

Editorial

Editorial of Special Issue “Unconventional Drone-Based Surveying”

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1. Introduction

Nowadays, Unmanned Aerial Vehicles (UAVs), as well as Unmanned Surface Vehicles (USVs) or also Unmanned Underwater Vehicles (UUVs), later on simply called drones, have reached a sufficient degree of maturity to allow their use for various purposes. Drones are used in remote sensing, as shown by [1] and references therein, where regulatory and safety facts are also discussed, in particular in geological mapping [2] and architectural surveying [3]. New applications continually appear; among them, disaster management, precision agriculture, weather forecast, wildlife monitoring, search and rescue, law enforcement, shipping and delivery, and also entertainment, with different type of sensors.

This increasing diffusion of drones has various reasons. On the one hand, technologically advanced low-cost drones, generally equipped with GNSS receivers and, often, also equipped with compact inertial platforms, are available today. On the other hand, nowadays, besides professional and prosumer cameras for Structure-from-Motion photogrammetry (SfM), other relatively affordable sensors like light infrared cameras [4] or compact LiDARs [5] are available. Last but not least, the drone-based survey can be performed by planning the navigation consistently with the specific application. Furthermore, the aspect of the use of drone swarms, or in any case of operations in environments where there are numerous drones in motion simultaneously, is always better studied [6].

In some applications the use of drones is now completely standardized. However, there is significant room for growth both to improve the accuracy and resolution of survey products, optimizing flight plans (in general, navigation plans) according to them, and to identify new applications [7]. These systems are suitable both for routine surveys, even predefined at scheduled times, and for surveys in emergency conditions. However, it must not be forgotten that the simplicity of the survey and the possibility of greatly automating the survey and data processing activities in any case require an adequate evaluation of the quality of the results, as shown, e.g., by [8] in the case of evaluation of surface deformations due to induced liquefaction.

For all these reasons, the special issue of Drones “Unconventional Drone-Based Surveying”, to which this Editorial is dedicated, was born. The articles published in the framework of the Special Issue are briefly described in Section 2, while the main lessons learned are discussed in Section 3, with emphasis on multidisciplinary, reliability, exportability of the techniques used and, obviously, quality of the obtainable results. Insights about future researches are also provided.

2. Overview of Contributions

The papers included in this Special Issue cover a wide spectrum of applications related to the unconventional surveying using drones in different areas of the world and



Citation: Pesci, A.; Teza, G.; Fabris, M. Editorial of Special Issue “Unconventional Drone-Based Surveying”. *Drones* **2023**, *7*, 175. <https://doi.org/10.3390/drones7030175>

Academic Editor: Diego González-Aguilera

Received: 28 February 2023

Accepted: 1 March 2023

Published: 3 March 2023



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characterized by multi-source data. The accepted works are briefly presented here in order of publishing.

Go and Choi [9] implemented a system to detect the location of acoustic sources generated on the ground using a drone equipped with an array of microphones. In order to reduce the noise generated by the drone, and better identify the acoustic signals of interest, the authors successfully applied spectral subtraction method. Moreover, they implemented a method to locate the acoustic sources by fusing flight information from the navigation system of the drone. The validation of the proposed method was performed using a drone mounted with a 32-channel microphone array and the verification of the sound source location detection method was limited to the explosion sound generated from the firecrackers: in the experiment conducted at the Chungnam National University stadium (Korea), the authors detected the acoustic source with a ground distance of 151.5 m between the drone and the explosion location, and errors of 8.8° and 10.3° for the horizontal and vertical angles respectively.

Savkin et al. [10] analyzed safe navigation of an USV in proximity to a UUV. In this context, the authors aimed to maximize the amount of data successfully transmitted between the vehicles using underwater acoustic communications, while minimizing the probability of collisions between them. For these reasons, they implemented a real-time navigation algorithm belonging to the class of sliding mode control laws. The authors verified that the developed algorithm is asymptotically optimal, because as the interval subdivision parameters tend to infinity, the value of the cost function that describe the amount of successfully transmitted data converges to the global maximum. In addition, they checked the effectiveness of the proposed method with MATLAB simulations.

Liu et al. [11] evaluated accuracy of the direct georeferencing GNSS-assisted UAV method linked to the number and distribution of ground control points (GCPs) in the study area. After collected data in Xishan, Taiyuan, Shanxi Province (China) using a FEIMA D2000 multi-rotor UAV, the authors developed several photogrammetric projects varying the number and distribution of GCPs (measured by means of a GNSS real-time kinematic—RTK receiver) used in the bundle adjustment (BA) process of the Agisoft Photoscan software. The evaluation of the obtained results was performed using the root mean square error (RMSE) of ground-measured checkpoints (CPs) and the Multiscale Model to Model Cloud Comparison (M3C2) distance. In this context, in the direct georeferencing the authors obtained 0.087 m and 0.041 m in the vertical and horizontal RMSE, respectively. Finally, they suggested the use of at least 1 GCP in the BA, while when the resolution of the GCPs is greater than 10/12 GCP/km² horizontal and vertical errors decrease slowly.

Shelekhov et al. [12] investigated the effects of a turbulent atmosphere on a quadcopter for low-altitude surveys on morphologically complex urban areas. The authors provided the equations for fluctuations of the longitudinal and lateral wind speed; the fluctuations are proportional to the variations of the pitch and roll angles. In the experiment conducted in Academgorodok, Tomsk (Russian Federation) they used a DJI Phantom 4 Pro quadcopter in the hover mode and combined with AMK-03 ultrasonic weather stations. Turbulence spectra with high spatial resolution in the atmosphere on complex areas, under different weather conditions and seasons were obtained. The authors concluded that, on the one hand, the quadcopter is a promising tool for solving problems related to the drone movement control under unfavorable weather conditions and that, on the other hand, such a kind of UAV can be used to provide climatic data in urban environments.

Huang et al. [13] presented a solution related to the coverage control of a multi-UAV system with downward facing cameras: for this issue the authors extended a coverage control algorithm to include a new sensor model and two constrains, the view angle and the collision avoidance. They provided the theoretical analysis to solve the issue of the view angle in the design of the coverage problem linked to the collision avoidance. Subsequently, the authors performed computer simulation tests using the MATLAB software; results showed automatic coverage with cameras of the area of interest (AOI) by multi-UAV.

However, in their proposal the i -th UAV can be outside to the AOI and cannot manage invisible and blacked areas.

Villeneuve et al. [14] developed an experimental test rig to study the effects of icing on the rotor of a Bell APT70 drone rotor in take-off/hover flying mode. In the Anti-Icing Materials International Laboratory—AMIL (Canada), a 9-m-high cold chamber which allow the study of the ground effect and rotor proximity to the icing nozzle array at different rotor heights (h) was used by the authors for the test rig. Results of preliminary experimental comparison of aerodynamic parameters between rotor heights at $h = 2$ m and $h = 4$ m showed no differences. Further icing tests were performed by the authors at lower height taking advantage by the experimental convenience and increased distance from the nozzles. The studies related to the effects of ice on UAV performances are relevant in extreme environments, and the development of ice protection systems for drone applications in these situations is needed.

Gnanasekera and Katupitiya [15] studied a method to avoid collisions of aerial drones. They proposed an algorithm based on collision cone approach to avoid a collision in a time-efficient way (PHS—Purely Heading Solution). In this context, possible scenarios were analyzed including three methods to avoid a potential collision with dynamic obstacles: heading change, speed change and combined heading and speed change. The method proposed by the authors was mathematically demonstrated to be the most time-efficient, compared with other available works, and validated with simulation conducted in a MATLAB-based testing platform. Experiments were conducted using a matrice 600 Pro hexacopter in an open field in Menangle, New South Wales (Australia). Some differences between simulation and experimental results were observed by the authors. These differences were due to the dynamics of the drone and external resistances, e.g., the wind.

Cutugno et al. [16] assessed the quality of sparse point cloud extracted from UAV and using both free-and-open-source software (MicMac[®]) and commercial software package (Agisoft Metashape[®]). To this aim, they conducted a survey test over Conte della Cerra street, a historical overpass in the Vomero neighborhood of Naples (Italy) using a DJI model Mavic 2 Pro UAV. The authors extracted the 3D data using the two software and the photogrammetric results were evaluated analyzing the image residuals, the GCPs and CPs statistic errors, the relative accuracy assessment, and the Cloud-to-Cloud distance comparison. They obtained comparable results highlighting that the MicMac[®] open source software can produce reliable results and similar with those generated by a commercial software package.

Diaz et al. [17] developed a new drone-based system for bathymetric surveys: the “Bathy-drone” is composed by a multi-rotor drone that, by means of a tether, drags a small vessel on the water surface; the latter is equipped with a commercial sonar unit that has down-scan, side-scan, and chirp capabilities and is linked to a GPS-reference onboard. The authors conducted extensive tests over a 5 acre pond located at the University of Florida Plant Science and Education Unit in Citra (Florida) using a DJI Matrice 600 drone. To evaluate the performances of the system, they acquired the ground-truth data of the pond by using a Trimble RTK GNSS system on a pole. Results of the comparison provided a deeper average measurement of 21.6 cm of the Bathy-drone compared with the ground-truth, justifying the integration of RTK and inertial measurement unit (IMU) corrections.

Salas López et al. [18] analyzed the accuracy in positioning of the direct georeferencing approach together with the use of GCPs: they evaluated the repeatability and reproducibility of Digital Surface Model and ortho-mosaic photogrammetric products of a commercial multi-rotor system equipped with a GNSS receiver in urban environments. The authors conducted a test on an urban area of the Chachapoyas city (Peru) using a DJI Phantom 4 RTK UAS and acquiring 10 GCPs and 4 Validation Points with a Trimble R10 GNSS receiver worked in PPK (Post-Processing Kinematic) mode. They obtained viable solution of the direct georeferencing for applications in urban areas. In addition, PPK solution using at least 1 GCP significantly improved the RMSE when compared with the use of 5 or also 10 GCPs without PPK.

Fabris et al. [19] investigated expeditious survey procedures using low-cost photogrammetric sensors for the structural analysis of degraded historical buildings. The authors performed the 3D survey of Illasi Castle (northern Italy) using a Parrot Anafi low-cost drone, a single-lens reflex (SLR) camera, and a smartphone. They generated four different 3D models by means of the SfM technique from the acquired data using the Agisoft Metashape software. To evaluate accuracies and performances of the fast and low-cost photogrammetric approach, the authors compared the obtained models with a high-resolution and high-precision terrestrial laser scanning survey performed using the Leica ScanStation P20 instrument: they obtained standard deviation values of the point cloud differences of about 2–3 cm for the model generated integrating the images acquired with the drone and SLR camera, and double values when the images acquired with the smartphone were used. Subsequently, the best 3D model was used in the finite element (FE) analysis that provided the safety assessment of the historical building.

3. Lessons Learned and New Research Perspectives

The articles published in the framework of this Special Issue concern several topics (they are presented here, unlike in the previous chapter, in order of affinity of the research topics): surveys with non-optical sensors, in particular acoustic [9] and sonar [17]; use of USV and UUV, including maximization of exchanged information via underwater acoustic communication channel and minimization of collision risk [10]; use of a swarm of drones or one or more drones in an environment where other drones are flying, including maximization of obtained information and minimization of collision risk [13], whereas [15] shows a method for avoiding collisions of independent UAVs; use of a UAV physically connected to a vessel equipped with a sonar [17]; solving of issues related to flying in hard environment, in particular turbulent atmosphere [12] and icing [14]; direct georeferencing with different approaches [11,18]; comparison between open source and commercial SfM packages [16]; low-cost cultural heritage applications including numerical modeling [19].

3.1. Non-Optical Sensors

The compact camera is the most common type of sensor carried by a UAV; the data are subsequently processed by means of SfM, even if this poses some problems discussed e.g., by [8]. However, today other types of compact sensors are also available and can be successfully used. If the aim is the localization of an acoustic source, the presence on board of engines and drive systems poses problems due to noise that can be solved by means of an array of microphones and by subtracting the modeled drone-related acoustic noise, as shown by [9]. The main lesson learned is that sensor architecture and noise estimation and subtraction are both necessary to obtain relevant results affected by acceptable uncertainties. New research lines may concern on the one hand the optimization of the sensor array design, and on the other hand the definition of time-varying noise models (therefore time-frequency analysis) to take into account the different motion conditions of the drone in different phases of the flight. In perspective, this could be implemented by a manufacturer of UAVs specifically designed to identify acoustic sources.

The bathymetric system articulated into a vessel towed by a multicopter UAV by means of a tether, presented in [17], on the one hand it is an interesting result and on the other it can lead to interesting developments. The system is conceived for bridge infrastructure inspection and marine geomatics and the developments are consistent with this. Since obstacles such as bridges, pilings, and trees are commonly near bodies of water, the introduction of an active vessel control with a servo-actuated rudder is necessary. This means that vessel control and multicopter UAS control could be semi-independent, with the need to solve the problems associated with the presence of the tether.

3.2. Multiple Drones, Swarms of Drones and Navigation in Crowded Environment

A standard survey typically involves a single drone that performs the measurements from several viewpoints progressively reached during the navigation. However, in the case

of multimodal observations or in case of need for simultaneous observations from different points of view, several drones may be needed, not necessarily of the same type (e.g., some UAVs, UAV(s) and USV(s), USV(s) and UUV(s), or other combinations). Furthermore, it is increasingly probable that a drone may have to operate together with similar systems but not managed by the same operator or in any case by the same control system, with the need to dynamically adapt to the scenario in order to avoid collisions.

The experiments shown in [10] demonstrate the safe navigation of an USV in proximity to a UUV with maximization of data transmitted between the vehicles using underwater acoustic communications and minimization of the probability of collisions between them. The developments will concern two main research lines: (i) solution of the issues related to USV operating in proximity to a surfaced UUV, mainly due to loss of both Wi-Fi radio-frequency communications and acoustic connectivity because of wave motions and surface currents that could lead to sporadic submersion of the UUV; (ii) study of scenarios where a USV operates together with several UUVs, or where there are teams of several USVs and UUVs, in particular with the introduction, among other things, of decision systems that can identify which UUV must be placed in acoustic communication with a given USV at a given time. Both research lines require the development of controllers suitable to the specific applications.

The use of a swarm of UAVs is advantageous when compared to a single one. In some case, a single UAV could take an excessive long time to carry out a task or could not be able to accomplish it effectively. The research challenge is then to develop the appropriate cooperation logic so that the UAVs work together to complete missions effectively and efficiently. A possible solution of the challenges related to the use of several multirotor UAVs with downward facing cameras is proposed by [13], where the key factor is that coverage control involves the collision avoidance. In this way, the whole interesting area can be covered with cameras without collisions, as demonstrated by simulations. Future researches will focus on: (i) evaluation of the deformation of reality that may arise in the image due to the differentiation of the tilt angle or rotation; (ii) handling invisible and obscured areas, to have a truly 3D coverage system; (iii) implementing the method as a real multi-UAV system.

The research activity carried out by [15] also deals with prevention of collisions between UAVs, even in this case the focus is on operation of a single UAV in an environment potentially crowded by other independent UAVs. The main learned lesson, obtained by both simulations and real flight tests, is that the better way to avoid a potential collision with dynamic obstacles is changing the heading. This is because changing in speed and changing in both speed and heading are characterized by slower response time and, therefore, are less effective. Future developments will be mainly aimed at enhancing performance in 3D environments and facing the impact of the wind resistance by using an additional controller.

3.3. Flight in Hard Environment

A drone is generally used in environmental conditions suitable for observation, for example by avoiding operations in windy days or in days in any case unsuitable for flying or, in general, for navigation. However, if a drone (or set of drones) is used in monitoring and/or in emergency conditions, it may be necessary to operate in difficult weather conditions. It could also be necessary to monitor atmospheric turbulence, in which case, by definition, the conditions under which the flight is performed are potentially difficult. The latter case is addressed in [12], whose lesson learned is that a quadcopter can operate in hovering in a turbulent atmosphere providing the turbulence spectra at low-altitude. Future researches will focus on use of quadcopter UAV swarms in order to provide profiles of atmospheric turbulence in both the vertical and horizontal planes.

Another interesting case of study of UAV behavior in hard environment is shown by [14], which propose an innovative experimental test rig to study the effects of icing on the rotor of a drone in take-off/hover flying mode. The key results are the design of test rig and the fact that the ground effect does not take place if the UAV rotor height is 2 m. Further

developments will allow the study of different active and passive solutions to the icing problematic. In this way, the impact of ice on UAV performance can be investigated and ice protection systems for drone applications can be developed.

3.4. Direct Georeferencing

Direct georeferencing (DG) essentially consists in the use of the localization data provided by the GNSS receiver integrated in the drone to georeferencing the final photogrammetric model with the use of a low number of GCPs acquired with topographic techniques. This is easy to say but complex to do, given that the accuracy of a receiver is not sufficient and that at least the use of differential GNSS is necessary. Possible solutions of some issues related to DG are provided by [11,18]. Both the research teams highlight the importance of use of RTK positioning with a base station, which nowadays is accessible not only to the researcher, but also to the practitioner. In particular, [11] finds that a density of 10–12 GCPs/km² allows an accuracy of some centimeters for the final result and that a decisive increase in density does not lead to a significant improvement in accuracy. In [18], the fact that the use of a single GCP with PPK mode allows better results than several GCPs without GNSS data in PPK mode is highlighted. This last result is very interesting where it is required the surveying of areas that are difficult to access. Future developments will concern on the one hand the use of lenses which, while compatible with light UAVs, have satisfactory characteristics (or which, thanks to pre-calibration, can in any case allow good photogrammetric modeling), and on the other hand the improvement of RTK positioning.

3.5. Low Cost Surveying and Modeling

In the past, surveys were often very expensive (think, for example, of the cost of a laser scanning instrument, or of a photogrammetric survey carried out with a helicopter). Today, photogrammetric surveys can be carried out by means of drones of adequate performance. However, the surveys require the use of support techniques (for example, GNSS) and the data processing still requires the use of software packages that can provide the desired products (3D models or further quantitative analyses).

In particular, [16] shows that the use of an Open Source package such as MicMac allows to obtain results completely comparable to those obtainable using commercial packages of a higher level (and therefore cost). It should also be considered that a key element of Open Source software is the possibility of having additional free tools intended for the solution of specific problems and which can make such a kind of software even richer than the commercial one. Therefore, further developments will be aimed at defining correct procedures for 3D model generation and quality assessment employing ultra-low-cost equipment, as well as at disseminating the corresponding implementations.

Sometimes, for example in the case of buildings damaged by natural events (earthquakes, landslides, etc.), it may be necessary to carry out expeditious surveys with relatively limited technical and financial resources. The study shown in [19] demonstrates that low-cost sensors and expeditious surveys can be used to provide 3D photogrammetric models with accuracy adequate for the subsequent Finite Element modeling (several centimeters), including the comparison between the observed crack pattern and the obtained principal stress distribution. This is interesting for assessing the conditions of historic buildings, especially if disasters affecting large areas occur.

3.6. Conclusive Remarks

The articles published in the framework of the Special Issue “Unconventional Drone-Based Surveying” show that the drone (not necessarily flying, but also operating on the surface or underwater) can be used in different contexts and equipped with different sensors. The environment in which the drone can acquire data may not be the classic one of a survey implemented in optimal conditions, but one in which various systems (interconnected or even independent of each other) can operate simultaneously, even in

unfavorable weather conditions. This because the surveying could be required to be carried out in a short time for monitoring purposes.

All the articles refer to ongoing studies, to be continued in order to provide useful tools and data for both the researcher and the practitioner. The Editors of this Special Issue hope that these articles will spark discussion and inspire new research lines.

Author Contributions: A.P., G.T. and M.F. contributed equally to all aspects of this Editorial. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The guest Editors would like to sincerely thank all the Authors who contributed to this Special Issue and the Reviewers who dedicated their time and provided the Authors with valuable and constructive recommendations. They would also like to thank the Editorial team of Remote Sensing for their support.

Conflicts of Interest: The authors declare no conflict of interest.

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