**THE FUTURE OF UAVS IN ECOLOGY: AN INSIDER
PERSPECTIVE FROM THE SILICON VALLEY DRONE
INDUSTRY**

Journal:	<i>Journal of Unmanned Vehicle Systems</i>
Manuscript ID	juvs-2016-0008
Manuscript Type:	Editorial
Date Submitted by the Author:	22-Mar-2016
Complete List of Authors:	Crutsinger, Gregory; 3D Robotics, Short, Jason; 3D Robotics Sollenberger , Roger; 3D Robotics
Keyword:

THE FUTURE OF UAVS IN ECOLOGY: AN INSIDER PERSPECTIVE FROM THE SILICON VALLEY DRONE INDUSTRY

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INTRODUCTION

There has been a growing excitement in ecology around Unmanned Aerial Vehicles (UAVs), referred to here also as ‘drones.’ The Federal Aviation Administration (FAA) designates drones as any aircraft flown by a pilot via a ground control system or autonomously through use of an on-board computer. The size and the pace of innovation of the drone industry are increasing at a fantastic rate. Thousands of companies compete globally, with more emerging daily. These drones are controlled by different autopilots and vary widely in capabilities (e.g., flight time, range, speed, payload). Along with the explosion in production, prices have dropped exponentially. It is beyond speculation that drone technology will transform industries and research institutes worldwide, including the field of ecology. Almost overnight drones have significantly improved our ability to collect high-resolution spatial data at repeated intervals, eliminating the need (at least at smaller spatial scales) for costly over-flights by manned aircraft, as well as multiplying the efficiency of traditional observation conducted on foot.

In addition to diversification in vehicle type, drones are being integrated with an array of cameras, sensors, and software applications. This expansion is happening apace; it’s difficult for those of us fully embedded in the industry to keep up with it, let alone for researchers whose main focus might not be UAV technology but rather using drones as a research tool. The goal of this article, then, is to provide an inside look at the leading edge of the drone industry from the perspective of an ecologist (and colleagues) working for a Silicon Valley drone company. We intend to do the following: (1) Give ecologists a working understanding of existing and emerging technology (remaining as brand-neutral as possible); (2) advise on a starting place for integrating drones into field research; (3) advocate for immediate adoption and development of drone technologies specific to ecology; and (4) encourage “thinking big” about the potential for drones to revolutionize the study of ecosystems. We will also argue for the increasingly pressing need to establish standard best practices for research and publication.

The industry today - Over the past two years the use of drones has skyrocketed. The FAA reported in early February of 2016 that the number of drones on the national registry now exceeds the number of registered traditional aircraft, this less than two months after effecting the drone registration mandate. Interestingly, owing in part to the agency's deliberate pace in developing regulations for civil and commercial use, the consumer market has driven most of the innovation, primarily in advancements suiting hobbyist, photography, and cinema use cases. As a result, most drones on the market today are "micro-drones" (weighing under 4.4 pounds). The most popular of these are outfitted with a stabilized camera system, offer flight times of ~10-30 minutes, and range in price from ~ \$300 – 5000 USD. Because of consumer demand for high-quality aerial photos and video, the majority of these drones are multirotors, which offer more stability and the capacity to hold position, as opposed to fixed-wing vehicles that can fly for longer durations but can't hover and are more difficult to launch and land.

The consumer industry has produced impressive hardware in an astonishingly short time. In the past year, the private sector has made great strides in the resolution, size, and cost of RGB cameras (including 4K video); autonomous flight and camera control technology; geotagging images for photogrammetric stitching, as well as the stitching software itself; the safety and intelligence of lithium polymer (LiPo) batteries; the accuracy and reliability of GPS flight stabilization; repairing hardware on the go; and, perhaps most significant to the spike in popularity, the simplification of the user interface vis-à-vis the complex remote controls of days long past (i.e., a year ago). In fact, this list itself will likely need updating by the time of publication.

Thanks to these advances, novice users can learn to fly and start capturing cinematic aerial imagery in minutes, something that used to demand months or years of practice. With the latest mission planning software, drones can automatically take off, capture imagery of a given area specified on a tablet, then land and wirelessly upload that data to the cloud. In fact, consumer drones today are so powerful that many models are perfectly adequate for the needs of scientists, such as high-resolution mapping (down to

1-5 cm/pixel). For the price of a mid-grade laptop, you can choose from a range of vehicles available for real-time aerial surveys, many for sale in popular “big box” retail outlets. What’s most impressive — and in some ways alarming — is that many of these advancements have come in the past few months (and in some cases weeks).

In addition to RGB cameras, drones can be outfitted with a number of lightweight sensors relevant to ecology, including multispectral cameras for vegetation surveys, thermal cameras, and LIDAR (Fig. 1). These sensors are available on high-end drones today and are beginning to be integrated into consumer-class drones. Integration of alternative payloads will further ramp up with the rise of the commercial drone industry (discussed below).

Where is the industry headed relevant to ecology? - The primary reason the consumer market has driven the majority of innovation in the U.S. is because the Federal Aviation Administration (FAA) has restricted the commercial use of UAVs (profiting from drone services). Currently, commercial use is gated by an application process that often takes months and requires the minimum of a sport pilot license, which can cost thousands of dollars to acquire. However, U.S. commercial rules are expected later in 2016, which will open the commercial market. This is the only reason drones are not regularly seen inspecting cell towers, monitoring weather, live-streaming television news, photographing real estate, mapping farmland, or on the benches in every scientific lab across the country. But all this is coming, and soon.

Hardware: cheaper, better, and easier. - In terms of hardware, the drone industry will focus on general advances in flight time and safety. Battery technology is a major hurdle not just for drones but for the tech industry as a whole; this demand will incentivize rapid development. We will see lighter and less expensive sensors for obstacle avoidance and scene awareness, including sonar, optical flow, computer vision, and navigation LIDAR. The industry will also likely develop air traffic systems that facilitate

communication between drones, manned aircraft, and the ground in order to help the FAA manage low-altitude air space. For example, NASA is creating the Unmanned Aircraft System Traffic Management system to enable low-altitude operations, partnering with major companies such as Alphabet (née Google) to tackle the task (<http://utm.arc.nasa.gov/index.shtml>). Additionally, most drones today can't fly autonomously without GPS, can cover only smaller spatial scales, and aren't dust- or weather-proof. However these capabilities are likely in the pipelines of many drone manufacturers.

Software overtakes hardware. - Perhaps the most significant advancement in drone technology relevant to ecology can be found in the launch of 'smart drone' technology — the interaction of drones with powerful onboard computers, data collection devices, smartphone applications, and, perhaps most importantly, the cloud. Cloud integration will realize the potential of drones for massive data collection, analysis, and distribution. To put this in perspective, using a drone today for the sole purpose of taking an aerial photograph is the equivalent of using an iPhone™ only to call a relative on her birthday. Additionally, free and open software development kits and web APIs currently accessible to anyone with a basic background in coding allow for the development of software ('drone apps') that can be tailored to specific needs; this is a great resource for technical education and for developing software for specific research uses.

Ecologists need to start driving software innovation. - A starting place for ecology-specific software would be standardizing mission planning for different sampling methods (e.g., transects, mapping, block designs, and individual plots). In a basic proof-of-concept app (we call it "Section") developed for this article, a drone (the 3DR Solo; Fig. 1, top panel) can be flown manually to a given altitude and pointed in a compass direction chosen at random. Upon pressing "play" on the tablet, the drone points the gimbal-stabilized camera straight down and flies a 300 m transect, snapping photos at an automatically calculated photo overlap (Fig. 2a). What might have taken an hour on the ground, stretching a meter tape randomly

in the field and dropping a PVC quadrat along it, now takes less than a minute. This function will be released this year as an update to the primary Solo app (Solo software version 2.4).

Drone software already allows for geofencing (creating virtual flight boundaries), an important safety feature. However, geofencing can also comprise surveys within a given area and improve fleet management when multiple investigators are involved (e.g., each individual could be confined to a specific site). Data can then be pushed from the drone to a phone or tablet and then to cloud repositories for cohesive organization. These data can then be shared across teams or published. Drone apps could also coordinate ongoing multi-site research programs within and across universities or state and national agencies; for instance, assembling 50-hectare plots that run through the Smithsonian Center for Tropical Forest Science, Organization for Tropical Studies field courses, biological field stations, or the National Ecological Observatory Network (neonscience.org).

Apps for citizen science could be truly revolutionary. - Smart drones open the door to standardized crowd-sourced data in ways previously unimaginable. For example, an app loaded with preset missions to map given areas could be created for hobbyist drone pilots around the world to download for free. Many common consumer drones can fly a 1 km transect at 50-100 m altitude with 80% photo overlap at 12 megapixels in just a few minutes, requiring a citizen pilot to donate less than 25% of the life of a single rechargeable LiPo battery (essentially free). Consequently, 100K drone pilots across North America, and many times that number around the world, could be called to action to monitor the spread of invasive species, document shifts in phenology or species range with climate change, survey before/after storms or fires, estimate wildlife populations, etc.

Virtual reality will bring a new perspective to fieldwork. - On top of cloud integration is the recent move in the drone industry towards 360° cameras (Fig. 2b) and virtual reality (VR). Ecologists can now quickly fly a set transect with a drone collecting video in 360°, save that video and later carry out surveys

using VR glasses (e.g., Oculus Rift™ or Google Cardboard™). The use of 360° imagery for repeated drone flights throughout the year will present a challenge for time-series data analysis, but it has remarkable potential to change how ecologists use field surveys and teach (see Appendix A for an example 360° video).

Rules and regulations. - Drones pose a challenge for FAA. The United States has the busiest airspace in the world — over 75,000 manned flights *a day* — and the FAA is charged with keeping it safe. The organization must safely and wholly integrate drones into the National Airspace, and though they would like to do it at a pace that won't check innovation or attenuate economic potential, they're taking their time to get it right. Today the regulations might seem fuzzy to people not deeply involved with the drone industry, but good news: We expect official regulations in 2016. This will make it easier for research institutions to start using drones. See appendix B further details on current drone regulations.

CONCLUSIONS

Gone are the days where ecologists had to spend a small fortune on a drone or have one built to their own specifications. Of course, many research applications still require customized vehicles, payloads, and software; however, research-grade drones tend to be expensive (\$25 – 100K USD), their customization takes time, and replacements are not readily available. Further, it's arguable whether the data these drones produce for the average need in ecology are better than what can be obtained for a fraction of the cost by a consumer vehicle; documented comparisons of systems for scientific use are virtually non-existent, or are the equivalent of consumer holiday gift guides listing side-by-side specifications. So while the arrival of affordable drone technology brings tremendous opportunity for data collection, it also raises an immediate demand for rigorous comparative testing.

A call to action.

Basic questions related to the field sciences need to be addressed:

- How precise are different drones/autopilots in flying missions in space, over time, and under different weather conditions?
- Do results differ among mission planning programs? How would we resolve these differences?
- How do different cameras and photogrammetric stitching software engines compare in aerial mapping and across disciplines? Which are optimal for ecology?
- Does the accuracy of NDVI estimates of cameras small enough to fit on consumer-grade drones vary across seasons and/or different ecosystem types?
- How does LIDAR compare to photogrammetry for different ecological applications?
- How do drones impact different wildlife species? What is the duration of these impacts and how can they be mediated?

Note: We are not advocating that scientists should be averse to adopting the latest and greatest drone technology. In fact, the opposite is true: We must conduct rigorous comparative testing as new technology is introduced over the coming years by a red-hot industry, with rapid dissemination to the field as a whole. This raises significant logistical challenges (legal complications aside) to research funding, as well as to editors and reviewers who need to understand the technology cited in manuscripts.

Further, ecological journals will need to determine what data are required for publication. Researchers can submit the make and model of a given vehicle, but what about the specs of custom-built vehicles? For open-source autopilots, should the associated flight logs be required? Perhaps authors should also have to submit the mission-planning files (possible only in some software packages). Should we account for variances in GPS accuracy, and if so, how? For associated maps or 3D models, should authors be required to upload the individual geotagged photos so other researchers can compare among diverse software stitching and analysis engines? What file format(s) will be required? And where will these data (and there will be terabytes) be stored? Given the diverse applications for drones, methods will also likely be

published or presented at conferences that span many different disciplines but are directly relevant to ecology. How will these publications be tracked across disciplines to minimize duplication?

So how do you move forward?

We encourage you to start using drones now to understand the technology and track the industry. Do not wait for technology to slow down; it will not slow for a while, and your team will be even further behind. If you are concerned about regulations, purchase a drone personally and fly as a hobbyist to familiarize yourself with the technology. Take advantage of countries with more lenient regulations for teaching workshops or conducting fieldwork. If you would like to teach with drones immediately, then build a large flight net. Students standing outside nets with drones inside also tend to be positively viewed by university administrators and safety officers, and you will be exempted from FAA regulations in this ‘indoor’ space.

As for cost, do not be tempted by expensive commercial drones on the market. Start with a drone in the ~\$500 - 3500 range, and buy some small toys (~\$50-100 for Hubsan™ X4 or Blade™ Nano QX) to practice flying in your house. Your kids will love this (your spouse may not). There is a huge demand for curricula in academia in general, and for ecological uses specifically. Develop it, teach it, and make it broadly available.

Network with the drone industry as much as possible by going to larger drone shows. However, dozens of for-profit drone trade shows are now popping up, some of which are neither useful nor well attended by the industry. Attend larger events (e.g., AUVSI, Interdrone). Similarly, beware of “vaporware,” or hyped-up new drone companies or products announced to the public but never actually shipped to customers (or canceled). Join an online drone community such as DIYdrones.com and educate yourself on the technology. Continue to have UAV sessions at meetings such as the Ecological Society of America

annual meeting, as well as at different working groups. Above all, reach out to those of us embedded in the industry.

Given that agriculture, oil and gas, construction, inspection, and real estate are huge, wide-open and lucrative markets, there may be low incentive for larger drone companies to fund ecology-specific sensor integration in the short term unless it piggybacks on other commercial applications (e.g. CO₂ sensors). However, scientific sensor companies may be incentivized to integrate specific sensors/accessories if there is high demand from the scientific community. Also, to date, not a single scientific supply company commonly used by ecologists is distributing drones. Ask and these companies will respond.

Don't let your institution relegate drones to the engineering or airspace department. Drones can be used across disciplines; therefore, a central drone library is probably the best long-term approach at the department or university level, as opposed to individual labs purchasing their own. Vehicles could then be checked out from the library by students and researchers who meet departmental training standards (there are no national standards yet), while a single person or a set could be tasked with monitoring mission logs, inspections, repairs, battery charging, accessories, etc.

Above all, have fun! Autonomous video shots taken from the air are amazing for talks and presentations, and they're inspirational to students. It's a brave new world. Take a deep breath and take off.

ACKNOWLEDGEMENTS

Drs. D. Simberloff and D. Inouye provided helpful comments on this manuscript.

FIGURE LEGENDS

Figure 1. Depicts a Solo™ drone platform by 3D Robotics™ (top panel), an example of an open-source, consumer-level drone for aerial data collection. Many affordable drones are emerging from manufacturers with the ability to carry increasingly lightweight payloads such as multispectral cameras (the Sequoia camera by Parrot™; lower panel left), thermal cameras (the Tau 2 by Flir™; lower panel center), and LIDAR (the Velodyne™ puck; lower panel right).

Figure 2. Schematic (a) depicting the automated drone transect shot (called “Section”) created specifically for scientific applications using the 3D Robotics Solo drone. In addition, 360° imagery (b) can be collected using hemispherical cameras, such as the Kodak SP360 (see appendix B for an example 2-dimensional video).

269 Figure 1

271 Figure 2.

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273 APPENDIX A

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285 3DR Solo drone outfitted with Kodak SP360 cameras to collect 360° imagery for later surveys in the lab
286 using virtual reality glasses.

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APPENDIX B

Hobbyist drone use (flying and filming for fun) is 100% legal, as long as you adhere to certain ground rules (Appendix B). This means that if you want to get practicing and experimenting on your own today, you can as a hobbyist. The FAA also plans to launch an app called [B4UFLY](#) (Appendix B) which will advise drone users of any flight restrictions in their area, based on their GPS location. You can also check out [Airmap](#) (www.airmap.io) or similar mobile apps that serve the same purpose. Many consumer drones today offer real-time access to these companies' information through their own apps.

To fly for commercial use today (if you're making money or use drones to enhance or promote your business in any way), you need to apply for a special permit from the FAA; it's called a Section 333 Exemption (333). More good news: It's getting easier and easier to get a 333. The FAA has approved over 3,000 of these exemptions at the time of this writing; in January of 2015 they had granted 12. However, if you are operating as a public agency (as opposed to commercial), you need to apply for a different permit, called a Certificate of Authorization (COA). The FAA states on its website (www.faa.gov/uas/public_operations/) that the typical COA takes about 60 days to process. A 333 requires that the applicant hold a minimum of a sport pilot's license; the licensing requirements for a COA are less clear, but typically the FAA requires a PPL — private pilot's license — for a COA. (Please confirm your requirements with the FAA directly.)

So which does your ecology department need? It seems state schools (qualified as government entities) would need a COA, but that's not actually cut and dried. The FAA has issued blanket COAs for six test sites around the country; but some are for universities that are cleared to operate in more than one state. What's more, these sites are cleared for research *about* drones (i.e., technology, performance, etc.), which doesn't include research for how drones can be *used*. Many other state universities (<https://www.eff.org/document/faa-list-certificates-authorizations-coas>) have COAs; however, these

universities operate at approved test sites. Bottom line: The FAA actually holds that state universities do *not* qualify as government entities

(http://www.cjr.org/united_states_project/matt_waite_drone_journalism_lab.php), making them ineligible for a COA; under this interpretation even state schools are lumped in with commercial entities and need 333s to operate drones legally.

It's all up in the air, so to speak. If you or your department or school wants or needs permission to fly immediately, we suggest calling the FAA and asking what you and your university need to do to incorporate drones into research and education. And if you want to get a 333, we actually suggest waiting a little while; we expect the FAA to release official regulations very soon, which will in all likelihood mean a new (and hopefully easier) licensing process. We warn against hiring expensive drone consultants to fill out the 333 application for you. There are many firms out there taking advantage of the confusion in this process.

Perhaps ironically, these licensing requirements have trammelled the pace of academic research more than that of private or commercial innovation; "ironically" because we have controlled environments, rigorous and standardized safety and procedural protocols, and often work on or have access to a swath of uninhabited land. As a result, we've fallen behind our commercial counterparts, and we need to start catching up. We urge that the academic voice in general, and the ecologist's voice in particular, advocate forcefully on behalf of the interests of universities when it comes to regulation. We can rise to the challenges, and, in part owing to the very nature of our institutions and in part to our history of driving research, we can help figure out how to maximize utility and minimize risk. This is important to ecologists in particular: We must have access to national parks (currently mandated no-fly zones), state and national forests, wildlife refuges and field stations. National leadership must understand the value of the potential over the risk.

However, you don't have to wait, or even apply for an exemption. If you want to get flying now (and you should!), there is a very simple end-around: a flight cage. Building an enclosed flight net is an inexpensive, quick, and easy solution. All you need is netting that makes four walls and a ceiling (unlike solid walls, netting allows for GPS connectivity). For example, Kansas State University - Salinas built a 200 × 300 × 50 foot-tall netted pavilion to support their UAV degree program and address the close proximity of their campus to the Salinas airport. However, you can even use a batting cage or pull a net over the top of a tennis court. As long as the area is entirely closed off, the FAA doesn't count it as navigable airspace. We suggest building one as soon as you can so you can get flying, learning, and experimenting as soon as possible

Steps toward a 333 exemption.

1. Purchase a drone.
2. You have your drone and you know that you would like to use it for business purposes.
3. Submit your petition for exemption. Instructions and checklists are on the [FAA website](#). [Here is template](#) for a Section 333 Exemption submission, curated by 3DR specifically for the Solo drone. You may still have to provide additional information with the exemption request. The FAA likes to see a [User's Manual](#) for the aircraft and sometimes an Operations Manual that describes how you plan to operate in the National Airspace, how you'll abide by the steps you've outlined and what you are doing to mitigate risk.
4. Go to your local [FSDO](#) office and pick up the AC 8050-1 forms to reserve the N-number for your Solo. Your N-number will be sent you so you can fill out the remainder of the registration forms.
5. Next: Wait... It takes 90 - 120 days for the FAA to approve new 333 exemption requests.
6. [Register your aircraft](#).
 - a. In most cases the original proof of purchase (receipt) will take the place of [AC 8050-2](#).
 - b. Fill out form [AC 8050-88](#). This establishes that the drone belongs to you (in the FAA's eyes and databases). [Here](#) is a version that has Solo specific information already populated.
7. Send your documents to the [Aircraft Registration Branch](#).
8. Submit an application for a COA [here](#) if your operational parameters fall outside of the blanket COA that is granted with the 333 exemption.
9. Go fly!

FAA Know Before you Fly (<http://knowbeforeyoufly.org/>) safety guidelines for sUAS recreational users:

- Follow community-based safety guidelines, as developed by organizations such as the Academy of Model Aeronautics (AMA).
- Fly no higher than 400 feet and remain below any surrounding obstacles when possible.
- Keep your sUAS in eyesight at all times, and use an observer to assist if needed.
- Remain well clear of and do not interfere with manned aircraft operations, and you must see and avoid other aircraft and obstacles at all times.
- Do not intentionally fly over unprotected persons or moving vehicles, and remain at least 25 feet away from individuals and vulnerable property.
- Contact the airport and control tower before flying within five miles of an airport or heliport.
- Do not fly in adverse weather conditions such as in high winds or reduced visibility.
- Do not fly under the influence of alcohol or drugs.
- Ensure the operating environment is safe and that the operator is competent and proficient in the operation of the sUAS.
- Do not fly near or over sensitive infrastructure or property such as power stations, water treatment facilities, correctional facilities, heavily traveled roadways, government facilities, etc.
- Check and follow all local laws and ordinances before flying over private property.
- Do not conduct surveillance or photograph persons in areas where there is an expectation of privacy without the individual's permission (see AMA's privacy policy).