Geographia Technica, Vol. 19, Issue, 1, pp 34 to 42

LiDAR RTK Unmanned Aerial Vehicles for security purposes

Valerio BAIOCCHI[1*], Sabina FORTUNATO[1], Francesca GIANNONE[2], Valerio MARZAIOLI[1], Felicia MONTI[1], Roberta ONORI[3], Lorenzo RUZZI[4], Felicia VATORE[1]

DOI: 10.21163/GT_2024.191.03

ABSTRACT:
Unmanned aerial vehicles (UAVs) are nowadays considered a technology with high development potential. UAVs in the photogrammetric field offer the advantage and possibility of reaching and covering even inaccessible areas of territory with extreme simplicity and in a relatively short time; their contribution has become of fundamental relevance in various fields, including precision agriculture, 3D modeling and security purposes.
UAV evolution in recent years has been enhanced by the growing development of miniaturized sensors (optical and LiDAR - Light Detection and Ranging) and by the availability of increasingly efficient navigation systems that integrate inertial systems (IMUs), digital compasses, gyroscopes, GNSS (Global Navigation Satellite System) and GNSS-RTK (GNSS Real Time Kinematic) receivers.
In this paper a procedure for security control operations of an area through UAV survey is presented and the possibilities offered by the latest generation of drones in the field of security are analyzed. For this purpose, the presence of objects and people on a building roof are simulated and three surveys have been carried out with different types of drones (with or without GNSS RTK) and sensors (optical or LiDAR). The two models obtained by optical images were processed with photogrammetric algorithms; finally, the two optical and LiDAR point clouds were compared in the open-source software CloudCompare using Cloud to Cloud (C2C) command, which allows to calculate the three-dimensional components of the distances between the reference point cloud and the individual points of the other cloud. The results clearly show the identification of people and objects introduced in two of the three surveys performed.

Key-words: *UAV, SFM, UAV-LiDAR, security, GNSS.*

1. INTRODUCTION

Unmanned Aerial Vehicles (UAV), or more simply drones, are establishing as one of the most rapidly developing technologies in recent years (Kovanič et al. 2023). As evidence of this, a few years ago the Massachusetts Institute of Technology (MIT), considered by many to be the most authoritative university in the field of technology, highlighted the UAV in its annual ranking of technologies with the greatest development potential. The contribution of this technology has become of fundamental relevance in various fields, including precision agriculture (Tsouros et al. 2019; Kim et al. 2019; Del Cerro et al. 2021; Zottele et al., 2022), architectural and environmental applications (Achille et al. 2015; Venturi et al. 2016; Romeo et al., 2019; Petropoulos et al., 2021), 3D modeling (Cavalagli et al. 2020; Zollini et al 2020; Baiocchi et al. 2017; Pepe et al., 2022), early damage assessment (Dominici et al. 2017; Baiocchi et al. 2013; Baiocchi et al. 2014), archeological survey (Alessandri et al. 2022; Ballarin et al., 2015) and security purposes (Gurturk et al., 2023; Sivabalaselvamani et al. 2022; Namburu et al. 2023; Kolster et al. 2022).

[1]*Department of Civil Construction and Environmental Engineering, Sapienza University of Rome, 00184 Rome, Italy; correponding author* valerio.baiocchi@uniroma1.it, Sabinadolphin@hotmail.com, valeriomaria.marzaioli@uniroma1.it, felicia.monti@uniroma1.it, felicia.vatore@uniroma1.it*
[2]*Niccolò Cusano University, Via Don Carlo Gnocchi 3, 00166 Rome (Italy);* francesca.giannone@unicusano.it
[3]*European Union Satellite Centre (SatCen), Madrid, Spain;* roberta.onori@satcen.europa.eu
[4]*SITERRA STP S.r.l., Rome, Italy;* info@siterra.it

Their evolution in recent years has been due to the increasing availability of navigation systems that integrate inertial systems (IMUs), compasses, gyroscopes and GPS/GNSS (Global Positioning System/Global Navigation Satellite System) receivers, inexpensive and miniaturized.

The first drones were born with optical camera and a point positioning GNSS receiver on board, in this configuration the reconstruction of 3D model is based on SFM - Structure From Motion algorithms (photogrammetric approach) and, therefore, the images are oriented using some control points (Ground Control Point – GCP) for reconstructing the position and attitude of the drone. Furthermore, the elaboration of optical data to obtain the point cloud require a considerable processing time.

A further important development of UAV technology has begun to affirm recently and concerns the positioning method using GNSS RTK receivers (Ekaso et sl. 2020; Eker et al. 2021), which allows the positioning of the vehicle to be processed with differential corrections and not simply point positioning. This brings the GNSS mounted on drones to have an improved accuracy from a few tens of meters (without RTK) to potentially a centimeter (with RTK) (Varbla et al. 2021).

The use of a precise GNSS RTK system has the great advantage of being able to perform surveys without having to detect the Ground Control Points (GCPs); this is an important aspect when the times to carry out the survey must be quick and when accessibility to the study area is not guaranteed.

Moreover, the possibility of using RTK receivers on the drone has also allowed the creation of drones with laser or LiDAR sensors (Torresan et al. 2018), and this is because in the LiDAR drone each point is acquired in a different instant and therefore it would not be possible to use GCPs to position the survey correctly.

Drones with LiDAR sensors allow to reconstruct clouds of three- dimensional points as well as optical images that can be obtained using software based on SFM algorithms.

The LiDAR has the following advantages:

1) no processing time to compute the points cloud which is already the native product downloaded directly from the drone;
2) possibility to operate even at night, in the fog, in the mist or in the presence of smoke;
3) possibility of acquiring the vegetable covers and the solid objects images in several separate echoes allowing in practice to see under the trees, shrubs or other plant coverings.
4) possibility, still under development, of acquiring water depth in the first meters in the lakes, rivers and sea water (Mandlburger et al. 2020) with the so-called "green light" laser scanning.

It is easy enough to imagine that all the stated characteristics of LiDAR drones make them particularly interesting for security control operations.

The main objective of this paper is thus to study and evaluate the possibilities offered by the latest generation of drones in the field of security. The specific purpose of this experiment was to evaluate the ability of the latest generation of drones (LiDAR with RTK positioning) to identify people and objects even in low visibility conditions such as in the presence of trees and/or at night For this purpose, three different surveys were carried out with different types of drones and sensors, the presence of objects and people on a building roof within the survey area was simulated.

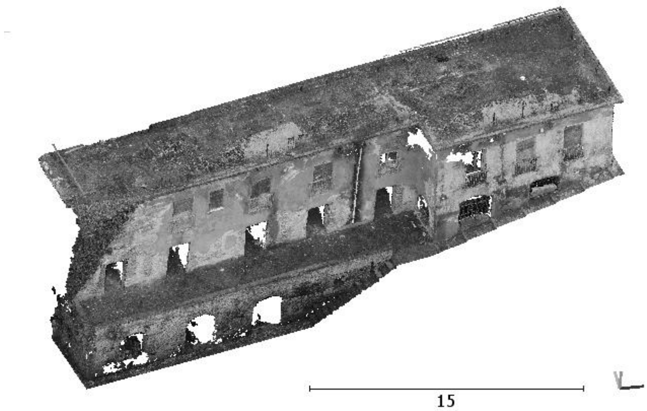
2. STUDY AREA

The area of the survey is quite large, about 63 hectares, and with variable morphologies which include buildings, an internal road network and a small port area (**Fig. 1a**). The time required to survey the entire area is about 30 minutes per drone, i.e. about three hectares per minute but this must be considered as a very indicative information because it depends on various factors and on the specific characteristics of drones and sensors, always in constant evolution.

The experimentation was conducted on a smaller area, within the overall area, containing a series of buildings developed on several levels (**Fig. 1b**). On the test area we proceeded to simulate the introduction of two or three people of average height (1.75 cm) plus three medium-sized bags including two backpacks and the case of one of the drones (DJI Phantom 4 pro) which is the only rigid bag of the three, with dimensions 20.32 * 30.48 * 36.8 cm. (**Fig. 1c**).

In the surveyed area 5 Ground Control Points (GCPs) have been identified (**Fig. 1a**), they are necessary to orient the three-dimensional model and evaluate the precision of georeferencing (Costantino et al., 2022). It is important to underline that the complexity of the area analyzed has allowed the acquisition of a small number of points and in a non-ideal conformation.

(a)



(b) (c)

Fig. 1. (a) Location of the study area and point cloud of the whole area obtained with the photogrammetric survey; the points represent the GCPs measured (EPSG: 6708); (b) Point cloud of the sub-area used for the simulation; (c) The three bags used for the simulation

3. DATA AND METHODS

3.1. Sensors and methods

The simulation involved the use of various types of drones and sensors to test their possible use for security purposes. Since it was decided to test drones with optical acquisition, it was necessary to acquire the images during the day; the most interesting sensor for these purposes is the LiDAR sensor mounted on an RTK drone for which daylight is not required and ground control points are not strictly necessary.

The instrumentation used in the simulation consist of two different drones, the DJI Matrice 300 RTK (referred as *Matrice*) and the DJI Phantom 4 pro (referred as *Phantom*), and two types of sensors, optical camera and LiDAR sensor; in detail: the *Matrice* drone with the DJI P1 optical camera and then the DJI L1 LiDAR sensor; the *Phantom* drone with the integrated optical camera, i.e. a camera with 1” CMOS sensor, effective pixels: 20M, lens with field of view (FOV) 84° 8.8mm/24mm (35mm format equivalent), f/2.8-f/11 auto focus 1m - ∞.

The scanning mode of the LiDAR sensor has been set to 480 points/m^2, while the drone equipped with the optical sensors has acquired nadiral and oblique with 45° angle images.

For the georeferencing and the accuracy validation of the different types of surveys, Ground Control Points were acquired with GPS GNSS E-Survey E300 Pro system, a geodetic class receiver used in RTK mode with respect to HxGN Smartnet network (HxGN 2023) which allows to take advantage of the 4 major GNSS constellations.

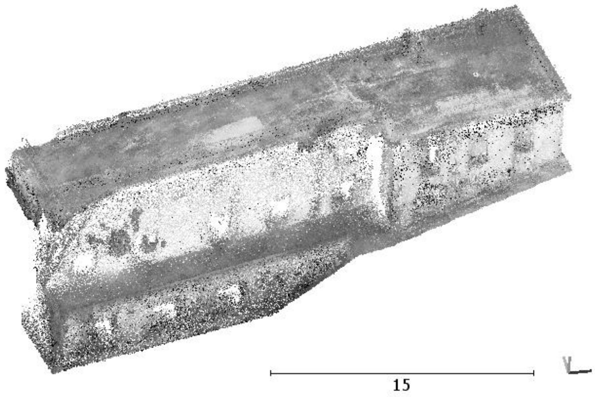
The photogrammetric reconstruction of the three-dimensional model performed starting from the images of *Matrice* drone was processed with DJI Terra 3.4.4 software. The model was georeferenced according to the information obtained in the RTK position correction mode, therefore without the use of GCP. Instead, the three-dimensional model obtained by the images of *Phantom* (nadiral acquisition) was created with Agisoft Metashape 1.5.1 software and oriented with the help of all GCPs, reaching an average accuracy of 8.6 cm. This accuracy value was obtained by correcting the altitude problem often encountered using this type of drone in this specific software environment. In fact, often the “Absolute Altitude”, that is the height reported in the EXIF (specific part of the header of the image file in which the georeferencing information is shown) is incorrect. It is possible to correct the altimetric information of all images by importing the "Relative Altitude", also recorded in the XMP header, which corresponds to the altitude with respect to the take-off point and add the altitude of the take-off point. Respectively, the two phases of the procedure are carried out with the commands “Read Relative Altitude” and “Add altitude reference”.

As anticipated, the variety of instrumentation used for the survey is characterized by different sensors, mounted on different supports, which use different positioning modes. Thus, the resulting three-dimensional models are characterized both by the different physical properties of the sensors and by the different internal and external orientation parameters of drone. However, CloudCompare, in particular Cloud-to-Cloud algorithm (CloudCompare 2023), was used to estimate the distance between two point-clouds. Distances are calculated on the cloud identified as “compared” with respect to the points of the “reference” cloud. It has been observed that it is generally better to set the densest point cloud as the “reference” cloud. At the end of the process, a new scalar field was applied to the compared cloud which describes the absolute distance and three scalar fields which correspond to the distance calculated along each dimension. In the tests conducted with the Cloud-to-Cloud tool, the local model for identifying the corresponding points of the closest neighbor was used, as the tests were performed on buildings characterized by regular surfaces and by low roughness.

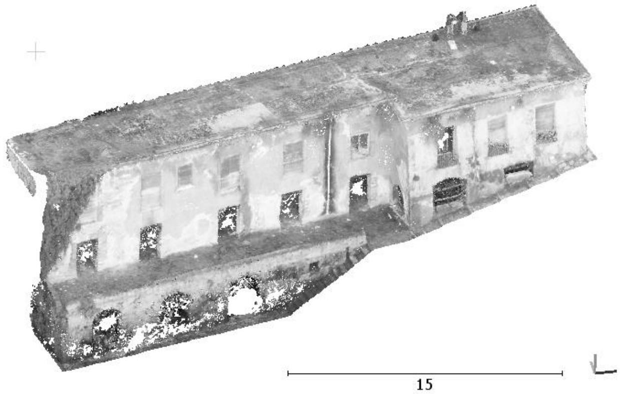
3.2. Datasets

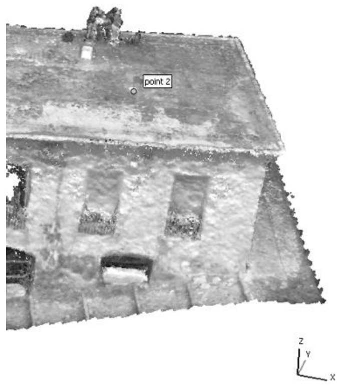
To analyze the effectiveness of a survey carried out with the drone for security purposes, a series of flights were carried out with the different drones, obtaining three distinct coverages of the study area:

- optical point cloud: 3 827 725 points acquired with *Matrice* drone with the optical camera (**Fig. 1b**). It can be observed that neither people nor bags are present;
- LiDAR point cloud: 759 969 points with *Matrice* drone with the LiDAR sensor; the number of points directly depends on the acquisition density set a priori, in this case 480 pt/m2 (**Fig. 2a**). It can be seen that there are three people present, but the bags are less evident.
- optical point cloud: 670 744 points acquired by *Phantom*, (**Fig. 2b and 2c**). It can be seen that two people and the bags can be observed very well.



(a)





(b) (c)

Fig. 2. (a) LiDAR point cloud acquired with *Matrice* drone; (b) Optical point cloud acquired with *Phantom* and (c) a detail of the *Phantom* cloud where two people and three bags are visible.

The time for downloading data depends sensibly on various factors, including: the flight altitude for optics, the density of the points for LiDAR surveys, the size of the area to be surveyed, the speed at which the SD card is read, and the speed at which it is written to the workstation's mass memory. In our case the data were downloaded in a few minutes up to a maximum of ten minutes.

The LiDAR data downloaded were already configured as a point cloud and ready for the next step, which is the comparison with any previous surveys; while the data acquired by optical sensors, on the other hand, require processing in photogrammetric software, which can take a few hours to obtain the point clouds.

In the processing of the two optical clouds there is a further difference which is that the images acquired by the drone with GNSS point positioning only (in our case *Phantom*) require the survey of some reference points (GCPs); on the other hand, in the case of images acquired by drone with RTK GNSS (in our case *Matrice*) this operation is not strictly necessary, although it is generally advisable at least on one point per check. However, in the present experimentation, the ground control points have been used to verify the images acquired by *Matrice* drone as well, revealing slight systematic deviations in altitude that seem to suggest the need for a further verification of the difference in instrumental altitude between the phase center of the GNSS antenna and the center of pick-up of the optics of the drone itself.

4. RESULTS

The two optical and LiDAR clouds were compared in the open-source software CloudCompare v. 2.12.4; although the data processing to obtain the point clouds has been performed on the entire surveyed area, the comparisons in CloudCompare, described hereafter, concern the sub-area identified for the simulation (**Fig. 1b**). The comparisons were performed using Cloud to Cloud (C2C) command, which allows to calculate the three-dimensional components of the distances between the reference point cloud and the individual points of the other cloud. As expected, it is convenient and more rigorous to use the denser cloud as the reference surface, then two comparisons were performed using the photogrammetric cloud obtained by *Matrice* with optical camera as reference. Furthermore, it should also be remembered that there are neither people nor objects to identify on the *Matrice* optical cloud and, therefore, its comparison with *Phantom* and LiDAR point clouds is significant in terms of identifying objects or people. The first comparison was performed between **LiDAR and optical point clouds obtained both with the** *Matrice* drone (**Fig. 3**), while the second was achieved between the two optical point clouds, the *Phantom* and the *Matrice* one (**Fig. 4a and 4b**).

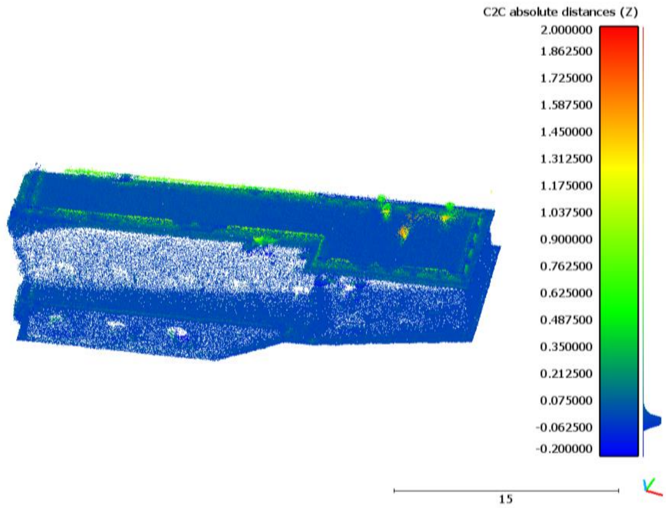


Fig. 3. Comparison between LiDAR and optical point clouds obtained both with the *Matrice* drone.

(a) (b)

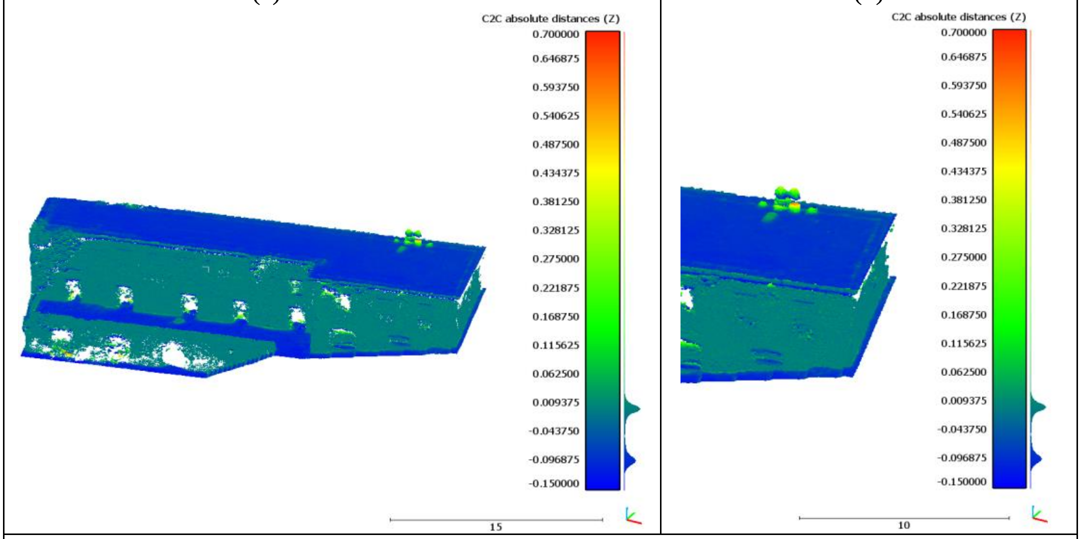


Fig. 4. (a) Comparison between optical point clouds obtained with *Matrice* (reference) and *Phantom* optical point clouds and (b) a detail with people and bags highlighted.

The **figures 3 and 4** show the points of the "Compared cloud" with a color palette representing the distance values along the z component computed from the surface interpolated of the reference cloud, which in both cases was the photogrammetric one obtained by the optical images of the *Matrice* drone. The processing time for the two comparisons was: 1.66 sec for the first comparison and 0.25 sec for the second one. It can be seen that the people and objects introduced are absolutely visible with both the LiDAR sensor (**Fig. 3**) and the optical sensor of the *Phantom* drone (**Fig. 4b**).

5. DISCUSSION

In this experimentation we used two drones with three different sensors and different positioning configurations:

- drone DJI Phantom 4 pro with GNSS point positioning (without RTK) and optical sensor;
- drone DJI Matrice 300 with GNSS RTK positioning and optical sensor;
- drone DJI Matrice 300 with GNSS RTK and LiDAR sensor.

All three configurations provided three-dimensional models that proved to be adequate in terms of accuracy, only the model obtained by LiDAR has a slightly lower resolution but still sufficient in comparison with the models by optical images. On the other hand, models obtained by optical images require a considerable processing time (in one of our tests more than five hours) to achieve the point cloud with the photogrammetric algorithms. This consideration is valid for both tests with optical images, for *Phantom* drone (without RTK) it is also necessary to know the coordinates of a set of GCPs computed with GNSS survey and thus there are two disadvantages in terms of time and survey management because direct access, if available, to the study area is required.

Based on these considerations and remembering that when a survey is performed for security purposes processing time is a key aspect, it can be deduced that an optimal strategy is as proposed, in detail:

- acquisition of the reference 3D model - at this stage processing time is not a key issue, so the reference point cloud can be acquired with an optical camera (which provides a very detailed 3D model) or with LiDAR sensor set at high resolution (the resolution affects the acquisition time);
- area security check: when the survey is carried out for security control of an area, LiDAR drone instead becomes practically an obligatory choice because it is the only one that allows to obtain the point cloud instantly, even if not very dense; this configuration can allow comparison with a denser model and identification variations in morphologies (in particular altimetric) consisting in the presence of people and objects. Furthermore, the acquisition of the point cloud with LiDAR sensor is to be preferred to the optical one both because it allows to operate without lighting (therefore also at night) and because it should be able to potentially "see" under the vegetation that is generally crossed (at least in part) by laser beams.

6. CONCLUSIONS

From the experimentation carried out it has been shown that drones are now a completely mature technique also for the detection of small changes in an environment, allowing to identify, in an almost automatic mode, variations in small dimensions such as small bags and/or people.

For the real effectiveness in a security control scenario, the response time is obviously strategic and therefore it is strategically important the speed with which the newly acquired three-dimensional model is available and ready for comparison with the reference model. As a consequence, a most effective strategy could be to acquire the reference model with an optical drone while certainly the survey model must be performed with a LiDAR drone.

For future developments it would be interesting to carry out tests in areas covered by vegetation and further tests to verify what is the cause of the small systematism at high altitude observed in the two clouds obtained by the *Matrice* drone.

The use of drones has numerous and considerable possibilities for further development in the field of security, for the control and visualization of objects and people on the surface perhaps also using thermal images and/or infrared sensors to identify variations in temperature of various origins.

REFERENCES

Achille, C, Adami, A, Chiarini, S, Cremonesi, S, Fassi, F, Fregonese, L, Taffurelli, L. (2015) UAV-Based Photogrammetry and Integrated Technologies for Architectural Applications—Methodological Strategies for the After-Quake Survey of Vertical Structures in Mantua (Italy). Sensors.; 15(7):15520-15539. https://doi.org/10.3390/s150715520

Alessandri, L., Baiocchi, V., Melandri, G., Monti, F., Canu, A., Ruzzi, L., and Servodio, G. (2022) Efficient three-dimensional survey techniques and their comparison in open software in the archaeological test site of "Ninfeo maggiore" and "Ninfeo minore" of Formia (Latina, Italy), Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII-4/W1-2022, 13–20, https://doi.org/10.5194/isprs-archives-XLVIII-4-W1-2022-13-2022.

Baiocchi, V., Dominici, D., Milone, M.V., Mormile, M. (2014) Development of a software to optimize and plan the acquisitions from UAV and a first application in a post-seismic environment. European Journal of Remote Sensing, 47 (1), pp. 477 – 496 DOI: 10.5721/EuJRS20144727

Baiocchi, V., Dominici, D., Milone, M.V., Mormile, M. (2013) Development of a software to plan UAVs stereoscopic flight: An application on post-earthquake scenario in L'Aquila city. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 7974 LNCS (PART 4), pp. 150 – 165 DOI: 10.1007/978-3-642-39649-6_11

Baiocchi, V., Giammarresi, V., Ialongo, R., Piccaro, C., Allegra, M., Dominici, D. (2017) The survey of the basilica di Collemaggio in L' Aquila with a system of terrestrial imaging and most proven techniques. European Journal of Remote Sensing, 50 (1), art. no. 1316523, pp. 237 – 253. DOI: 10.1080/22797254.2017.1316523

Ballarin, M., Balletti, C., Guerra, F. (2015) Action cameras and low-cost aerial vehicles in archaeology
Proceedings of SPIE - The International Society for Optical Engineering, 9528, art. no. 952813
DOI: 10.1117/12.2184692

Cavalagli, N., Gioffrè, M., Grassi, S., Gusella, V., Pepi, C., Volpi, G.M., (2020) On the accuracy of UAV photogrammetric survey for the evaluation of historic masonry structural damages. *Procedia Structural Integrity*, Volume 29, Pages 165-174, ISSN 2452-3216, https://doi.org/10.1016/j.prostr.2020.11.153.

Cloudcompare (2023) https://www.danielgm.net/cc/

Costantino, D., Rossi, G., Pepe, M., Leserri, M. (2022). Experiences of TLS, terrestrial and UAV photogrammetry in Cultural Heritage environment for restoration and maintenance purposes of Royal Racconigi castle, Italy. Proceedings IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage University of Calabria, Italy, October 19-21, 2022

Del Cerro, J., Cruz Ulloa, C., Barrientos, A., de León Rivas, J. (2021) Unmanned Aerial Vehicles in Agriculture: A Survey. Agronomy; 11(2):203. https://doi.org/10.3390/agronomy11020203

Dominici, D., Alicandro, M., Massimi, V. (2017) UAV photogrammetry in the post-earthquake scenario: case studies in L'Aquila, Geomatics, Natural Hazards and Risk, 8:1, 87-103, DOI: 10.1080/19475705.2016.1176605

Ekaso, D., Nex, F., Kerle, N. (2020) Accuracy assessment of real-time kinematics (RTK) measurements on unmanned aerial vehicles (UAV) for direct geo-referencing, Geo-spatial Information Science, 23:2, 165-181, DOI: 10.1080/10095020.2019.1710437

Eker, R., Alkan, E. & Aydın, A. (2021). A Comparative Analysis of UAV-RTK and UAV-PPK Methods in Mapping Different Surface Types. European Journal of Forest Engineering , 7 (1) , 12-25 . DOI: 10.33904/ejfe.938067

Gurturk, M., Masiero, A., Toth, C., Dabove, P., Di Pietra, V., Vettore, A., Guarnieri, A., Mugnai, F., Soycan, M.
(2023) Dataset for positioning and tracking cars and pedestrians from UAV imagery and static LiDAR. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS

Archives, 48 (1/W1-2023), pp. 161 – 165. DOI: 10.5194/isprs-archives-XLVIII-1-W1-2023-161-2023HxGN

Smartnet (2023) La più grande rete GNSS, https://hxgnsmartnet.com

Kim, J., Kim, S., Ju C., Son, H. I. (2019) Unmanned Aerial Vehicles in Agriculture: A Review of Perspective of Platform, Control, and Applications, in IEEE Access, vol. 7, pp. 105100-105115, doi: 10.1109/ACCESS.2019.2932119.

Kolster, M.E., Wigh, M.D., Lima Simões da Silva, E., Bjerg Vilhelmsen, T., Døssing, A. (2022) High-Speed Magnetic Surveying for Unexploded Ordnance Using UAV Systems. *Remote Sens.*, 14, 1134. https://doi.org/10.3390/rs14051134

Kovanič, Ľ., Topitzer, B., Peťovský, P., Blišťan, P., Gergeľová, M.B., Blišťanová, M. (2023) Review of Photogrammetric and Lidar Applications of UAV. Applied Sciences.; 13(11):6732. https://doi.org/10.3390/app13116732

Mandlburger G, Pfennigbauer M, Schwarz R, Flöry S, Nussbaumer L. (2020) Concept and Performance Evaluation of a Novel UAV-Borne Topo-Bathymetric LiDAR Sensor. Remote Sensing.; 12(6):986. https://doi.org/10.3390/rs12060986

Namburu, A, Selvaraj, P, Mohan, S, Ragavanantham, S, Eldin, ET., (2023) Forest Fire Identification in UAV Imagery Using X-MobileNet. Electronics; 12(3):733. https://doi.org/10.3390/electronics12030733

Pepe, M., Alfio, V. S., Costantino, D. (2022). UAV Platforms and the SfM-MVS Approach in the 3D Surveys and Modelling: A Review in the Cultural Heritage Field. Applied Sciences, 12(24), 12886

Petropoulos, G.P., Maltese, A., Carlson, T.N., Provenzano, G., Pavlides, A., Ciraolo, G., Hristopulos, D., Capodici, F., Chalkias, C., Dardanelli, G., Manfreda, S. (2021) Exploring the use of Unmanned Aerial Vehicles (UAVs) with the simplified 'triangle' technique for soil water content and evaporative fraction retrievals in a Mediterranean setting. International Journal of Remote Sensing, 42 (5), pp. 1623 – 1642 DOI: 10.1080/01431161.2020.1841319

Romeo, S., Di Matteo, L., Kieffer, D.S., Tosi, G., Stoppini, A., Radicioni, F. (2019).The use of gigapixel photogrammetry for the understanding of landslide processes in alpine terrain. Geosciences (Switzerland), 9 (2), art. no. 99 DOI: 10.3390/geosciences9020099

Sivabalaselvamani, D., Selvakarthi, D., Rahunathan, L., Munish, M., SaravanaKumar, R., Sruth, S. (2022) Forest Fire and Landmines Identification with the Support of Drones Surveillance for Better Environmental Protection: A Survey: Proceedings of the Fourth International Conference on Smart Systems and Inventive Technology (ICSSIT-2022) IEEE Xplore Part Number: CFP22P17-ART; ISBN: 978-1-6654-0118-0.

Torresan, C, Berton, A, Carotenuto, F, Chiavetta, U, Miglietta, F, Zaldei, A, Gioli, B., (2018) Development and Performance Assessment of a Low-Cost UAV Laser Scanner System (LasUAV). Remote Sensing; 10(7):1094. https://doi.org/10.3390/rs10071094

Tsouros, D.C., Bibi, S., Sarigiannidis, P. G. (2019) A Review on UAV-Based Applications for Precision Agriculture. Information; 10(11):349. https://doi.org/10.3390/info10110349

Varbla, S., Puust, R., Ellmann, A. (2021) Accuracy assessment of RTK-GNSS equipped UAV conducted as-built surveys for construction site modelling, Survey Review, 53:381, 477-492, DOI: 10.1080/00396265.2020.1830544

Venturi, S., Di Francesco, S., Materazzi, F., Manciola, P., (2016) Unmanned aerial vehicles and Geographical Information System integrated analysis of vegetation in Trasimeno Lake, Italy Lakes & Reservoirs Research & Management 21(1):5-19 DOI:10.1111/lre.12117

Zollini, S, Alicandro, M, Dominici, D, Quaresima, R, Giallonardo, M. (2020) UAV Photogrammetry for Concrete Bridge Inspection Using Object-Based Image Analysis (OBIA). Remote Sensing.; 12(19):3180. https://doi.org/10.3390/rs12193180

Zottele, F., Crocetta, P., Baiocchi, V. (2022) How important is UAVs RTK accuracy for the identification of certain vine diseases? Proceedings 2022 IEEE Workshop on Metrology for Agriculture and Forestry, MetroAgriFor 2022 - Proceedings, pp. 239 – 243 DOI: 10.1109/MetroAgriFor55389.2022.9964928