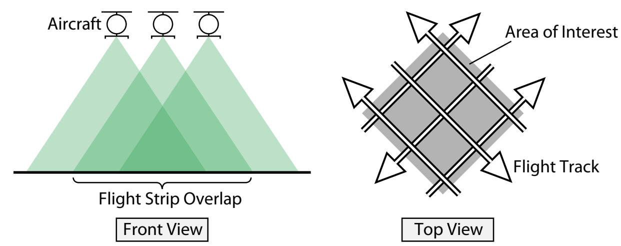

Fig. 2. As described in (Hinks et al., 2009), high quality point data for urban areas can be obtained from heavily overlapped flight strips (left) in two diagonal directions (right).

2.2. Visualisation

Once the ALS data have been acquired, it is necessary to visualise them. Visualisation is also a common processing step for the building extraction process. As explained in Section 1, an overhead view is constructed either directly from the return pulse intensities or by generating a grey-scale image from the point elevations in the ALS data. The latter will be referred to herein as an elevation image. Sometimes, when the ALS system is able to record colour values for the points (e.g. the ALS system that has been used in this project), a colour image can also be created to visualise the ALS data.

Elevation images for visualising urban centres have two characteristic problems: non-uniform building geometries and loss of architectural details. In a typical urban centre, there is a wide range of building sizes, heights, and shapes. Since a human is relatively insensitive, only 10–20 (out of the 256 grey-scale levels) can be consistently discerned. Thus, if an image contains centimeter-scale measurements for buildings that range from 10 m to 100 m in height, an elevation image either appears saturated, in which case tall buildings are in effect truncated or very coarsely represented. In such cases the geometric details captured by the ALS scan are lost in the visualisation.

In contrast, colour images are easier to interpret, but colour represents surface properties rather than geometry. Since pavement and road materials are very similar to those of buildings, detecting building footprints for densely packed buildings surrounded by streets and sidewalks can be extremely challenging by colour alone. Moreover, urban centres are also populated by transient objects such as vehicles and pedestrians, which draw attention due to their contrast against the background. As a result, neither elevation nor colour images are ideally suited for visualisation of urban centres.

3. Test data

For this study, an area of approximately 1 km^2 in the city centre of Dublin, Ireland was selected. Data acquisition involved a winter 2007 flight, based on the patterning proposed by (Hinks et al., 2009), which included flight strips that overlapped by 67%. Specifications of the airborne LiDAR system and the collected data are summarised in Table 1.

4. Occlusion images

The previous section identified the difficulties in visualising building footprints from elevation and colour images. Alternatively, what is desired is an image derived directly from