

MONITORING CHANNEL CHANGE IN GRAVEL BED RIVERS: HYPERSCALE SURFACE MODELLING BY MEANS OF TERRESTRIAL LASER SCANNING

Cambios topográficos en lechos de ríos de gravas: obtención de modelos topográficos de múltiple escala a partir de láser terrestre

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Resumen: La aplicación de láser escáner terrestre permite la obtención de datos topográficos a una resolución y rapidez sin precedente (i.e. alcances entre 10^1 - 10^3 m con resoluciones de 10^{-3} m; 10^4 observaciones por segundo). Esta nueva tecnología ofrece el potencial de adquirir rápidamente información topográfica a múltiple escala, permitiendo un análisis detallado de los cambios topográficos de lechos de ríos al igual que el estudio de la complejidad topográfica a escala de grano (i.e. *proxy* rugosidad de partícula) y su evolución temporal. En este trabajo se presenta (a) una metodología integrada para el desarrollo de modelos topográficos de múltiple escala de ríos de gravas a través de láser escáner, y (b) un análisis de los beneficios de esta tecnología en la evaluación de los cambios topográficos a escala de tramo de río. Los resultados obtenidos muestran como esta tecnología ofrece nuevas oportunidades en el estudio de la morfodinámica de ríos.

Key words: terrestrial laser scanning, gravel- bed river, morphodynamics, topographic change

Palabras clave: láser terrestre, ríos de gravas, morfodinámica, cambios topográficos

1. INTRODUCTION

Recent developments in survey instrumentation and remote sensing have enabled the collection of dense and precise topographic data. This new situation yields the opportunity to build high-resolution Hyperscale Digital Elevation Models. Terrestrial Laser Scanners (TLS) are capable of acquiring unprecedented volumes of survey-grade observations over ranges 10^{-2} – 10^3 m at 10^{-3} m accuracy. This new technology offers the potential to acquire rapidly topographic information at the resolution of bed grain-scale upwards. In this paper we present (a) an integrated methodology to develop reach-scale topographic models to monitor channel change in fluvial systems by means of TLS, and (b) an analysis of the gains of this technology on assessing channel

changes in fluvial systems.

2. DEVELOPING REACH-SCALE TOPOGRAPHIC MODELS

TLSS (Fig. 1A) are capable of acquiring rapid and accurate topographic information from multiple stations (Fig. 1B). Point clouds obtained at these stations can be registered to the same coordinate system by means of coincident points (being namely provided by topographic targets). Once registered, a full 3D topographic (dry areas) model is obtained (e.g. Fig. 1C). Although bathymetric LiDAR (Light Detection And Ranging) technologies have been implemented to monitor sub-aerial coastal topography, at the present, do not provide the required resolution to represent the complexity of river channels down to patch-grain scales. Within this context,

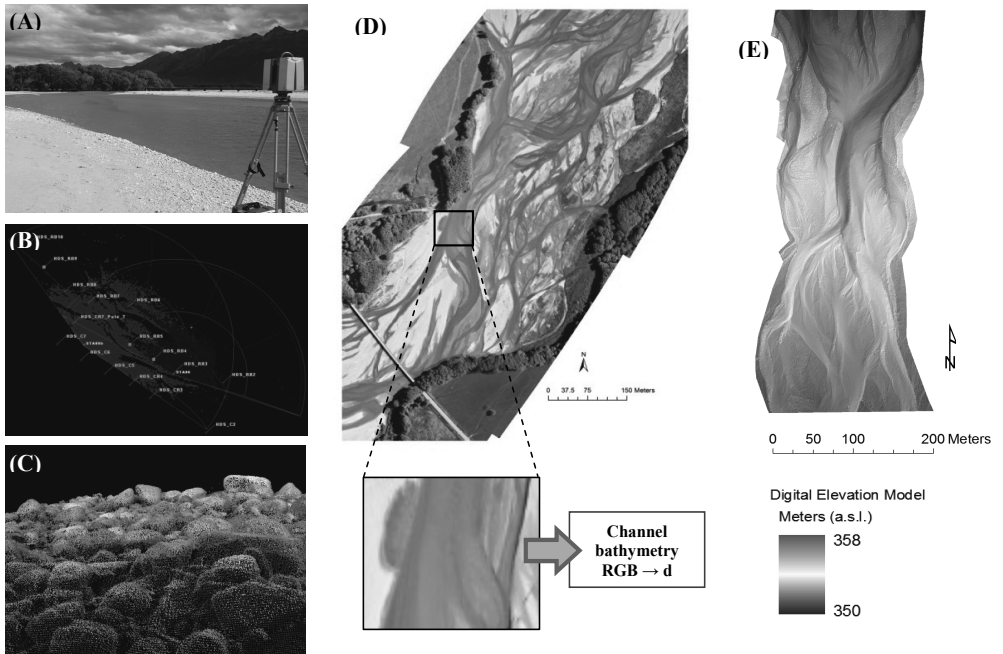


Fig. 1. (A), a HDS6100 TLS in operation in the River Rees (New Zealand). (B), a view of two point clouds registered at the same coordinate system. (C), survey observations from multiple locations allow the reconstruction of 3D topographic models. (D), rectified aerial mosaic of the lower River Rees. Pixel brightness provided a proxy of water depth until saturation. (E), topography Hybrid Model of the Feshie River (Scotland).

current TLS-based sampling strategies in river systems require sub-aerial data to be supplemented to derived models of aerial surfaces (e.g. Williams et al., 2011). In river systems where channels are rather shallow, optical remote sensing techniques, empirically calibrated, have been demonstrated that provide the capability of obtain accurate inundate channel topography (e.g. Williams et al., 2011). Numerous Unmanned Aerial Vehicles (UAV) platforms are currently available to obtain close range aerial photography (e.g. Vericat et al., 2009). Aerials are rectified to a common projection and coordinate system (e.g. Fig. 1D). Once registered, at-a-reach empirical optical deep water correction models may be obtained by correlating the pixels brightness provided by the 3-bands of the photography to water depth. Water depth measurements need to

be obtained in the field enclosing the full ranges of depths in the reach. Once obtained, the model can be propagated across the entire wet channel. Alternatively, channel bathymetry can be directly obtained by means of conventional RTK-GPS surveying, although this method may be limited by the required scale and resolution. The combination of both TLS-based (dry) and Optical-or-GPS-based (wet) strategies provide an opportunity to generate topographic-hybrid models (e.g. Fig. 1E, hereafter Digital Elevation Models, DEM) that allow studying channel changes in the full spectrum of the floodplain at unprecedented resolutions.

3. POST-PROCESSING: DEFINING GROUND SURFACES AND UNCERTAINTIES

3.1. Defining ground surfaces

Digital Elevation Models obtained at different periods can be compared and topographic changes evaluated. The complexity (density, 3D, noise, etc.) of TLS-derived topographic models require methods and workflows to derive those terrain products suited for application in each specific subject. TopCAT, an open source algorithm designed to analyse large 3D point clouds (Brasington et al., 2012), allows unifying point densities, creating multi-resolution gridded terrain products, and calculate statistical measures of the point clouds; ideally suited for application in morphodynamics. Between other statistics, TopCAT allows calculating the minimum elevation in each x_i-y_i grid domain (domain defined by the user where i is refereeing the size of the grid). This value is considered the *ground elevation*.

3.2. Determining the threshold level of detection

Assessing topographic changes require distinguishing real changes to these related to uncertainties in the individual models. The threshold level of detection (LoD) of each DEM of difference (DoD) was estimated following Brasington et al. (2003). Briefly, the error in each DoD was propagated as:

$$\text{LoD} = t [(SDE_1)^2 + (SDE_2)^2]^{-0.5}$$

where, LoD is the threshold level of detection of the DoD; t is the critical t -value at a given confidence interval ($p=0.84$ in this case; and being a large data set $t \sim 1$); and SDE_i is the standard deviation error of the DEM_i (where i is the period of each model). The SDEs for the TLS-based data set is spatially variable and can be usefully represented by the detrended standard deviation of the elevations in each grid x_i-z_i domain (from TopCAT; e.g. Williams et al., 2011); while the standard error in the GPS-based data set is constant and determined by: (a) decimating each data set in two: i) set 1 containing 95% of

the observations and ii) set 2 with the reminding 5%. (b) Set 1 is used to calculate a DEM_{i-e} while set 2 is used to compare those values to the ones modeled by the DEM_{i-e} . (c) The standard deviation of the residuals (i.e. $Z_{i-set2}-Z_{DEM_{i-e}}$) is considered the SDE for a given period i . By propagating these errors, those DoD values smaller than the LoD are removed, being considered below the threshold level of detection.

4. DETECTING TOPOGRAPHIC CHANGES BY TLS: DOES IT MATTER?

A 1 km reach of the River Feshie (Scotland, Fig. 1E) was surveyed during two consecutive years (2006-2007) to evaluate the magnitude of channel change. Topographic observations were obtained independently by means of (a) Terrestrial Laser Scanning and (b) traditional RTK-GPS. TopCAT was applied to derive the ground surface elevation. First we have created Digital Elevation Models (DEMs) per each of the data sets: TLS-2006, TLS-2007, GPS-2006 and GPS-2007. Channel bathymetry for the TLS-based DEMs was derived from RTK-GPS survey observations (i.e. Hybrid Models). We then calculate the DEMs of Difference (DoD: $DEM_{2007}-DEM_{2006}$) per each acquisition method applying its specific LoD. Results (e.g. Fig. 2) reveal significant differences in the topographic signatures recorded by the two methods. In summary, for the whole reach, in much as 160% more information on bed changes can be recovered using TLS when compared to traditional GPS survey methods. As can be seen in Figure 2, the majority of the differences in DoDs estimates occur on (a) tortuous topographies (e.g. sharp bends and banks) where the density of GPS observations is not the sufficient to represent ground-surface complexity; and (b) low relieve surfaces (e.g. top bars) where although the magnitude of changes can be small the frequency of these is

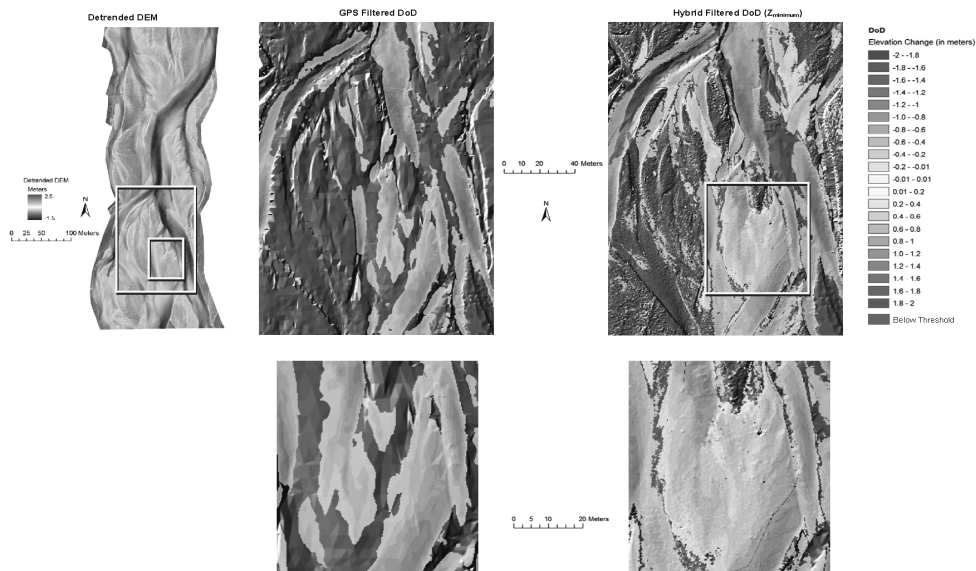


Fig. 2. Evaluating topographic changes in a braided river (the Feshie, Scotland) by means of GPS-based and TLS-based topographic models (after Rychkov et al., 2012).

rather high.

5. FURTHER OPPORTUNITIES AND FINAL CONSIDERATIONS

Our ongoing research (see further details in www.reesscan.org) highlights the potential of TLS on retrieving grain-scale sorting patterns from the statistical attributes of the point clouds (e.g. Brasington et al., 2012). The detrended standard deviation of elevations at regularly square domains (x_i - y_i) statistically correlates with the median grain size distribution of the bed surface. These results show as TLS data sets provides new opportunities in the study of morphodynamics, being of interest for morphometric analysis, sediment budgeting and for boundary models for hydraulic simulations.

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