Unmanned Aerial Vehicles (UAVs) for Documenting and Interpreting Historical Archaeological Sites: Part I—Attack of the Drones

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ABSTRACT

Unmanned aerial vehicles (UAVs), or "drones" as they have come to be known, are now widely popular in many countries around the world. The newest versions are affordable, easily controlled, and can provide a very useful platform for aerial imagery, videography, and photogrammetry at archaeological sites. They have particularly useful applications at historical sites with standing architecture or surface features, and can help reveal structural layouts and details not visible from the ground. Part I of this discussion covers how to get started with a UAV for archaeology, the legal issues, the nature and costs of the equipment, flight control, and the pitfalls to be avoided. Part II will cover the primary applications for archaeology (particularly historical archaeology), some of the important attributes of digital cameras, aerial imaging, and postprocessing of such data, and the potential future applications of UAV-based techniques.

Introduction

Major news outlets recently broke the story that on 26 January of this year a drone crashed on the White House lawn (Cowan 2015). This reportedly resulted from a night of heavy drinking by a government employee who happened to own a DJI® Phantom unmanned aerial vehicle (UAV) and was attempting to impress a woman (Meyer 2015). Despite the primarily amorous intent, this "attack of the drones" was a catalyst for turning the media eye toward the increasingly popular hobby of flying UAVs and using them for a wide range of activities across not just the United States, but many other parts of the world.

A UAV refers to any aerial vehicle that is unpiloted or piloted remotely, according to the International Civil Aviation Organization (ICAO 2006). They may also go by the acronyms RPA (remotely piloted aircraft) or UAS (unmanned aerial system). In the case of military UAVs, they are controlled by remote pilots through secure satellite connections or ground stations. Commercial or non-military UAVs are usually operated via a radio controller (RC) or a Wi-Fi connection. But they may also be entirely autonomous and preprogrammed prior to take off, or use sensors to guide their flight by onboard or remote computer. Their primary application in recreational, commercial, or research settings has been in their ability to provide high quality, low altitude aerial imagery and videography. There are some commercial applications in which they are being used to deliver goods, but weight restrictions and battery life make that very limited for the time being. Their use within archaeology typically falls within the definition of remote sensing.

Types of UAVs

Fixed-wing UAVs refer to remotely piloted lifting body aircraft widely used in military applications; they have been around (without the weaponry) as hobbyist RC aircraft for many years. The newest craze, however, is primarily about rotational motor craft: quadcopters, hexacopters, and octocopters (4, 6, and 8 rotors, respectively). These vehicles maintain very stable flight by computerized control of pairs of rotors turning in opposite directions. In this sense they differ from RC helicopters, which have one horizontal rotor for lift and one vertical rotor for directional control and stability. Of these multirotor aircraft, octocopters provide the greatest amount of lifting power and are typically used in the television and film industries for acquiring high quality video of sporting or news events. They are probably also the most stable platforms, but tend to be quite large and expensive—on the order of $2,500 and up for a basic model. In contrast you can find quadcopter UAVs priced anywhere from $50 to $2,000, depending on their size, power, and capabilities. Hexacopters tend to fall in between price-wise (often from $1,000 to $3,000) and are a good compromise between lifting power and stability. Microdrones (almost always quadcopters) may be as small as large insects (also called nanodrones) and can mount chip-based high-resolution electronic cameras. The disadvantage is that they lack power, stability, operational distance, and are subject to the slightest breezes. The smallest are mainly suitable only for the indoors where they can be controlled by digital sensors to produce some amazing synchronized choreography (e.g., KMel Robotics 2012).

Larger RC or Wi-Fi piloted quadcopters can be quite useful for flight training as they tend to be light, responsive, and surprisingly durable when crashed (because if you have one, you will crash it many times). They, too, are affected by moderately strong wind conditions and typically lack a global positioning system's (GPS) navigational control to correct for drift. Some have built-in imagery and video capabilities, but they tend to be lower resolution than mountable digital cameras. Moving up to a hexacopter or octocopter is a strategy that should occur only after having a range of flight experiences with a quadcopter as the equipment becomes progressively more expensive.

Flight Restrictions

A number of countries around the world are currently reexamining some of their regulations concerning the recreational and commercial use of UAVs. Archaeology as a discipline, along with other research applications, unfortunately falls into somewhat of a gray area regarding their use. Most researchers who have been employing them on projects consider that they fall under the category of recreational use, or what is sometimes referred to as the model aircraft designation.

By strict definition in most countries, any use of a UAV for which one is being compensated monetarily or in-kind constitutes a commercial endeavor. Technically, for an archaeological project then, one should use them only in cases where it is clear that no compensation is being offered. A cultural heritage application would typically fall under a commercial operation, unless the use of the UAV functions entirely as a donated service. In a research application, use of a UAV is recreational if governmental or university funding did not pay for it. But it is generally accepted in most countries that, as long as safety regulations are being met, even governmental or grant-sponsored drone equipment can be operated without a commercial license on a research project. New regulations underway in the United States, Australia, and the United Kingdom should clarify this.

As most legislation in these three countries stands today, you should have a commercial UAV operator's license or some other form of governmental permission if the device is not being used for recreational purposes. Even when the case can be made for a noncommercial use, there are still flight and operational restrictions on all UAVs. Figure 1 summarizes the nature of operational restrictions for UAVs in the United States, Australia, and the United Kingdom. Enforcement rarely occurs outside of urban areas, but you should always check with your local community, state, or federal guidelines before you take off. This maxim also applies to transporting UAV equipment on airlines. Always check with the airlines and customs or security to be sure you are complying with all regulations. You do not want to have your expensive equipment confiscated.

Getting Started with a UAV

There are a wide range of UAVs available on the market, both fully assembled and ones that come unassembled. This discussion will focus on one example and provide insight into the author's experiences with it. Figure 2 shows the current UAV configuration that the author uses for aerial imagery at historical archaeological sites; it consists of three primary components: the UAV itself, the RC controller, and the camera assembly. In this case, the UAV is a DJI F550 hexacopter. It is manufactured in China and comes as a kit (DJI, Inc. 2015).

Since the F550 (also known as the Flame Wheel) comes as a kit, it is not preassembled (Figure 3). If you purchase a kit UAV—from nearly any manufacturer—then you have to be prepared to assemble it with little or no instruction, and you need to be relatively competent with understanding electrical connections and soldering. There are numerous videos available online (at YouTube® for example) of others building nearly any kind of UAV kit out there. You must be aware, however, that the provided components, such as the motors as well as the navigational and controller units, change frequently, and any given video may be out of date regarding the way in which connections are made or parts calibrated. Get advice from your local hobby shop or someone with experience.

Country	Oversight Authority	Documents	Type	Restrictions				
				Weight	License: Recreational	License: Commercial	Height	People
United States	Federal Aviation Authority (FAA)	14 CFR Part 91—FAA-2014-0396: Interpretation of the Special Rule for Model Aircraft	Small	< 25 kg (55 lbs.)	No	Yes	< 120 m (400 ft.)	unspec. dist.—not "near" or "above"
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				unspec. dist.—not "near" or "above"	not within 8 km (5 mi.) unless approved	unaided visual line of sight (VLOS)	Local laws and ordinances	not in or near stadiums
			Large	Weight	License: Recreational	License: Commercial	Height	People
				> 25 kg (55 lbs.)	Yes	Yes	proposed upper limit: 5486 m (18,000 ft.)	unspec. dist.—not "near" or "above"
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				unspec. dist.—not "near" or "above"	not within 8 km (5 mi.) unless approved	equipment dependent	Local laws and ordinances	special exemptions required
	For More Information: https://www.faa.gov/uas/model_aircraft/ http://knowbeforeyoufly.org/for-recreational-users/ https://www.faa.gov/uas/media/model_aircraft_spec_rule.pdf https://www.faa.gov/uas/publications/model_aircraft_operators/							
Australia	Civil Aviation Safety Authority (CASA)	CASR (Civil Aviation Safety Regulation) Part 101, Advisory Circulars (AC101-1,4-10), CASR Part 102 is expected in 2016	Micro	Weight	License: Recreational	License: Commercial	Height	People
				< 2 kg (4 lbs.)	No	Currently: Yes Proposed (2016): No	< 120 m (400 ft.): controlled airspace only	not within 30 m
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				not within 30 m	not within 5.5 km (3.4 mi.) unless approved	VLOS, daytime only	not where a reasonable expectation of privacy exists	not within 30 m of private property unless approved
			Small	Weight	License: Recreational	License: Commercial	Height	People
				> 2 kg and < 100 kg (4–220 lbs.)	No	Yes	< 120 m (400 ft.): controlled airspace only	not within 30 m
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				not within 30 m	not within 5.5 km (3.4 mi.) unless approved	VLOS, and daytime only unless approved	not where a reasonable expectation of privacy exists	not within 30 m of private property unless approved
			Large	Weight	License: Recreational	License: Commercial	Height	People
				> 100 kg (220 lbs.)	Yes	Yes	< 120 m (400 ft.): controlled airspace only	not within 30 m
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				not within 30 m	not within 5.5 km (3.4 mi.) unless approved	VLOS, and daytime only unless approved	not where a reasonable expectation of privacy exists	not within 30 m of private property unless approved
	For More Information: http://www.casa.gov.au/scripts/nc.dll?WCMS:STANDARD::pc=PC_100376 http://www.casa.gov.au/wcmswr/_assets/main/newrules/ops/nprm/nprm1309os.pdf http://www.rpastraining.com.au/casr-101-uav-drone-legal-or-illegal http://www.gizmodo.com.au/2014/10/what-are-the-rules-about-operating-a-drone-in-australia/							
United Kingdom	Civil Aviation Authority (CAA)	CAP 722: Unmanned Aircraft System Operations in UK Airspace—Guidance; CAP 658: Model Aircraft: A Guide to Safe Flying	Micro	Weight	License: Recreational	License: Commercial	Height	People
				< 7 kg (14.5 lbs.)	No	Yes	< 120 m (400 ft.): controlled airspace only	> 50 m or > 30 m at take-off and landing
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				> 50 m or > 30 m at take-off and landing	not within an Aerodrome Traffic Zone (ATZ) without permission	VLOS: < 500 m (1640 ft.) horizontally, < 120 m (400 ft.) vertically	Local laws and ordinances, > 150 m away from congested areas or open-air assemblies of 1000+ people	not allowed to drop any object or animal from an RPA at any altitude
			Small	Weight	License: Recreational	License: Commercial	Height	People
				> 7 kg and < 20 kg (14.5–44 lbs.)	No	Yes	< 120 m (400 ft.): controlled airspace only	> 50 m or > 30 m at take-off and landing
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				> 50 m or > 30 m at take-off and landing	not within an ATZ without permission	VLOS: < 500 m (1640 ft.) horizontally, < 120 m (400 ft.) vertically	Local laws and ordinances, > 150 m away from congested areas or open-air assemblies of 1000+ people	not allowed to drop any object or animal from an RPA at any altitude
			Large	Weight	License: Recreational	License: Commercial	Height	People
				> 20 kg and < 150 kg (44-330 lbs.)	No, but exemption from CAA is req.	Yes	< 120 m (400 ft.): controlled airspace only	> 50 m or > 30 m at take-off and landing
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				> 50 m or > 30 m at take-off and landing	not within an ATZ without permission	VLOS: < 500 m (1640 ft.) horizontally, < 120 m (400 ft.) vertically	Local laws and ordinances, > 150 m away from congested areas or open air assemblies of 1000+ people	not allowed to drop any object or animal from an RPA at any altitude
			V. Large	Weight	License: Recreational	License: Commercial	Height	People
				> 150 kg (330 lbs.)	Yes	Yes	Conventional aircraft restrictions apply	
				Buildings / Utilities	Airport / Aircraft	Visual Flight	Privacy	Other
				Conventional aircraft restrictions apply				
	For More Information: http://www.caa.co.uk/docs/33/CAP722.pdf http://www.caa.co.uk/docs/33/CAP658%204%20Edition%20Amend%201%20June%202013.pdf http://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=5631 http://droneflight.co.uk/pages/summary-of-uk-legal-requirements							

Figure 1. UAV operation regulations and restrictions in the United States, Australia, and the United Kingdom. (Graphic by author, 2015.)

Figure 2. Example UAV configuration. (Photo by author, 2015.)

Figure 3. DJI F550 kit and tools used for assembly. (Photo by author, 2014.)

Power Supply

Almost all larger UAVs are powered by three- to six-cell lithium ion polymer (LiPo) batteries. If your UAV is preassembled it may already come with the proper LiPo battery, but this may not always be the case. Either way, you will want to purchase several extra batteries because even the most powerful batteries rarely provide more than about 15 minutes of flying time, and most take 30–45 minutes, minimum, to charge. Small UAVs may already come with the correct battery chargers, and microdrones may be small enough to derive power from nickel-metal hydride, silver-oxide, or even alkaline batteries. If you build your UAV from a kit, then you may need to seek advice about the proper battery size and you may have to solder the battery connectors in yourself. All LiPo batteries require special chargers as they are very volatile and if not properly balanced can explode. This is why you are not allowed to check them in your luggage on most airlines and must carry them in your hand baggage. In any case, it is necessary to be familiar with the nature of LiPo batteries, their use, charging, and storage.

Piloting the UAV

The F550 hexacopter provides a lifting capacity of about 2 kg (4.4 lbs.) and can easily carry the battery as well as the mounted camera and gimbal assembly (Figure 4). Most quadcopters have a more limited lifting capacity of 1 kg (2.2 lbs.) or less. The F550 has enough power to remain stable in steady winds of more than 25 mph (40 kmph), but gusty winds can play havoc on your ability to control it even at lower speeds. Unlike the larger hexacopters or octocopters, most quadcopters should not be flown in winds exceeding 15 mph (24 kmph).

Figure 4. GoPro Hero 3+ camera and Walkera two-axis gimbal. (Photo by author, 2015.)

The F550 uses an onboard DJI Naza-M V2 flight computer to control each of the six rotors, send power to any auxiliary devices (such as the camera gimbal), maintain the GPS connection, and automatically take over and land the UAV if radio contact is lost. The flight controller is programmed through a USB connection with a laptop computer and its proprietary software (DJI Naza-M Assistant 2.2). You can set the flight options, calibrate the RC controls, and test for proper settings/conditions without taking off. The flight return mode can switch between an option to immediately land if the radio signal is lost, or to return to the point of departure at a certain flying height (such as 20+ m to avoid trees). You also can set the intelligent orientation control (IOC) that determines the UAV flight direction with respect to your ground location.

The RC controller is a Futaba® 14SG, 14-Channel 2.4GHz device (Figure 5). It has a maximum range of around 2 km, which is farther away than you can maintain visual contact in most conditions. Some UAVs are controlled through a Wi-Fi connection and proprietary apps that can be loaded onto smartphones or tablets. In those cases, the operational distance may be less than 100 m without a Wi-Fi booster. Some UAVs may be preprogrammed to remain stable and level in the air until a Wi-Fi connection is reestablished, in which case you may need to get under it as soon as possible to reconnect, or it may drift off with the wind. Some Wi-Fi connected UAVs are programmed to land immediately if the connection is lost.

The RC controller needs to be programmed with the specifications of the UAV for which it is going to be linked, and a radio receiver is mounted to the UAV and plugged into the flight controller. This means you can use the same controller for multiple UAVs by creating programs for each and moving the receiver between them, or linking to multiple receivers. The controller can be programmed in almost any configuration, but the normal setup is that the right control stick operates the forward/backward flight (pitch) along the Y axis and left/right flight (roll) with the X axis. The left control stick increases/decreases thrust (elevation) along the Y axis, and left/right rotation (yaw) on the X axis. Some preassembled UAVs have their own RC controller, which cannot be used on other UAVs. You must always be aware of the battery level of your RC controller as well as the LiPo on board the UAV. The RC controller needs to be fully charged or you may still lose the radio connection.

Onboard Camera

The camera assembly here is a GoPro® Hero Silver 3+ mounted on a Walkera® two-axis brushless gimbal. The GoPro allows a maximum video resolution of 4K (3840 × 2160 pixels or 8.29 megapixels). This translates to an image size of 32.5 × 18.3 cm (12.8 × 7.2 in.) at 300 dots per inch (dpi), and an aspect ratio of 16:9 (HDTV). The maximum frame rate at that resolution is 30 frames per second. At a lower resolution of 1080p (standard HDTV: 1920 × 1080 pixels or 2.07 megapixels) the image size is 16.3 × 9.1 cm (6.4 × 3.6 in.) at 300 dpi, the aspect ratio is 16:9, and the maximum frame rate is 60 frames per second. For still imagery, the maximum resolution is 12 megapixels (4200 × 2800 pixels: an actual megapixel value of 11.76) at an image size of 35.6 × 23.7 cm (14 × 9.3 in) at 300 dpi and an aspect ratio of 3:2 (Cinema). It can take image bursts of between 3–30 images per second.

The GoPro camera stores the video and imagery on a micro SD (11 × 15 mm) high capacity (SDHC) 32 gigabyte card. It connects with the computer by a USB cable that allows the user to download the video/imagery as well as charge the camera. Video with a GoPro includes audio, but built-in camera UAVs often do not have an audio track on the video. Video format for the GoPro is .mp4 (MPEG-4), while built-in cameras may use .wmv (Windows media video) or .avi (audio video interleave). For most settings the options also include wide angle, medium, or narrow fields of view. See Part II of this discussion for details on imagery and video formats.

While the UAV is in flight you can connect to the GoPro via Wi-Fi, view the live image, and control the imagery options via the downloaded GoPro app on either your tablet or smartphone. The author has found the connection to have a slight lag and it is lost when more than about 100 m away. With some RC controllers, however, you can piggyback the Wi-Fi connection on the radio signal (with the right equipment) and therefore extend that distance. If your UAV has a built-in forward-facing camera, then the Wi-Fi connection may provide live video through the flight control app as well. This is known as first person view (FPV). Flying the UAV by FPV via either the flight control or GoPro apps on a smartphone or tablet is extremely difficult and is a learned technical ability (or the job of a second person). There are now headsets available for connecting with and operating many UAVs through FPV.

The gimbal is a device that keeps the camera level along two or three axes. Two-axis gimbals correct for pitch and roll, while a three-axis gimbal also corrects for yaw. As you are flying the UAV, you often make rapid changes in pitch, roll, or yaw, and these effects prevent you from getting clear and precise imagery and video. The gimbal uses an electrically powered gyroscope to control either actuators or brushless motors and maintain the same position set during the take off. Actuators tend to stop and start, make an electronic noise, and cause a vibration separate from the UAV rotors. Brushless motors are quieter and, when working properly, very smooth. You set the default pitch or roll attitude of the gimbal prior to take off (if you want to look down at a 45° angle for instance). If programmed into the RC controller, you might also control the pitch and roll of the gimbal independently from the flight itself using separate switches.

A proper gimbal will provide some vibration dampening from the flight rotors. A common occurrence with multirotor video is a phenomenon known as rolling shutter (also called jello or jelly). This is caused by the shutter speed being slightly ahead or behind the rotational speed of the rotors, and the vibration being transferred through the body of the UAV as the camera is recording the pixel lines. It causes a ripple effect seen in the video. This can sometimes be corrected in postprocessing, but rarely can be eliminated entirely. UAVs with built-in cameras suffer dramatically from this effect. The only real solution is to dampen the mounting points where the gimbal or fixed camera assembly touches the frame. Gimbals usually have soft rubber dampeners, but you can also space the mounting screws/brackets with a soft flexible material like Moongel® (RTOM, Inc. 2015), which is used for percussion instruments.

Part II of this discussion addresses the nature of aerial imagery, postprocessing, and other applications for historical archaeology.

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