# LIDAR DATA ANALYSIS WITH DIGITAL IMAGE CORRELATION (DIC) IN OBTAINING LANDSLIDE DISPLACEMENT FIELDS: A CASE OF GSCHLIEFGRABEN LANDSLIDE-AUSTRIA

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**Abstract:** Comparison of LIDAR datasets were shown as useful in obtaining information about displacement fields of active landslides. Iterative closest point (ICP) and digital image correlation (DIC) are two main approaches used for this aim. Whereas ICP is based on precisely matching point-clouds, DIC is based on cross-correlation of remotely sensed digital imageries. Although DIC is a popular application in fluid mechanics for quantifying flow velocity, its successful applications in estimating displacements resulted from landslides are available. Studies indicate that DIC is more suitable than ICP when computing displacements in the order of magnitude of several meters. DIC is applied to any raster dataset representing a surface property considering the specific advantages and disadvantages of these techniques. In the present study, DIC was applied for an active landslide (named Gschliefgraben) located in Upper Austria. Two time series of LIDAR data obtained in 11th February 2008 and 28th April 2008 was used. The precision of DEMs with 1*1m raster cell size is 20 cm (horizontal) and 15 cm (vertical). Because Gschliefgraben is a big landslide system, DIC analysis was only made for small part of landslide area located close to the crown (head). This part was selected because more activation was observed between two series with visual inspection. Within the study area two separate active parts were observed. According to results, between two time series, the mean displacement rates in these more active parts within study area were obtained 0.66 m (max. 2 m) with sub-pixel precision image matching.

**Keywords:** Digital image correlation, Displacement field, Landslide, LIDAR

## Introduction

Understanding of landslides and their mechanisms is crucial for reduction of landslide hazard. Because landslides are responsible for human casualties, property damage and environmental degradation. Quantification of kinematics of the movement, mostly superficial displacements, is a way of monitoring of a landslide (Gili et al., 2000). Periodic acquisition and analysis of a series of observations over time are needed for monitoring landslides (Stumpf, 2013). Remote sensing is one of the most important technique used in landslide monitoring (Savvaidis, 2003), especially LIDAR systems have gained wider acceptance due to increasing availability, possibility of high density point clouds, and very high resolution 3D information of terrain with high accuracies (Baldo et al., 2009; Barnhart and Crosby, 2013; Jaboyedoff et al., 2012).

Comparison of LIDAR datasets have been shown as useful in obtaining information about displacement fields of active landslides. Iterative closest point (ICP) and digital image correlation (DIC) are two main approaches used for this aim (Daehne and Corsini, 2013). Whereas ICP is based on precisely matching point-clouds, DIC is based on cross-correlation of remotely sensed digital imageries. DIC is an image processing technique used to measure deformation by comparing two digital images (Take, 2015). This technique was originally developed in the field of experimental solid mechanics (Peters and Ranson, 1982). Although DIC is popular in fluid mechanics for quantifying flow velocity, beginning in the late 1990s, DIC was also noticed as well-suited technique to geotechnical engineering applications (White et al., 2001; Take, 2003; Sadek et al., 2003). Image correlation have currently become one of the most efficient techniques to determine horizontal ground displacements due to volcano (Walter, 2011), earthquakes (Van Puymbroeck et al. 2000), landslides (Delacourt et al., 2004; Aryal et al., 2012; Travelletti et al., 2012; Daehne and Corsini, 2013), glaciers (Kääb et al., 2005), ice flows or sand dune migrations (Rosu et al., 2014).

In the present study, two time series of LIDAR data obtained in 11th February 2008 and 28th April 2008 was used to apply DIC analysis in Gschliefgraben landslide. The precision of DEMs with 1*1m raster cell size is 20 cm (horizontal) and 15 cm (vertical). DIC analysis was applied by using image correlation software (CIAS), which matches offsets between two images based on normalized cross-correlation. DIC analysis was only made for small part of landslide area (about 10 Ha) located close to the crown (head) of landslide.

## Materials and Methods

### Study Area and LIDAR Datasets

Gschliefgraben landslide system, located in Upper Austria (municipality Gmunden), was selected as study area (Figure 1). The top, left, right, and bottom coordinates of the area in MGI/Austria GK M31: EPSG Projection are 306000.25, 35399.75, 38500.25, and 303899.75, respectively. Detailed information on this landslide, an earth flow amounting about 3.8 million $m^3$ accumulated solids, was well represented by Marschallinger et al. (2009). In the present study, two time series of LIDAR data obtained in 11th February 2008 and 28th April 2008 was used. The precision of DEMs with 1*1m raster cell size is 20 cm (horizontal) and 15 cm (vertical) (Figure 2).

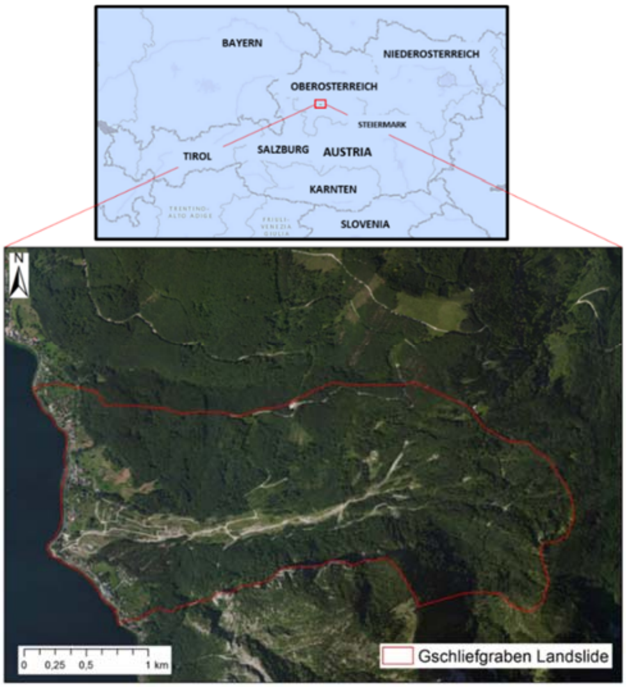


**Figure 1.** Location map of Gschliefgraben Catchment

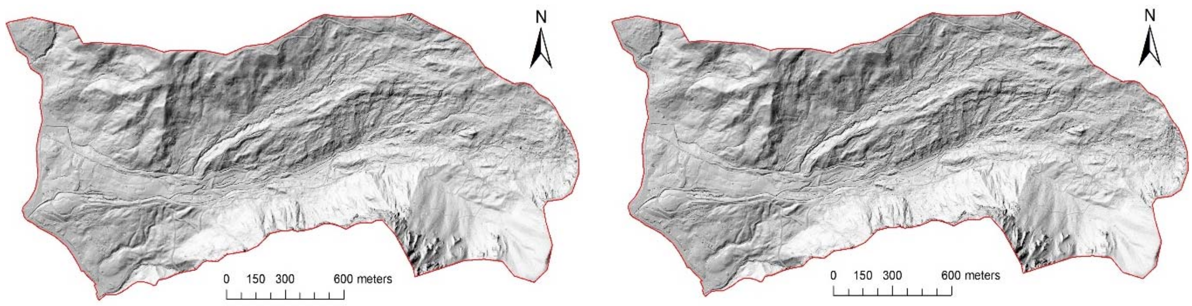


**Figure 2.** Shaded reliefs of LIDAR data: $11^{th}$ February 2008 (left) and $28^{th}$ April 2008 (right).

### Digital Image Correlation

Digital image correlation (DIC) is a deformation measurement technique to obtain 2D/3D displacement field by correlating two image acquired at different time (Travelletti et al., 2012). The detailed description of cross-correlation applied to image can be found in the literature (Adrian, 1991). DIC uses pixel intensity values to calculate incremental displacements with subpixel accuracy (Take, 2015). The basic parameters of the correlation are the “sliding window”, the “search space” and “step” (Rosu et al., 2014). One of images of the series is chosen as a reference image. All images are divided into small rectangular regions consisting of NxN pixels (vary from 7x7 pixels to 70x70 pixels and even more) (Malesa et al., 2011). DIC algorithm is then tracking the position of each subset from the reference image in all other images of the series. Corresponding subsets are matched by finding the maximum of the normalized cross-correlation function coefficient. For each subset in-plane displacement vectors are then calculated. The basic working principle of DIC is given in Figure 3. In the present study, DIC was applied to image pairs of "hillshade" grayscale images, derived from LIDAR DTMs. Because Gschliefgraben is a big landslide system, DIC analysis was only made for small part of landslide area located close to the crown (head) (Figure 4). This area was selected because more activation was observed between two series with visual inspection. Within the study area two separate active parts were observed.

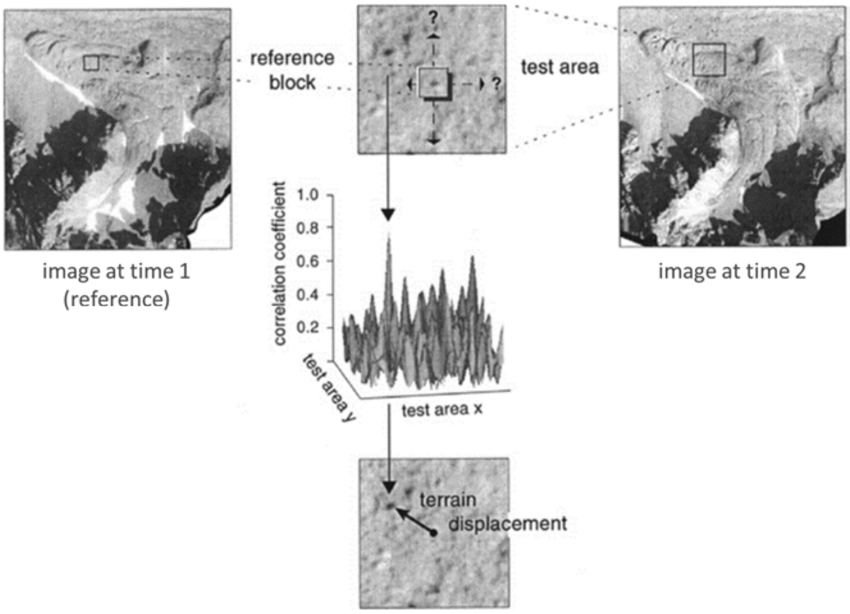


**Figure 3.** Schema of measuring surface displacements from two images acquired at different time by block-correlation techniques (Kääb and Vollmer, 2000)

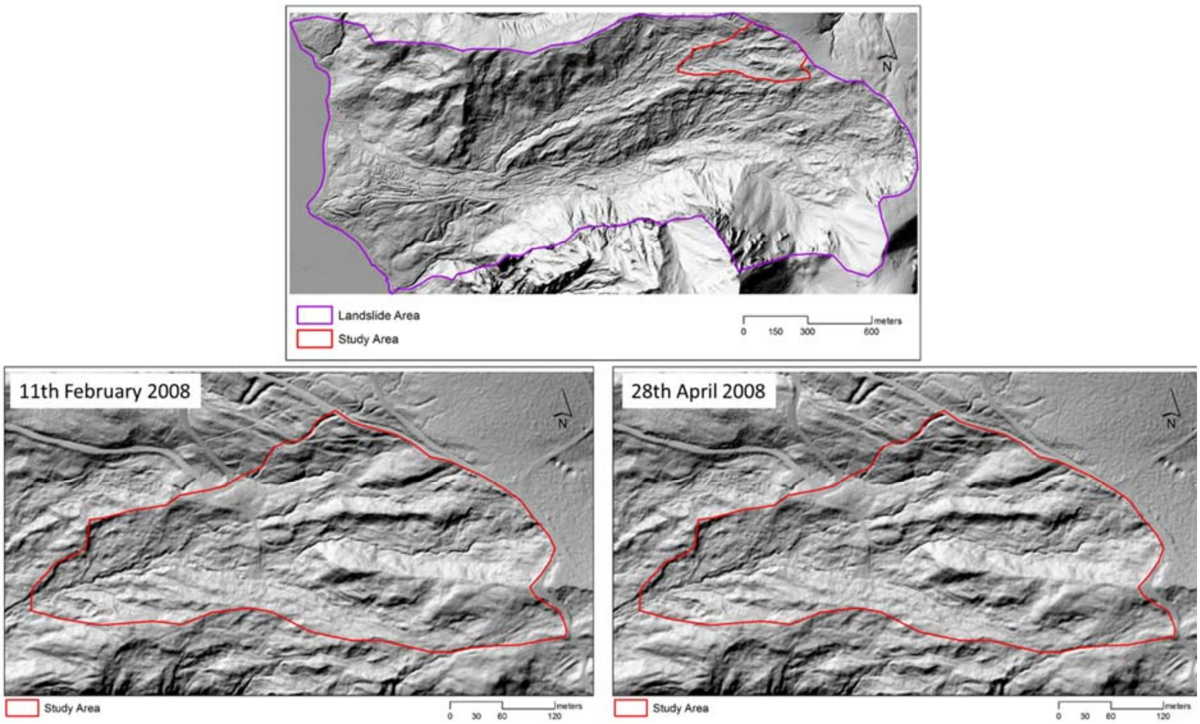


**Figure 4.** Selected active part of Gschliefgraben landslide for DIC analysis

DIC analysis was applied by using image correlation software (CIAS), which matches offsets between two images based on normalized cross-correlation. CIAS was originally written by M. Vollmer and A. Kääb (Kääb and

  

Vollmer, 2000). The inputs (i.e. both images need to be exactly same resolution and to be single channel (grayscale). The output is ASCII list of offsets in Cartesian and polar coordinates and correlation coefficients. Measuring an individual horizontal displacement vector basically follows two steps (Kääb and Vollmer, 2000): (1) choosing image section with sufficient contrast in image at time 1, called as "reference block", (2) searching the corresponding image section within a sub-area in the image at time. The ground coordinates of central pixel within the reference block are known due to usage of already georeferenced data ("Geotiff"). The difference of coordinates of central pixel within reference block and coordinates of corresponding location of central pixel in test block where correlation coefficient is maximum provides displacement. The size of the test area has to be chosen according to expected displacement. Also, textural characteristics of the ground surface have to be taken in to account for choosing the size of reference and test blocks (Kääb and Vollmer, 2000). In the present study, size of reference block was 16, and size of test block was defined as 64. Then, results from DIC was compared with displacements estimated from tracking well-constrained morphological features on shaded relief images (Daehne and Corsini, 2013; Esparmer, 2010).

## Results and Discussion

DIC analysis was used to determine displacement fields from two time series (11$^{th}$ February 2008 and 28$^{th}$ April 2008) of LIDAR data with 1 m resolution in Gschliefgraben landslide. Between two time series there are 77 days. Shaded relief data with 1 m resolution were generated before DIC analysis was applied. CIAS software was selected, even though there are many other options (such as Cosi-corr, DPIVsoft Matlab, etc.) to apply DIC, because CIAS enables the users to use Geotiff data which is georeferenced, thus any further step is not necessary to convert the results to real world units. In the present study, there is no field check or any GPS surveying, however clearly identifiable features over the moving mass were tracked via visual inspection was carried out to get displacement rates in order to compare DIC results. The results were obtained as compatible with manually identified displacements rates.

Study area selected for DIC analysis is 10.19 Ha and there are two more active parts clearly identifiable by visual inspection. DIC analysis provided high displacements within these 2 more active parts of landslide (depicted in Figure 5) as expected. According to results, between two time series, displacement rates within study area were obtained between 0-32.2 m with sub-pixel precision image matching. DIC provided displacements for 25445 points. The mean displacement was obtained as 0.23 m. In the study area, 51 of all points have displacements higher than 2 m of which mean of maximum correlation coefficient is less than 0.70. Of these points, only 3 points showed displacement more than 30 m, 10 points showed displacement more than 20 m, 21 points showed displacements more than 10 m, and 17 points showed displacements more than 2 m. These points were interpreted as unrealistic (extreme) values of displacements which are not compatible with real situation.

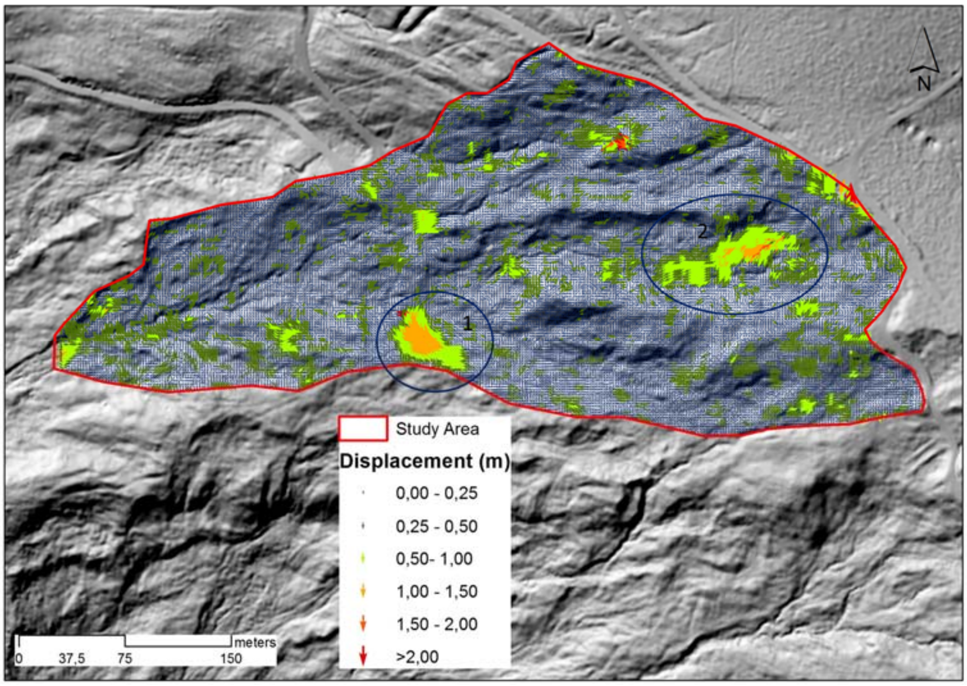


**Figure 5.** DIC results and two more active part of landslide (coded as 1 and 2)

Displacements obtained from DIC in two more active parts, coded as 1 and 2 (see Figure 5), were given in Figure 6 and Figure 7. Between two time series, the mean displacement rates in these more active parts within study area were obtained 0.66 m (max. 2 m) with sub-pixel precision image matching. In first active part of landslide (code no 1), displacements were observed as mean of 0.86 m and also higher than 2 m of displacements available (red circle in Figure 6) was interpreted as unrealistic. Movement direction was observed as NW, as expected due to topography. As similar to 1 coded active part of landslide, higher than 2 m of displacements was interpreted as unrealistic in 2 coded active part of landslide. Mean displacement in the 2 coded active part of landslide was obtained as 0.64 m. The movement direction in this active part of landslide was observed as SW within the upper slope, and as W within the lower slope.

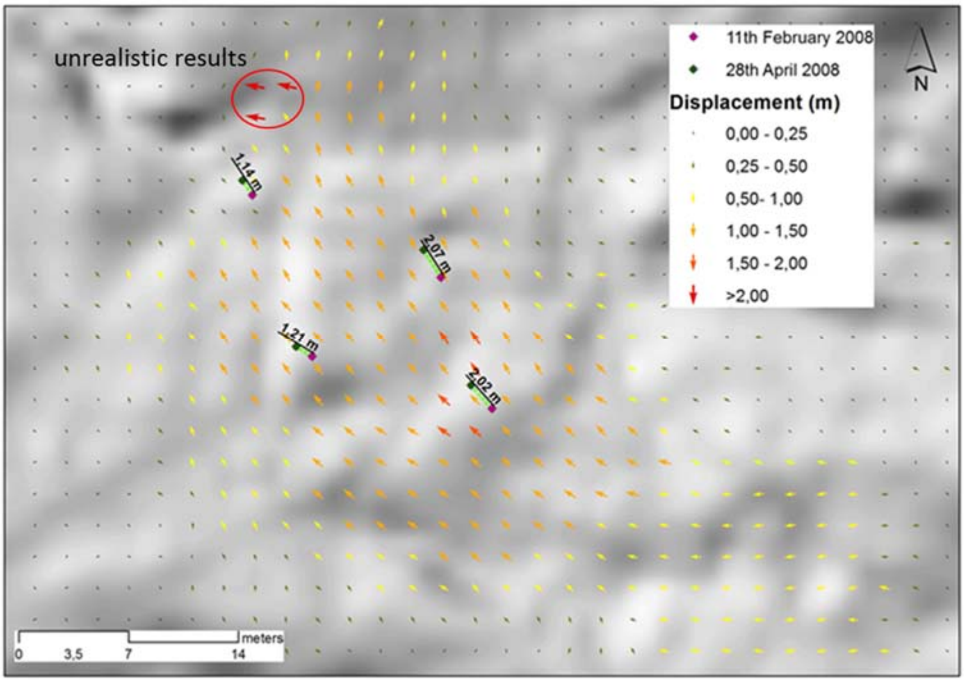


**Figure 6.** DIC results and displacements from manually tracked features on shaded relief within 1 coded active part of landslide

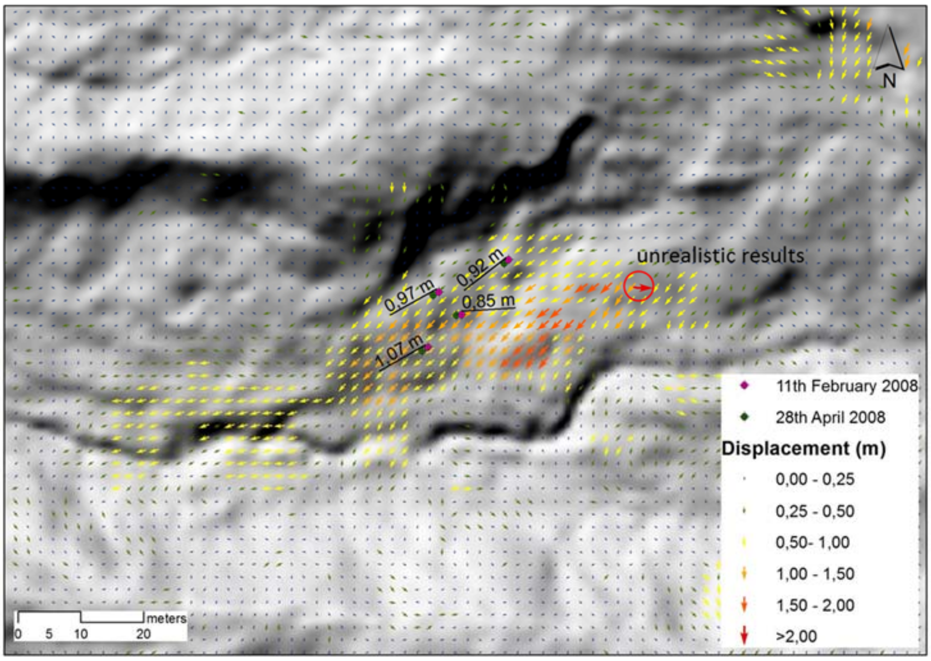


**Figure 7.** DIC results and displacements from manually tracked features on shaded relief within 2 coded active part of landslide.

  

## Conclusion

Our study showed that the DIC analysis applied to shaded relief from LIDAR data can provide spatially continues, smooth, and compatible displacement fields with real situation. As Aryal et al. (2012) and Daehne and Corsini (2013) stated, the accuracy of DIC displacement measurements is of the order of a few meters, which might be an acceptable limit. The success of DIC applied to LIDAR data is closely related to presence of morphological features which must maintain their shape remaining identifiable in shaded relief maps (Daehne and Corsini, 2013). Because we couldn't have any information from field or any axillary data (such as GPS), the compatibility of displacements were evaluated by using displacements obtained by manual tracking of identifiable features over moving mass. Although the DIC analysis preferably requires having knowledge of displacement magnitude to constrain the parameters, the first-hand knowledge of displacement can easily be acquired by comparing positions of identifiable features over time (Aryal et al., 2012).

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