**DAILY ASSESSMENT FORMAT**

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| **Image of session** |
| **Report –**  In my first session today I have studied about –Photogrammetric products from satellite stereo images (DEM and derivatives & Orthoimage) **The use of 3D surface imaging technology is becoming increasingly common in craniofacial clinics and research centers. Due to fast capture speeds and ease of use, 3D digital stereophotogrammetry is quickly becoming the preferred facial surface imaging modality. These systems can serve as an unparalleled tool for craniofacial surgeons, proving an objective digital archive of the patient's face without exposure to radiation. Acquiring consistent high-quality 3D facial captures requires planning and knowledge of the limitations of these devices. Currently, there are few resources available to help new users of this technology with the challenges they will inevitably confront. To address this deficit, this report will highlight a number of common issues that can interfere with the 3D capture process and offer practical solutions to optimize image quality.** ABSTRACT Very high-resolution satellite stereo images play an important role in cartographical and geomorphological applications, provided that all the processing steps follow strict procedures and the result of each step is carefully assessed. We outline a general process for assessing a reliable analysis of terrain morphometry starting from a GeoEye-1 stereo-pair acquired on an area with different morphological features. The key steps were critically analyzed to evaluate the uncertainty of the results. A number of maps of morphometric features were extracted from the digital elevation models in order to characterize a landslide; on the basis of the contour line and feature maps, we were able to accurately delimit the boundaries of the various landslide bodies. Introduction Optical satellites are now able to collect very high-resolution imagery over large land areas with a high level of detail, and the spectral and spatial resolutions of satellite data play a significant role in ensuring the accuracy and reliability of the derived maps.  For instance, the GeoEye, WorldView and Pléiades satellites provide imagery with a ground sampling distance (GSD) of approximately 50 cm in panchromatic mode. Moreover, during 2014, a few satellite companies received permission to collect and sell imagery at up to 25 cm panchromatic and 1.0 m multispectral GSD.  For decades, aerial imagery had been the only approach available for generating digital elevation models (DEMs) over large areas. Although airborne photogrammetric flights with new digital aerial cameras make it possible to capture highly detailed imagery, the drawback is that they require “ad hoc” photogrammetric flights at detailed scale and the handling of a high number of frames.  Unmanned aerial vehicles (UAVs) allow more detailed imagery to be acquired but only over very small areas (Niethammer, James, Rothmund, Travelletti, & Joswig, [2012](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  Several current satellite missions not only provide high-resolution images but are also able to acquire stereo-images that make it possible to create a DEM (Y. Hu, Cheng, Q. Hu, Cheng, Hu, Li, & Zeng, [2011](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Jacobsen, [2009](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084), [2013](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Murillo-García et al., [2015](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)). Also, various software packages such as ENVI (Exelis), ERDAS (Hexagon Geospatial), Geomatica (PCI Geomatics), SOCET SET (Bae Systems), ArcGIS (ESRI) and many others are extensively used to extract DEMs from very high-resolution stereo-imagery. Therefore, VHR optical satellites are now capable of producing images and hence DEMs that can compete with traditional aerial photogrammetric products (Aguilar, Del Mar Saldaña, & Aguilar, [2014](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Jacobsen, [2011](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Yaşa, Erbek, Ulubay, & Özkan, [2004](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  DEMs, contour line maps, 3D exploration and ortho-rectified images can help us to analyze characteristic terrain features as well as changes in morphometry, provided that these products are reliable and accurate (Agugiaro, Poli, & Remondino, [2012](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Fraser & Ravanbakhsh, [2009](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Gómez-Candón, López-Granados, Caballero-Novella, Peña-Barragán, & García-Torres, [2012](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Guarnieri, Masiero, Vettore, & Pirotti, [2015](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Meguro & Fraser, [2010](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Poli & Caravaggi, [2016](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Poli & Toutin, [2012](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  Consequently, particular attention must be paid in the creation of a reliable numerical model that correctly describes the topography.  The imagery georeferencing phase is therefore a very important step in ensuring the reliability of the products derived from the imagery (Toutin, [2004](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)). For VHR satellite imagery, most researchers recommend the use of either 3D physical or rigorous models (Dolloff & Settergren, [2010](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Grodecki & Dial, [2003](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)) or the vendor supplied rational polynomial coefficients refined through a small number of high accuracy ground control points (GCPs) (Aguilar, Del Mar Saldaña, & Aguilar, [2013](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Hanley, Yamakawa, & Fraser, [2002](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Hu, Tao, & Croitoru, [2004](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  Another frequently used georeferencing method is the rational polynomial function (RPF) model, which requires the availability of a large number of high accuracy GCPs. Numerous GCPs can be quickly acquired from the latest large-scale map, or with a more accurate method like a GNSS survey using the surveying technique positioning service in real time (network real-time kinematic – NRTK), now widespread in many countries. By using the DEM derived from satellite imagery, it is then possible either to directly extract the contour lines or to create a map via image ortho-rectification (Capaldo, Crespi, Fratarcangeli, Nascetti, & Pieralice, [2012](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Daliakopoulos & Tsanis, [2013](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Deilami & Hashim, [2011](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Saldaña, Aguilar, Aguilar, & Fernández, [2012](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  Geological analyses of terrain morphology are often based on contour lines maps derived from DEMs (Drăguţ & Eisank, [2011](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Lu, Stumpf, Kerle, & Casagli, [2011](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)). Starting from a reliable and accurate DEM, it is possible to extract a number of land-surface parameters, which are useful to accurately delineate and quantify landslides and other similar features using geomorphometrics criteria (Dramis, [2009](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Hengl & Reuter, 2009). In detail, Geographic Information Systems (GIS) have greatly contributed to the study and mapping of the landforms (Chacón & Corominas, [2003](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Huabin, Gangjun, Weiya, & Gonghui, [2005](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  However, apart from Leoni et al. ([2009](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)), Li, Zhu and Gold ([2005](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)), Wilson and Gallant ([2000](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)), few scientific papers or textbooks tackle the elaboration of a DEM suitable for carrying out analysis in packaged software (Shean et al., [2016](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  A major problem in this sense is the absence of standards for extracting DEMs useful for such analyses. While traditional photogrammetric surveying can count on many codified procedures to produce DEMs and cartography (Hugenholtz et al., [2013](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)), similar codings do not seem available for VHR images.  In this work, we have elaborated a VHR stereo pair collected by the GeoEye-1 satellite: the stereoimage covers an area with different morphology where mountainous, partly shadowed zones alternate with hilly and flat ones. A well-known landslide compound, which has been the object of a few geomorphological studies (Calcaterra et al., [2014](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); De Vita, Carratù, La Barbera, & Santoro, [2013](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)), affects a small area of the imagery.  The geomorphometrical mapping process has been critically evaluated step by step from the georeferencing phase to the DEM and maps production phases, in order to achieve reliable and accurate products. We produced a number of contour line and features maps in order to better analyze the landslide compound and to delimitate its different bodies. Direct knowledge of both the terrain morphology and the trend of the landslide allows us to directly verify the parameters used to elaborate the DEM. Methods If the aim of the survey is landscape characterization in order to monitor changes over time, the outcome of any image elaboration step – georeferencing, image matching, DEM extraction and morphometrical feature extraction – should be subjected to critical analysis. Georeferencing For geomorphological purposes, the image georeferencing phase is of primary importance. The georeferencing accuracy of high-resolution satellite imagery is not a function of spatial resolution alone, as it is also dependent upon radiometric image quality, satellite platform attitude and the precision of the GCPs survey. The most frequently used georeferencing algorithms are based on rigorous models or on use of RPFs.  In this work, we have tested the physical model embedded within the software Geomatica (called “Toutin’s model”), the physical one embedded in Socet Set (called “rigorous simultaneous”) and the RPF model embedded in Geomatica (called “Rational Function”).  The software user’s guides suggest using only a few points (from 6 to 10 for Geomatica, even less for Socet) to geo-reference the image if the rigorous model is used. This is why we used only a small number of points as GCPs. The remaining were used as check points (CPs) for testing the accuracy of the output (e.g. to evaluate the difference between the value measured on the terrain and that measured on the georeferenced image).  In order to georeference the image, we run a NRTK GPS surveying campaign. To obtain a homogeneous distribution of well-“matched” points, control points were chosen in close proximity to the nodes of a regular grid; grid spacing was fixed while bearing in mind the number of points required for image georeferencing, which depends on the type of mathematical transformation used. The grid was overlaid onto the image and the GCPs position was selected nearby these nodes taking care of choosing “stable” details clearly visible on the image, such as artifacts or natural objects ([Figure 2](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084#F0002), left panel). Due to the presence of many mountainous districts, devoid of any stable points that can be easily identified on the image, in some areas, there are no points in correspondence of the grid nodes.  Regular grids have been drawn on the image to obtain a homogeneous distribution of well-“matched” points. Control points have been chosen in close proximity of the nodes of the grid. Green circles indicate areas on the images that are close to visible control points, yellow triangles indicate “bad” points with issue of collimation (since they are located in shady areas of the image), red squares are on the location of grid nodes where it was not possible to find a point to collimate (mountain areas and/or without artifacts). Left panel: GGCPs; right panel: MGCPs. DATUM is ETRS89, frame ETRF00.  [https://www.tandfonline.com/na101/home/literatum/publisher/tandf/journals/content/tejr20/2017/tejr20.v050.i01/22797254.2017.1372084/20180328/images/medium/tejr_a_1372084_f0002_oc.jpg](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)  In order to design the surveying campaign, it is necessary to consider whether the site offers good road access or it is isolated. In this case, neither a good cellular phone signal nor a good satellite DOP value, which are necessary conditions for the GPS NRTK survey, can be expected.  Thanks to the speed of the GPS measurements, once we had reached the survey area, we decided to measure several neighboring points in order to then choose which could be better collimated on the image and which was the best in terms of measurement quality.  A total of 29 points were deemed suitable for use as either GCPs or CPs in our experimental testing. The position accuracy for the points measured using the NRTK technique is estimated to be better than 10 cm.  Positions were directly obtained in the European Terrestrial Reference System 1989 (ETRS89), the European and National geodetic system, European Terrestrial Reference Frame 2000 (ETRF00).  A few other points were acquired from the latest available map, the Cartografia Tecnica Regionale at a scale of 1:5000. The cost of data acquisition from the map is obviously much lower than with the surveying campaign, so many more points were measured on the map. The point acquisition pattern was designed so as to have a homogeneous distribution ([Figure 2](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084#F0002), right panel). We have also taken care to ensure that the points whose coordinates were measured on the map correspond on the image to details that are both stable and well collimable.  Geomatica, if a geocoded map covering the area in the image is available, manages the geometric correction process through an OrthoEngine application which allows us to collect the GCPs directly on the map. The cursor must be positioned exactly over the location in the uncorrected image that we wish to use for control and later over the identical location in the geocoded image map. Good choices are road intersections in built-up areas or sharp river bends in natural environments. We have got our estimate for the elevation from a linear interpolation of the contour lines.  Obviously, the georeferenced map must have the coordinate system you have set for your image in the “set projection” panel.  Regarding the choice of the point location, besides the presence of homologous points on the image and on the map, a further necessary requirement is the possibility to acquire all three of their coordinates on the map with good accuracy; some areas lack points showing these features. The whole process would be improved if it were possible to give 2D (planimetric) and 1D (altimetric) point coordinates separately. Unfortunately, this is not possible as both software packages demand 3D points.  The planimetric root mean square error (RMSE(N,E)) of the map is about 1.2 m and the vertical error RMSE(H) is 0.75 m (Barbarella, Fiani, & Lugli, [2017](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)). The accuracy of these points is clearly lower than the one of the points measured directly on the terrain.  In summary, the GCPS used for georeferencing the stereoimage consists of two different sets: GPS GCPs (from now on, called GGCPs) and mapping GCPs (from now on, called MGCPs).  In [Figure 2](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084#F0002), the green circles indicate areas on the images near to visible control points, to be measured on the terrain (left panel) or on the map (right panel), the yellow triangles indicate “bad” points with some collimation problems because they are located in shadowed areas of the image and the red squares indicate the location of grid nodes where it has not been possible to find a point to collimate (mountain areas and/or without artifacts).  We should also homogenize the geodetic reference systems used. In our case study, both cartography and NRTK are framed in ETRF00. Therefore, no datum transformation was needed for planimetry whereas the height needs a transformation from ellipsoidal to geoidal using an accurate geoid height model specific to Italy (Pepe & Prezioso, [2015](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  In order to verify the numerical accuracy of the georeferencing, we provided the residual values computed by the software, i.e. the difference between the adjusted coordinates and the input ones, measured either on the ground or on the map. On the CPs, the software computed the shifts between the measured value of the coordinates and the value measured on the georeferenced image. DEM extraction In this phase, we studied the accuracy of the DEMs extracted using stereo-matching techniques from the stereo images. Two commercial software packages – Geomatica and SocetSet – were used for the image processing phases, including DEM extraction.  In both cases, the DEM extraction process makes use of image correlation to find matching features on the two images of a stereo pair, adopting strategies specific to the software used.  Geomatica used a feature-based matching model called normalized cross-correlation matching. This method finds the relative shift between two images by finding the shift that produces the maximum cross-correlation coefficient of the gray values in the images (Geomatics, [2010](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Lewis, [1995](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)).  The software requires epipolar images to extract the DEM, in order to reduce the time necessary to find corresponding points in image matching (Deilami & Hashim, [2011](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)). At this stage, it is helpful to add some tie points to improve the digital matching in a few “critical” zones, mainly in the shadowed areas of the mountain slopes. A hierarchical approach using a pyramid of reduced resolution images was the method adopted in order to find these matching features.  In this phase, two parameters need to be chosen: “DEM resolution” (the size of the pixel in the final DEM) and “DEM detail”. Specifically, the latter determines how precisely to represent the terrain in the DEM. Selecting “very high”, “high”, “medium” or “low” determines the time at which to stop the correlation process. In the case of failed correlation, in order to enhance the continuity of the DEM surface, we set the “fill holes” option so as to automatically filter the elevation values by interpolating the failed areas; however, this strongly influences the reliability of the resulting DEM.  With Geomatica, the first tests to verify the DEM accuracy were carried out by varying both the parameter “resolution” (from 0.5 m i.e. “very high” to 10 m i.e. “low”) and “detail”. Different levels of detail were set.  Moreover, we have made a number of tests using different types of terrain. Finally, we chose “mountanous” for the whole image because this choice gave us better results.  Socet Set (BAE Systems, [2007](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)) used ATE (Automatic Terrain Extraction), an object-based area-matching model and Next Generation Automatic Terrain Extraction, a hybrid matching process (both edge and area based), which performs image correlation and edge-matching on each image pixel (Zhang, [2006](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)). We used adaptive ATE, suitable for satellite imagery, mostly natural terrain.  When using Socet Set, some parameters also have to be set in order to create the DEM, including the number of pyramid levels on which the model is created, the resolution of the output DEM, the correlation strategy (adaptive or nonadaptive) and the use of some filters to remove artifacts such as trees or buildings.  We made a number of tests, varying some parameters. Finally, we set the following parameters: “high” for smoothing, “high” for precision, “low” for speed and “automatic” for seed DEM. The DEM grid size was fixed at 2, 1 and at 0.5 m, for testing purposes.  In order to transform the DEM from a DSM (digital surface model) into a DTM (digital terrain model), an automatic filter must be applied to the whole image in order to eliminate or reduce the presence of vegetation and artifacts.  For example with Geomatica, above-surface features such as trees and buildings were mostly removed (minimized) by running the “DSM2DTM” filter implemented in the software package. The filter searches for the local minimum based on a user-defined kernel (filter) size to obtain the bare soil profile (DTM). The kernel size was set to 10 × 10 m in planimetry. If the difference between the local height minimum and the average elevation is higher than 5 m, the related data are removed.  In order to verify the accuracy of the DTMs we produced, we run tests by comparing the coordinates measured on the ground with those measured either directly in stereoscopy on epipolar images with Geomatica or on the orthophotos with Socet Set.  An overall check of the goodness of the results obtained in image processing can be carried out with Geomatica by analyzing the correlation score for each DEM pixel recorded by a score channel that is generated for each level of detail chosen. In the event of unsuccessful correlation (values less than 20), a failure value is assigned to those pixels in order to recognize them.  An analogue numerical value called “Figure Of Merit” (FOM) is computed in Socet Set.  An additional check of the output was performed by analyzing contour lines from a visual point of view as well as from a numerical one, in order to verify whether the model generated from the stereo pair is compliant with the actual terrain. On a small part of the image, representing an area whose morphology is well known to us, we were able to evaluate the compliance of the DEMs extracted with the morphology of the actual terrain. Feature maps extraction In making a classification of the various homogeneous parts of the landslide, the advice of geomorphologists played a fundamental role. Indeed, those who know the area well were able to identify the different landslide polygons; their analysis is usually based on a visual inspection of the contour line maps; so, we provided the geomorphologists with contour maps at different contour intervals.  Starting from the DEM, it is possible to elaborate other derived products potentially relevant for geomorphological and geomorphometric investigation. In particular, for geomorphometric landscape studies, the five basic parameters which have to be computed are, according to Evans’ general geomorphometric method (Evans, [1980](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Evans & Chorley, [1972](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)): elevation, slope, aspect, profile and tangential curvatures.  Considering the local trend of the terrain in the neighborhood of a point, expressed by the function *z* = *z* (*x*, *y*), both slope and aspect can be expressed through the first derivative of this function whereas curvature makes use of its second derivative.  These variables can be computed in correspondence of each cell on the DEM grid. They approximate the trend of the terrain with a polynomial of second or fourth degree and then numerically compute the derivatives using a given neighborhood of each pixel.  Numerous formulas are proposed in the literature to make this computation (Hengl & Reuter, 2009). We used a specific ArcGIS tool, called “Spatial Analyst PLUS” (Esri, [2011](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)), adding some specific scripts for the analysis of spatial raster data. The software uses the Horn algorithm (Horn, [1981](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)) to compute the first derivatives, and Zevenbergen and Thorne’s method (Burrough & McDonnell, [1998](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084); Zevenbergen & Thorne, [1987](https://www.tandfonline.com/doi/full/10.1080/22797254.2017.1372084)) to compute the curvature using the second derivatives. |