Computers & Geosciences 88 (2016) 115–131

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Case study

Improving merge methods for grid-based digital elevation models

J.P. Leitão [a,*], D. Prodanović [b], Č. Maksimović [c]

[a] Eawag: Swiss Federal Institute of Aquatic Science and Technology, Switzerland
[b] Department of Civil Engineering, University of Belgrade, Belgrade, Serbia
[c] Department of Civil and Environmental Engineering, Imperial College London, London, UK

ARTICLE INFO

Article history:
Received 21 April 2015
Received in revised form
24 October 2015
Accepted 5 January 2016
Available online 6 January 2016

Keywords:
Data merging
Digital elevation models
Grid-based rasters
Terrain analysis

ABSTRACT

Digital Elevation Models (DEMs) are used to represent the terrain in applications such as, for example, overland flow modelling or viewshed analysis. DEMs generated from digitising contour lines or obtained by LiDAR or satellite data are now widely available. However, in some cases, the area of study is covered by more than one of the available elevation data sets. In these cases the relevant DEMs may need to be merged. The merged DEM must retain the most accurate elevation information available while generating consistent slopes and aspects. In this paper we present a thorough analysis of three conventional grid-based DEM merging methods that are available in commercial GIS software. These methods are evaluated for their applicability in merging DEMs and, based on evaluation results, a method for improving the merging of grid-based DEMs is proposed. DEMs generated by the proposed method, called `MBlend`, showed significant improvements when compared to DEMs produced by the three conventional methods in terms of elevation, slope and aspect accuracy, ensuring also smooth elevation transitions between the original DEMs. The results produced by the improved method are highly relevant different applications in terrain analysis, e.g., visibility, or spotting irregularities in landforms and for modelling terrain phenomena, such as overland flow.

1. Introduction

1.1. General

Terrain Elevation Models such as TIN (Triangulated Irregular Network) and grid-based formats, e.g., DEMs (Digital Elevation Models), are the primary sources of elevation data used for most of the terrain analysis applications, such as overland flow modelling and other terrain surface-influenced phenomena (Saunders, 1999; Wilson and Gallant, 2000; Baghdadi et al., 2005). The resolution and accuracy of these data sources are of the utmost importance in modelling land-driven processes. As an example, the study of overland flow cannot be conducted when parts of the catchment area are excluded due to lack of high-resolution DEMs (Leitão, 2009). It is also not recommended to use a low-resolution DEM dataset for the whole catchment area when parts of the area are covered by high-resolution and high-accuracy DEMS.

In recent years, a new range of DEM acquisition technologies have become available; these include airborne and ground-based LiDAR (Light Detection and Ranging) and aerial photogrammetry based on images captured by Unmanned Aerial Vehicles (UAVs) (Küng et al., 2011; Moy de Vitry, 2014). The solution suggested here is therefore to merge the most accurate of all available DEM sources in order to produce a single DEM that covers the whole area of interest with the highest possible resolution and accuracy.

Through the process of merging DEMs, it is possible to generate DEMs that cover larger areas or refine existing DEMs after up-to-date surveys are conducted (Ruiz et al., 2011). Problems arise when DEMs are combined with, for example, sewer manhole surveying data, or when an old DEM of the whole catchment is to be merged with patches of updated LiDAR or OrthoPhoto data of streets and other fabric features. DEMs generated by different acquisition and interpolation techniques may have different characteristics; these may include spatial resolution, accuracy, geographic coordinate system, and acquisition dates. As a result, for the same location on the *xy*-domain of the terrain, two or more elevation values may be available depending on the dataset considered. Although these elevation differences (or inconsistencies) might be within the threshold for that particular elevation data set, due to their nature they can produce unrealistic and inconsistent terrain slope and aspect along the DEMs' borders (Katzil and Doytsher, 2003). Simple DEM merging methods may increase these inconsistencies (Luedeling et al., 2007), and this may, in turn, produce incorrect modelling results such as, for example, unrealistic overland flow patterns resulting in unrealistic overland flow modelling results. Therefore, there is a need for novel methods that can generate complete and accurate DEMs. Such methods must be able to extract all and only the correct data from different elevation

* Corresponding author.
E-mail addresses: joaopaulo.leitao@eawag.ch (J.P. Leitão), eprodano@hikom.grf.bg.ac.rs (D. Prodanović), c.maksimovic@imperial.ac.uk (Č. Maksimović).

http://dx.doi.org/10.1016/j.cageo.2016.01.001
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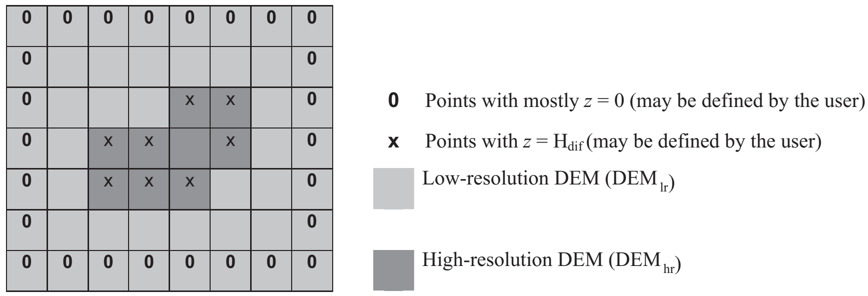

Fig. 1. Possible location of points used to generate the DIF surface (interpolation points).

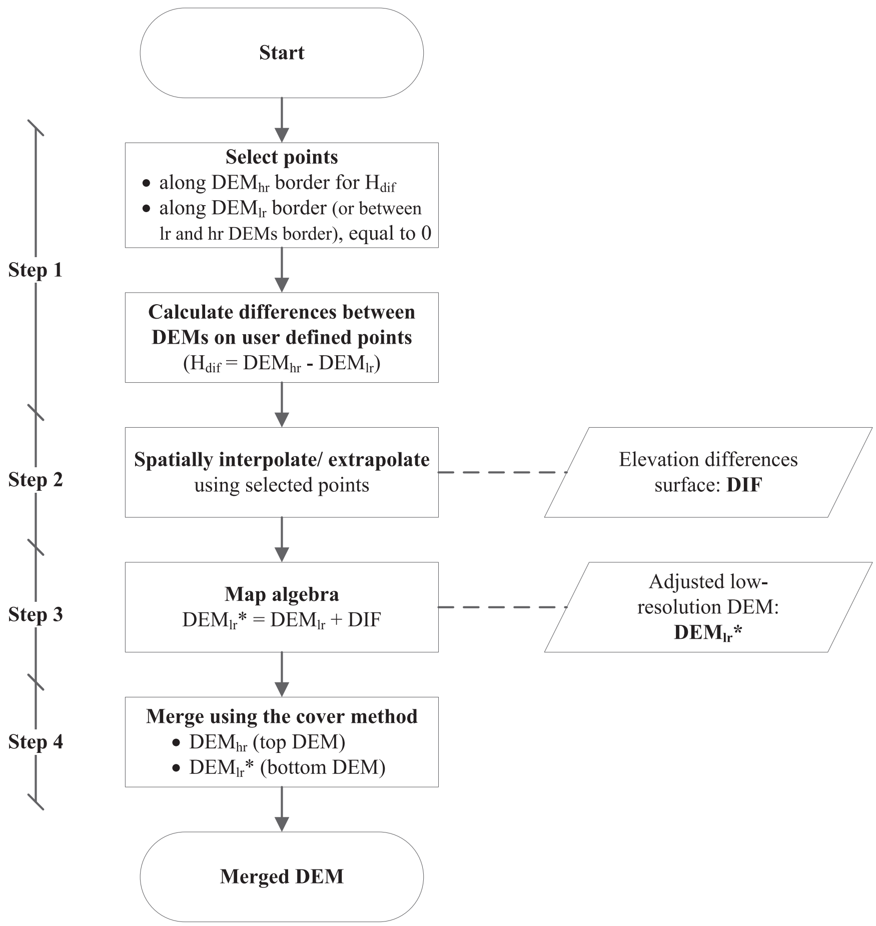

Fig. 2. Flowchart of `MBlend`.

data sets (Ravanbakhsh and Fraser, 2013). Such methods must retain the key features of the most accurate DEMs, placing particular emphasis on the boundary areas between the different DEMs.

With several data sources available, the aim of merging DEMs is to combine one or more elevation data sources such that each area is represented by a combination of the most accurate sources available (Bourgine et al., 2004).

1.2. Conventional DEM merging methods

Commercial Geographic Information Systems (GIS) software provide functions for merging two or more grid-based (raster) data sets. These methods assume that grid-based DEMs have the same spatial resolution (cell size), and also the same coordinate system. The conventional methods to merge DEMs are: (i) `Cover` type methods, (ii) `Average` type methods and (iii) `Blend` function methods (Eastman, 2012; ESRI, 2011).

`Cover` type methods do not operate any elevation adjustment on the DEMs; DEMs are just superimposed. The DEM resulting from this spatial operation has cell values equal to the top DEM in the area represented by this DEM; in the remaining area the cell values are equal to the values of the bottom DEM. The main issue is that the resulting DEM may have significant elevation discontinuities (cliffs) along the boundary between the DEMs, and this creates erroneous slope and aspect values (Hickey, 2000).

In the `Average` and `Blend` methods, elevation adjustments are performed within the overlapping area of the DEMs being merged. `Average` methods assign the average value of the elevation within the overlapping area of the two DEMs. Hence, only the elevation values within the overlapping area are changed.

There are, however, averaging methods that consider weighted averages; this is the case for the Mosaic tool available in the IDRISI software (Eastman, 2012). In an attempt to resolve the issue of elevation discontinuities reported in the case of the `Cover` DEM