Canadian Archaeological Association
Association canadienne d'archéologie

Drones (Unmanned Aerial Vehicles – UAVs)

Recommended Data Collection Procedures for Locating Unmarked Graves

Introduction

'Drones', also known as Unmanned Aerial Vehicles (UAVs) or RPASs (Remotely Piloted Aerial Systems), are useful for aerial mapping of Canadian 'Indian Residential School' (IRS) cemeteries and unmarked graves. Rotary-wing UAVs offer the greatest utility because they are more maneuverable in flight. This includes smaller four blade quadcopters designed for consumer use, as well as larger and more sophisticated six or eight blade machines intended for professional applications.

Lower cost UAVs are usually equipped with built-in cameras, while professional-grade machines can interchangeably mount cameras or thermal, multi-spectral and laser sensors ('Light Detection and Ranging' or LiDAR). Thermal sensors detect surface temperature differences while multi-spectral (or hyperspectral) sensors measure differential patterns of plant growth/health and soil moisture. Under the right conditions these sensors may enable detection of unmarked graves.

Aerial LiDAR systems send laser pulses downwards to measure distance to the ground. The sensor measures the time taken for millions of points of laser light to leave the UAV, strike the surface below, and then return. This three-dimensional information forms dense 'point clouds' that precisely define the surface (vegetation cover and the ground beneath). Ground surface points can be sufficiently dense to reveal low mounds or shallow depressions formed by graves. Lower cost UAVs equipped with conventional cameras can also generate useful photogrammetric output as illustrated with the examples below. This software uses the images to produce photomosaics (produced from overlapping photos) and digital elevation models (DEMs). Under certain conditions these DEMs can reveal subtle elevation changes such as those caused by graves. These geographically referenced images can be further analyzed using Geographic Information Systems (GIS) software (see the GIS document in this series).

Most UAVs are equipped with sensors that enable safe and stable flight. They are controlled through two-way radio communication between the aircraft and the ground controller. The latter is usually paired with a tablet or cell phone to provide telemetry information and the UAV camera view. Many UAVs can also be programmed to fly in grid patterns while automatically collecting overlapping photographs (Figure 1). UAV flights require appropriate site preparation and an understanding of data precision and accuracy required to achieve the research objectives. Such mapping projects also require licensed pilots and trained crews who follow federal government regulations that are designed to protect people, property and other aircraft.

1) Planning

Flight planning is dependent on mapping objectives, site extent, vegetation cover and airspace status. Let us assume the use of a rotary-wing quadcopter equipped with a conventional camera flying in unregulated airspace. To collect imagery suitable for photogrammetric processing, the UAV should be flown along transects at a standard height and speed (Figure 1). Photographs are taken along these transects at intervals that allow standardized overlap between adjacent images. This is difficult to achieve using manual flight, but semi-autonomous flight planning software greatly improves efficiency and output quality.

Such software is installed on the tablet used in conjunction with the aircraft controller. Using an internet connection, maps (often Google Earth) provide geographic context to identify the flight area. After assigning the flight elevation, degree of image overlap and flight speed, the planning software automatically establishes flight transect lines (Figure 1). The completed plan is saved for upload to the UAV at flight initiation, whereupon it will automatically take off, complete the flight transects and return to the landing zone. However, the pilot can regain manual aircraft control at any time. The optimal flight elevation is dependent upon the image resolution sought, the coverage area, and in consideration of objects that might be hazardous to the UAV. Selecting flight elevation reflects a balance of considerations. Lower elevation flights generate high resolution images but require more photographs to achieve the required coverage. Higher elevation flights require fewer photographs, but at the expense of image resolution. Depending upon the camera used, a flight elevation of 40 metres will provide ground image resolution of about 1.5 cm per pixel, while offering a reasonable degree of flight efficiency and safety.

Electrically powered UAVs usually offer between 20 and 30 minutes of flight time per battery. Since battery life varies with air temperature, wind velocity and battery age, it is prudent to limit flights to no more than 80% of estimated battery duration. The efficiency of semi-autonomous flight planning software can enable flights over smaller areas using only one battery. For example, an area of about 1.5 hectares (15,000 m^2) flown at 40 m elevation at a speed of 2.4 m/second (with 85% overlap between images) will collect about 260 images within a 15-minute flight (one battery). The resolution of such imagery will vary depending upon the camera used. The 260 images in this example flight would require about 2.18 gigabytes on the micro-SD card installed on the UAV. When mapping larger areas, semi-autonomous flight planning software can accommodate multi-battery operations.

2) Site Preparation

Vegetation cover upon the survey area may be problematic for effective aerial mapping. If it is overgrown with forest, shrubs or tall grass, photogrammetric processing will not be fully effective. Topographic mapping may require systematic vegetation removal to expose the ground surface – something that might also be required before using ground penetrating radar, electrical conductivity/resistance, or magnetometer devices. This ground preparation requires considerably more time and effort than the actual UAV mapping flight.

UAV missions require a pilot and observers. The pilot controls the aircraft, while the observers monitor the UAV and alert the pilot about approaching aircraft and other hazards. Preflight planning also includes determination of airspace status over the survey area and gaining appropriate approval if the planned flight occurs in controlled airspace. Pre-flight preparation also involves consideration of weather, wind and lighting conditions, and condition of the UAV hardware and firmware, etc. This might also include establishment of scales and reference makers with known geographic coordinates (Ground Control Points or GCPs).

3) Flying Regulations

In Canada, UAV flights are governed by regulations and licensing administered by Transport Canada. UAVs must be registered, and pilots must be licensed to a level appropriate for the airspace conditions over the survey area. This is mindful of the potential hazards associated with UAV flight.

4) Maximizing map precision and accuracy

Most UAVs are equipped with sophisticated instruments to ease flying and to reduce crash risk. This includes a Global Navigation Satellite System (GNSS), barometric altimeter, compass, collision avoidance sensors and a gimbal to reduce image motion distortion. UAVs are controlled through two-way radio communication between the aircraft and the ground controller. The controller is linked to a tablet or cell phone that provides telemetry information and the UAV camera view. Most UAVs are equipped with GNSS capable of $^{\pm}$2-5 m. accuracy, and with a barometric altimeter that can be affected by varying atmospheric pressure and elevation. This introduces some degree of imprecision into the output from mapping flights. Repeated test flights reveal georeferencing (X Y) results to within about 1.5 metres, but the elevation models reveal even greater variation between flights over the same area. This reflects the technical limitations of consumer-grade UAVs. For some purposes this level of accuracy might be sufficient, but if the UAV mapping output is to be integrated with other georeferenced data this imprecision might be problematic. It can be addressed in two ways: 1) use of professional grade UAVs equipped with better quality GNSS receivers capable of differential correction; or 2) establishment of Ground Control Points (GCPs) prior to the UAV flight, each with accurately determined geographic positions. The more accurate GCP coordinates can then be used to refine the photogrammetric output. In some circumstances this will render results to accuracy within a few centimetres. This high level of precision and accuracy may be important when attempting to integrate diverse spatially registered data within GIS software.

5) Photogrammetry and data analysis using GIS

A UAV mapping flight might yield hundreds of overlapping images that can be integrated for more detailed analysis using photogrammetry software. Such software identifies common points in overlapping photographs and uses them to re-orient, warp and mosaic the images together. The output includes a large-scale aerial photograph that is geo-referenced in cartesian space. Digital Elevation Models (DEMs) derive from calculation of the elevation of common points viewed from different perspectives in the overlapping images. These XYZ points form a dense point cloud that are then interpolated to produce the DEM.

Since these maps are georeferenced, they can be uploaded into Geographic Information Systems (GIS) software to undertake further spatial analysis. They can be transformed into different cartesian grid systems, integrated with other suitably georeferenced map data (i.e. the output from GPR survey), and subjected to further analysis. For example, the DEM can be colourized to visually represent subtle relief, or subjected to contouring functions. Such digital processing and analysis offer a time-efficient means of extracting analytic meaning from the collected data.

6) Examples of UAV output

Two UAV flights are included here to illustrate the utility of conventional aerial photography. The first is a 2016 flight over the Cecilia Jeffery Residential School cemetery area near Kenora, Ontario as an informal early test of drone mapping for IRS cemetery investigation. The second is a 2021 flight over a late 19th and early 20th century cemetery at Bingwi Neyaashi Anishinaabek (BNA) First Nation near Lake Nipigon, Ontario. Permission to use the latter output was granted by BNA First Nation.

The Cecilia Jeffery Residential School first opened at Shoal Lake, Ontario (1902–1929), whereupon it was moved to Round Lake near Kenora (1929–1974). Three burial places are reported near Round Lake (Figure 2). The burials at the oldest location were exhumed in 1952 to permit road construction and were reburied in a new cemetery area south of Round Lake. The oldest of the two cemeteries south of Round Lake is within a narrow strip of forested land, with the most recent within a nearby rectangular fenced clearing that is currently overgrown with tall grass (Figure 2). While the ground surface is obscured by vegetation, the UAV flight generates a much higher image resolution map than the conventional satellite image and permits better detection and interpretation of surface conditions. For example, a detail of the UAV imagery reveals a few white-painted wood crosses protruding from the tall grass within the most recent cemetery. With careful removal of this vegetation, other cemetery details might become apparent.

The oldest known cemetery at BNA First Nation likely dates to the late 1800s, prior to the 1950s eviction of the community from leased land containing their reserve to make way for a provincial park. The community requested mapping in the spring of 2021 and granted permission for the output to be used here. Since the community's recent reclamation of their reserve lands, the historic cemeteries have been carefully maintained within fenced clearings. While most of the wooden crosses have long decayed and disappeared, surface irregularities suggest the distribution of old graves (Figure 3). These collapsed grave shafts are hinted at with differential vegetation growth within the photo mosaic. When the digital elevation model is enhanced using colour and finely spaced contour lines (2.5 cm), these grave shafts are more readily apparent.

UAV mapping flights can yield high-resolution photographic and topographic survey maps. If accurately geo-referenced, they can be used as base maps to overlay similarly geo-referenced output from other remote sensing methods such as Ground Penetrating Radar. This facilitates exploration of how each data type supports (or challenges) the insight gained from other methods. This multiple method approach serves to strengthen and refine interpretations about the landscape and inform decisions about future investigative steps.

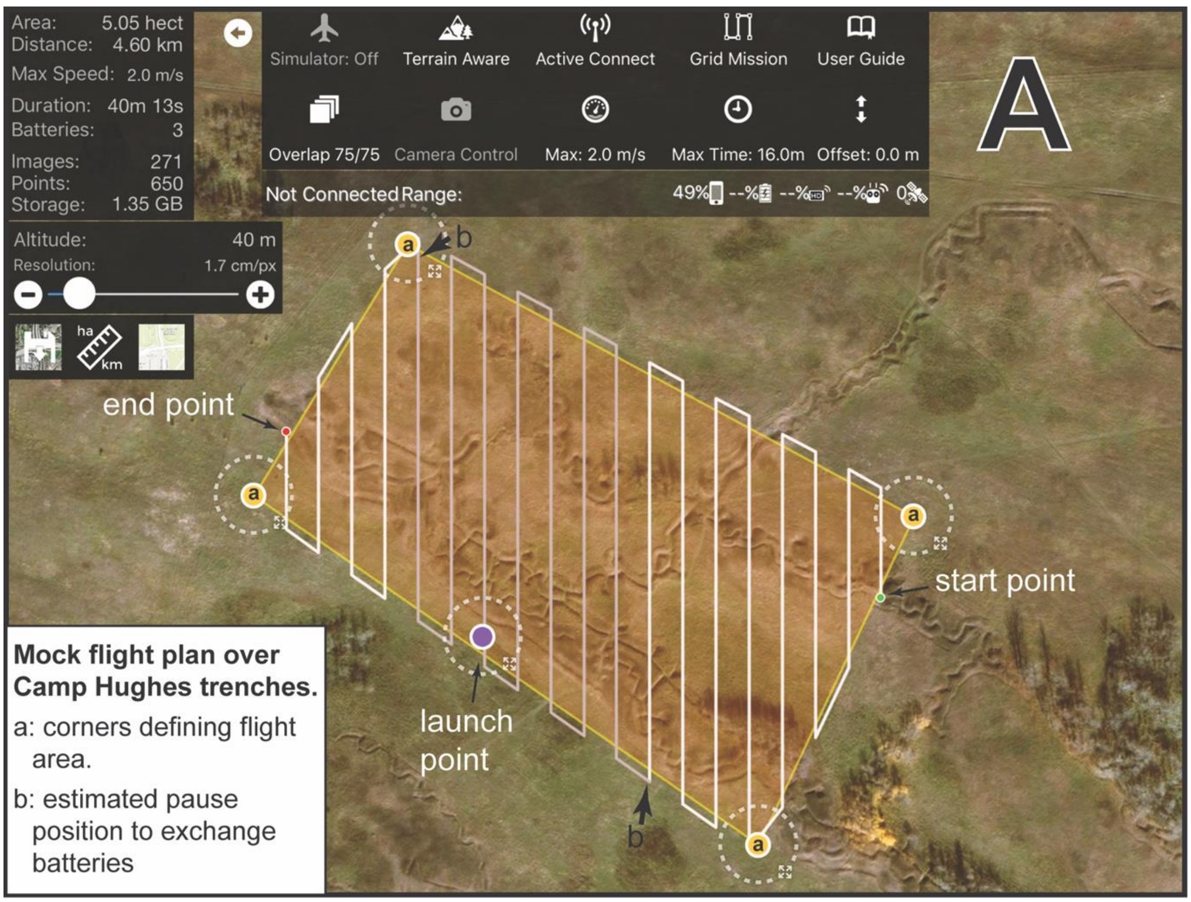

Figure 1. Mock semi-autonomous UAV flight plan over former military training trenches at Camp Hughes, Manitoba. The flight parameters are selected during planning and are saved for later execution. Once launched, the UAV will follow these flight lines at the specified elevation and speed, automatically taking pictures to achieve the desired image overlap.

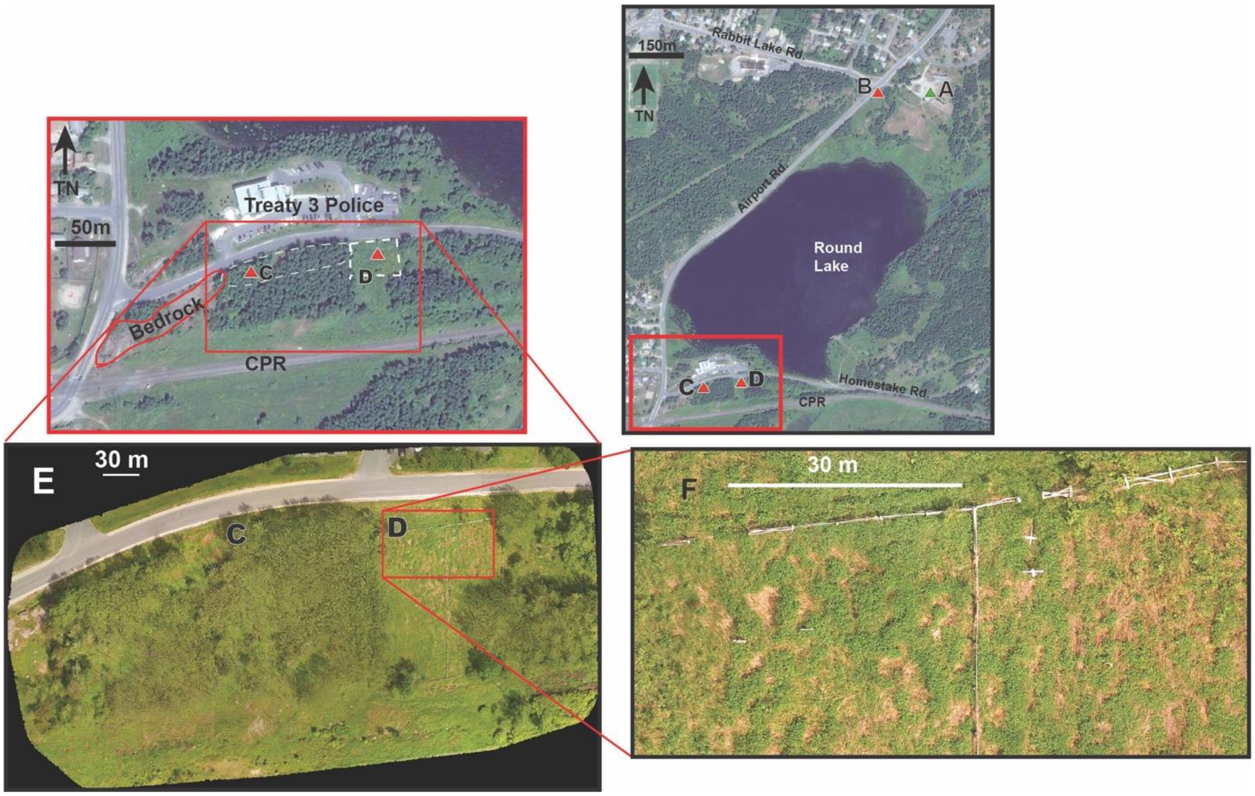

Figure 2. Aerial documentation of the cemeteries reported at Cecilia Jeffery IRS in Kenora, Ontario. The upper two images are Google Earth satellite images, with modest image resolution that becomes increasingly blurry as one zooms in. The lower two images derive from a UAV flight at 40 m elevation. While the ground detail is obscured by vegetation, the much higher image resolution allows detection of ground features of analytic interest.

A Cecilia Jeffery IRS (approx.)
B Six graves exhumed in ca. 1952
C Old Cemetery
D New Cemetery

The two most recent burial areas at Cecilia Jeffery IRS are located at the south end of Round Lake. The oldest is within a deciduous woodlot at the west end of the UAV photomosaic image (**E**). Detail photo **F** illustrates a portion of the most recent cemetery within a fence and marked with a few crosses that protrude through the tall grass.

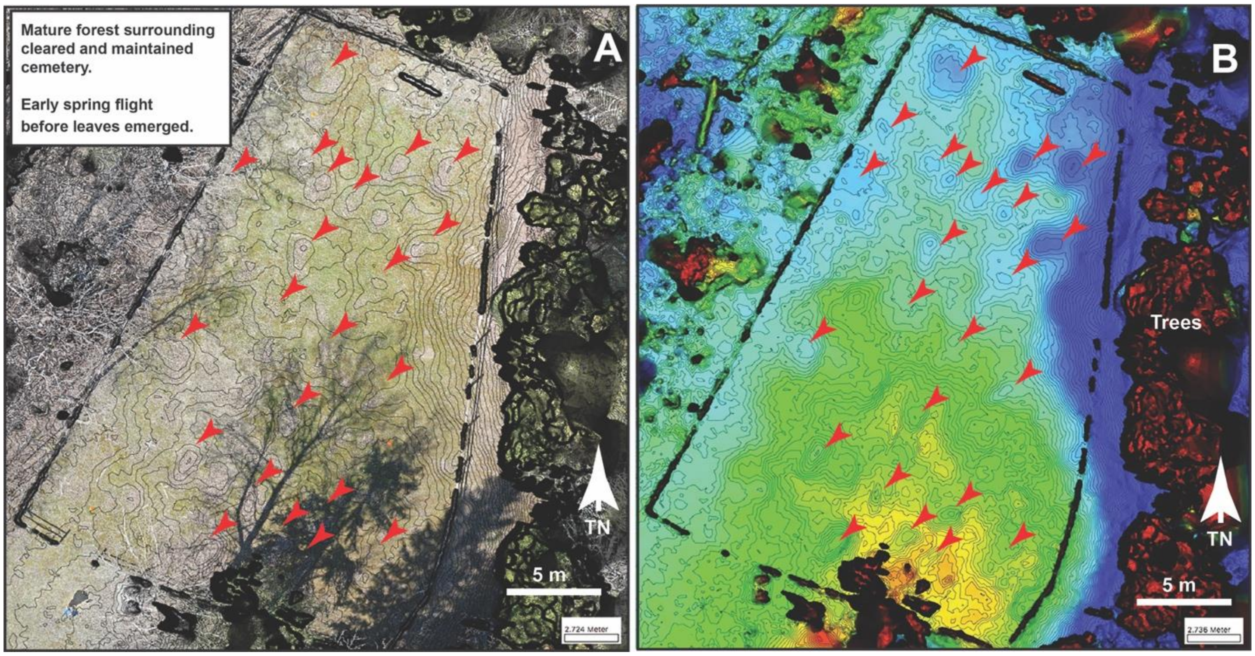

Figure 3. UAV photogrammetric output of a historic cemetery at Bingwi Neyaashi Anishinaabek First Nation (Sand Point FN), Lake Nipigon, Ontario (with permission of BNA FN). This cemetery lay abandoned for over 50 years after the community was evicted to make way for a provincial park. It is now maintained with regular grass cutting, making grave depressions visible even though most of the wood crosses have disintegrated. Image A is the photomosaic overlaid with contour lines deriving from image analysis within GIS software. Image B is the elevation model with the 'heat map' colourized to emphasize the relief change of interest across the surface of the cemetery area. Blue represents low areas while yellow/orange defines high areas. Extreme highs and lows are uniformly shaded red or blue respectively. GIS software is used to generate finely spaced contour lines to emphasize subtle ground undulations that represent collapsed graves for which the wood grave markers have long disappeared.

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