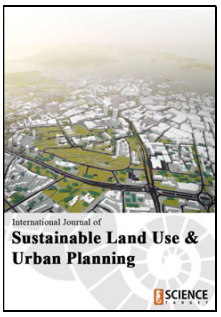
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Drone Applications for Environmental Management in Urban Spaces: A Review

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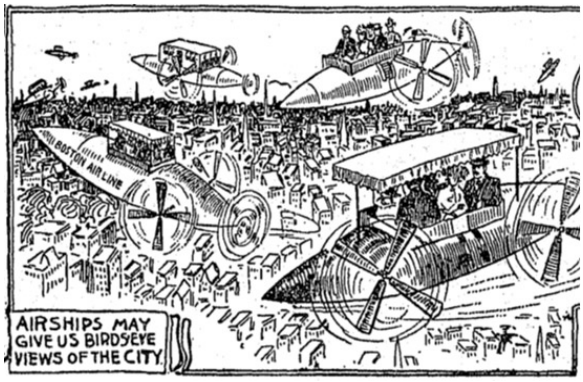
Abstract. Options for environmental management have improved dramatically over recent years. Sensors for air and water pollutants, and subsets of the electromagnetic spectrum, have become smaller, cheaper, and more bundled into comprehensive units. Aerial sensor platforms have also expanded in the form of low-altitude unmanned aerial vehicles (micro-drones), but their use in populated spaces is increasingly restricted for safety and privacy reasons. This article discusses potential applications of drones for use in environmental monitoring and management of urban spaces as well as the potential risks. Applications better suited to an Internet of Things approach include those in which frequently repeated or continuous measurements are needed from a location proximal to existing infrastructure. Surveillance applications are likely to move to higher altitude drones with better safety and security systems. The main niche for small drones is difficult to access spaces under which there are few to no people, but this still includes many potential applications.

Keywords. *drone, environmental monitoring, air quality, water quality, efficiency*

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Introduction

Swarms of drones flying through a city centre, finding leaks in water pipes, delivering coffee, recording accidents, and generally making a Smart City hum with efficiency… Is this the city of tomorrow or a contemporary example of over-reaching futurism? The recent focus on drones internationally has sparked a wide variety of proposals for their use, as seen through the range of entries to the UAE Drones for Good awards (Prime Minister's Office, 2015). The announcement of Prime Air by Amazon in 2013, a project to develop a delivery drone to cover the "last mile" of small parcel distribution, grabbed the attention of the wider community. Prime Air has been described as viable only as a public relations stunt (Wohlsen, 2013) and alternatively to have commercial merit for its novelty and facilitation of rapid purchases (Welch, 2015). If it does become reality, it is likely to remain a niche service due to high costs and operating constraints (McKinnon, 2015). Drones can carry a wide range of sensors with an equally wide range of applications to aerial points that were previously expensive, or impossible, to reach. Additionally, they can broadcast (e.g., insecticides, pollen), retrieve (e.g., air, water, leaf samples), or transport physical items (e.g., feed) with precision and, perhaps, reduced disturbance to the site.



Boston Globe, 24 Dec 1900 (Novak, 2011)

However, drones also pose a risk to public safety, privacy, and security (General Civil Aviation Authority, 2015). Their implementation must be weighed against the financial and other costs associated with these risks and also against less risky ground-based alternatives. Some proposed applications for drones would be deliv-

ered more safely through emerging Internet of Things networks, whereby a vast amount of data is collected from a vast number of fixed points and vehicles, centralized through the Internet, and analysed in real time. Some monitoring applications may be more practically delivered through multipurpose drones operating permanently at high altitude, delivering data to the community in much the same way that satellites now do, but better. The aim of this article is to explore the niche of the low-altitude drone in urban settings, with a particular view to environmental management. In what circumstances are the risks to the public lower than the benefit gained?

The word "drone" is not clearly defined, but it is the preferred term for public discourse (Stanley, 2013). Like the term "unmanned aerial vehicle" (UAV), it refers to an unmanned flying object that is capable of aerial self-stabilization and is not a kite, balloon, or satellite. The term "unmanned aircraft system" (UAS) is broader, including any wireless communication and detached hardware used to control the flight path. A fourth term, "remotely piloted aircraft systems" (RPAS) refers to the subset of UASs that are incapable of fully autonomous flight missions, and may also include remotely controlled aircrafts that are not self-stabilizing. Most drones are not operated autonomously even if they have the capability, for reasons of economy, legality, or convenience. For example, large military drones are too expensive to justify any increased risk of crashing, regardless of how small. Even when programmed for autonomous flight, drones require substantial human input between flights to perform safety checks, change batteries (or refuel), and, in many countries, to fulfil the legal requirement to remain within line-of-sight.

The world market for civilian drones is significant and growing. Units sold in the US currently exceed 15000 per month ("Welcome to the Drone Age," 2015). Forecasters predict growth to a volume measured in multiple billions of US dollars by 2020 (Grand View Research, 2015; Research and Markets, 2015). This growth is being driven by adoption in agriculture, law enforcement, media (news and entertainment), and the energy sectors. A worldwide drone-based service industry for wind farm maintenance has been projected to reach US$6 billion by 2024 (Navigant Research, 2015). Currently around 70 countries use drones for national defence surveillance, and approximately five also use them for armed conflict (Franke, 2014).



http://bizarro.com/comics/june-2-2014/

Applications

Current proposals for drones mostly involve sensing some aspect of the electromagnetic spectrum. This includes maintenance inspections of infrastructure, broad scale environmental impact assessment, and numerous other examples. Amazon's Prime Air project, on the other hand, is an attempt to use drones for delivery of commercial products. The future may reveal new applications for drones, but the list below is an attempt to categorize the range of possible uses. Some applications may cross boundaries. Samples for air and water quality could be collected for laboratory analysis or assessed *in situ* with on-board sensors.

Platform for aerial sensing:

- Electromagnetic spectrum (visible light, infrared, ultra violet) — For these applications,

a drone is different to a satellite only in that it operates at a much lower altitude. This allows for much greater detail with less atmospheric interference but will normally require research and development to automate the analysis of the enormous amount of data produced. It also enables sensing of wavelengths that decay over long distances.

- Atmospheric composition — An emerging field is the use of drones for pollution monitoring (see below), but drones might also replace weather balloons in some circumstances.
- Data collection from detached sensors (e.g.; camera traps, sound recorders, animal tracking devices).
- Sound— Aerial sensing of sound could theoretically be achieved with a drone that can switch from powered to gliding modes. This might be a useful method in the future for detection and/or population estimation of some species.

Platform for aerial transport (in each case below, drones may have the advantage of being able to conveniently reach locations that are otherwise difficult or expensive to get to):

- Delivery—Movement of an object from point to point.
- Broadcast— Dispersal of liquids, gases, or particulates (e.g., pollen) over a wider area.
- Retrieval— Collection of liquid, gas, or solid samples for later analysis.

The following is an attempt to outline current research into applications that could be applied in an urban environment.

Water

Several research teams are working on drones that can collect water samples. Higher end models are in demand by the oil industry to help them meet environmental regulations (Rosenblum, 2015). Monitoring of natural and public waterways near intensive farming is focused on nitrate runoff, which is a major cause of water acidification, eutrophication, and toxicity. Hence, the US Department of Agriculture is backing a $1M UAS water sampling project (University of Nebraska-Lincoln, 2014), and researchers at the Spanish Doñana National Park have systems under trial (Schwarzbach, Laiacker, Mulero-Pazmany, & Kondak, 2014). There is potential to greatly improve the efficiency of routine water monitoring by eliminating the need for boats, but current models are limited to calm weather and stationary or slow-moving water. Some collect samples while hovering above the surface, but there are both fixed-wing and multirotor models that can land on and take off from a water surface. Within lakes, drone sampling is preferable to boats, not just for time-saving but also because repeated sampling of the same location can be performed to submeter accuracy (Thaler, 2014), and site disturbance is minimal. Commercially available sensors for *in situ* water analysis include temperature, conductivity (a proxy for salinity), pH, dissolved oxygen, and oxidation reduction potential.

Air

Drones are routinely employed to assess volcanic activity and other large scale environmental events (Dunbabin & Marques, 2012). China's use of micro-drones to monitor air pollution moved from experimental to large scale in late 2013 (Xuefeng, 2015), but adoption elsewhere has been slower. Recent developments in sensor technology have resulted in compact, bundled packages (Snaddon, Petrokofsky, Jepson, & Willis, 2013) that measure a variety of air pollutants and natural components. These packages have been developed for Smart City / Internet of Things (IoT) projects, in which mass produced sensors are placed throughout a city to produce real-time geographically based air quality information but are also suitable for a drone platform. The list of sensors available from one IoT supplier (Libelum) in 2015 included temperature, humidity, air pressure, CO, CO_2, O_2, O_3, NO, NO_2, SO_2, NH_3, CH_4 (and combustible gases), H_2, H_2S, HCl, HCN, PH_3, EtO, Cl_2, and particulate matter (PM1, 2.5 and 10). Wind can be measured without additional sensors by assessing the compensation required to maintain a steady GPS position or flight path.

The arguments for using drones to measure air quality are less direct than for water quality,

since human health is affected only by near-ground air. Potential applications include:

- Sampling air quality over a broad area in a short period of time, using a fixed-wing drone— This application would dramatically improve air quality information but at a significant risk to safety.
- Sampling pollution point sources, such as an industrial or a construction site— Research is required to determine the reliability of air samples taken by drone from above a site, compared to those taken at or near-ground. This may lead to greater compliance of industry to environmental regulations.
- Sampling vertically, using a multirotor drone at a single GPS location— This may help to predict near-future changes in ground-level pollution, particularly of particulate matter.
- Models of wind movement may be useful for assessing the impact of a new construction on surrounding areas or to optimize the placement of a wind farm (Jensen, Morgan, Chen, Clemens, & Hardy, 2009).
- Research— Improve our understanding of the movement of pollutants during specific meteorological and temporal conditions.

Sprays

Two separate Chinese drone retailers (DJI and MMC) released a product in 2015 specifically designed for spraying crops. The same equipment could be used for weed control on golf courses and public urban green spaces or for insect control throughout an urban settlement. The potential for reducing labour costs is probably less significant in urban settings, but there are other advantages, including:

- Greater precision of chemical application, thus reducing wastage and pollution
- Easier access to slopes, canopies, waterways, rooftops, and green traffic islands
- Reduced human exposure to airborne spray particles

Electromagnetic Spectrum

There is a wide range of sensors to measure aspects of the electromagnetic spectrum, and models developed specifically for drones are becoming more common. The scope for drone inspection services is potentially endless. Energy companies have made substantial investments already. A drone-based service industry to inspect wind turbines could reach US$6 billion by 2024 according to a commercial intelligence company (Navigant Research, 2015). Drones are a practical way to evaluate safety compliance on a construction site (Irizarry, 2012). Urban settings have a range of possibilities, but there is little, if anything, that has moved beyond the experimental stage to routine application.

There is little doubt that higher altitude drones will become commonplace over cities for security and communication purposes once risks have been addressed. It is likely that data will be disseminated for other applications, as currently happens with satellite data.

Visible light (RGB)

Cameras for visible (red / green / blue) light (380 – 750 nm) are common and relatively cheap due to the retail market, though they are not optimized for aerial operation. For example, satellite cameras use a “push broom” method in which a one-dimensional strip of image is collected as the platform moves. An inventory of urban trees was developed for a suburban block using RGB sensors, but the process required streamlining to improve efficiency (Ritter, 2014).

Repeated sampling can be used to identify changes in land structure (Carvajal, Agüera, & Pérez, 2011; Niethammer, Rothmund, Schwaderer, Zeman, & Joswig, 2011; Rau, Jhan, Lo, & Lin, 2011) such as water erosion, sand accumulation, or land subsidence. A specific example involves Japanese solar farms, which are often built on reclaimed land and are therefore subject to reduced efficiency if that land subsides (Matsuoka et al., 2012).

Heat

Far infra-red cameras (8 – 15 μm) have theoretical value for evaluating the energy efficiency of individual buildings or over a broader scale. Thermal variation can also indicate water or industrial leakages or illegal water discharge

into public water bodies if there is a sufficient temperature difference or evaporative cooling in the affected area.

Near infra-red

Plant health can be estimated by observing the "red edge"—a ratio of visible red light (670 – 680 nm)— to non-visible near infra-red light (750 – 850 nm) that is a proxy for chlorophyll (Cho, Sobhan, Skidmore, & de Leeuw, 2008). Several vegetation indexes can be calculated (Cho & Skidmore, 2006; Miller, Hare, & Wu, 1990), the best known of which is the Normalized Difference Vegetation Index (NDVI). Vegetation indexes can be calculated from broad (NIR camera) or narrow bands (multispectral camera), with slight differences in results.

Undiscovered applications

A multispectral camera focused on specific bands might be able to quickly detect the presence / absence of specific chemicals. Research into absorption spectra has been focused on the use of satellite data to explore geology, so knowledge of the absorption spectra of specific pollutants is lacking.

Benefits of Staying Grounded

The main alternatives to the use of drones in urban monitoring (i.e., using a drone as a platform for sensors) are satellites and Internet of Things (IoT) technology. Satellites have low resolution and frequency of sampling, but this technology continues to improve. A ground-based sensor can record information from a fixed geographic location continuously, whereas a drone-based sensor records a fixed point in time over a wider geographical range. An IoT system involves many (perhaps thousands) sensors being placed in fixed locations throughout a city, providing real-time feedback that can be used for such things as regulating traffic flow or indoor temperature (Kyriazis, Varvarigou, Rossi, White, & Cooper, 2013). IoT is subject to concerns of data security and privacy (Patton et al., 2014), but not the safety concerns of drones. Public concerns of privacy are less than with drones, since people soon cease to notice the presence of a fixed sensor (Jarvis, 2014). Use of the term "IoT" began to rise in 2013/2014 but appears far less frequently than the term "drone" (Figure 1).

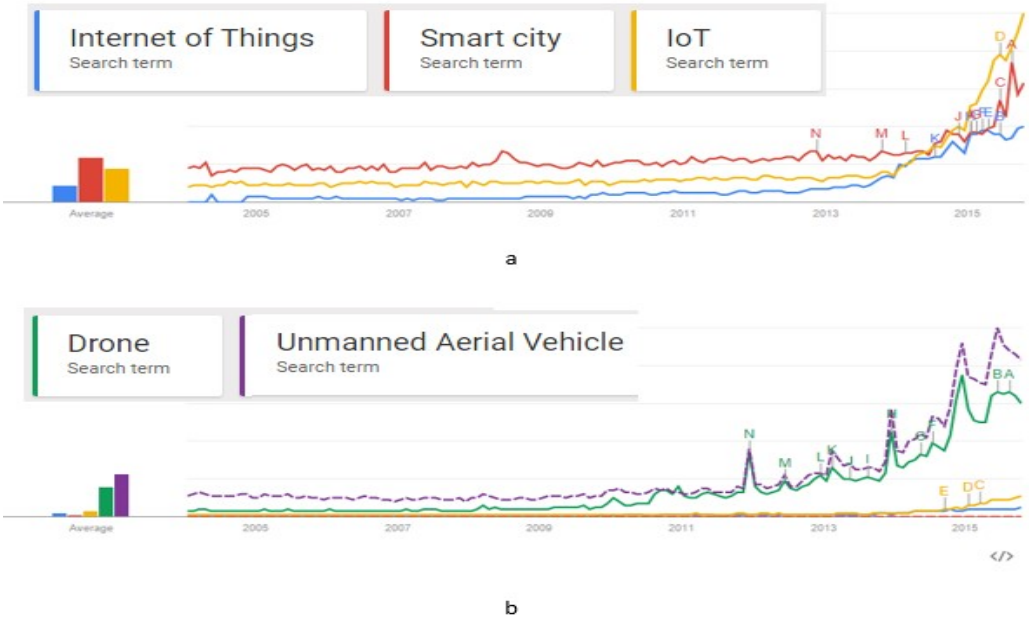


Figure 1: Trends for the terms (a) Internet of Things, its acronym IoT, and Smart City as recorded by Google Trends (www.google.com/trends). Figure 1(b) contains the same terms, plus the terms Drone and Unmanned aerial vehicle.

An example from medicine is live human organ transfer between hospitals, a time-sensitive application which currently occurs by road. The drone solution is to have a customized UAV within timely reach of every hospital within a region, but doing so would require flying over roads and populated spaces, and out of the operator's direct line of sight. The IoT solution is to continue to improve the management of infrastructure (traffic lights, road works, and police diversions) to minimize transit time by road. The IoT solution is low risk and transferable to other tasks, such as other ambulance work, diversions for heads of state, etc., while the drone solution is high risk to both the public and the payload and requires the maintenance of specialized equipment. The drone solution is therefore impractical in cities with even a basic IoT infrastructure.

The rise of cellular phone data to predict road traffic conditions in real time is a sobering reminder that solutions may come from unexpected sources. Before 2007, traffic conditions were compiled from helicopter observations, police communications, and voluntary calls to radio stations. It was easy to imagine an IoT solution to provide early warning of problems by placing thousands of sensors on, say, streetlights throughout the city; but it never happened. In 2007, Google combined ZipDash, a traffic analysis company it had purchased three years prior, with its Google Maps engine, and provided real-time traffic data for 30 US cities. The system is superior to an IoT solution since in addition to traffic flow, it records the start and finish of each journey, and thus is highly informative for city infrastructure planning.

Limitations

The benefits of a drone-based service must outweigh the risks and also be competitive with ground-based methods. A balance between benefits and risk can only be found once drones have been more widely adopted and their benefits subsequently investigated (Volovelsky, 2014). This is justification for having legislation at a local / state level so that different benefit/risk ratios can be explored (Kaminski, 2013). Three broad types of risk can be identified (General Civil Aviation Authority, 2015):

- Safety
- Security, including privacy
- Aircraft delays

Aircraft delays have an economic consequence to the airline, environmental consequences to the public through increased emissions and noise pollution, and consequences to passengers. The airline cost estimate for US aircrafts operating worldwide in 2014 was US$81 per aircraft per minute, though cost varies with aircraft type, whether the delayed aircraft is in flight, and other factors (Airlines For America, n.d.). Consequently, a delay of just ten minutes to a single aircraft can be more expensive than the retail price of a drone that caused the delay, and precautionary closure of a busy runway for an hour may collectively cost the airlines US$100 000. On the other hand, unwarranted legislation can lead to significant delays and cancellation of conservation work (Vincent, Werden, & Ditmer, 2015).

Safety and Aircraft Delays

Safety concerns include the risk of aerial collisions with piloted aircrafts, wildlife, and inanimate objects and collisions to ground level (Figure 2). Operation in the tightest airspaces can only be permissible when the safety record of a drone category is equal or superior to manned aerial vehicles (MAVs) (General Civil Aviation Authority, 2015). Commercial MAV accidents resulting in at least one fatality are 0.73 per million departures (Boeing, 2014), though accidents are far more frequent at civil air shows, with 31 crashes per 1000 shows, of which 16 involve fatalities (Ballard & Osorio, 2015). Operational reliability of a specific UAS can only be established once a large number of flights have been logged (Stevenson, O'Young, & Rolland, 2015). Therefore, this information is currently very limited due to continued innovation of products and the absence of a requirement for operators to keep log books of all flights. A 2003 study concluded that UAS accident rates were 100 times higher than those of MAVs (Rash, LeDuc, & Manning, 2006), but the study is dated, and safety will improve as the evolving technology builds greater redundancy into the systems (Haddal & Gertler, 2010).

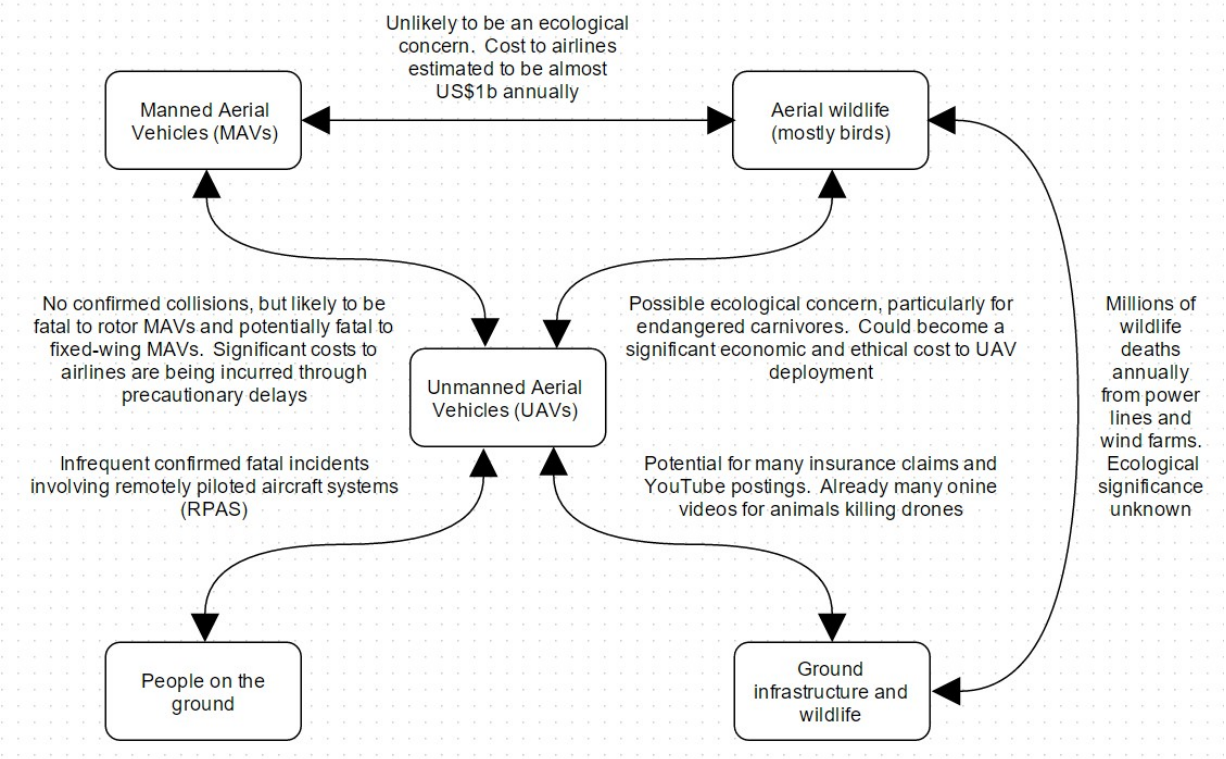


Figure 2: Safety concerns for UAVs separated by altitude and risk of fatality.

Since UAVs do not carry people, there is a strong argument that legislation developed for MAVs is unnecessarily restrictive, particularly in sparsely populated areas. The obvious testing ground for the technology is rural locations (Hinchliffe, 2015), where drone delivery systems can be improved and safety records established with minimal risk to human injury. Models for ground impact risk unfailingly include population density under the flight path (Weibel & Hansman, 2006; Wu & Clothier, 2012). The propellers of small (<5 kg) drones are capable of inflicting serious injury, while medium (5-25 kg) drones could potentially kill an inattentive operator or spectator. Medium sized remote controlled aircrafts caused the death of a 14 year old girl in the UK (Sapsted, 2003) and two spectators at a 2006 event in Hungary (Stevenson et al., 2015). Nevertheless, when the US Federal Aviation Administration offered to shortlist six locations for drone experimentation, it was flooded with applications (Mildenberg, 2013) that were then granted throughout 2014 (Federal Aviation Administration, n.d.).

Drone sightings reported by MAV pilots to the US Federal Aviation Administration have increased dramatically in 2015, averaging more than 100 sightings per month (Levin, 2015). An industry report on the potential damage of a collision between UAV and MAV predicted significant damage to a commercial airliner, and a rotor MAV would not survive (Smith & Main, 2015). Components of a drone are potentially more damaging than bird tissue. Wildlife collisions have destroyed 245 aircrafts and killed 258 people globally since 1988. In the US, there were 13,668 collisions reported during 2014, causing 172,000 hours of aircraft downtime and costing $208 million (Dolbeer, Wright, Weller, Anderson, & Begier, Michael J., 2015). With indirect costs added, the bill may be as high as $951 million (Smith & Main, 2015). However, FAA requirements that jet engines be tested for resilience to bird impact have not yet been extended to drones (Smith & Main, 2015). Drone manufacturer DJI has responded with geo-fencing software, whereby the drone will not cross a pre-programmed line delineating an airport or national border. Additions to DJI geo-fencing in

November 2015 enable models to even detect temporary no-fly zones, such as sporting events. NASA is developing an air traffic control system, whereby drones are fed information about the locations of other drones within the airspace.

Risk to wildlife is another matter, which may lead to a public backlash against UAS technology if not addressed. UAVs operate at an altitude that is more susceptible to wildlife collisions than commercial aircrafts (Lambertucci, Shepard, & Wilson, 2015). Most MAV collisions with birds occur below 150m altitude even though MAVs spend very little time in this altitude range and decrease proportionately with increasing altitude (Dolbeer, 2006). Ground-based objects, such as power lines and wind farms, cause the death of millions of birds annually (Martin, 2011) and have been publicly blamed for the decline of some species. However, the significance of collisions to wildlife populations and biological systems is poorly understood, requiring further research to understand how different species utilize three-dimensional space at the local scale (Dai, Bergot, Liang, Xiang, & Huang, 2015).

Research into sense-and-avoid technologies for use on small UAVs has been recently reviewed (Yu & Zhang, 2015). Currently, there are no solutions that combine the requirements of weight, reliability, and ability to function in a range of meteorological conditions, but research continues. Additionally, MAV sense-and-avoid systems must be updated to better detect smaller crafts (Chait, 2010). Systems that require UASs to broadcast their position, direction, and intention are somewhat promising but don't allow for avoidance of wildlife or ground objects. Software that enables multiple drones to coordinate their movements in-flight have been developed but require further improvement (Marques, Ribeiro, Pinto, Sousa, & Martins, 2015). An approach not covered in the review is to use memristors to mimic a biological neural network and thus "learn" to recognize classes of objects (Hambling, 2015). For MAVs, it is well recognized that human observation is a vital addition to automated sense-and-avoid systems (Yu & Zhang, 2015).

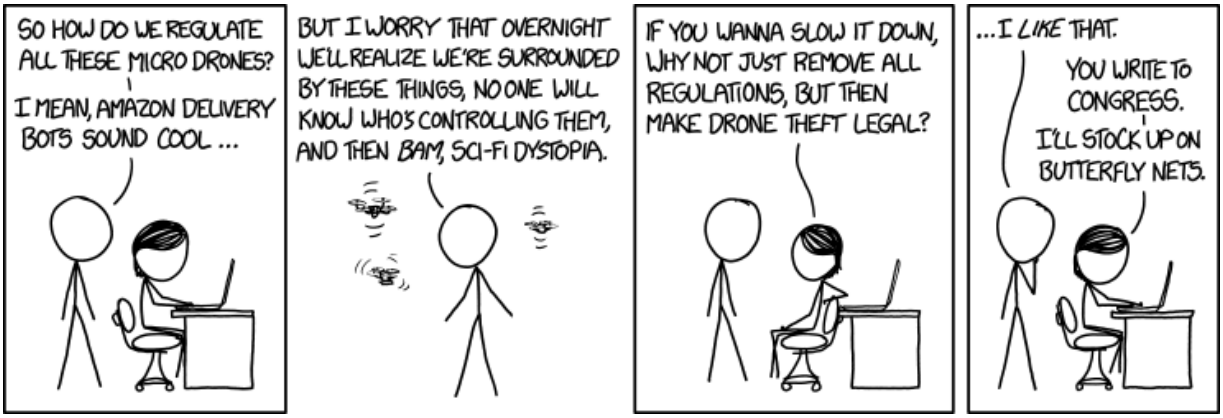
Security and Privacy

Security includes risks to the public, to commercial interests, and to national interests. A breach of security may involve a UAS being used for unlawful actions or may involve the illegal blocking or intercepting of signals between lawful UAVs and their ground controls. Of particular concern is the risk to privacy, particularly for camera-carrying UASs (currently the majority). There are still many gaps and uncertainties in the regulation of small drones, including micro-drones (Clarke & Bennett Moses, 2014).

Security

On August 25, 2010, the US Navy lost control of a UAV and could only intervene after it had flown 37 km toward, and then over, Washington DC airspace (Bumiller, 2010). On January 26, 2015, a DJI Phantom drone crashed into vegetation on the South Lawn. It was undetected by the White House radar system, which couldn't distinguish it from a bird, and Secret Service officers who heard it were unable to intervene before it crashed (Schmidt & Shear, 2015). Multiple other events have occurred near the White House, including two since then (CBS News, 2015; Schmidt, 2015). The incident prompted DJI to include the White House in its no-fly areas demarcated by the drone's GPS software, but this has two vulnerabilities: (1) that a drone be spoofed to enter a no-fly area and (2) that a drone be forced to land by spoofing it to think it's already in a no-fly area (Fox-Brewster, 2015)

Communications between civilian UAS components are typically unencrypted and therefore susceptible to jamming, hacking, and/or spoofing attacks (Rivera, Baykov, & Gu, 2014). By using a GPS spoofer, it is possible to change the location calculation of a UAV without any direct contact with a UAS component, thus making the UAV "believe" that it is at a different coordinate (Shepard, Bhatti, Humphreys, & Fansler, 2012). This threat could be mitigated by requiring that receivers are capable of recognizing and ignoring a spoofed signal, but such a fix would not replace existing receivers or prevent the manufacture of illegal receivers. Spoofing of drones has been demonstrated by industry, but not yet used maliciously.



http://xkcd.com/1523/

- In 2013 a security researcher modified a Parrot AR Drone 2 so that it could automatically detect and disconnect another UAV from its ground station, then reconnect it to an alternative ground station (Fincher, 2013). The researcher Samy Kamkar, a former hacker, managed this soon after Amazon announced plans to deliver parcels by drone.
- In 2015 a team at Chinese Internet security company Qihoo demonstrated spoofing of a DJI Phantom 3 using open source software (Fox-Brewster, 2015).

Several security breaches of military drones have been publicly discussed (Rivera et al., 2014).

Privacy

Governments are increasingly using UASs for civilian purposes, such as surveillance of borders and suspected crimes and criminals (Chait, 2010), and rescue missions (Karp & Pasztor, 2006). Photojournalists will increasingly use them to cover scenes that are otherwise difficult to capture, such as protests and natural disasters (Jarvis, 2014). There is potential conflict with the US Constitution's Fourth Amendment and to the United Nations' Article 12 of the Universal Declaration of Human Rights. For higher altitude UASs, these conflicts are an extension of those already discussed for satellite information, but low-altitude UASs are more akin to paparazzi. Privacy is a fundamental human right, but definitions of this right are vague (Volovelsky, 2014). Public concern for domestic surveillance is muted due to familiarity with pre-existing helicopter and satellite surveillance (Greenwald, 2013) and to widespread acceptance of security cameras (Jarvis, 2014). Parliamentary concerns regarding Amazon's Prime Air announcement were of excessive surveillance, including for commercial purposes i.e., "checking out a person's patio to see if that individual needs new patio furniture from the company" (Horsey, 2013). However, any legal restrictions to protect privacy will also limit freedom of speech and freedom to gather legal information (Kaminski, 2013). Until recently, civilian drone use in the US was not restricted by privacy laws but instead by the Federal Aviation Administration (Calo, 2011). During 2013, eight US states enacted drone surveillance legislation and another 34 states introduced bills and resolutions (Farber, 2014).

Conclusion

Drones have the potential to be used for an enormous range of applications, many of which involve urban settings. A wide range of sensors, improvements in data post-processing, and continuing evolution of the drones themselves are expanding the potential uses. However, the risks to safety, security, and privacy remain significant and often underappreciated. Security and privacy issues are solvable, though they may take time and result in increased take-off weight; but protecting the safety of people, infrastructure, and wildlife is likely to curtail the range of permitted uses for some time.

Low risk urban applications include monitoring that involves vertical flight only or flights over unpopulated areas such as water bodies or

steep slopes. Other applications may be better performed by an alternative platform. Satellite data is improving but is still limited by cost, convenience, and resolution. Internet of Things is a technology still in its infancy with the advantage that data collection is continuous. It is preferable for any application that requires frequently repeated measurements from a location that is proximal to existing infrastructure, whether the infrastructure is fixed or mobile. This includes most air quality and some maintenance applications.

Applications involving remote sensing may shift to higher altitude drones, which can be larger and thus carry more safety and security features. These drones are likely to become a permanent platform above cities, providing a range of data services that can be disseminated appropriately.

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