New Trends in Geomatics, in the Era of Low-cost Sensors, Free and Open Source Software and HPC GeoBigData infrastructures

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This review briefly presents some methodologies and applications developed at the Geodesy and Geomatics Division (DICEA) of University of Rome "La Sapienza". Directly related to the current and increasing availability of new and innovative software and hardware, they are already ready for industrial applications and hopefully can broaden the interaction between Geomatics and other scientific and technological disciplines.

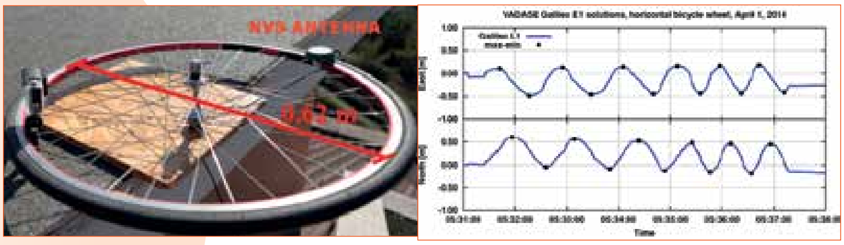

Fig. 1 - Real-time tracked movements with VADASE using GALILEO E1 observations acquired by a low-cost single frequency receiver with a patch antenna

The present and continuously increasing availability of more and more low-cost sensors (in the frame of the Internet of Things (IoT)), Free and Open Source Software (FOSS) and High Performance Computing (HPC) infrastructures for managing GeoBigData has obviously a strong impact in Geomatics. The availability of these hardware and software tools enables both to develop new applications but also to stimulate new challenging investigations related to the modeling of the observations supplied by these sensors, in the well known circular fashion between science and technology (Sansò and Crespi, 2015).

Exploiting GALILEO for real-time displacements detection with low-cost single frequency receivers

In last years, mainly thanks to their low cost, single frequency GNSS receivers started to be used in many applications. Evaluation kits, based on this kind of hardware, are nowadays available at few hundreds of Euros. Most of them are able to collect code and phase single frequency observations not only from GPS systems but also from other GNSS constellations like GLONASS, GALILEO and BEIDOU.
On a technical point of view, these kits are quite easily usable and it is possible to set them up in order to broadcast both real-time streams (for real time precise positioning application) and collected observations in RINEX format (for post processing analysis).
Our research group carried out many experiments on this topic. In particular, we investigated also through low-cost receivers the potentialities of GALILEO system, starting from the very first availability of GALILEO signals. Thanks to these research, the VADASE team was awarded by ESA on 1st April 2014 as one of the first 50 users worldwide able to get a "fix" with GALILEO system (Branzanti et al., 2014).
Through the application of the VADASE variometric approach (Benedetti et al., 2015), we managed to reconstruct the movement of a low-cost NVS patch antenna, suitably fixed to a bike wheel, processing E1 phase observations in a real-time scenario, achieving 1 cm accuracy; this experiment clearly showed the relevant potential of the low-cost single frequency receivers for real-time movements detection (Fig. 1).
Moreover, many tests were performed in order to evaluate the potentialities of low-cost single frequency receivers also in Network Real Time Kinematic (NRTK) positioning. It was demonstrated that, using u-Blox receiver with GPS, it is possible to achieve fixing times

(less than a minute) and accuracies (few centimetres) not so far to double frequency approach, provided good surveying conditions (full sky visibility, stable and reliable Virtual Reference Station augmentation needed to handle ionospheric delays through double differentiation with very short baselines) are guaranteed and an external topographic antenna is used.
The contribution of GALILEO E1 observations in NRTK positioning is currently under investigation.
Finally, in the last months, a focus on GPS and GALILEO interoperability with VADASE was undertaken. VADASE routines have been extended to make it possible to use GPS and GALILEO phase observations in a twin fashion mode: independent solutions or staked observations combined solutions. Some tests have been carried out in collaboration with the University of Trento (Tesolin et al., 2017) using u-Blox receivers.
Also in this application, results are very promising, paving the way to a wider use of single frequency receivers also as multi-constellation low-cost permanent stations. For these purposes a single frequency low cost GNSS permanent station, named LOW1 (Fig. 2), has been installed and activated at the Faculty of Civil and Industrial Engineering - University of Rome "La Sapienza". Single frequency observations are routinely collected and archived at 1Hz observation rate since doy 100 of 2017; all the data are available to the scientific community.

3D Modelling of Archaeological Small Finds by Low-Cost Range Cameras

Nowadays 3D models may play a key role in archaeology and cultural heritage management in general, since they can easily provide answers to scientific needs in the field of conservation, monitoring, restoration and mediation of architectural, archaeological and cultural heritage.
It is thus essential to identify new techniques, capable of easily providing low-cost and real-time 3D models of cultural heritage objects, with the required accuracy. Range cameras can give a valuable contribute to achieve this goal: they are active imaging sensors, low-cost and easy-to-use, able to natively measure the distances of several points at high frame rate (30 - 60 Hz) and can be used as 3D scanners to easily collect dense point clouds practically in real time. Furthermore, Simultaneous Localization And Mapping (SLAM) algorithms, such as KinectFusion (Izadi et al., 2011; Newcombe et al., 2011) leverage the depth data and the high frame rate that range cameras offer, in order to fuse the depth maps captured from different view points as soon as they are acquired. In this way, through the use of user-friendly scanning apps (through Augmented Reality, the 3D model appears in real time on the tablet/smartphone connected to the device, guiding the user during the scanning), range cameras can collect easily and practically in real time the overall 3D model of the scanned scene. In addition, such sensors are continually evolving and they will be soon integrated in consumer grade smart devices, enabling their use together with other sensors.
Thanks to all these features, nowadays this technology is sufficiently ripe to play an important role for modelling archaeological objects. Indeed, range cameras can be easily used for documenting small finds, thus representing a valid alternative to the often time consuming traditional techniques, and preserving at the same time the mental energy of archaeologists for the study and interpretation of the artefacts discovered during excavations.
Therefore, our research group has investigated the 3D modelling capabilities of a promising low-cost range camera, the Structure Sensor™ by Occipital™ for rapid modelling

Fig. 2 - Low-cost GPS permanent station LOW1

Fig. 3 - Comparison between the model of a globular jug obtained with the Structure Sensor and with photogrammetry: the first can be easily obtained in real-time by a not expert user (archaeologist, etc.), the second required a high level of competence for processing the images with a dedicate software

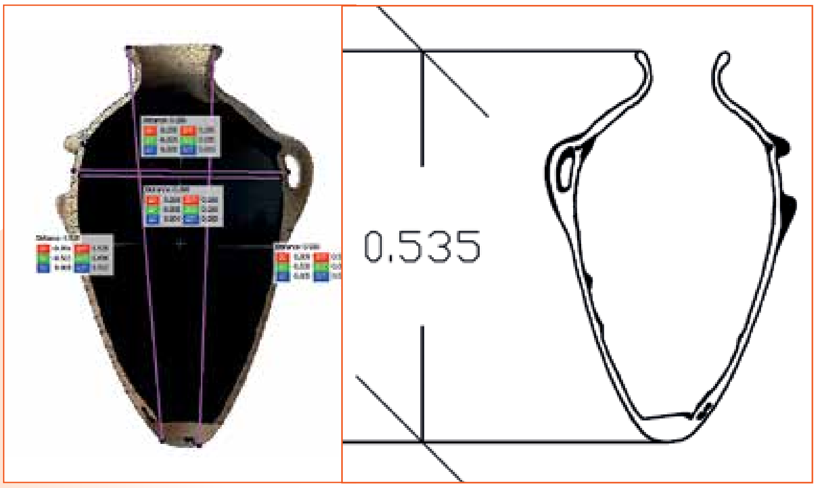

Fig. 4 - Example of measurements that can be taken on models (in meters)

archaeological objects, in order to assess the metric quality of their 3D geometry reconstruction (Ravanelli et al., 2016, 2017a, 2017c). In general, the performed analysis shows that Structure Sensor is capable to acquire the 3D geometry of a small object with an accuracy comparable at millimeter level to that obtainable with the more traditional photogrammetric method, even though the finer details are not always correctly modelled (Fig. 3). The obtained results are therefore very promising, showing that the range camera used for this work, due to its low-cost and flexibility, is a suitable tool for the rapid documentation of archaeological small finds, especially when not expert users are involved.

Finally, it is worth underlining that a "geomatic" 3D model, showing therefore a geometry with a real metric, provides all the necessary information to completely describe the archaeological small finds. Furthermore, it allows to take a posteriori in depth measurements, such as the volume computation and section visualization (Fig. 4).

Digital Image Correlation Software for Displacement Field Measurement in Structural Monitoring Applications

Recently, there has been a growing interest in studying non-contact techniques for strain and displacement measurement in structural monitoring applications. For this reason, a free and open source 2D Digital Image Correlation (DIC) software, named py2DIC and completely written in Python, was developed at the Geodesy and Geomatics Division of DICEA, University of Rome "La Sapienza" (Ravanelli et al., 2017b).

In particular, DIC is the term used in structural engineering applications to refer to the well-known template matching method, generally used in photogrammetry and computer vision to retrieve homologous points. DIC is indeed an optical technique able to measure full field displacements and to evaluate the corresponding strain field, by comparing digital images of the surface of a material sample at different stages of deformation.

The potentialities of py2DIC were investigated by processing the images captured during a tensile test performed in the Lab of Structural Engineering, where three different Glass Fiber Reinforced Polymer samples were subjected to a controlled tension by means of a universal testing machine.

The results, compared with the values independently measured by several strain gauges fixed on the samples, denote the possibility to successfully characterize the deformation mechanism of the analyzed material (Fig.s 5 and 6). Py2DIC is indeed able to compute displacements at few microns level, in reasonable agreement with the reference, both in terms of displacements (again, at few microns in the average) and Poisson's module (Fig. 7).

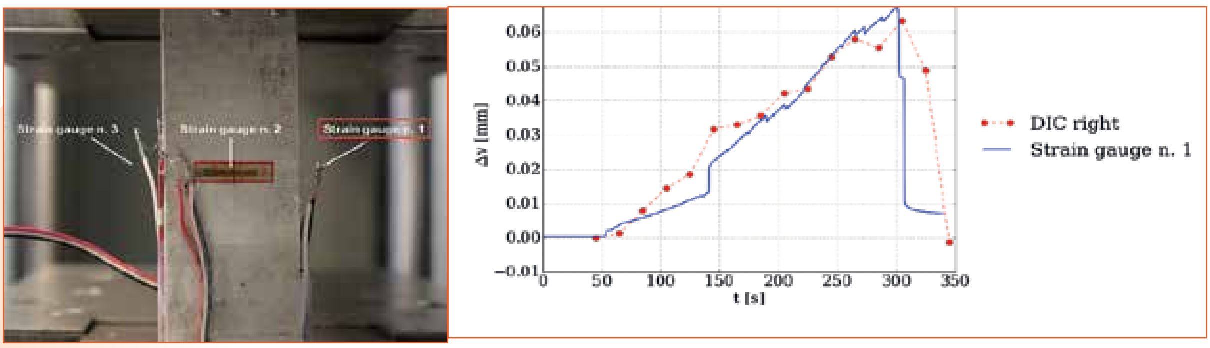

Fig. 5 - Comparison between the vertical displacements obtained by the *py2DIC* software and the strain gauges measurements

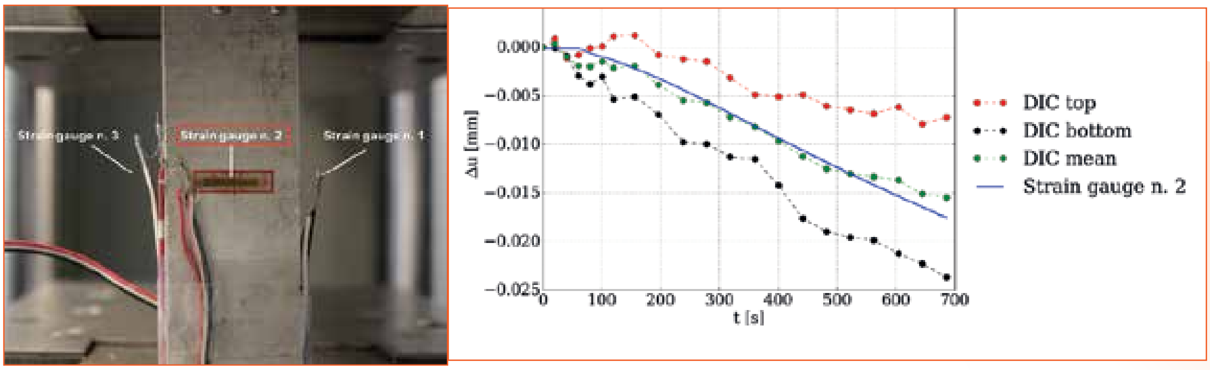

Fig. 6 - Comparison between the horizontal displacements obtained by the *py2DIC* software and the strain gauges measurements

A New and Unified Approach for Digital Surface Models generation from optical and SAR satellite imagery: DATE FOSS4G

By now, satellites are overwhelmingly present in our daily life, for a big variety of different services and applications (weather report, navigation system, Earth observation, ect.). In particular, remote sensing data obtained from space, complement and complete Earth-based measurements: they are essential if a global view of our Earth is required.

One of the most important applications of remote sensing, is the generation of Digital Surface Models (DSMs), that have a large relevance in many engineering, environmental, surveying, Earth sciences, safety and security applications. DSMs can be derived with different approaches, the stereoscopic approach, starting from satellite images, is a well-established one. Every day, a big amount of images are acquired by the thousands of satellites orbiting around the Earth, creating a multi-view and multi-temporal bunch of images, that allow to obtain redundant information for monitoring and analysing our world.

The development of a Free and Open Source Software (FOSS), able to generate DSMs from such satellite images, is therefore a topic of great interest. In the framework of 2014 Google Summer of Code, our research group developed DATE, a Free and Open Source for Geospatial (FOSS4G), having as early purpose a fully automatic DSMs generation from high resolution optical satellite imagery acquired by the most common sensors (Di Rita et al., 2017a, 2017b). Nowadays, it is also able to exploit Synthetic Aperture Radar (SAR) images for radargrammetric applications (Di Rita et al., 2016). As a matter of fact, SAR satellite systems may give important contribution in terms of Digital Surface Models (DSMs) generation considering their complete independence from logistic constraints on the ground and weather conditions (Nascetti et al., 2015). In recent years, the new availability of very high resolution SAR data (up to 20 cm Ground Sample Distance) gave a new impulse to radargrammetry and allowed new applications and developments (Capaldo et al., 2011).

The main idea behind DATE, is to overcome the issues related to epipolar resampling for satellite images, for which epipolar geometry achievement is not straightforward (Di Rita, 2017): epipolarity is achieved in the object space (Ground quasi-Epipolar Imagery (GrEI)) (Fig. 8) thanks to the images ground projection. Moreover, DATE key features include also the capability to handle a large amount of data since it manages to process different images in a sequential and totally automatic way; the use of computer vision algorithms in order to improve the processing efficiency and make the DSMs generation process fully automatic; the free and open source aspect of the developed code (https://github.

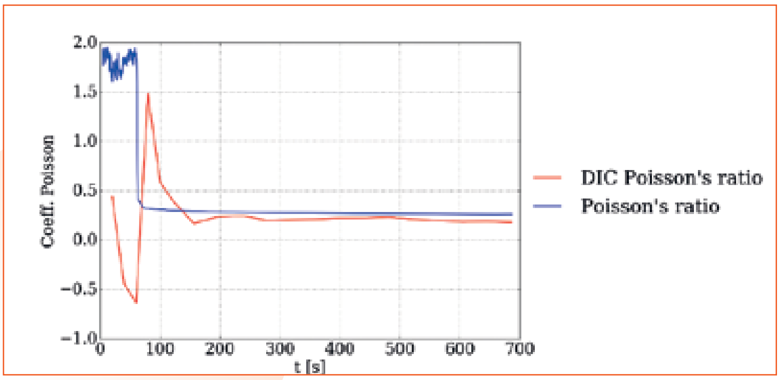

Fig. 7 - Comparison between the Poisson's ratio obtained by the *py2DIC* software and the strain gauges measurements

com/martidi/opencv_dsm/tree/imageStack). An innovative approach based on a coarse-to-fine pyramidal scheme is adopted to take advantage of iterative solutions at gradually increasing resolution in order to refine the epipolarity constrain between the image pair: raw satellite images resolution is initially reduced by a downsampling factor, then these sampled images are projected in a ground geometry using an a-priori (freely available and even coarse) DSM, in order to generate orthorectified images with a transversal parallax error below the initial reduced resolution. These orthorectified images can act as GrEI and can undergo a dense image matching procedure at the chosen reduced resolution, obtaining the initial DSM corresponding to the first pyramidal level; this DSM becomes the input for the next pyramidal level.
The achievable results are good in terms of statistical parameters, and they are comparable with those obtained through different software (even commercial) by other authors on the same test sites, whereas in terms of efficiency DATE outperforms most of them.

Google Earth Engine potentials and capabilities for GeoBigData management and analysis

Google Earth Engine (GEE) is a computing platform recently released by Google "for petabyte-scale scientific analysis and visualization of geospatial datasets" (Google Earth Engine Team, 2015). The GEE can be used to run geospatial analysis using a dedicated HPC infrastructure. GEE enable users to access geospatial information and satellite imagery, for global and large scale remote sensing applications. The free and public data archive includes more than 30 years of historical imagery and scientific datasets, daily updated and expanded: it contains over than two petabytes of geospatial data instantly available for analysis.
The main idea behind GEE is that, also for the analysis of satellite and geospatial data, we are now moving towards the Big Data paradigm and consequently it is necessary to change the processing way from the standard procedure "bring data to users" to the opposite "bring users to data": as a matter of fact, users can directly upload algorithms to the dedicated infrastructure removing the required time for data transfer and allowing the development of innovative applications. The platform supports generation of spatial and temporal mosaics, satellite imagery composites without clouds and gaps, as well as a variety of spectral indices, and can also be expanded and modified by the user even for customized applications (Pekel et al., 2016; Donchyts et al., 2016). Indeed, GEE also includes an application programming framework that allows scientists to access to computational and data resources, to scale their current algorithms or develop new ones.
As a significant example of GEE potentials, we analyzed the possibility to implement and deploy a tool for large-scale DSMs comparison, with a focus on two available free global DSMs (SRTM and ASTER GDEM) precision and accuracy, with respect to a more accurate reference DSM, that is the National Elevation Dataset (NED) for the American States, and a LiDAR DSM for the Italian region (Nascetti et al., 2017). Over the years, several studies have been conducted to evaluate the accuracy of both SRTM and ASTER DSMs, but in most of the cases the accuracy has been evaluated only on limited areas (Colmano et al., 2007; Koch et al., 2001).
The main goal of this analysis was to perform a more global assessment exploiting the potentialities of GEE, and to demonstrate its capability for a nearly-global assessment of SRTM and ASTER accuracy. Proper routines to evaluate standard statistical parameters to represent DSM precision and accuracy (i.e. mean, median, standard deviation, NMAD, LE95) were implemented inside the GEE Code Editor. Moreover, the routines were used to characterize the accuracy of the input DSM within different slope classes. The evaluation has been performed on five different wide areas: four American States (Colorado, Michigan, Nevada, Utah) and one Italian Region (Trentino Alto-Adige, Northern Italy). The selected areas provide different land use, land covers and slopes, and are

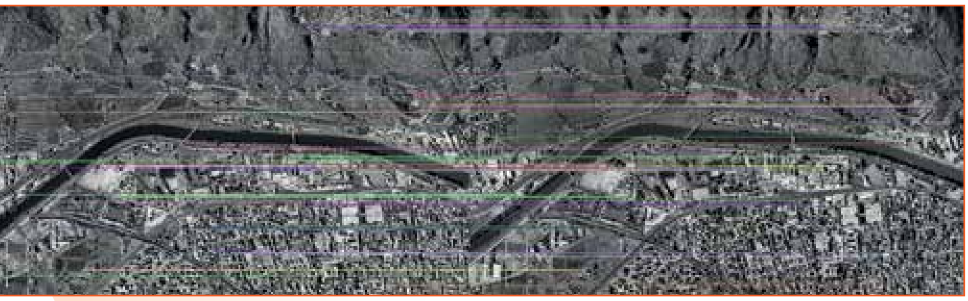

Fig. 8 - Comune di Fiumicino: confronto tra le sezioni di Censimento 1991 e quelle del 2001 e tra le sezioni di Censimento 2001 e quelle del 2011 (Fonte : Istat, Portale Cartografico Nazionale).

therefore suited for a comparison aimed at accuracy and reliability understanding.
Overall, all the results achieved (Fig. 9 represents the results for Colorado) are pretty consistent showing a good accordance in their behaviour: SRTM and ASTER achieve almost the same results when compared both to NED and to LiDAR. In particular, the accuracies decrease with the increase of the slopes, with better results generated with SRTM for the first classes and, instead, a better behaviour shown by ASTER for the higher classes. This is due essentially to the different nature of the two DSMs (SRTM is SAR-based, ASTER is optical-based) and it could lead to make some assumptions about an optimum free nearly-global DSM: starting from the knowledge of the slope classes where they present a better accuracy with respect to the other, a more accurate global DSM can be generated as a result of an integration of both

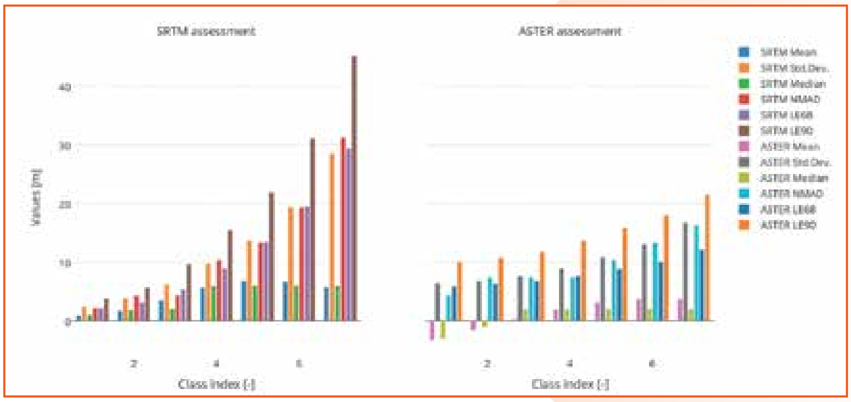

Fig. 9 - Colorado: SRTM and ASTER assessment results

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ABSTRACT

Nowadays, the increasing availability of low-cost sensors, Free and Open Source Software and High Performance Computing infrastructures allows Geomatics to widen its application scope, by stimulating new challenging investigations related to the modeling of the observations provided by these new tools.
In this review, some methodologies and applications, developed at the Geodesy and Geomatics Division (DICEA) of University of Rome "La Sapienza", are shortly presented. Directly related to the mentioned software and hardware new availability, they are already ready for industrial applications and hopefully can broaden the interaction between Geomatics and other scientific and technological disciplines.

KEYWORDS

Geomatics; Low-cost Sensors; Open Source Software; GeoBigData infrastructures

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