

Chapter 2

Concepts and Issues

Gianluca Casagrande and Davide Del Gusto

Abstract This chapter is intended to describe the main concepts and issues of applying small UAVs to geographic observation. The discussion begins with an overview of drones as flying platforms (2.1). We then introduce a fundamental concept, *accessibility*, or the set of criteria to *have* the needed technology (2.2). The following point, called *field deployability*, considers aspects regarding how the drone can get to *be used* in practice, based on technical and organizational steps (2.3). General but crucial concepts of the emerging national and international regulations about small drones are then discussed (2.4). In the last Sect. (2.5), a case study is presented in order to explain how mission planning should be approached based on available technology and operational needs.

Keywords sUAV • RPAS • Accessibility • Field deployability • UAV regulation

2.1 Friend or Foe: The Small Flying Drone

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Conceptually, the idea of unmanned aerial vehicles, i.e., flying machines capable of operating without an onboard crew, is quite old. Many activities, either in war or peace, may be so “dull, dirty, or dangerous” that one can find it more appropriate not to involve human operators in them. Current implementations are able to perform several different tasks including observation, measurement, and transport (Beloev 2016; Hristov et al. 2016).

The currently widespread UAVs derive from military ancestors (Birtchnell and Gibson 2015). However, as it has been the case with other world-renown technologies (e.g., GPS, GLONASS, GIS, etc.), the widest developments are often the result of booming civilian applications, invariably rising as soon as technologies become affordable. From that moment on, the development continues, often way beyond the initial pioneers’ intentions and imagination.

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Complex taxonomies have been developed, through time, for drone categories, architectures, and application scenarios. Watts et al. (2012) include three categories for long-endurance UAVs: HALE, MALE, and LALE (where LE stands for Long-Endurance and HA, MA, and LA for High Altitude, Medium Altitude, and Low Altitude, respectively); two categories feature short endurance (LASE, LASE Close). Then come two minor categories (MAV/NAV), plus a VTOL category (Vertical Takeoff and Landing). This taxonomical approach suggests a conceptual prevalence of fixed-wing machines, a clear emphasis on large and medium drones and on their operational similarity with manned aircraft. As of this writing, this approach appears to be prevailingly oriented to military, institutional, or, in general, high-profile technical operations. In many instances of these scenarios, fixed-wing architectures are more applicable than rotary wings or other formulas (trikes, blimps, balloons, etc.).

If we were to adopt those authors' terminology, our book discusses prevailingly MAV/NAV and corresponding-size VTOLs. These, in fact, appear to be the most widespread kinds of UAVs on the civilian market. The term "small" applied to drones is quite generic, and a lot of remarks should be added for the sake of completeness. For the sake of simplicity, nevertheless, let us refer to UAVs within a classical weight limit of 25 kg. This should be considered – with some exceptions – as an upper limit in our discourse (Figs. 2.1–2.9).



Fig. 2.1 A typical small fixed-wing UAV for scientific and professional applications: the FlyGeo 24 Mpx has a cruise speed of 39 km/h (~24 Mph), an endurance of approximately 30 min, and a total weight of 2.8 kg (6.17 lb). Platforms of this kind can transport a relatively wide range of remote sensors, including visible, near-infrared, thermal, and multispectral devices (Image: FlyTop www.flytop.it)



Fig. 2.2 Medium-sized multirotors (above, a 6 kg or 13 lb FlyNovex hexacopter) are suitable for several types of applications spanning from precision farming to detail 3D modeling, to high-profile aerial photo/video documentation. Due to their efficiency and flexibility, they enjoy widespread popularity among professional users, in spite of often severe regulation constraints to their use (Image: FlyTop www.flytop.it)



Fig. 2.3 Depending on their size and takeoff speed requirements, fixed-wing UAVs can be launched by hand or by catapults. Drones of this type can land on small spots, either manually or automatically. Below, a FlySecur UAV standing on its field launcher (Image: FlyTop www.flytop.it)

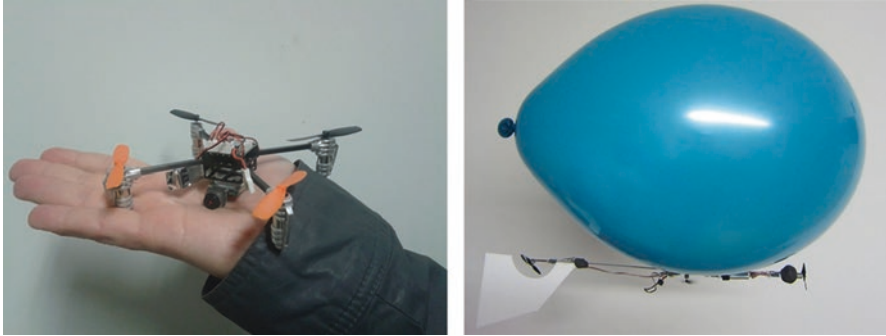
Fig. 2.4 A small helium-filled drone airship (1.5m³ of capacity) can remain aloft and active for hours. This type of drone is suitable for tethered and free flights for general observation, but it can be precisely controlled only under particularly calm meteorological conditions. Larger and more powerful blimps have better performance in outdoor applications, but weather (particularly wind) remains a major variable (Image: Associazione Dirigibili Archimede, <http://dirigibili-archimede.it/>)



Having established this basic boundary, small UAVs can then be described as belonging to almost any possible architecture and as flyable through manual, semi-automated, or fully automated procedures.

In this book, we will mostly refer to some specific and widespread families of UAVs, but it is worth considering this very complex set of technologies in its broader range at least here.

A very basic distinction is made between rotary wing and fixed-wing UAVs. Rotary wing UAVs are normally helicopters and multirotors, relatively similar in the fact that both develop their lift by spinning propellers. A major difference, how-



Figs. 2.5 and 2.6 In principle, drones can be very small machines, and yet they can cover specific tasks. *Left*: a modified Walkera Ladybird quadcopter fitted with an FPV camera. This UAV weighs about 70 g (0.15 lb), can be flown and controlled well in light wind, and is able to broadcast a 640×480 px analog TV signal up to 20–30 m distance (Image: GREAL – European University of Rome). *Right*, a micro-blimp (SpyBlimp) created by applying a small payload (including a tiny video camera) to an individual helium-filled balloon. This type of drone could be used in indoor spaces for inspection purposes (Design, build, and image by Yvon Masyn)



Fig. 2.7 Miniaturization is one of the main development factors for the civilian drone market. While technical performance is increasing, smaller drones are less invasive and easier to deploy. The FTD300X is a custom reengineered variant of the Parrot Bebop drone. Featuring a maximum size of 35 cm and a total weight of 297 g (0.65 lb), it belongs to a category of ultralight commercial micro-drones applicable to observation tasks from video footage to qualitative inspection and aerophotogrammetry (Image: FlyToDiscover)

ever, is that helicopters generally use rotors with variable pitch blades. Multirotors typically rely on differential power, accurately distributed among more simple fixed-pitch propellers. Multirotors may be less agile than helicopters, but they are generally as much precise and often configured so as to be more stable and easier to fly. This family of machines is quite differentiated and normally includes UAVs powered by 3, 4, 6, 8, or even more engines.

Fixed-wing UAVs are basically airplanes. Drones are implemented in this architecture depending on several types of operational needs. Due to its high aerodynamical efficiency, a popular configuration for fixed-wing small UAVs is the so-called “flying wing” configuration. In this type of aircraft, the airframe consists in a more or less swept or delta wing, with a very small fuselage (or no fuselage at all) and no classical tail; yaw stability and control is generally enhanced by applying relatively small vertical winglets, while roll and pitch are ensured by differential control of surfaces such as ailerons, spoilers, and flaps. The efficiency in terms of drag reduction is so high, compared with traditional configurations, that flying wing aircraft were periodically proposed in manned implementations as well. In pre-computer era, though, these machines proved unstable and potentially dangerous, so their use remained limited for a long time.

The problem appears to be completely overcome by drones – and they are generally expendable, after all.

Multirotors and flying wings are currently dominating the market in geographical and geography-related fields due to their flexibility and reliability as aerial observation platforms. Nevertheless, there are many other types of drones which may serve well in several fields. Classical airplane architectures are common for larger UAVs, including motorgliders and motorized parachutes (Lelong et al. 2008). The latter are also used due to good endurance and payload capability along with small encumbrance.

Peculiar types of UAVs are also used for specific purposes, e.g., flight-testing (an interesting example in Adams et al. 2013) or in-flight recognition and manipulation of objects. Other solutions include hybrid maneuvering capabilities, e.g., flying drones able of advanced ground motion, flying multicopter UAVs equally able to move underwater, etc.

Drone-blimps are a kind of so-called “lighter-than-air” UAVs. Compared to “heavier-than-air” machines, they share strengths and weaknesses of their manned counterparts. Airships are indeed capable of lifting relatively heavy payloads, and they are able to fly for long time, as their endurance relies on the lifting capability of gas rather than on the power developed by engines. On the negative side, drone-blimps, like the giant airships of the past, are extremely weather sensitive and require fairly complex organization and equipment for their deployment.

By observing the progressive release of new versions for models on the market, the impression is that drones evolve more as ICT platforms than aerotechnical products.

The efficacy of small UAVs in general – and in geographic applications in particular – relies upon the fact that they are generally flexible and reliable carriers of instrumental payloads. Such payloads can be visible-light cameras or other types of data acquisition and measuring devices.

Current small UAVs are remotely managed by a pilot/crew via a remote pilot station (RPS), also often referred to as ground control station (GCS), by a more or less reliable flight control links. Drones are generally capable of recording data onboard and they also exchange both flight and payload data with the RPS in real-time. Normally, the pilot can see (on screen or through First Person View – a.k.a. FPV – devices) aerial views from the drone. Additional data – commonly height, speed and position, among others – are also displayed.

Depending on types, small UAVs can easily be managed by a pilot, either alone or with the help of a system operator and one or more observers. Although regulatory and practical factors often suggest or require that the pilot keeps visual contact with the UAV, a very common feature of UAS is real-time telemetry and imagery down-link. These allow for the so-called First-person-view (FPV) operation: the crew may observe the target by the view acquired from one or more drone video camera(s) while, at the same time, monitoring the flight parameters and conditions of the drone.

UAVs flourished as electronic flight control systems (FCS) evolved from initially full manual to increasingly automated (Hristov et al. 2016).

A PwC report (PwC 2016, p. 4) summarizes the worldwide market perspectives of small UAVs. Estimations are based on the likely commercial value of business and labor which can be replaced, in each one of the involved industries, by the use of drones. As of 2015, the figure was 127.3 billion USD, so divided: infrastructure (45.2), agriculture (32.4), transport (13.0), security (10.5), media and entertainment (8.8), insurance (6.8), telecommunication (6.3), and mining (4.3). This points to a clear trend, especially considering that some applications for future drones have not been identified yet. Nevertheless, it should be noted that even when a potential use is foreseeable, that does not necessarily mean that it will come soon or ever. For some applications, current drones are still technologically immature; for some others, their use will not be allowed for a relatively long time. For others, finally, they might just not turn out useful or competitive in practical terms.

News about the impressive performance of small drones in remote sensing may be deceiving to some potential users. As a matter of fact, given a certain goal, the specific available UAV can be effective or not. In our experience, observation by drones can prove partially conclusive or inconclusive depending on inadequate system configurations or insufficient planning. The design and technical features of a drone can prove suitable or not for the requested tasks; the deployment scenario may impose limitations from an organizational point of view; juridical requirements for using that particular drone in that particular site are an independent and often tricky variable.

In order to avoid problems, it is convenient to devote preventive attention to all the possible caveats other than the strictly technical ones. Operational pretesting of available equipment and protocols is also good practice, to ensure that the UAS operates predictably and reliably.

2.2 Accessibility

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Accessibility is a key concept in UAV-based geographic observation. A wide set of variables should be considered. The aim is to achieve efficacy at the lowest possible cost, where “cost” means the overall effort – whether financial, technical, or bureaucratic – needed to set up the systems, deploy them on the field, and successfully use them.

The accessibility of a technology determines how many operators and workgroups will be able to use it. A “linear” increase in the number of users may cause – and it often does – a “nonlinear” increase in the number of applications and developments.

The most basic meaning of the word “accessibility” is normally associated with the financial side of the activities. If it is not economically expensive, then more workgroups and individuals can afford to acquire the technology. Hence they can now do things that were previously possible to high-end users and high-tech systems only (Aden et al. 2014). This also implies the ability of widening and enhancing the networks of users. Workgroups and individuals can now use better tools for their scientific and application work, leading to a positive chain reaction in terms of innovation (Carrivick et al. 2013).

With regard to UAVs, a large set of examples could be indicated. In cultural heritage research, for instance, it is no surprise that cutting-edge technology is employed to survey world-renown archaeological sites. It is surprising, though, to verify that more modest technologies can provide very good quality data about minor landmarks. By spreading the use of these second-class tools on second-class targets, a large patrimony of valuable assets can be investigated and monitored. Similarly, it is perfectly obvious that high-tech UAVs are used by civil protection services during emergencies and disaster recovery. It may look less obvious that low-tech UAVs could be used by low-budget local institutions to conduct preventive and early warning surveys in their territories. In general, this technology would allow to monitor structures and elements previously or possibly involved in emergencies (Bendea et al. 2008; Beloev 2016). Preventive measures and early warning actions could make a difference in discovering and interrupting a chain of events to disaster.

Furthermore, if it is true that, for highly specialized purposes, correspondingly high sophistication is required, it is also true that in many ordinary, real-life cases such sophistication is not actually needed or the qualitative gap can be considered acceptable (Casagrande et al. 2015; Pérez et al. 2015; Fryskowska et al. 2016).

Additionally, there are uses for which it may be more appropriate to deploy the simpler and more modest vehicle, rather than the top-class one.

The importance of purely basic, inspective, or descriptive data acquisition is often neglected as scientific research on sensors, methods, and techniques constantly pushes toward enhancements.

However, a narrow-minded excessive emphasis on the importance of systems and technologies might lead to the wrong attitude of neglecting the potentials of simpler and humbler solutions. Banal as it can seem in theory, practice shows that the widespread and meaningful use of simple techniques and technologies might prove more scientifically, economically, and socially relevant than isolated, spot applications of cutting-edge solutions. Someday, those very cutting-edge solutions would become standard honest tools, giving way to even more advanced systems; and the argument will still hold true. In the end, the rush for technological state of the art may deceive us into underestimating the other, crucial components of good science and applications: a smart and well-thought observation methodology, good quality of data acquisition and processing, reliable conclusions, and the most widespread possible use of them.

Accessibility is related to a wide set of technological variables in the choice of UAV systems.

The difference between off-the-shelf UAVs and custom-built ones seems to melt down to a simple conceptual distinction. Off-the-shelf technology provides the user with ready-to-fly, well-tuned-up systems. As a drawback, much of that technology is proprietary and allows limited customizability. This is no big deal to general users but may cause legitimate frustration among specialists.

Prototypes or custom implementations, often (not always) relying on open-market components, have the advantage that solutions can be fully tailored on the specific needs (Giges 2016). Potentially efficient, nonconventional solutions can also be tested by following this approach (Yun et al. 2013; Zhao et al. 2015).

On the other hand, a remarkable quantity of work is generally needed for setting up and fine-tuning the systems. Reliability testing is also needed to make sure that UAVs can actually be deployed in a real-life context and operate safely.

A topic that must be taken into account is that, in at least some geographic applications, drones should be used keeping in mind their primeval vocation. In the beginning, they were supposed to be sent doing dull, dirty, and dangerous tasks.

This means that, as long as safety, security, and privacy are guaranteed, an operator should be enabled (and prepared) to sacrifice the drone for the sake of the results if they are particularly relevant. If the overall costs (either financial or organizational) are perceived to be excessive, then the drone prevails on its purpose, and this might not always be in the best interest of the users or the community.

In our experience (Casagrande et al. 2015), accessibility corresponds to essentially three criteria in systems choice and operational framework:

1. Immediate availability

- (a) Use of general market products.
- (b) Use of open-source or de facto standard hardware and software (when possible).
- (c) Avoid restricted proprietary solutions unless fully compatible with de facto standards.
- (d) Keep configurations as simple as possible.

2. Portability

- (a) Adopt de facto standard solutions for data acquisition, transfer, processing, and presentation.
- (b) Design systems and workflows in such a way that outputs are reliably comparable with those of other techniques.

3. Extensibility

- (a) Design configurations with modularity in mind.
- (b) Keep systems and operational profiles, (if possible) open to change.

Accessibility is quite an adaptive concept. It basically translates into getting the best possible set of tools while, at the same time, keeping all the costs at a reasonable

minimum. An important element is to properly select the flying platform and the associated sensors while taking into account the operational scenario and other contextual conditions. An example of the concept of practical accessibility as we just stated can be summarized as follows.

A geographic laboratory drone fleet includes three VTOL UAVs. The first one is a minimal size machine fitted with a built-in video camera; the second one is a medium-size device able to mount different types of sensors within – say – 100 g (0.22 lb) of mass. The third one is a fairly large, heavy-lift drone able to fly with 6 kg (13 lb) of net payload; this too can have different sensors installed. The proposed field activity is to have a first, very expeditious documentation of a poorly studied and very wide area. The field operation will last a few days, and very limited ground support will be available in the meanwhile. If this is the case, then the minimal drone would probably be the most appropriate choice. It is lightweight and fairly small in size; its requirements in terms of power are relatively modest, which is important if the available energy supply is limited, in order to maximize flight time. The most accessible solution in this case is to operate the smallest and less invasive drone available. Note: given the proposed operational scenario, a fixed-wing UAV would have probably been more efficient, but the available fleet includes multirotors only.

Based on the same assumptions about the fleet, let us consider another case.

The planned activity consists in the thermographic inspection of a group of inhabited buildings, right in the middle of a historical town. However, thermal cameras are not available at the lab: it is therefore necessary to purchase one. If the overall conditions of the area suggest (or impose) to fly a small, lightweight, and noninvasive drone, then the choice should be to deploy the medium-size machine: it is a good trade-off in terms of dimensions, and it can install a small thermal camera in order to perform the inspection. A typical disadvantage would be the relatively high cost of the sensor, but the medium-size platform is the best choice since it can be cleared to operate in that particular urban area. On the other hand, if the overall conditions of the survey area are considered to be sufficiently safe to operate the largest drone and there is no adverse legal requirement, then the heavy lifter could be deployed.

If this is possible, then a heavier thermal camera can be acquired: a less miniaturized one and therefore, probably, less expensive.

In this case, the accessibility element of the equipment is the larger thermal camera. The UAV is capable of carrying it, and the more affordable sensor leaves margins for other items.

These examples were given to show that the concept of accessibility is application and context dependent. Choices should be steered having feasibility and cost-effectiveness in mind.

2.3 Field Deployability

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2.3.1 Authorizations and Organizational Overhead

Field deployability is basically the operator's ease in taking the UAVs to where they are supposed to operate and in performing the intended work.

It depends both on regulation and technical aspects. From the point of view of regulation, two questions are particularly important. The first one is the juridical framework in which the drone is to be operated. This is frequently determined by the type of technology and by the taxonomical category to which the UAV belongs in the regulatory context.

The second question is the organizational overhead implied by the regulation in addition to the specific UAV requirements.

This particular issue involves the operators, the pilots, and the operation per se. A general convergence in countries which published UAV regulations is toward formal qualification for pilots and validation/authorization for the drones. Specific rules are being established in terms of where, when, and by whom drones can be flown (Ogden 2013; Villa et al. 2016). This topic will be further discussed in Sect. 2.4. A general emerging criterion is that the less potentially invasive the UAV is, the less restrictions will apply to it and the less constrained the organization will be in using it, the less qualified and specialized the technical crew will need to be in order to work. In an average real-life research or professional workgroup, any-time simplifications are achieved, the overall feasibility of the job improves exponentially.

At the moment, drones are subject to specific limitations preventing them from normally flying over some areas. Regrettably, some of these are densely anthropized locations, which could be, for this very reason, extremely interesting in geographic analyses. This kind of limitation might be eased in the future by the rise of smaller, more reliable flying platforms.

The point is whatever the goals of the intended observation are, a correct determination of permissible operations is a major part of the planning.

Technical qualification and authorization issues involve civil aviation authorities (CAAs). Privacy, another hot topic in drone operations, is regulated at different levels by national and international laws. Then comes, in principle, another set of bureaucratic obligations which may affect the planning and conduction of a geographic survey: formal authorization might be required by authorities/entities controlling or managing the study *areas*. This could mean multiple independent authorization processes, each one of them having go/no go value. All of these activities add to what we had previously called the "organizational overhead." A survey flight on a specific area may require participation and the presence of specialists, technical persons, and, if necessary, the activation of support services. The organization which is running the activity must be able to deal with all related actions *and so on*.

In the authors' experience on the field, simplification always proved an essential ingredient to success (Figs. 2.8 and 2.9).



Fig. 2.8 Typical professional drones can be deployed on the field by the use of individual vehicles which could often carry all of the needed equipment (Image: FlyToDiscover, www.flytodiscover.it)



Fig. 2.9 A Sensefly eBee flying wing just deployed on the field, ready for takeoff (Image: Giuseppe Gallo)

2.3.2 *Safety and Reliability*

Once the operation is planned and approved, another set of questions must be considered. This time the main variable is the drone itself. First of all, is the UAV inherently safe for people and things? Technology is generally progressing, and the overall reliability of drones is developing along. Blimps and balloons have normally a relatively low damage potential due to their natural buoyancy, relatively high drag, and small weight. Fixed-wing drones can be very fast and relatively heavy, and their airframes are sometimes able to cause damage; in principle, however, their capability to glide is a mitigating factor in the case of possible failures. In many cases, moreover, fixed wings are built with lightweight composite materials whose specific mass is modest. The combination of the two things makes those airframes able to quickly deform and brake up in case of impact, so as to minimize potential damage.

Rotary wing drones behave in different manners depending on their architecture: their relatively high weight and small drag would cause these types of drone to suddenly plunge in case of a mechanical failure.

In favorable conditions, helicopters can remain fairly controllable and be guided to emergency landings; this is not the case for multirotors, which rely on redundancy to sustain malfunctions. If multiple engine redundancy is not available, multirotors just fall if one engine fails.

In order to improve the safety of small drones, some industries have developed emergency parachutes and other devices – activated by independent control links – to provide a second line of recovery in case the drone should suffer catastrophic failures or become uncontrollable. Among many other elements, the availability of electrical brushless motors allowed to replace, in many applications, the use of traditional internal combustion engines. This turned out as an important step toward reliability. Flight control systems are the other important elements of UAV safety. First generation drones were able to give a minor contribution to their own controllability and navigation; current systems provide the pilots with sophisticated assisted controls and quite complex automated procedures: takeoff, landing, emergency return to homebase, programmable autonomous navigation, etc. The pilot does not directly interact with the controls of the drone, but, in most cases, it interacts with the flight control system. This means that in the case of a failure or interference to this crucial component, a drone could become uncontrollable and either crash immediately or – which is much worse – go astray and become an unpredictable cause of damage. Some currently produced drones are equipped with redundant avionics and better system protections. Still, the certified reliability of most small drones is lower than accepted aeronautical standards, and their actual potential to cause damage is highly dependent on their weight, material, and shape. If, on the one hand, a perfectly reliable drone is yet (if ever) to come, on the other hand, it is clear that the real safety level of a specific UAV depends on its architecture and flying principles but also on the quality of its components, the configuration of its systems, and even the techniques used in its construction. Maintenance, obviously, would be a

major factor. The knowledge of these multiple elements with specific regard to the deployed drone can provide indications about the actual safety of a specific UAV and indicate criteria for its use.

2.3.3 Flight Handling Qualities and Usability

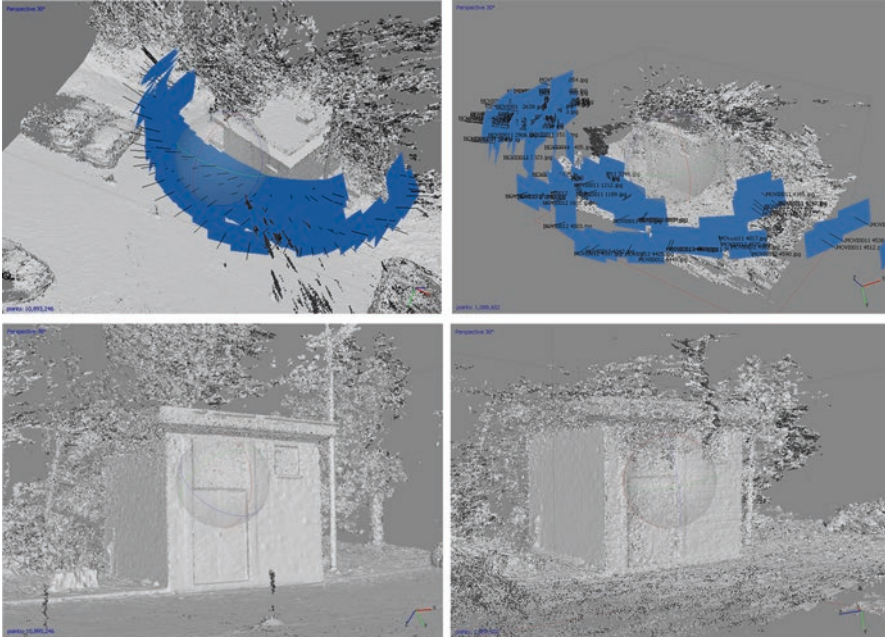
The banal consideration that drones are not created equal – at all – brings up an important aspect: what are the actual handling qualities and performance of the machine to be deployed? Drones, like manned aircraft, have specific flight qualities which may be more or less suitable toward specific applications. We already mentioned that rotary wings are stable and maneuverable platforms for small area surveying, whereas fixed wings are more aerodynamically efficient and generally provide better services for longer transects or wider area observations. Blimps would be able to give outstanding endurances and good lifting capabilities, but they are very sensitive to weather conditions, etc.

Within each category though, different models feature different behaviors; this may affect the usability of the drone in many ways. A most critical element is how much training, skill, and technical effort is actually needed. Problems may rise if the UAV is inherently difficult to control, especially in precision maneuvers. Some systems require complex and error-prone procedures to perform expected tasks; in some other cases, automatic functions are insufficiently precise or unreliable. These are only a few of many possible issues (Figs. 2.10, 2.11, 2.12, and 2.13).

The more a UAV is difficult to fly and operate, the more specialized and skilled the flight crew will have to be, thus increasing the organizational overhead and limiting the practical usability of the drone.

Then comes operational reliability, which does not necessarily involve safety. A reliable drone is actually able to perform its tasks in a predictable and stable manner. Reliability involves the overall behavior of the UAV during its operation and its inherent qualities as data acquisition platform. Functional issues may occur that could not be classified as technical failures but rather unsatisfactory behaviors. Such is the case of inadequate performance of some devices (sensors, data links, GNSS, etc.). Typically, behaviors of this kind can be found in customized implementations when due to UAV-payload compatibility problems, one of the two components is negatively affected by the other. For example, many multirotor operators are familiar with sudden unpredictable distortions of acquired images. These may be caused by vibrations from the engines in particular flight conditions such as hovering in turbulence or fast descents in the prop wash vortex rings. The fact that a drone shows undesired behaviors may expose it to becoming an unreliable acquisition platform.

Another apparently obvious aspect of usability is how the UAV can withstand mishaps such as heavy landings and crashes. Drone survivability in case of crash is not secondary; the success of field operations is often dependent on the fact that the equipment is able to operate even in case of a crash. The fragility/robustness of a



Figs. 2.10, 2.11, 2.12, and 2.13 Comparison of tridimensional models of the same sample building, obtained from images acquired by two different UAV systems. Images on the *left* (Figs. 2.10 and 2.12 camera positions and mesh, respectively) refer to the use of a medium-budget professional drone with assisted control and gyrostabilized full-HD camera; corresponding images on the *right* (Figs. 2.11 and 2.13) refer to a low-cost, fully manual drone with 720p non-stabilized camera. After flights, video frames were fed to a standard software (Agisoft PhotoScan), and a mesh was developed from both input set. The most important issue in the use of the low-end drone was the need of manually selecting sufficiently sharp images among a large number of poor-quality frames shot from more irregular trajectories. Such operation proved time-consuming and quite invasive on the workgroup's activity. Acquisition and processing of frames from the higher-quality system were more rapid and straightforward. Still, both methods led to the creation of a recognizable model of the target building. The actual value of each model depends on the final purpose: the choice between solutions must take into account the overall cost, deployability, and efficacy of the system (Images: GREAL – European University of Rome)

UAV system is obviously related to size and weight. In general, though, it is important to be able to rely on stubborn airframes and effectively resistant components, so that a banal mistake or marginal environmental conditions do not necessarily knock the drone out of the operation.

An important factor is the possibility of performing maintenance works on the field; for this to be achieved, the drone must be easily inspectable and appropriately modular so that components can be substituted without having to perform complex operations on other unrelated systems. Finally, the UAV should not need complex and cumbersome accessories to allow for its operation.

2.3.4 Batteries: A Specific Issue in Logistical Overhead

Finally, field deployability depends upon the logistical overhead required to bring the drone and the other service components on the area of activity.

Logistical overhead involves drone transportation issues, battery and battery management systems, type and complexity of support equipment, and personnel. Let us consider each aspect.

In general, small drones can be transported with relative ease. Transportation is dependent on the size of the equipment, and this, in turn, requires some additional material for its storage onboard vehicles. Many problems originate from the payload which is supposed to be flown in the survey. Payload, in fact, determines the characteristics of the needed drone and that determines what materials must be made available on the field so that the drone can fly.

In present-day situation, an element which must be taken into account very specifically when dealing with logistics involves how the drone is supposed to be powered. If the UAV has a common brushless electric powering, the question translates into batteries, battery storage, and recharging devices.

Currently available technology uses so-called LiPo batteries as prevailing power sources for small drones. Originally developed as lithium-polymer cells, actual products may show various materials and manufacturing standards. Although new implementations provide better handling features and safer construction, LiPo cells are famous for their bad behavior in case of inappropriate handling, wrong recharging, and even accidental impacts or damage. A possible consequence of these errors is that the batteries would start to operate unpredictably; another possibility is that they simply catch fire, with no need for any other ignition source.

This suggests the adoption of appropriate physical protections and safety procedures in recharging, storing, transporting, and loading-unloading batteries (Fig. 2.14).

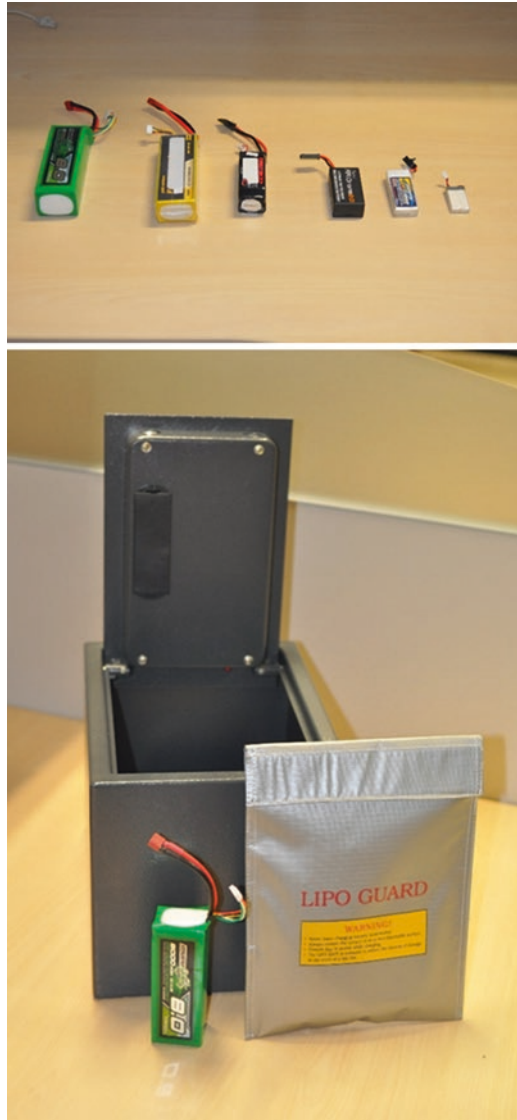
Small drones have different power absorption rates depending on architectures, and this leads to significant differences in battery types, size, and features: blimps could stay aloft for a long time with minimal use of the battery; fixed wings are generally capable of remarkable endurances with medium-size batteries; rotary wings and particularly multirotors would need relatively large batteries to fly, and their power consumption is quite rapid. Adequate logistics should therefore be adopted in each case, and various trade-offs may be necessary.

2.4 Regulation: A Matter of Philosophy?

Davide Del Gusto

Regulation concerning professional and recreational use of drones is being developed, in different countries, based on mainly three primary concerns: safety, security, and privacy. Safety deals with ensuring that the UAV cannot cause damage to people or properties due to unintentional causes, such as malfunctions or pilot errors.

Fig. 2.14 Above is a collection of traditional LiPo batteries for small UAVs. *Left to right*: 4 cell 8,000 mAh; 4 cell 5,000 mAh; 3 cell 2,250 mAh; 3 cell 2,000 mAh; 2 cell 1,000 mAh, 1 cell 760 mAh. Below: a possible safe approach for storing and transporting large traditional LiPo batteries is to put them into a fire-proof bag and to put bags into a metal case (Image: GREAL – European University of Rome)



Security is involved in preventing the use of drones or some of their operational features (e.g., data links) for malicious actions such as terrorist attacks, criminal acts, or other types of violation. Privacy is becoming increasingly important as it is clear that new previously unknown juridical aspects emerge from the drones' capability of providing closeup aerial views of personal and/or secluded spaces. This involves quite complex matters, as data can be collected by private as well as governmental operators (Finn and Wright 2012; Smith 2013; Arteaga Botello 2016; Bracken-Roche 2016; Hilton and Shaw 2016; Wang et al. 2016).

Security aspects of drones in general (and small drones in particular) are being discussed with increasing interest by experts. The subject is, however, substantially out of our topic, and we will not go through it.

As far as safety is concerned, development and management of regulatory frameworks rest with civil aviation authorities (CAAs). In this field, obvious criteria depend on risks determined by the use of a certain drone and its potential to interact with general air traffic. Small drones are generally considered to have correspondingly small impact in safety aspects. For instance, their size, mass, and materials are generally sufficient to cause direct hazard to persons in outdoor spaces and possibly to vehicles, but in most cases, buildings are believed to provide adequate sheltering. Collisions and near misses with aircraft are possible and did occur in some occasions between low-altitude manned air traffic and small drones, with relatively limited consequences so far. The potential of causing major damage and catastrophic mishaps remains nevertheless very high. Overall range of small drones is relatively modest due to power consumption and total available energy supply, but altitude can clearly be a problem as many small unmanned aircraft can climb and be controlled at remarkable vertical distance from the control stations. A normal low-cost, off-the-shelf UAV can be theoretically piloted at 1,000–2,000 m (~3,300–6,600 ft) over the control station. These heights are typical of general aviation flights and of commercial airline climb-outs and approaches. Slight modifications to engines, propellers, and/or data links may enable small customized drones to operate at altitudes up to over 5,000 m (~16,000) above sea level.

Given these remarks, it is easy to understand why regulators are so concerned in ensuring that small UAVs are properly separated from sensitive ground objects and air traffic at all times.

Development goes toward an integration with manned air traffic systems depending on justifiable need, locations, and operational scenarios. This generally translates into establishing borders and boundaries that UAVs are never supposed to cross: allowed heights are variously limited depending on the characters of the involved airspace; no-fly zones are established over relevant and sensitive areas. These typically include airports, governmental infrastructures, industrial areas, densely populated places, areas occupied by crowds during public events, etc.

In spite of their limited range, as drones can fly over inhabited spaces, a major issue is to fine-tune regulation according to the ascertained levels of potential hazard of the UAV itself. Flyaways are righteously considered a major threat, in principle.

A standard commercial hexacopter can normally fly (and even climb!) at speeds around 40 km/h (~25 Mph), for 10–20 min; this means that an uncontrollable flying drone could pose a threat to people on the ground or in the air at quite far a distance from its takeoff base. In order to avoid this type of event, technology has developed – and regulation often requires – multiple preventive measures such as geofencing, terminating devices, tethering cables, restricted buffer zones, etc.

So far about general concepts, then comes real life.

By reviewing regulatory evolutions about UAVs in several countries, it turns out that some concepts seem to be rather uniformly perceived by the international communities; some others are not.

There is an overall consensus on the fact that recreational drones should be regulated differently from professional ones; it also appears widely recognized that regulation should hold safety aspects as a main driver and classify requirements based on that. The practical result, however, is a relatively wide range of solutions and trends. They all contribute to indicating how debate and conceptualization of drones as “real” aircraft in a “real” airspace are far from being over.

A complete and detailed study of national regulations would be out of the scope of this book. Our intention is just to present some general concepts which appear to be considered by several civil aviation authorities in different countries.

We have based the following comments on selected data drawn from www.droneregulations.info website and by information issued by national CAAs. In order to more effectively relate the contents of our summaries to the cited documents, we have adopted the following citation style: each cited document is indicated by the name of the country and year of publication in footnote, in alphabetical order. This allows to immediately view countries which issued regulation about a certain topic, relevant to our discussion. In the reference list at the end of the chapter, each document is indicated beginning with the name of the country and year of publication. All used documents are included in the reference list at the end of this chapter.

We have no ambition whatsoever to provide a complete and fully exhaustive review of the entire regulatory sources; our purpose is to briefly present some remarks on subjects which appear to be widespread in the regulations we have considered.

Since the effective use of small drones for geographic observation is possible only by taking regulations into account, users are obviously necessitated to include them in their planning process from the very beginning, as technical solutions might be conditioned by regulatory requirements.

2.4.1 Professional vs. Recreational Drones

Most of the examined regulations explicitly indicate a difference in juridical nature between drones used for professional and sport/recreational purposes¹. Terminology itself varies, as drones used for fun and sport are variously called “models”² and in

¹e.g. Argentina (2015), Australia (2017), Azerbaijan (2015), Bangladesh (2016), Belgium (2016), Brazil (2016), Canada (2014), China (2015), Croatia (2015), Cyprus (2015), Czech Republic (2013), Finland (2017), France (2017), India (2016), Italy (2016), Jamaica (2016), Mexico (2016), Netherlands (2015), Philippines (2015), Portugal (2016), South Africa (2015), Ukraine (2016), United Arab Emirates (n.a.), United Kingdom (2015), USA (2016).

²e.g. Australia (2017), Austria (2014), Italy (2016, 2017), United Kingdom (2015), USA (2016).

some cases “toys”³, while professional drones are called UAVs or, more frequently, RPAS/RPA (remotely piloted aerial system/remotely piloted aircraft).

In fact, the “ontological” distinction is quite variable and not always associated with technical features. In general, all commercial applications are automatically classified as professional. In some cases, however, operations which involve any kind of non-sport-/leisure-related activity can be classified as professional, even if conducted for no revenue (e.g., Italy 2016; 2017). In general, there appears to be consensus that the main difference between professional and nonprofessional drones rests with their application; technical distinctions are also made in some national regulations, but the criteria are various and subject to change.

2.4.2 Pilot and Operator Qualification

Many – but not all national regulations tend to indicate complementary requirements for pilots and operators in spite of some interchange ability and variability in the formal naming for both⁴. Although often coincident, the two figures are conceptually different. In general, a drone operator, like with any other commercial aircraft, is the individual or company which is commercially operating the vehicle and manages its technical and revenue activity. The pilot is the qualified person who flies the drone on behalf of the operator and, according to the operator’s intentions, under her/his professional responsibility as “pilot in command.”

The qualifications and technical and bureaucratic requirements for both an operator and a pilot are variously defined by national CAAs based on different criteria, involving the specific drone, the size and purposes of the drone fleet, the operational scenario, etc.

Depending on national legislations, professional UAV pilots are subject to passing different kinds of medical examinations⁵, different types of theoretical/regulatory training, and practical training sessions⁶. For example, in some countries, pilot’s physical fitness must be ascertained by aeromedical tests equivalent or coincident with those required for manned aircraft (PPL, LAPL, microlight license, etc.).

³e.g. Austria (2014), Portugal (2016), Rwanda (2015), Slovakia (2015).

⁴e.g. Argentina (2015), Azerbaijan (2015), Botswana (2015), Brazil (2016), Cameroon (2016), Canada (2014), Chad (2014), Colombia (2015), Côte d’Ivoire (2017), Gabon (2014), Ghana (2016), India (2016), Italy (2016), Jamaica (2016), Malaysia (2008), Mauritania (2014), Mexico (2016), Netherlands (2015), Nigeria (2015), Portugal (2016), Rwanda (2015), South Africa (2015), Togo (2015), United Kingdom (2015), USA (2016).

⁵e.g. Argentina (2015), Belgium (2016), Canada (2014), Cyprus (2015), Ghana (2016), Italy (2016), Mexico (2016), Nigeria (2015), Rwanda (2015), South Africa (2015).

⁶e.g. Cameroon (2016), Dominican Republic (2015), Italy (2016), Philippines (2015), United Kingdom (2015), USA (2016).

As far as aeronautical competence is concerned, small UAV pilots are expected to have a basic but solid knowledge of the rules of the air as per national specifications. This kind of knowledge is typically limited for operations in noncontrolled airspace, but it can also include other types of airspace. Since practically all national regulations mandate certain separation of any small UAV from airports, their ATZ, and other restricted areas, a sufficient ability to read aeronautical cartography and documentation such as NOTAMs is assumed. In some cases, even small UAVs may need to apply for authorizations to enter airspaces in which direct interaction with ATC is necessary: in those cases, appropriate licensing would be mandatory for a standard radio communication by the UAV pilot/operator.

As far as a pilot's practical training is concerned, some countries require specific sessions and examinations; some other countries appear to leave the practical training to the UAV pilot or to the operator, once theoretical competence has been demonstrated.

Depending on specific national contexts and technical requirements established for a specific drone and/or its intended application, different obligations rest on the operator and/or the pilot.

In some cases, operators are expected to have and document an organizational, technical, and commercial infrastructure which must be adequate for the type of operations to be conducted.

National qualifications for small UAV pilots are generally non transferrable from one country to others without some sort of ad hoc clearance or validation examination.

2.4.3 UAV Registration/Validation

In many cases, professional UAVs are supposed to be known to the authorities⁷. This may consist in declaring the existence of the drone, its specific features and data, and its intended purpose; or it may consist in a complete validation process by the respective CAA, including more or less complex documentation. The general idea is that the authorities should be able to identify and trace the drone at any time, especially in the case of mishap or misconduct. Several solutions are in place and will possibly be further developed in the future. Typically, UAVs must bear plates with identification/registration codes; some regulations consider the application of in-flight identification devices (e.g., transponders). Flight recorders and other solutions are being tested to ensure that this univocal identification of

⁷e.g. Argentina (2015), Australia (2017), Bangladesh (2016), Belgium (2016), Botswana (2015), Brazil (2016), Chile (2015), China (2015), Cyprus (2015), France (2012), Germany (2017), Ghana (2016), Israel (2011), Italy (2016), Malaysia (2008), Mexico (2016), Nigeria (2015), Philippines (2015), Rwanda (2015), Slovakia (2015), Slovenia (2016), South Africa (2015), Spain (2016), Sri Lanka (2017), United Kingdom (2015), USA (2016), Vietnam (2008).

drones (as associated to their respective operators and pilots) is possible with increasing accuracy.

2.4.4 UAV Categorization

In most cases, national regulations seem to classify drones based on their weight⁸. This is pretty obvious from a safety point of view, but it may prove insufficient for some specific purposes (such as training requirements or operational scenario definitions). In fact, several additional criteria for UAV classifications are put in place by national CAAs. Some of these classifications are also based on “internal” features of the drone or its operational purposes⁹: equipment, deployment, etc. Some others relate to the operational scenarios, as it will be specified in the next section. In the end, drones appear to be occasionally subject to complex multi-aspect categorization which affect more or less directly the corresponding qualification requirements for the pilots and the operators.

2.4.5 Operational Scenarios

Drones can technically operate in virtually all available environments: limitations – sometimes severe – are defined in different countries and by individual CAAs within a certain country. The operational scenarios are the main discriminating element when it comes to deliver the drone to the field and launch it. It would be obvious to say that the more interference the operation causes to people and things (in terms of safety/security/privacy, etc.), the more restrictions should be in place. That is in fact what CAAs try to do; but the outcome is widely differentiated. Most regulations forbid to fly over densely populated areas and “crowds” or “people gathering” or “open-air assembly of people”¹⁰; what exactly the terms mean varies quite a bit from one CAA to the other. Georgia (2016) and Ireland (2015), for example, explicitly indicate 12 or more people to form a crowd and prohibit flight over them, United

⁸ e.g. Argentina (2015), Australia (2017), Belgium (2016), Botswana (2015), Brazil (2016), Canada (2014), China (2015), Colombia (2015), Cyprus (2015), Czech Republic (2013), Denmark (2004), Dominican Republic (2015), Finland (2017), Germany (2017), Ghana (2016), Indonesia (2015), Ireland (2015), Italy (2016), Lithuania (2014), Mexico (2016), Nepal (2015), New Zealand (2015), Portugal (2016), Romania (2016), Rwanda (2015), Slovakia (2015), Slovenia (2016), Spain (2016), Sri Lanka (2017), Ukraine (2016), United Arab Emirates (n.d.), United Kingdom (2015), USA (2016).

⁹ e.g. Austria (2015), China (2015), France (2017).

¹⁰ e.g. Argentina (2015), Australia (2017), Bangladesh (2016), Belgium (2016), Brazil (2016), Chile (2015), Colombia (2015), Czech Republic (2013), Denmark (2004), Fiji (2016), France (2017), Germany (2017), Ghana (2016), Indonesia (2015), Italy (2016), Jamaica (2016), Malaysia (2008), Nepal (2015), Rwanda (2015), Slovakia (2015), Sri Lanka (2017), United Kingdom (2015), USA (2016).

Kingdom (2015) and Nepal (2015) indicate “more than 1,000 persons” for a 150 m mandatory separation. In most cases, a specific threshold number of people is not indicated.

Safety relevant areas include generally built zones¹¹. An important practical variable is whether the zone is sparsely built or densely built. No clear quantitative threshold of density appears to be given in most regulations. Other areas of limited or forbidden access are those open to vehicle transit and various kinds of infrastructures. Although many regulations explicitly prohibit to fly over (more or less) inhabited areas, no-fly rules often include individual buildings, persons, vehicles (including vessels), and animals¹². Besides specific and more or less severe restrictions, a general distinction can be inferred, from the documents we have examined, in the requirements for the use of UAVs in depopulated areas and for those in populated areas. A formal distinction appears to be made, for instance, in Italy (2016) regulation as it states that operations (not drones nor sites) should be divided into “critical” and “noncritical.” This refers, respectively, to operations with specific hazard conditions and to others which can be considered unarmful even in the case of accidents.

Small drones are often limited in their permissible operational range. Widespread height limits above ground level are 120 and 150 m (i.e. roughly 400 ft and 500 ft) although allowed maximum heights can be as low as ~30 m (100 ft) (Nicaragua 2014) and permissible horizontal distances are variously assigned from 30 m (~100 ft) (Nicaragua 2014) to 1,000 m (~3,300 ft) (e.g. Lithuania 2014) and 1,500 m (~5,000 ft) (Colombia 2015), depending on various technical features and operational conditions.

Metric indications are obviously subject to further limitation due to other operational restrictions (e.g., presence of inhabited buildings). Another element, related to distance but more generally involved in operational limitations, is whether flights are to be performed in VLOS (Visual Line of Sight), EVLOS (Extended Visual Line of Sight), and BVLOS (Beyond Visual Line of Sight).

VLOS is the condition in which the remote pilot is able to see the drone. EVLOS is the condition (somewhat unspecified) by which the drone is in sight of a remote pilot either because the pilot is equipped with supporting personnel/systems that allow a visual contact with the drone or because the drone is flown in VLOS by a pilot who then hands it over to another pilot whose position allows a new VLOS condition¹³. BVLOS is the condition by which the drone is simply out of sight and is flown instrumentally¹⁴. Some CAAs mandate that BVLOS could be performed only by drones fitted with “sense-and-avoid” devices (not yet standardized) so as to ensure separation from other air traffic. The regulatory management of potential risks based on operational scenario and technical features of drones is one of the most differentiated aspects of UAV-related legislation.

¹¹ e.g. Bangladesh (2016), Canada (2014), Denmark (2004), Ghana (2016), Italy (2016, 2017), Lithuania (2014), Slovakia (2015), United Kingdom (2015).

¹² e.g. Azerbaijan (2015), Bangladesh (2016), Canada (2014), Cyprus (2015), France (2017), Ghana (2016), Italy (2016), Lithuania (2014), Malaysia (2008), Mexico (2016), Slovakia (2015), Sri Lanka (2017).

¹³ e.g. Brazil (2016), Italy (2016, 2017).

¹⁴ e.g. Austria (2015), Brazil (2016), China (2015), Ghana (2016), Italy (2016), USA (2016).

An explicit distinction is made, by some CAAs between nonparticipating persons and persons belonging to the organization operating the UAV (e.g., Bangladesh, Italy).

2.4.6 *Flight Areas and Limitations*

Most regulations indicate no-fly areas, although some of them are explicitly stated and some others are not. Usual forbidden areas – unless specific clearances are granted – are airports and surroundings. A safe distance is often required, essentially to prevent any interference between manned air traffic and the drone¹⁵.

For similar reasons, flying drones within emergency areas may be restricted to authorized operations, as uncoordinated UAV flight could interfere with rescue air traffic¹⁶.

In general, areas of cities or territories can be specifically restricted to drones¹⁷, along with other areas which are already forbidden to usual air traffic (e.g., prohibited, restricted, and dangerous zones); given that drones can be deployed close to institutionally, politically, or strategically relevant buildings, additional no-fly zones for drones are variously defined, either permanently or provisionally.

2.4.7 *Privacy*

Although privacy is becoming a major concern, only a few national CAAs are explicitly including it in their regulations. This might be due to the fact that the right to privacy and sanctions against violations are covered in other parts of the respective national legislations. A most basic requirement is that anytime a survey or observation flight is performed, permission must be granted by the owner or the manager of the observed area, or by other people involved¹⁸. Some regulations specify that recording and preservation of data (images, video footage, etc.) acquired by the drone must be authorized specifically by the owner of the privacy right. As an alternative, the data itself must be acquired in such a way so as to prevent personal or privacy-relevant data to be included in the process. This is the

¹⁵e.g. Australia (2017), Belgium (2016), Brazil (2016), France (2017), Germany (2017), Italy (2016, 2017), Jamaica (2016), Malaysia (2008), Nepal (2015), Rwanda (2015), Sri Lanka (2017).

¹⁶e.g. Australia (2017), Chile (2015), Germany (2017).

¹⁷e.g. Argentina (2015), Bangladesh (2016), China (2015), Denmark (2004), France (2017), Georgia (2016), Germany (2017), Ghana (2016), India (2016), Indonesia (2015), Italy (2016), Mexico (2016), Nepal (2015), Portugal (2016), Rwanda (2015), Slovakia (2015).

¹⁸e.g. Cyprus (2015), Germany (2017), Ghana (2016), Jamaica (2016).

case, for instance, when images are taken at a resolution that does not allow recognition of accidentally viewed persons¹⁹.

2.5 Small Drones and Geographic Survey: Not Everything, Just What They Are Really Good At

Gianluca Casagrande

A thought-provoking work by Jackman (2016) considers the rhetorics of “possibility” and “inevitability” commonly associated to the use of UAVs. In observing commercial narratives and the quick evolution of technologies, small drones are often associated with the idea that virtually any kind of need can be fulfilled by emerging products. From some points of view, such an idea may prove inaccurate.

On the one hand, technology is still at a relatively early stage of its development: how it will end up being integrated with practical uses and regulatory frameworks is still to be fully understood. On the other hand, real-life applications bind the user to deal with available systems in actual scenarios. Many variables involve their effective capability of providing the intended information. In the previous sections, we have discussed aspects of geographic relevance such as scales and area coverage. We have also discussed how different drone implementations play a role in those aspects. We have then discussed field deployment and the general concept of accessibility; finally, we proposed an overview of typical legal issues.

Correct mission planning involves a full understanding of the UAV overall performance. Most of all, however, it involves the ability to recognize whether the drone is effective for the intended purpose *or not*.

A thorough examination of pros and cons about the use of drones for reification surveys is presented by Campbell and Katz (2016). The authors appropriately observe that small drones are suitable for some kinds of applications and just unsuitable for others.

Limited payload capabilities restrict the set of usable instrumentation to sufficiently miniaturized systems. This limits the applicability of other, more effective technologies until they become sufficiently small and sufficiently cheap to be installed on drones.

Current drones are able to cover and document larger areas than those normally walked by an individual surveyor in corresponding time; however, for surfaces above 10,000 acres (~4,000 ha or ~40 km²) according to the cited authors, manned aircraft become more cost-efficient. In cartographic and photogrammetric applications, the best accuracy a commercial drone can normally provide is in the range of a few centimeters, adequate to topographic mapping and sometimes for architecture as well, but yet below the performance of other traditional techniques. The popular photographic and photogrammetric procedures, around which drones are booming, have a

¹⁹e.g. Italy (2017), art. 34.

typical limitation when the terrain surface is beneath dense land cover. Airborne laser scanning can be more efficient in discriminating surfaces, but its adoption on board small drones is still relatively rare and severely affects affordability.

Besides these general considerations, it is worth noting that the actual capability of small UAVs to perform the job intended by users depends heavily on the nature of the available technology. An example – a meaningful one, in our opinion – is drawn from a case in our own work on the field.

The purpose of the activity was a specific comparative research about small drones in close-range archaeological photogrammetry. Tests were conducted in early 2016 at Otricoli (Terni, Italy).

The idea was to conduct a comparison between two different minimal multi-rotor UAVs, fitted with built-in cameras. They were later to be compared to a standard small UAV equipped with an action camera. The goal was to assess the respective aerophotogrammetric capabilities. The three drones were used to perform an acquisition survey in a real archaeological site. The criteria for surveys were chosen according to probable typical profiles and contexts for minimal-drone operations:

1. Expeditive data acquisition and processing.
2. Close-range photogrammetry of relatively small areas and buildings.
3. Limited field support.
4. Drones were supposed to be flown manually or in GPS-assisted manual mode and in free flight (i.e., not programmed) trajectories.

Images were acquired, for all three drones, by sectioning video clips into individual frames. This was considered to present a credible worst-case scenario. Indeed, in the particular case, individual frames bore no exif nor positional data. A standard photogrammetric software (Agisoft PhotoScan) was used for processing. Another standard professional software (PhotoModeler Scanner) was used to compare results and to perform additional computations in order to assess accuracy.

Drones were flown in very close-range passes, at no more than 5 m distance from the target objects, i.e., vertical archaeological remains. A system of ground control points had been established and measured by TST in order to evaluate accuracy of systems under comparison. Weather was overcast, and wind was calm.

The three drone systems (UAV + cameras) operated as expected, and errors were within acceptable limits. Drone “A” (weight 0.13 kg or ~0.29 lb) was the most financially and operationally accessible and the easiest to deploy on the field. It was rather challenging as far as piloting was concerned and provided no assistance in flight control; hence all operations were necessarily in fully manual mode. This UAV was also the most sensitive to turbulence due to minimal weight and relatively high drag. It did not provide any stabilization to the camera. The obtained 2 Mpx images were therefore affected by frequent blurring and distortions. A very time-consuming process was the manual selection of images which were then to be fed into the photogrammetric software. No adequate automatic selection system was

available. For these reasons, careful examination was to be performed in order to preselect a series of sufficiently sharp and geometrically correct images.

In summary, the most accessible flying platform was indeed the most difficult one in terms of sensor quality and required the longest time for data processing. The intermediate drone, UAV “B” (weight 0.29 kg or ~0.64 lb), whose accessibility was still high, was a semiprofessional platform with a 3-axis digitally gyrostabilized camera; images (full-HD video frames) had very good geometric quality but only a fairly good chromatic quality, and the sensor suffered minimal but perceivable blurring when oriented to the extreme of the rotation area. Yet, image selection was easy and processing proved straightforward. The largest drone, UAV “C” (still a small UAV but a 2.3 kg or ~5 lb hexacopter), employed a standard action camera whose use is typical in archaeological surveys. The camera was mounted on a 3-axis mechanically gyrostabilized gimbal. Its full-HD images were consistently sharp, and colors were at state-of-the-art quality. Yet, the UAV + camera system was the less accessible and the less field deployable; it was also, by far, the most financially expensive and the most complex to manage from a regulatory point of view.

In the discussed case, the true sense of the comparison stood in the accuracy assessment. The average error was found to be 2.4 cm for UAV “A,” 1.2 cm for UAV “B,” and even 1.4 cm for UAV “C.” If we discount the decimals, we can state a point that – we believe – is the essential one. In the course of a close-range photogrammetric acquisition, drones “B” and “C” had substantially the same performance as far as the purpose of the operation was concerned: both were suitable for 1:20 or 1:50 scale representations. Drone “B” costed only about 50% of drone “C.” Drone “C” was more cumbersome to deploy, and it could be operated only with many more regulatory restrictions. Drone “A” costed just about 4% of drone “C” and provided a significantly larger accuracy error, but the overall error was still perfectly acceptable for expeditive archaeological surveys (i.e., suitable for 1:100 scale representations).

A few days after the above-described activity, drones “B” and “C” were also used in another kind of comparative situation. Although it was not planned and intended to be a strict comparison, it turned out to be so *de facto*. The two machines were now used to take simple, panoramic aerial views of a natural and archaeological area in Tor Caldara (Rome, Italy). In both cases, footage was taken to provide some qualitative description of the site, its cultural heritage, and natural assets. At the time of flights, weather was clear, and a constant moderate wind was blowing across the observation area.

The difference in the quality of images and the kinematic capabilities of the two drones gave a clear indication of their value as systems for that particular operation. Drone “C” provided state-of-the-art footage, with a perfectly stabilized video (thanks to the quality of sensor and excellent stabilization system). It also allowed for smooth and fast spatial transitions from one view to the next one. Due to the inherent mass and the quite large amount of available motor power, the drone could perform all the intended maneuvers without revealing any evident disturbance by

wind. Wide trajectories at 200–500 m (~600 to ~1,600 ft) distance from the control station could be performed safely, thanks to the 10–15 min endurance time. The stable and reliable real-time video telemetry communication channel allowed to perform FPV-assisted maneuvers.

Drone “B,” a lightweight quadcopter with about 8 min endurance, was able to produce perfectly stabilized images whose overall chromatic quality appeared to be less appreciable than the other system. Due to its smaller dimensions and modest absolute power, the drone could perform stable panoramic view transitions by maneuvering around the area; however, because of the lower airspeed and the presence of the wind, motion relative to the ground appeared to be variable. Maximum distance was intentionally contained within 150 m (~500 ft), also to reduce occasional degradation of the FPV signal. Moreover, in one occasion during the flight, at a distance of about 150 m from the ground station, drone “B” suffered a temporary disconnection of the flight control and data link channels, presumably due to a temporary obstruction of the direct line of sight between the transmitter and the receiver as the drone was passing “behind” a building. The connection was promptly reestablished by changing the position of the control station. The drone, which had stopped its navigation and was holding in hovering, resumed controlled flight. This type of inconvenience never occurred to drone “C.”

For the sake of completeness, it is worth mentioning that drone “A,” although briefly, was indeed flown on that same day. It produced low-quality panoramic images which were impossible to use for professional video documentation, albeit adequate for general observation of the site in its basic features. A drawback in that type of application would be that drone “A,” unlike the other two UAVs, could not downlink any FPV signal. For this reason, the recorded view could not be evaluated by the pilot during shooting. Furthermore, in other situations, drone “A” had proved quite prone to signal loss whenever, at distance of 50 m (~160 ft), obstacles should interfere with transmitter-receiver alignment.

It is additionally worth noting that drones “B” and “C” were both programmable, depending on operational conditions, to remain hovering or to navigate back to homebase and auto-land in case of signal loss. Drone “A” had only a single fail-safe functionality: it switched to auto-landing mode and descended to the ground, on the spot, immediately after signal loss. This would have practical consequences in the likely case the drone would have landed in a place difficult or impossible to reach for the pilot.

In summary, during the second (informal) test, we had taken the three drones into another operational context, i.e., in wider area video documentation. Drone “A” showed poor performance and unsatisfactory reliability (though retaining its perfectly inoffensive nature). This suggested that its use was operationally inappropriate in that type of application, unless for extreme cases in which no other solutions were viable. Drone “B” proved adequate for semiprofessional quality footage, and drone “C” proved fully adequate for professional documentation.

References

- Adams Z, Benedict M et al (2013) Design, development, and flight test of a small-scale cyclo-gyro UAV utilizing a novel cam-based passive blade pitching mechanism. *Int J Micro Air Veh* 5(2):145–162
- Aden ST, Bialas JP et al (2014) Low cost infrared and near infrared sensors for UAVs. *Int Arch Photogramm Remote Sens Spat Inf Sci*. XL-1. doi:10.5194/isprsarchives-XL-1-1-2014
- Argentina (2015) Administración Nacional de Aviación Civil – Proyecto de reglamento provisional de los vehículos aéreos no tripulados. Available via <http://www.anac.gov.ar/anac/web/uploads/normativa/resoluciones/anexo-resolucion-041-2015.pdf>. Accessed 20 Apr 2017
- Arteaga Botello N (2016) Política de la verticalidad: drones, territorio y población en América Latina. *Región Soc* 65:263–292
- Australia (2017) Australian government – Civil Aviation Safety Authority. Advisory circular. AC 101–01 remotely piloted aircraft systems – licensing and operations. Available via <https://www.casa.gov.au/files/101c01pdf>. Accessed 31 Aug 2017
- Austria (2015) Aviation Agency – Operation of Remotely Piloted Aircraft Systems (RPAS). Available via https://www.austrocontrol.at/en/aviation_agency/licenses__permissions/flight_permissions/rpas. Accessed 20 Apr 2017
- Azerbaijan (2015) Republic of Azerbaijan – State Civil Aviation Administration. Unmanned aircraft operations. Available via http://www.caa.gov.az/index.php?option=com_k2&view=item&id=297:unmanned-aircraft-operations&Itemid=174&lang=en. Accessed 31 Aug 2017
- Bangladesh (2016) Civil Aviation Authority, Bangladesh. Circular. Regulations for Operating Remotely Piloted Aircraft Systems (RPAS). Available via <http://www.caab.gov.bd/corporate/rpas.pdf>. Accessed 20 Apr 2017
- Belgium (2016) 10 Avril 2016. Arrêté royal relatif à l'utilisation des aéronefs télépilotes dans l'espace aérien belge. Available via http://www.ejustice.just.fgov.be/cgi_loi/change_lg.pl?language=fr&la=F&cn=2016041002&table_name=loi. Accessed 20 Apr 2017
- Beloev IH (2016) A review on current and emerging application possibilities for unmanned aerial vehicles. *Acta Technol Agric* 19(3):70–76. doi:10.1515/ata-2016-0015
- Bendea H, Boccardo P et al (2008) Low cost UAV for post-disaster assessment. *Int Arch Photogramm Remote Sens Spat Inf Sci XXXVII B8*:1373–1379
- Birchneil T, Gibson C (2015) Less talk more drone: social research with UAVs. *J Geogr High Educ* 39(1):182–189. doi:10.1080/03098265.2014.1003799
- Botswana (2015) Civil Aviation Authority of Botswana – legal requirements for operating remotely piloted aircraft in Botswana
- Bracken-Roche C (2016) Domestic drones: the politics of verticality and the surveillance industrial complex. *Geogr Helv* 71:167–172. doi:10.5194/gh-71-167-2016
- Brazil (2016) Ministério da Defesa – Comando da Aeronáutica. Tráfego Aéreo. ICA 100–40 Sistemas de aeronaves remotamente pilotadas e o acesso ao espaço aéreo brasileiro. Available via <https://www.decea.gov.br/static/uploads/2015/12/Instrucao-do-Comando-da-Aeronautica-ICA-100-40.pdf>. Accessed 20 Apr 2017
- Cameroon (2016) République du Cameroun. Autorité Aeronautique – Instruction n° 12/C/CCAA/DG/DCRCA du 18 novembre 2016 fixant les modalités de demande d'autorisation d'utilisation d'aéronefs télépilotes dans l'espace aérien et sur le territoire camerounais pour des opérations ponctuelles de travail aérien. Available via <http://www.dasis.ccaa.aero/documents/numeration0002.pdf>. Accessed 31 Aug 2017
- Campbell L, Katz D (2016) The drone as a tool. What drones do well and what they don't. *Point of beginning*. October: 26–29
- Canada (2014) Transport Canada. Review and processing of an application for a special flight operations certificate for the operation of an unmanned air vehicle (UAV) system. Available via [https://www.tc.gc.ca/media/documents/ca-standards/\(SI\)_No._623-001_2_en.pdf](https://www.tc.gc.ca/media/documents/ca-standards/(SI)_No._623-001_2_en.pdf). Accessed 20 Apr 2017
- Carrivick JL, Smith MW et al (2013) Developments in budget remote sensing for the geosciences. *Geol Today* 29(4):138–143. doi:10.1111/gto.12015

- Casagrande G, Salvatori F et al (2015) A “Low-tech” approach as a strategy for effective UAV surveying of landscape and cultural heritage. Experiences from the lab and the field. *Documenti Geografici* 2:33–65. doi:[10.19246/dg.v0i2.80](https://doi.org/10.19246/dg.v0i2.80)
- Chad (2014) Autorité de l’Aviation Civile – RAT 02 Règles de l’air. Available via <http://adac-tchad.org/wp-content/uploads/2015/05/RAT-02-REGLES-DE-LAIR.pdf>. Accessed 20 Apr 2017
- Chile (2015) Chile – Dirección General de Aeronautica Civil. DAN 151 Operaciones de aeronaves pilotadas a distancia (RPAS) en asuntos de interés público, que se efectúen sobre áreas pobladas. Available via https://www.dgac.gob.cl/portalweb/rest-portalweb/jcr/repository/collaboration/sites%20content/live/dgac/categories/normativas/normas_DAN/documents/DAN_151-20150413.pdf. Accessed 20 Apr 2017
- China (2015) 编号:AC-91-FS-2015-31 中国民用航空局飞行标准司-轻小无人机运行规定 (试行). Available via <http://www.caac.gov.cn/XXGK/XXGK/GFXWJ/201601/P020160126526845399237.pdf>. Accessed 20 Apr 2017
- Colombia (2015) Aeronáutica Civil de Colombia – Requisitos Generales de Aeronavegabilidad y Operaciones Para RPAS (Numeral 4.25.8.2). Available via <http://www.aerocivil.gov.co/autoridad-de-la-aviacion-civil/certificacion-y-licenciamiento/Documents/PROYECTO%20BORRADOR%20CIRCULAR%20RPAS.pdf>. Accessed 20 Apr 2017
- Côte d’Ivoire (2017) Autorité Nationale de l’Aviation Civile de Côte d’Ivoire – Decision n° 00003436 / ANAC /DSV/DSNAA/DTA Portant Règlement Aéronautique de Côte d’Ivoire relatif aux aéronefs télépilotes RACI 3009 Available via: <http://www.anac.ci/anac/web/docs/RACI%203009.pdf>. Accessed 31 Aug 2017
- Croatia (2015) Pravilnik o Sustavima Bespilotnih Zrakoplova Available via http://narodne-novine.nn.hr/clanci/sluzbeni/2015_05_49_974.html. Accessed 31 Aug 2017
- Croatia (2006) Ministry of the Sea, Tourism, Transport and Development – ordinance on rules of the air. Available via <http://www.mvep.hr/zakoni/pdf/353.pdf>. Accessed 20 Apr 2017
- Cyprus (2015) Cyprus government gazette – Civil Aviation Act 2002 (as amended). Ministerial decree issued in accordance with Articles 5 (1) and 260. Available via [http://www.mcw.gov.cy/mcw/dca/dca.nsf/All/BF026F4CECA35180C2257DB30030A750/\\$file/UAVS%20Decree%20402-2015-english%20translation%20last%20revision%20jan%202016%20\(3\).pdf](http://www.mcw.gov.cy/mcw/dca/dca.nsf/All/BF026F4CECA35180C2257DB30030A750/$file/UAVS%20Decree%20402-2015-english%20translation%20last%20revision%20jan%202016%20(3).pdf)
- Czech Republic (2013) Civil Aviation Authority Czech Republic. Unmanned aircraft regulatory framework in the Czech Republic. Available via http://jarus-rpas.org/sites/jarus-rpas.org/files/czech_uas_regulatory_framework_en.pdf. Accessed 20 Apr 2017
- Denmark (2004) Civil Aviation Administration – Denmark – BL 9–4 regulations on unmanned aircraft not weighing more than 25 kg. Available via [http://selvbetjening.trafikstyrelsen.dk/civil-luftfart/Dokumenter/English/Rules%20and%20Regulations/Regulations%20for%20Civil%20Aviation%20\(BL\)/BL%2009-series/BL%209-4,%203%20edition.pdf](http://selvbetjening.trafikstyrelsen.dk/civil-luftfart/Dokumenter/English/Rules%20and%20Regulations/Regulations%20for%20Civil%20Aviation%20(BL)/BL%2009-series/BL%209-4,%203%20edition.pdf). Accessed 20 Apr 2017
- Dominican Republic (2015) Instituto Dominicano de Aviación Civil – Resolución No. 008-2015 que regula el uso y operacion de los sistemas de aeronaves pilotadas a distancia (RPAS) o drones en el territorio nacional
- Fiji (2016) Civil Aviation Authority of Fiji – Fiji aeronautical information circular. Operation of Remotely Piloted Aircraft Systems (aka RPAS, U.A.V. or Drones). Available via http://www.caaf.org.fj/index.php?option=com_jdownloads&Itemid=61&task=finish&cid=891&catid=82. Accessed 20 Apr 2017
- Finland (2017) Finnish Transport Safety Agency, Use of Remotely Piloted Aircraft and Model Aircraft, 23 December 2016, Available via https://www.trafi.fi/filebank/a/1483970125/4a6ac53bf4b1cb434d7f85a15f36dde0/23661-OPS_M1-32_RPAS_2016_eng.pdf. Accessed 31 Aug 2017
- Finn RL, Wright D (2012) Unmanned aircraft systems: surveillance, ethics and privacy in civil applications. *Comput Law Secur Rev* 28(2):184–194. doi:[10.1016/j.clsr.2012.01.005](https://doi.org/10.1016/j.clsr.2012.01.005)
- France (2017) Arrêté du 17 décembre 2015 relatif à l’utilisation de l’espace aérien par les aéronefs qui circulent sans personne à bord, Version consolidée au 13 avril 2017, Available via <https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000031679868&dateTexte=20170413>. Accessed 31 Aug 2017

- Fryskowska A, Kedzierski M et al (2016) Calibration of low-cost RGB and NIR UAV cameras. *Int Arch Photogramm Remote Sens Spat Inf Sci XLI-B1*:817–821. doi:[10.5194/isprsarchives-XLI-B1-817-2016](https://doi.org/10.5194/isprsarchives-XLI-B1-817-2016)
- Gabon (2014) Republique Gabonaise – Reglement Aeronautique Gabonais. Regles de l'air RAG 7.1. Available via <http://anacgabon.org/fr/images/pdf/rag7.1.pdf>. Accessed 20 Apr 2017
- Georgia (2016) Georgian civil aviation authority – drones. Available via <http://www.gcaa.ge/eng/RPAS.php>. Accessed 20 Apr 2017
- Germany (2017) Bundesgesetzblatt Jahrgang 2017 Teil I Nr. 17, ausgegeben zu Bonn am 6. April 2017, Verordnung zur Regelung des Betriebs von unbemannten Fluggeräten, Bundesanzeiger Verlag, pp. 683–688. Available via [https://www.bgbl.de/xaver/bgbl/startbk=Bundesanzeiger_BGBl&start=%2F%2F*\[%40attr_id=%27bgbl117s0683.pdf%27\]#__bgbl_%2F%2F*%5B%40attr_id%3D%27bgbl117s0683.pdf%27%5D__1504446223278](https://www.bgbl.de/xaver/bgbl/startbk=Bundesanzeiger_BGBl&start=%2F%2F*[%40attr_id=%27bgbl117s0683.pdf%27]#__bgbl_%2F%2F*%5B%40attr_id%3D%27bgbl117s0683.pdf%27%5D__1504446223278). Accessed 31 Aug 2017
- Ghana (2016) Ghana Civil Aviation (Safety) Directives, 2016 – part 28. Remotely Piloted Aircraft Systems. Available via <http://www.gcaa.com.gh/extweb/images/final%20rpas%20safety%20directive.pdf>. Accessed 20 Apr 2017
- Giges NS (2016) Printing UAVs on demand. *Mechanical Engineering*, November 2016: 12 and 15
- Hilton RK, Shaw JM (2016) I see you. Drones, privacy torts and insurance claims. *Claims Magazine*, December: 21–23
- Hristov GV, Zahariev PZ, Beloiev IH (2016) A review of the characteristics of modern unmanned aerial vehicles. *Acta Technol Agric* 19(2):33–38. doi:[10.1515/ata-2016-0008](https://doi.org/10.1515/ata-2016-0008)
- India (2016) Government of India – Office of the Director General of Civil Aviation. Technical Centre, Opp. Safdarjung Airport, New Delhi – Air Transport Circular XX of 2016. Available via [http://dgca.nic.in/misc/draft%20circular/AT_Circular%20-%20Civil_UAS\(Draft%20April%202016\).pdf](http://dgca.nic.in/misc/draft%20circular/AT_Circular%20-%20Civil_UAS(Draft%20April%202016).pdf). Accessed 20 Apr 2017
- Indonesia (2015) Peraturan Menteri Perhubungan Republik Indonesia – Nomor Pm 180 tahun 2015 tentang pengendalian pengoperasian sistem pesawat udara tanpa awak di ruang udara yang dilayani Indonesia. Available via http://jdih.dephub.go.id/assets/uudocs/permen/2015/PM_180_Tahun_2015.pdf. Accessed 20 Apr 2017
- Ireland (2015) Irish Aviation Authority small unmanned aircraft (drones) and rockets order, 2015. Available via <http://www.irishstatutebook.ie/eli/2015/si/563/made/en/pdf>. Accessed 20 Apr 2017
- Israel (2011) DIRECTIVE הוראה – רישום, רישוי, תיעוד ושינויים לכטב"ם. Available via http://caa.gov.il/index.php?option=com_docman&view=download&alias=5209-2011-28&category_slug=2015-10-13-06-38-50-7&Itemid=669&lang=he. Accessed 20 Apr 2017
- Italy (2016) ENAC Regolamento (Regulation) – Mezzi aerei a pilotaggio remoto (Remotely Piloted Aerial Vehicles). Available via http://www.enac.gov.it/repository/contentmanagement/information/n1220929004/regulation_rpas_issue_2_rev%202_eng.pdf. Accessed 20 Apr 2017
- Italy (2017) ENAC Regolamento – Mezzi aerei a pilotaggio remoto. Edizione 2 del 16 luglio 2015 – Emendamento 3 del 24 marzo 2017. Available via http://www.enac.gov.it/repository/ContentManagement/information/N122671512/Regolamento_APR_Ed_2_Emend_3.pdf. Accessed 5 May 2017
- Jackman AH (2016) Rhetorics of possibility and inevitability in commercial drone tradespaces. *Geogr Helv* 71:1–6. doi:[10.5194/gH-71-1-2016](https://doi.org/10.5194/gH-71-1-2016)
- Jamaica (2016) Jamaica Civil Aviation Authority – flight safety notification general. Operation of unmanned aerial vehicles. Available via <http://jcaa.gov.jm/wp-content/uploads/2016/04/FSN-GN-2015-01.pdf>. Accessed 20 Apr 2017
- Lelong CCD, Burger P et al (2008) Assessment of unmanned aerial vehicles imagery for quantitative monitoring of wheat crop in small plots. *Sensors* 8(5):3557–3585. doi:[10.3390/s8053557](https://doi.org/10.3390/s8053557)
- Lithuania (2014) Civilinės Aviacijos Administracijos Direktorius – Įsakymas dėl Bepilotojų Orlaivių Naudojimo Taisyklių Patvirtinimo. Available via <https://e-seimas.lrs.lt/portal/legislAct/lt/TAD/7bb14b10849f11e39d2dc0b0e08d5f21>. Accessed 20 Apr 2017
- Malaysia (2008) Malaysia – Aeronautical Information Services Department of Civil Aviation. Unmanned aerial vehicle (UAV) operations in Malaysian airspace. Available via <http://aip.dca.gov.my/aip%20pdf%20new/AIC/AIC%20200804.pdf>. Accessed 20 Apr 2017

- Mauritania (2014) Agence Nationale de l'Aviation Civile – Reglement Technique Aeronautique RTA – 02. Regles de l'air. Available via <http://www.anac.mr/IMG/pdf/RTA022014.pdf>. Accessed 20 Apr 2017
- Mexico (2016) Dirección General de Aeronáutica Civil – Circular Obligatoria que establece los requerimientos para operar un sistema de aeronave pilotada a distancia (RPAS). Available via <http://www.sct.gob.mx/fileadmin/DireccionesGrales/DGAC-archivo/modulo3/co-av-23-10-r3.pdf>. Accessed 20 Apr 2017
- Nepal (2015) Civil Aviation Authority of Nepal – flight operations directives No. 07. Available via https://irevolution.files.wordpress.com/2015/05/caa_nepal-uav-regulations.pdf. Accessed 20 Apr 2017
- Netherlands (2015) Inspectie Leefomgeving en Transport – Ministerie van Infrastructuur en Milieu. Flights with remotely piloted aircraft systems (RPAS) – so called drones – in the Netherlands. Available via <https://english.ilent.nl/themes/rpas---remotely-piloted-aircraft-systems-drones>. Accessed 20 Apr 2017
- New Zealand (2015) Civil Aviation Authority of New Zealand – part 101 CAA consolidation. Gyrogliders and parasails, unmanned aircraft (including balloons), kites, and rockets – operating rules. Available via https://www.caa.govt.nz/rules/Rule_Consolidations/Part_101_Consolidation.pdf. Accessed 20 Apr 2017
- Nicaragua (2014) Instituto Nicaragüense de Aeronáutica Civil – Nota de Prensa. Available via <http://www.inac.gob.ni/wp-content/uploads/2014/11/Nota-de-Prensa-INAC.pdf>. Accessed 20 Apr 2017
- Nigeria (2015) Federal Republic of Nigeria – Official Gazette. Available via <http://www.ncaa.gov.ng/media/1273/aviation-part-10.pdf>. Accessed 20 Apr 2017
- Ogden LE (2013) Drone ecology. *Bioscience* 63(9):776. doi:10.1525/bio.2013.63.9.18
- Pérez M, Agüera F, Carvajal F (2015) Low cost surveying using an unmanned aerial vehicle. *Int Arch Photogramm Remote Sens Spat Inf Sci XL-1(W2)*:311–315. doi:10.5194/isprsarchives-XL-1-W2-311-2013
- Philippines (2015) Civilian Aviation Authority of the Philippines. Available via <http://caap.gov.ph/index.php/downloads/send/78-2015/293-mc-29-15-amendments-to-pcar-part-2-4-11>. Accessed 20 Apr 2017
- Portugal (2016) Autoridade Nacional da Aviação Civil Regulamento n. 1093/2016 – Condições de operação aplicáveis à utilização do espaço aéreo pelos sistemas de aeronaves civis pilotadas remotamente (“Drones”). Available via <https://dre.pt/application/file/105366569>. Accessed 20 Apr 2017
- PwC (2016) Clarity from above, PwC global report on the commercial applications of drone technology, May 2016. Available via <https://www.pwc.pl/pl/pdf/clarity-from-above-pwc.pdf>. Accessed 19 Apr 2017
- Romania (2016) Romanian CAA Directivă de navigabilitate – Emiterea certificatelor de identificare pentru aeronavele fără pilot la bord (RPAS). Available via <http://www.caa.ro/pdf/Directiva%20identificare%20UAV.pdf>. Accessed 20 Apr 2017
- Rwanda (2015) Civil aviation (unmanned aircraft system (UAS) regulations 2015 – arrangement of regulations). Available via http://www.caa.gov.rw/fileadmin/templates/Regulatory_Services/Annex_to_the_Ministerial_regulations_on_UAS_Regulations_17_March_2016.pdf. Accessed 20 Apr 2017
- Slovakia (2015) Dopravný Úrad. Transport Authority – Rozhodnutie č. 1/2015 z 19.08.2015, ktorým sa určujú podmienky vykonania letu lietadlom spôsobilým lietať bez pilota vo vzdušnom priestore Slovenskej republiky. Available via http://nsat.sk/wp-content/uploads/2014/08/DU_RPAS-merged.pdf. Accessed 20 Apr 2017
- Slovenia (2016) Uredbo o sistemih brezpilotnih zrakoplovov. Available via <https://e-uprava.gov.si/drzava-in-druzba/e-demokracija/predlogi-predpisov/predlog-predpisa.html?id=7217>. Accessed 20 Apr 2017
- Smith P (2013) Invasion of the drones? *N Y Times Upfront* 22:10–11

- South Africa (2015) South African Civil Aviation Authority – Remotely piloted aircraft systems (Part 101) regulations workshop. RPAS regulations (Part 101). Available via <http://www.caa.co.za/Documents/RPAS/Part%20101%20-%20RPAS%20Workshops.pdf>. Accessed 20 Apr 2017
- Spain (2016) Ministerio de Fomento – Ministerio de Defensa – Real Decreto por el que se regula la utilización civil de las aeronaves pilotadas por control remoto, y se modifica el Real Decreto 552/2014, de 27 de junio, por el que se desarrolla el Reglamento del aire y disposiciones operativas comunes para los servicios y procedimientos de navegación aérea y se modifica el Real Decreto 57/2002, de 18 de enero, por el que se aprueba el Reglamento de Circulación Aérea. Available via <https://www.fomento.es/NR/rdonlyres/63ECAE3A-B29E-45A7-A885-D314153883EE/139826/RDRPAS27102016.pdf>. Accessed 20 Apr 2017
- Sri Lanka (2017) Civil Aviation Authority of Sri Lanka – Requirements for Operation of Pilotless Aircraft (Unmanned Aerial Vehicles Unmanned Aircraft Systems/Remotely Piloted Aircraft/ Drones). Available via http://www.caa.lk/images/stories/pdf/Drones/SLCA_IS053_1st_Edition_Rev02_10JAN2017.pdf. Accessed 20 Apr 2017
- Togo (2015) République du Togo Ministère chargé de L'Aviation Civile – Règlements Aéronautiques Nationaux du Togo RANT 02 Règles de l'air. Available via http://anac-togo.tg/RANTS/RANT_02/RANT_02_regles_de_lair.pdf. Accessed 20 Apr 2017
- Ukraine (2016) Available via https://www.loc.gov/law/help/regulation-of-drones/ukraine.php#_ftn25. Accessed 20 Apr 2017
- United Arab Emirates (n.d.) General Civil Aviation Authority. Available via <https://www.gcaa.gov.ae/en/Pages/UASRegistration.aspx>. Accessed 20 Apr 2017
- United Kingdom (2015) Civil Aviation Authority – Unmanned Aircraft System Operations in UK Airspace – guidance. Available via <http://publicapps.caa.co.uk/docs/33/CAP%20722%20Sixth%20Edition%20March%202015.pdf>. Accessed 20 Apr 2017
- United States of America (2016) Federal Aviation Administration (FAA) and Office of the Secretary of Transportation (OST), Department of Transportation (DOT) - Operation and Certification of Small Unmanned Aircraft Systems. Available via: <https://www.federalregister.gov/documents/2016/06/28/2016-15079/operation-and-certification-of-small-unmanned-aircraft-systems>. Accessed 31 Aug 2017
- Vietnam (2008) The Government Socialist Republic of Viet Nam – decree on management of unmanned aircraft and ultralight aircraft. Available via http://moj.gov.vn/vbpq/en/Lists/Vn%20bn%20php%20lut/View_Detail.aspx?ItemID=2867. Accessed 20 Apr 2017
- Villa TF, Gonzalez F et al (2016) An overview of small unmanned aerial vehicles for air quality measurements: present applications and future perspectives. *Sensors* 16(7):1072. doi:[10.3390/s16071072](https://doi.org/10.3390/s16071072)
- Wang Y, Xia H et al (2016) Flying eyes and hidden controllers: a qualitative study of people's privacy perceptions of civilian drones in the US. *Proc Priv Enhancing Technol* 3:172–190. doi:[10.1515/popets-2016-0022](https://doi.org/10.1515/popets-2016-0022)
- Watts AC, Ambrosia VG, Hinkley EA (2012) Unmanned Aircraft Systems in remote sensing and scientific research: classification and considerations of use. *Remote Sens* 4(6):1671–1692. doi:[10.3390/rs4061671](https://doi.org/10.3390/rs4061671)
- Yun M, Kim J et al (2013) Feasibility of employing a smartphone as the payload of a photogrammetric UAV system. *ISPRS J Photogramm Remote Sens* 79:1–18. doi:[10.1016/j.isprsjprs.2013.02.001](https://doi.org/10.1016/j.isprsjprs.2013.02.001)
- Zhao B, Hellwich O et al (2015) Employing smartphone as on-board navigator in unmanned aerial vehicles: implementation and experiments. *Ind Robot: Int J* 42(4):306–313. doi:[10.1108/IR-01-2015-0016](https://doi.org/10.1108/IR-01-2015-0016)

Small Flying Drones

Applications for Geographic Observation

Casagrande, G.; Sik, A.; Szabo, G. (Eds.)

2018, IX, 161 p. 95 illus., 90 illus. in color., Hardcover

ISBN: 978-3-319-66576-4