

Remote Sensing and Assessment of Urban Forests with Unmanned Aerial Vehicles

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The two main types of UAVs in 2016, rotor-wing (photo courtesy author) and fixed-wing (courtesy PrecisionHawk).

Municipal arboriculture will soon have an important new tool as Unmanned Aerial Vehicles (UAVs, also Remotely Piloted Aircraft/RPAs, drones) take to the skies. This article will briefly explain how UAVs can be used for remote sensing of urban forests for risk assessment, visual inspections, pest detection, inventory data enhancement, and rapid response after disasters, among other tasks.

Introduction

The UAV revolution is here. UAVs are increasingly being used to inspect wind turbines, communication towers, utility and pipeline corridors, and other infrastructure. UAVs are often faster and safer than human inspection. One climber can inspect three or four wind turbines a day, but a UAV can inspect two turbines an hour, at a fraction of the cost, at no risk to human safety. Fortunately for municipal forestry, UAVs are increasingly being used for agricultural imaging and spray operations, which directly transfer to urban forestry. Arborists are in the early stages of UAV adoption at this time.

Today, there are two main types of UAV aircraft: fixed-wing and rotor-wing (photo above). Fixed-wing aircraft often resemble larger piloted aircraft, but also can look like flying wings. Fixed-wing aircraft generally have the longest flight times and thus cover more ground. A mission of 45-60 minutes per battery is

typical. Rotor-wing aircraft are commonly configured with four, six, or eight rotors. Rotor-wing aircraft can hover in place and are preferred for many types of infrastructure inspection as well as imagery and cinematography. A mission of 20 minutes per battery is typical. A third type of aircraft that flies as a fixed wing but has vertical takeoff and landing (VTOL) capabilities was recently introduced and soon should be familiar to many foresters.

The limiting factor for all three types of aircraft is current battery technology that restricts flight times. New developments in batteries and fuels that promise to significantly increase flight times from minutes to hours are being watched closely by the UAV industry.

The UAV revolution is made possible by several intersecting factors. Computing power is no longer an obstacle, allowing collection and processing of vast amounts of data (the entire process is often called "Big Data"). Materials technology allows lighter, stronger airframes and components. Optics and sensors get more sophisticated and accurate, smaller, and less expensive every year. Lastly, electronic components are undergoing rapid miniaturization and UAV componentry is currently near the cutting edge of the technology.

Lastly, almost all UAVs have advanced electronics such as Global Positioning Systems (GPS) that allow precisely pro-

grammed and guided autonomous missions and accurate measurements, communications that transmit accurate telemetry and data to a receiver, and gyroscopes that stabilize the aircraft. In addition, electronics that transmit a UAV's position and locate other aircraft are in final testing now; several countries and companies are testing a UAV air traffic control system to make skies safer. All these factors are expected to continue to make UAVs and associated systems continue to rapidly improve over the next few years.

The UAV revolution is proceeding at an unprecedented pace. This advancement comes at a good time for the urban forestry and arboriculture professions—the need for rapid pest detection, accurate inventories, and low-cost inspections continues to grow and UAVs can be an excellent tool for savvy municipal foresters and arborists.

Why UAVs for Municipal Forestry and Arboriculture?

The main benefits that UAVs bring to municipal forestry and arboriculture are rapid deployment, cost, flexibility, and image resolution.

Rapid deployment is a benefit for several aspects of municipal forestry and arboriculture, notably disaster response, assessments, inspections, and pest monitoring. As long as a UAV's batteries are charged, it typically can be airborne and collecting data or circling a tree in just a few minutes. Initial response

to disasters can be aided by the bird's-eye view from a UAV. For example, in October 2015 a passenger train derailed near Northfield, Vermont, and researchers from the nearby University of Vermont were on scene with a UAV in less than two hours. They took and processed hundreds of images, providing a valuable geo-referenced set of data for first responders in just hours¹.

Some assessments of the mission costs of UAVs vs manned aircraft find that UAV costs are anywhere from 40-70% less than other operations². A recent case study in Australia of tree canopy inspections that compared UAVs vs bucket trucks³ found UAVs could assess up to 12 trees an hour for about US\$30 per tree, as compared to about US\$125 per tree using a bucket truck. Currently, however, in the agriculture industry there is a limit to the cost-effectiveness of UAVs due to short battery life—a recent case study⁴ found that piloted aircraft had a better return on investment for missions over about 20 hectares (50 acres) compared to satellites and UAVs.

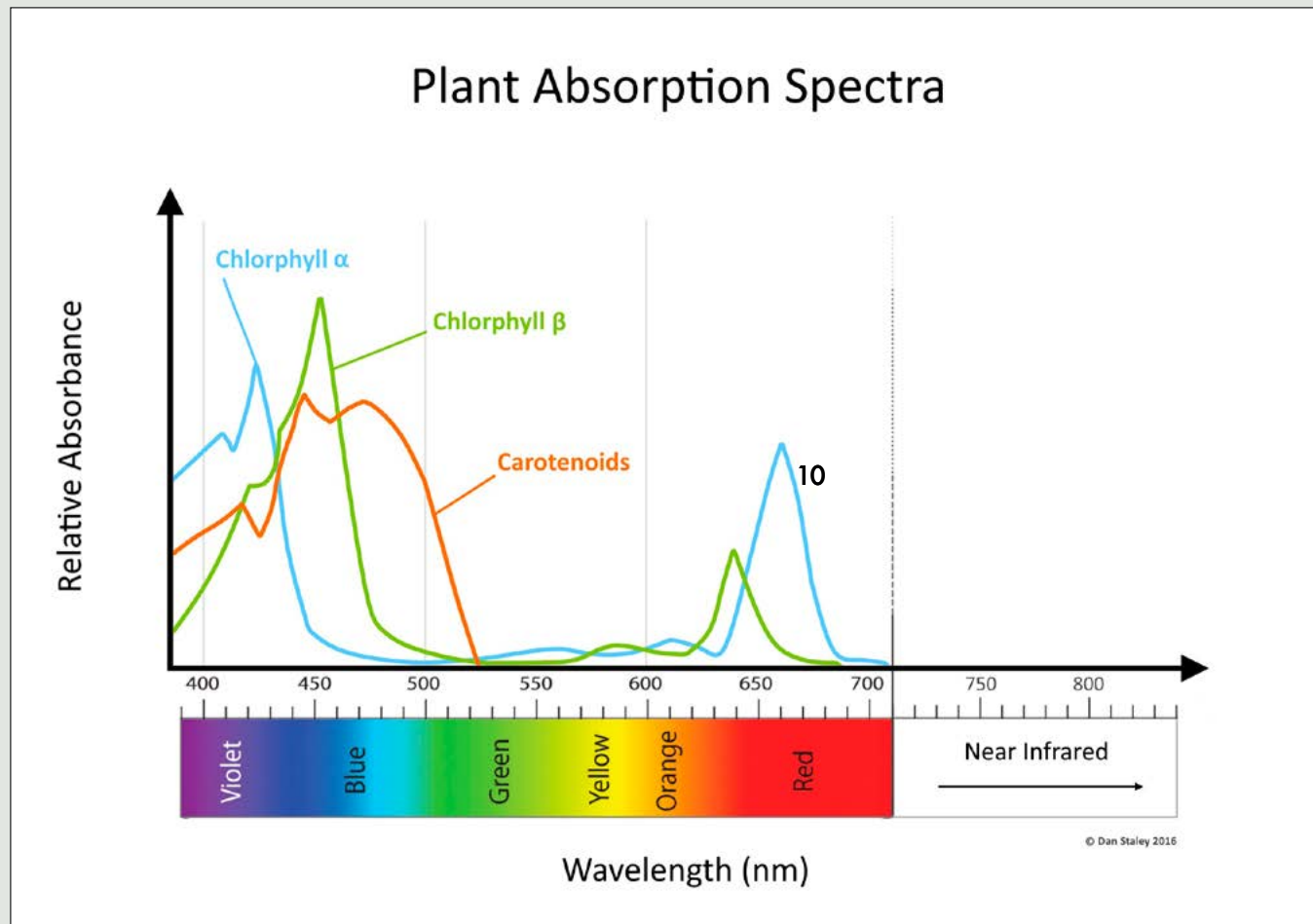
Flexibility is a key component to UAV remote sensing and assessment. Satellites and manned aircraft can be stymied by clouds, but UAVs can fly under most cloud decks, provided other weather is not limiting. The ability for immediate feedback based on in-flight data from UAV missions also allows the operator to easily choose a new course or change sensors if needed. There is



Typical view from a drone during visual inspection. Courtesy Bryan Archer, Galaxy UAV Systems

Why collect data in visual and non-visual EM spectra? Calculating the amount of leaf reflectance both in and outside the visual spectrum allows for analyses using a Vegetation Index (VI)—a mathematical analysis of EM spectral bands to highlight and visualize certain features of plants. For example, general health, photosynthetic activity,

vigor, water stress, overall biomass, and leaf senescence can be determined using the proper VI. The most commonly used VI in agriculture and environmental management is the Normalized Difference Vegetation Index (NDVI). Plant species often can be determined by their reflectance in specific wavelengths if the image resolution is sufficient.



Plants utilize more of certain wavelengths of light. Courtesy Dan Staley

minimal cost to delay (or move up) a UAV mission as well.

UAVs can fly closer to the ground than piloted aircraft, resulting in better image resolution—a key benefit when accuracy is essential. Typical sensor imagery from a UAV flying at 100 meters (330 feet) above ground level (AGL) is from 3-5 centimeters (1.5-3 inches) per pixel side at ground level (the "Ground Sample Distance" or GSD)—smaller than many deciduous tree leaves. A typical manned aircraft image taken from 450 meter (1500 feet) AGL typically has a GSD of about 6-20 centimeters (2.5-8 inches) per pixel⁵. High-quality satellite imagery typically has a GSD resolution of 30-50 centimeters (12-20 inches), considerably larger than a typical deciduous leaf.

What Data Can Be Collected with a UAV?

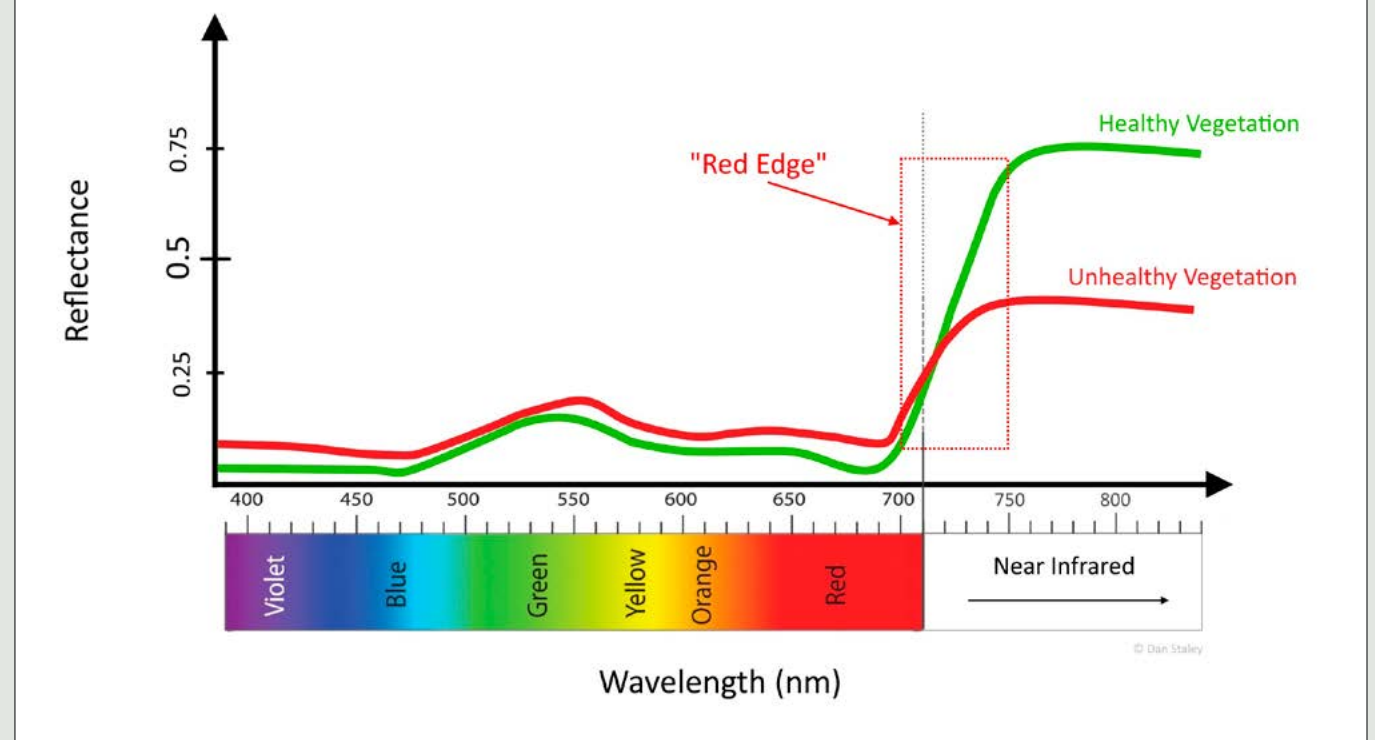
The miniaturization of everything is driving the decreasing size, weight, and cost of sensors, making sophisticated sensors

increasingly available to more users as prices fall. The most common sensor types carried by UAVs are visual, thermal infrared, multispectral, hyperspectral, and LiDAR.

Visual sensors—including video—are by far the most common payload carried by UAVs. Most quality UAV models come equipped with high-definition visual sensors. The real estate, construction, film, and infrastructure inspection industries are the main users of UAV visual imagery. Urban foresters and arborists likely will use visual imagery for most operations. Current standard visual sensors capture high-definition 4K images at 16 MB per image, with video at 1080p and frame rates at 30-60 frames per second.

Thermal infrared (IR) sensors carried on UAVs are most commonly used for infrastructure inspection—tiny cracks in wind turbine blades and faulty cells in photovoltaic panels are easily seen in the infrared. The United States Golf Association has started

Reflectance Spectrum of a Typical Green Leaf



Depiction of the "Red Edge" on the reflectance spectrum of a typical leaf. Courtesy Dan Staley

using thermal IR sensors on UAVs to study turfgrass health. Several manufacturers offer after-market IR sensors, with current typical costs ranging from about US\$2,500-10,000.

Multispectral sensors collect light in both the visual and near-infrared (NIR) electromagnetic (EM) spectra. The agriculture industry is by far the main user of multispectral imagery. Most multispectral sensor models collect four or five discrete, narrow bands of light per pixel; these bands coincide with wavelengths important to assess plant condition (Figure page 20). Most models collect one band each of red, green, and blue, plus one band in the NIR. Some models collect an extra band on the "red edge"⁶ (Figure above). In 2016, a typical new multispectral sensor costs between about US\$3,500-7,000.

Hyperspectral sensors collect all wavelengths in the EM spectrum between certain set values determined by the manufacturer. For example, one sensor model may collect wavelengths between 400-1,100 nanometers (nm), another between 400-2,500 nm. Each pixel in an image contains all wavelengths of light between the two set values. As a result, large amounts of data are contained in just one image. The sheer amount of data allows for a much more detailed analysis to be performed. Due to their current cost, hyperspectral sensors are not yet widespread and are mainly used by the mining and environmental monitoring industries. Currently, a typical new hyperspectral sensor for a UAV payload starts at about US\$45,000 and can

cost much more depending on additional features.

LiDAR is a remote sensing platform that uses pulses of laser light to precisely measure surfaces or objects. LiDAR can—depending upon how many points per unit area are collected—measure objects with accuracy measured in millimeters. LiDAR is used by the surveying, construction, energy, and infrastructure industries and is becoming relatively more common as prices fall. Typical LiDAR sensors are still heavy enough (many are over 5kg/11 lbs) that specialized UAVs must be used to fly LiDAR missions, although weight is dropping rapidly. In 2016, a new LiDAR sensor for a UAV payload can start at about US\$85,000 and can cost much more depending on weight, measurement accuracy, and other such features.

How Can UAVs be Used in Municipal Forestry & Arboriculture?

UAVs can be effectively used for a number of municipal forestry and arboriculture tasks, and it is important to know what type of work you are going to do with UAVs before making a decision to purchase equipment or hire a pilot to fly missions. It is also important to determine how you can share your data across departments for cost-sharing opportunities, or how to leverage the large amount of data you will collect but may not need, such as road surface or street furniture data.

Rotor-wing UAVs are best used for smaller-scale projects, in strong wind, for hovering and close inspection of trees, or to set

throwlines in large trees or palms. Fixed-wing UAVs are best used for large-scale projects of many acres/hectares, missions with multiple sensors, or long stretches of flight over road centerlines.

It is essential to know what kind of imagery you require. Why? Visual imagery can be processed by staff. Any other sensor data collected is measured in tens of gigabytes and must be processed by specialized software run on powerful computers. Such analysis is likely beyond the capabilities of most municipalities but is easily performed by any number of Big Data service companies. Data service companies are proliferating rapidly as the market for data analysis grows. There is likely a suitable company within an easy drive of many readers, but most business can be transacted over the Internet so proximity is not the most important factor in choosing a company. Consider choosing a data company that can deliver flexible product output based on *your* needs, rather than a seemingly lower-cost mass-market data service company offering a focused, limited set of products (“data in a box”).

Visual sensors can be used for risk assessment, inventories, disaster response, construction and permit monitoring, creating Digital Elevation Models, for crew safety assessment and monitoring, social media images, and education, among other tasks.

Thermal IR sensors can be used to monitor turf irrigation efficiency and to locate irrigation leaks, assess plant water stress, and assist in public safety and building efficiency analyses (for example, of heat loss from buildings and cooling from tree shade). There is some evidence thermal IR sensors can detect cavities in individual trees as well⁷.

Multi- and hyperspectral sensors can be used for assessing plant and forest health, early detection and monitoring of pest outbreaks, supplementing inventories, and monitoring seasonal progress of pests such as elm leaf beetle. Identifying tree species and locating invasive plant species or species of concern are also possible with these sensors.

LiDAR can be used to precisely measure tree canopies to monitor growth and change over time and to precisely measure any urban object such as signage or street lights—often at millimeter scale.

UAVs will soon be used to supplement inventories because individual tree canopy delineation is now easily performed by software algorithms using data collected in the IR spectrum. Some arborists are already using rotor-wing UAVs to rapidly set throwlines, especially for very large trees and palms.

Perhaps most importantly, early detection and monitoring of urban forest outbreaks of pests such as emerald ash borer, oak wilt, ash decline, and others will soon be performed using UAVs carrying multi- or hyperspectral sensors. Municipal foresters will rapidly and flexibly collect data with UAVs to set baselines of public forest health and to detect change over time. UAVs will aid in timely and flexible management action on pest outbreaks, pruning cycles, and drought stress, among other concerns.

Missions can be flown manually or be fully automated. Standardized, replicable flight plans will be easy to set, as a

mission plotted over road centerlines is all that is needed to monitor public trees in the right of way. Several brands of software exist today that can automate any conceivable municipal forest flight plan, and any flight plan can be saved to re-fly in the future to replicate past missions for consistency.

Lastly, flights at an elevation of 100 meters (328 feet) AGL will not only capture all public trees in rights of way but also vegetation extending to about 45 meters (148 feet) from a road centerline, providing urban forest managers additional data for management purposes if desired.

Legal Considerations

Because of the wide disparity between civil aviation authorities in different countries, space restrictions mean that this article cannot discuss UAV laws in detail. Readers should research both the national laws of their country as well as any local laws that may prevent flights for municipal forestry operations. Several countries do allow commercial UAV operations within their borders, but it is important to realize most countries’ civil aviation authorities are struggling to maintain safe airspaces while incorporating UAV technology. The speed of technological change is running far ahead of any government’s ability to react appropriately.

Privacy may or may not be addressed by civil aviation authorities. For example, in the United States, the Federal Aviation Administration has remained silent regarding privacy and aviation laws for UAVs and instead left decisions to the civil courts. Regardless of where you live, all commercial UAV pilots must adhere to existing law as well as make operational judgments about flying if neighbors express concern about their privacy. Always err on the side of caution where privacy is concerned, and even if the law is on your side, have a plan to cease operation if privacy concerns arise. It is better in the long run to be safe and respectful than to cause a conflict. 🌿

¹ Greenwood, F. 2015. [How Vermont Used Drones After a Train Derailment](#). *Slate* October 9, 2015.

² For example, see Mailey, C. 2013. [Are UAS More Cost-Effective Than Manned Flights?](#) *Association of Unmanned Vehicle Systems International Hampton Roads Chapter Newsletter*, October 24, 2013.

³ Moore, G.M. 2016. Drones Will Be Arboricultural Busy Bees. *Arborist News* 25:1 pp. 32-35.

⁴ See, for example, a Switzerland-based drone analytics case study, [Price Wars: Counting the Costs of Drones, Planes, and Satellites](#).

⁵ For example, a comparative analysis of remote sensing platforms in citrus orchards found UAVs had much better resolution than piloted aircraft: Sankaran et al. 2013. Huanglongbing (Citrus Greening) Detection Using Visible, Near Infrared and Thermal Imaging Techniques. *Sensors (Basel)*. 13:2 pp. 2117-2130.

⁶ A region in the electromagnetic spectrum occurring at about 705 nanometers (nm)—the region where there is a sudden change in the reflectance of vegetation, due to the fact that plants absorb and use visible light for metabolism, but use very little infrared light and so it is reflected, unused.

⁷ Catena, A. and Catena, G. 2008. [Overview of Thermal Imaging for Tree Assessment](#). *Arboricultural Journal* 30, pp 259-270.