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THE APPLICATION OF LOW-ALTITUDE NEAR-INFRARED AERIAL PHOTOGRAPHY FOR DETECTING CLANDESTINE BURIALS USING A UAV AND LOW-COST UNMODIFIED DIGITAL CAMERA

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Highlights

- Low-cost UAVs establish new concept for clandestine burial identification.
- NIR photos display better contrast between disturbed and non-disturbed soil.
- Non-intrusive techniques for clandestine burial identification.
- Limitations with low-cost cameras in image acquisition.
- Camera quality and modification produce better results.

Abstract: Aerial photography and remote sensing has been carried out in the past by numerous different platforms, utilizing imaging from across the electromagnetic (EM) spectrum to gain information about the earth. These techniques have additionally been found effective when locating mass graves and single clandestine graves created by perpetrators when concealing homicide victims. Applications for performing aerial photography and remote sensing are costly and therefore usually overlooked by police investigators, resulting in employing more contemporary geophysical methods for locating burials. Recent advances in technology however have seen the development of small Unmanned Aerial Vehicles (UAVs) for aerial photography which can be executed at lowaltitude and controlled remotely from the surface. This development has introduced low-cost approaches in detecting surface features, commonly utilised in the archaeological field for its accuracy in detecting anomalies, particularly when using near-infrared (NIR) photography. NIR aerial images have been shown to expose cropmarks of historical value which are unnoticeable in conventional colour photography, deriving from the visual area of the EM spectrum. However, little attempt has been made to investigate the practice of

NIR photography to detect clandestine graves using low-cost aerial platforms in the form of UAVs. This paper considers adopting a low-cost and non-invasive approach to detect clandestine graves through the implementation of a small UAV and an unmodified GoPro camera fixed with a near-infrared filter. The results presented here have recognised real-time suitability for using UAVs as an aerial photographic platform in the forensic archaeological field as well as noting the advantage of NIR photography as an ongoing technique for discriminating recent graves from their surroundings.

Keywords: Near-Infrared; Aerial Photography; UAV; Clandestine Grave

1. Introduction

Unmanned aerial vehicles (UAVs), or 'drones' have brought about significant increases in low-cost, close range possibilities for aerial photography and remote sensing, compared with more traditional aerial platforms used for image acquisition; such as using manned aerial vehicles (MAVs) or satellites[1,2]. Originally used for military purposes, the capability of using smaller UAVs mounted with Digital Still Cameras (DSCs) for capturing high resolution digital images has recently expanded amongst civilian use for recreational and commercial purposes, allowing photography to be remotely controlled from the ground surface [3–5]. UAV and remote sensing platforms for obtaining aerial imagery have therefore been increasingly used in various fields such as archaeology and by environmental agencies for purposes of gathering information about the surface when detecting, interpreting and measuring environmental features and anomalies [3,5–7]. However, there are areas where UAVs have not currently been fully exploited such as in the detection of anomalies which are of forensic and police interest. Nonetheless, recent research by Urbanová et al [2] has demonstrated the convenient use of UAV photography as professional investigative equipment for documenting outdoor crime scenes and surface evidence. Identifying soil disturbances on the other hand where anomalies are more inconspicuous is new to research involving UAV execution.

Clandestine burials created by perpetrators to conceal the human remains of their homicide victims are of great interest for research in the forensic archaeological field since where a body is unable to be found, prosecutorial efforts are hindered and remains cannot to be returned to the victims' families [8,9]. Some of the visual characteristics defining clandestine graves are commonly identified by; signs of spoil heap/depression measuring one-by-two metres; having anomalous vegetation growth patterns; animal scavenging, and possible covering using certain materials to erase suspicion [8–10]. Forensic and archaeological experts will therefore use a range of techniques across a variety of disciplines including geophysical methods, aerial photography, and canine units as a first step to locate these hidden burials so that recovery teams can be organised for the exhumation and identification of human remains [8,11–16].

Early work by France et al. [10] explores the usefulness of employing aerial photography as an effective method of delineating grave sites by identifying anomalous vegetation growth patterns and soil disturbances associated with excavation boundaries. Additionally, research by Kalacska and Bell [17], Kalacska et al [11] and [18] investigated the use of hyperspectral imaging for the detection of single and mass graves by identifying the in-situ spectral differences between grave and non-grave areas. These studies indicated that fly-over and satellite hyperspectral imaging can be an effective and non-intrusive tool implemented in the detection of clandestine graves, utilizing bands from across the electromagnetic (EM) spectrum. However, remote sensing and aerial photography have been considered as relatively high-cost and unpractised, resulting in more experienced geophysical techniques being executed; such as ground-penetrating radar (GPR), magnetometers and electrical resistivity [10,19–22]. These useful methods in the detection of clandestine graves are considered as relatively non-destructive, however the precise location of graves usually requiring this method additionally requires the operational expert’s presence on the site which could possibly damage unseen surface evidence and, in some situations, put personnel at high risk [17,23]. Aerial photography using UAVs and digital still cameras (DSCs) on the other hand offer non-intrusive and non-destructive advantages [23,24] and additionally offer an inexpensive solution to more traditional aerial platforms.

Conventional DSCs used in aerial photography are primarily designed to capture images in the visual colour wavelength (400-750nm) region of the EM spectrum, presented similarly to how the human eye perceives light. However, digital camera sensors (usually complementary metal-oxide semiconductor or charged-coupled device) have the advantage of being made of silicon (Si) and having a high sensitivity to near-infrared (NIR) light (750-1100nm), therefore allowing NIR images to be acquired from across the visible and NIR spectrum (450-1100nm) [25]. Infrared wavelengths can be seen to take up a larger area than the visible wavelengths but both range across a very small portion of the entire EM spectrum (Figure 1). NIR imaging is commonly confused with thermal imaging which operates in longer infrared wavelengths approximately between 8000-12000nm (8-12µm). This area makes use of an effect where surfaces and objects radiate different amounts of infrared light with the notion that where certain objects are warmer, they will therefore shine brighter in this spectrum and on thermal images [26]. Whereas, NIR photography captures reflected NIR radiation emitted by very hot objects (ie. the Sun) rather than recording object temperatures [25]. This type of reflected radiation is therefore usually captured to obtain images that are invisible to the human eye. Conventional DSC manufacturers usually apply blocking filters (hot-mirrors) to absorb and/or reflect these waves that pass the lens to allow light primarily from the visual region to reach the sensor, given why we see colour images in conventional photography [25,27–29]. Therefore, to obtain NIR images, these NIR blocking filters are usually removed by modifying cameras to allow light from across the visual and NIR spectrum to reach the sensor. It is not completely necessary to remove the NIR blocking filter to capture NIR images in some DSCs since a percentage of NIR light will transmit through the blocking filter, however results can be unpredictable [25,30]. Verhoeven [25] presents the beneficial application of using modified DSCs for NIR aerial photography in the archaeological field for identifying anomalous crop marks and features which are less noticeable in conventional colour photography. This is due to the differences in reflection/absorption of visual and NIR light from common surface materials (i.e. vegetation, soil, water).

The reflectance of green vegetation in the visible and near-infrared spectrums are relatively well known [24]. Environmental studies have established that the amount of photosynthetic tissue within plant species is a major factor in determining reflectance in the infrared region [31]. Green and near-infrared light is found to be a nonessential

component for photosynthesis in growing vegetation, given why humans view green vegetation in this colour (see Gates et al., 1965; Kalacska and Bell, 2006; Knipling, 1970). Therefore, a strong reflection from healthy vegetation also appears very bright within the NIR region, whereas stressed, diseased or non-photosynthetically active vegetation appears darkened with less NIR reflectance, presenting contrast between disturbed and non-disturbed vegetation to appear from this waveband [25]. The spectral characteristics of soil on the other hand have a very different reaction when reflecting NIR light. Soil reflectivity is difficult to determine due to significant variation from contrasting soil chemical and physical properties, such as organic matter, colour, vegetation cover, air, and water [24,33–36]. Soil is generally less reflective of NIR light where high moisture levels are present since it largely absorbs incident NIR, explaining why water has almost no reflection in NIR images appearing very dark [25]. This can be useful when distinguishing disturbed soil characterising clandestine graves from non-grave areas since redeposited spoil is inevitably more prone to moisture infiltration [8]. Buried remains have also been shown to have a considerable effect on the physical and chemical characteristics of soil fill overlaying deceased individuals due to depth and drainage variations [37]. Figure 2 depicts the [9,24,34–36] reflectance of the visual (0.45-0.75μm) and near-infrared (0.75-1.1 μm) EM radiation from different surface elements (healthy vegetation, dry vegetation, soil). Therefore, the NIR reflectance differences in healthy green vegetation, stressed vegetation and soil marks may be of benefit when attempting to locate areas of disturbed soil commonly characterising clandestine graves.

By using a low-cost UAV mounted with an unmodified low-cost GoPro camera with an adaption for acquiring near-infrared aerial photography, the purpose of this research is to implement a similar approach conducted by [25] but with the intent to locate graves rather than historical features. This is in an attempt to determine low-cost and nonintrusive alternatives of identifying clandestine graves compared to more contemporary methods. The purpose is then to compare conventional colour images with NIR images acquired from the same GoPro camera.

2. Methodology

2.1. Study Area

Given that it was not possible to study authentic clandestine graves, a burial area with similar characteristics was therefore chosen for the experiment. However, commercial cemetery burials have characteristics that differ greatly from illegal burials (headstones, body embalmment, common human presence) and therefore a natural burial ground was selected as a suitable alternative to conduct the study. Natural burial grounds are areas for human remains to be buried which seek to minimise environmental impact and to preserve or create habitats for wildlife [38]. This differs from conventional burials since headstones, plaques or other memorialisation features are not usually presented or permitted on many natural burial grounds within the UK [39].

The selected natural burial ground for the study is located within a Community Interest Company (CIC) named 'Westmill Woodland Burial Ground' in the bordered county of Oxfordshire/Wiltshire, England (Figure 3). The location is preserved as a natural burial ground at an elevation of c.100m above sea level (Grid Reference SU 23681 90895). The fielded ecosystem is managed for wildlife and natural burials with diminutive human presence other than during funeral ceremonies and for maintenance purposes. The burial ground comprises 138 individuals buried between 2000 and July 2017 in separate single graves, and either placed within willow, wooden or cardboard coffins, or shrouded in other biodegradable material. The soil profile in the area is identified as being a loamy texture with lime-rich over chalk or limestone [41].

2.2. Surveying Method for In Situ *Coordinates*

On the 23rd May 2017, surveying of the burial ground site began by determining the location of each grave based on visual characteristics from ground level through an intrusive walk-over technique. A Trimble GeoXH handheld unit (Trimble Navigation) was used to map the site perimeter and generate georeferenced grave area datasets. The Trimble GeoXH uses global navigation satellite system (GNSS) to maintain high accuracy geographical positioning system (GPS) data. Georeference location data was gathered from certain chosen area boundaries which contained known graves within the site. These are namely; Area 1, Area 2, Area 3, Area 4, Area 5, and Area 6. GPS data was then taken from the four corners of each located grave (disturbed areas of soil/vegetation) to map the specific location and number of all conspicuous graves. A total of 55 burials were located by visual means (excavational boundaries, partial vegetation regeneration). Some of the graves created prior to 2012 had been fully covered with regenerative vegetation to such an extent that visual detection was not possible. Survey data was then subject to differential correction during postprocessing and placed within OS mapping data downloaded through Digimap Edina ordnance survey collection. The areas of known graves located by intrusive means and recorded by GPS can be seen in Figure 4.

2.3. *UAV platform and DSC Image Acquisition*

The UAV platform used in the execution of airborne flight was a DJI Phantom 1 model with the Naza-M flight control transmitter (Figure 5a). The standard empty weight of this model

(excluding battery and propellers) is c.600g with max payload of c.365g being able to take a reasonable weight. Two batteries were used for the study, therefore each flight session allowed two flights to be executed (one with colour photography and other with the NIR filter adapted to the camera). The Phantom drone can fly up to 120m altitude under current flight legislation laws (July 2017) but for image acquisition, an altitude range of between 10-40 metres was applied. The specifications of the
Phantom UAV are shown in Table 1.

The GoPro Hero 3 (White Edition) camera was fixed to the UAV and used to acquire images in both the visual and NIR. To acquire NIR imagery using this camera, a *Zomei* NIR filter was purchased to transmit wavelengths of 850nm and is adaptable to the outer lens of the GoPro. This sports action camera contains a Sony IMX 117 complementary metal-oxide semiconductor (CMOS) sensor which captures images at 5 megapixels (2560 x 1920) in JPG format. The internal framework and capture settings are incapable of being modified without risking the quality of the camera, therefore the IR-blocking filter (hot-mirror) was not removed and the automatic capture settings (ISO, aperture, shutter speed, white balance) adapted to best fit the environmental lighting conditions. This meant that with the 850nm NIR filter adapted, the ISO increased to a fixed sensitivity of 400 with exposure time of ~1/3 sec and aperture of f/2.8, however this automatically adjusted when shooting normal colour photography. For each flight, images were taken automatically every two seconds using the cameras time-lapse function capability while altering the orientation and altitude of the UAV. The camera was set in a fixed position for each flight facing down at a vertical angle and the flight path was piloted in a sequential grid pattern with constant height (~20-40m). lighting conditions were important for image acquisition and therefore both NIR and visual colour aerial images were captured in the summer (July 2017) during the middle of the day, with approximately 50% cloud cover.

2.4. Image Correction and Processing

The limitation of image analysis capabilities associated with the technique used in capturing visual and NIR imagery proposes using simple image processing filters developed in MathWorks MATLAB R2017a for detecting grave features allows a qualitative comparison between the visual and NIR output images. The first step in the pre-processing of acquired images involved correcting the radial distortion created by the GoPro camera lens (Figure 6). Correction involved recovering the camera's intrinsic parameters and applying the correction to the entire image set through an algorithm. Images were given a contrast enhancement through histogram stretching (colour images) and greyscale contrast adjustment (NIR images) using the *imadjust* function, so that differentiations could be made between the types of imaging in relation to identifying grave locations. Using the images to detect grave edges involved applying a series of computer filtering masks which operate on a neighbourhood of pixel values. The RGB and NIR images were converted to greyscale using a function which eliminates hue and saturation information while retaining the intensity reflection of surfaces. Gaussian blurring was used to filter unnecessary noise before applying the edge-detection. This function uses a kernel convolution to distribute weight from the average of the centre pixel to neighbourhood pixels using the standard deviation ($\sigma = 6$) for both visual and NIR images.

The Sobel edge-detection algorithm was added to detect the abrupt changes in intensity values within the images (aim of detecting edges of disturbed soil). This method is commonly used in archaeology and other fields to detect features and edges on images taken from an aerial perspective. This filter uses two 3x3 convolution kernels to calculate the values of each gradient relative to the pixel grid in the vertical and horizontal (Gx, Gy) directions on a two-dimensional image (greyscale). Using the *edge* MATLAB function for implementing the filter returns the output image as a binary containing 0's (black) and 1's (white) where sharp intensity changes that represent edges equate 1's and everything else is 0's. For 'full-site' visualisation purposes, using the pre-processed greyscale versions of the normal visual and NIR images, two 3-D models were created in Agisoft Photoscan Professional.

A visual interpretation was performed on processed images since this is the traditional method of extracting visual information by comparing the image output from each data-set (visual RGB images and 850nm near-infrared images). With the aim of locating soil disturbances representing graves, the information extracted from visual images were compared to the known locations of graves as presented by the recorded GPS data (Figure 2).

3. Analysis of Results

Approximately 300 images were taken during each flight (~10 mins each flight/2 second image time-lapse), however many of the images were unusable due to motion blur distortion and therefore were excluded from the image set. The areas of most interest in relation to the graves identifiable by aerial photography (visual and NIR) were areas 2, 4, 5, and 6, to the east of the site. Vegetation cover in Area 1 and Area 3 had fully concealed all graves previously identified by GPS survey in both the visible and NIR images even after pre-processing. Figure 7 shows a normal colour (A1) image and a greyscale local contrast enhanced

version of a NIR image (B1) taken from the GoPro camera at a similar range and perspective of the eastern side of the site showing Areas 4, 5, and 6. A histogram stretching contrast enhancement of the visible (A2) and contrast adjustment of the NIR (B2) shows the latter to better expose graves with very little vegetation through contrasts in reflectance of vegetation and soil profiles, especially as seen by the single small grave in Area 6 which is almost inconspicuous from the colour enhanced aerial image. There is also some differentiation in the NIR image (B2) between the disturbed soil and the non-disturbed soil exposed by pathways having been created between each of the areas, whereas there is a strong similarity between these two soil types in the colour enhanced image (A2).

Vegetation cover over grave spoil is shown to have a big influence on the reflectivity in the NIR. Only a single grave in Area 4 can be identified by a disturbed soil feature in the NIR, however a second grave can be noticed in the visual images due to better quality and colour differences in the images. Figure 8 demonstrates an example where an enlargement of Area 5 from different visual and NIR contrast enhanced images shows that certain graves with exceptional vegetation cover are somewhat more conspicuous in the colour images, revealing distinct rectangular shaped areas of soil. This is an example of where colour has advantages in distinguishing

features through information gathered by colour channels (RGB) rather than the intensity values as seen in the greyscale NIR images, ranging from 0 (black) to 255 (white).

When converting the visual images to greyscale for enabling edge detection however, there is less intensity change between the disturbed soil and vegetation, creating little contrast. Figure 9 shows two greyscale 3D models of the burial ground created using the visual (a) and NIR (b) images which clearly show that the graves are more conspicuous in the NIR images. Therefore, when applying the edge-detection filter to the visual and NIR images, the excavational boundaries from the graves are noticeably more defined in the NIR images as seen by the numbered examples in Figure 10. Graves 2, 3, 4, and 5 are clearly defined rectangular shapes characterising graves, yet numbers 1, and 6 are just as inconspicuous in both NIR and visible processed images possibly due to reflectance change by vegetation cover at certain boundaries of these graves. Figure 11 (a) then shows a trace image of which graves are identifiable through the visual colour and NIR grayscale pre-processed images from Figure 10 (A1 and B1) and then a trace image (b) of the two Sobel images. This demonstrates that the excavation boundaries are distinguished more easily by the filter due to the low reflectance from soil and high reflectance from vegetation in the NIR, recognising a greater change in intensity. However, high amounts of noise are noticed in both binary edge detection images even with gaussian blurring filters adapted prior to implementation.

4. Discussion

The use of low altitude near-infrared photography using UAVs to detect clandestine burials is a new concept for conducting investigations in the forensic and archaeological field which the results show can be further explored. The research aim was to implement low-cost and easy-to-use technologies for results which open the approach for further practical research using UAVs and near-infrared photography for searching and identifying clandestine burials. The results support the view that digital cameras equipped to gather conventional colour and NIR images can be a valuable tool in identifying disturbed soil from non-disturbed soil and vegetation based on their reflectance characteristics. However, it has to be considered that there is an understanding of the spectral differences of various surface properties under certain lighting conditions, and the limitations of acquisition tools and processing approaches used in obtaining image results are recognised, as mentioned by Kalacska and Bell [24] and Verhoeven [25].

The results have highlighted the efficiency of implementing UAVs in the forensic as well as archaeological fields when conducting search investigations for anomalous features, making use of avoiding contact with the ground surface. However, it was identified that weather conditions have considerable effect on the acquisition and image processing phases. UAVs are unable to operate where weather conditions involve light and heavy rain as well as wind speeds exceeding fifteen miles-per-hour (mph). Cloud cover had considerable influence on the NIR images taken with the GoPro camera which incidentally caused heavier distortions and therefore quality of features was lost in the images. Additionally, the time-of-day (Sun position) had influence on the shadowing of features and vegetation which altered their appearance in both the visual and NIR images as well as when applying edge detection filters. Image processing approaches when analysing NIR photographic results can be considered as potential benefits when dealing with feature detection as compared with visual images due to the differences in intensities as established by the different spectral reflectance of graves and non-grave areas. The Sobel function implemented after gaussian smoothing had the best results in comparison to other functions including thresholding since there was a high amount of noise which was unable to be removed while image quality in either areas of the spectrum. This was the result of the GoPro's restricted capabilities during the image acquisition stage (fixed exposure settings, unremovable hot-mirror) which allowed limited image processing capacities (JPG format) and is therefore not considered as a suitable approach and which may be resolved by implementing higher grade and costlier consumer DSCs. Nevertheless, the post-acquisition phase of the analysis can be accomplished on site and in good time using a relatively low-cost laptop (Intel or AMD x86-64 processor, 2GB RAM, 6GB disk space) supporting either Windows, Mac or Linux and typically installed with MathWorks MATLAB R2017a. Practitioners with the knowledge and awareness of the post processing techniques available are able to carry out the analysis relatively quickly, which can contest the time necessary when planning and carrying out intrusive foot search techniques.

The time in which the graves were created were found to have considerable influence on the results given that the NIR aerial images exclusively revealed recent graves where vegetation regeneration had not fully concealed disturbed soil locations. However, due to colour information from the visual images, some graves unidentified in the NIR were identifiable due to minute differences in vegetation and soil colourations. In general, the method of identification used for the GPS surveying conducting a detailed foot-search appeared to be the most successful method in locating the graves, which is characteristic of the limitation of aerial photography and why more conventional approaches are still generally used.

The results have identified several recommendations which need consideration for further research related to the identification of clandestine burials by means of UAV implementation and near-infrared photography. Such recommendation involves employing a modified DSC with the IR blocking filter removed before adapting an IR transmitting filter. This will allow more NIR light to reach the sensor which should subsequently allow more detail and less distortion to be created in digital images. Additionally, manual adjustable exposure settings (ie. ISO, white balance, shutter speed) along with higher resolution and noise reduction capabilities are necessary. However, GoPro hybrid equivalent cameras of similar cost with the necessary manufacturing qualities for capturing in the NIR are available for purchase and could be of use for further attempts. Advanced models now have capabilities for calculating the Normalized

Difference Vegetation Index (NDVI) which can be used to identify anomalous vegetation species. Using this method, it may be of interest when identifying graves through anomalous vegetation growth over disturbed areas of soil. For costlier recommendations, using a DSLR camera for acquiring RAW imagery files will allow higher quality image processing. However, this will therefore require higher costing UAVs to carry a heavier pay load.

5. Conclusions

This research shows that by implementing a UAV with a low-cost unmodified GoPro camera for visual and NIR imaging, the ability to detect graves based on the different reflectance characteristics is available. However, limitations including vegetation covering, weather conditions and camera capabilities are factors which will affect the results and therefore need to be considered. UAV implementation as an aerial platform for photographic purposes is a highly valuable tool when gathering information from a perspective that allows large areas to be investigated, presenting its advantages during search investigations. Near-infrared aerial photography has also demonstrated its advantages in differentiating disturbed soil areas having little overlaying vegetation from surrounding, non-disturbed soil and vegetation. However, taking the inexpensive approach by using unmodified cameras with fixed automatic light exposure settings and a lens distortion 'fisheye' effect has its disadvantages which are characteristic of the distorted images acquired with the adaption of the NIR filter. Additionally, the method of identifying 55 known burials based on an intrusive approach had the best outcome of identifying areas of soil disturbance. Therefore, locating clandestine graves through UAV aerial photography techniques may be a very useful method and can be further explored by implementing higher-grade camera technologies for the improved acquisition and quality of images as well as greater capabilities for further processing techniques.

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Figure 1: *The electromagnetic (EM) spectrum showing the varying wavelengths (λ) divided into categories of radiation (Freedman and Kauffman, 2007, Figure 5-7).*

Figure 2: Typical spectral reflectance characteristics of primary earth surface cover elements ([32], Figure 1.18).

Figure 3: *Map and satellite images showing the location of the research site in relation to major UK cities. Taken from Google Maps* [40].

Figure 4: *Georeferenced ordnance survey map of 'Westmill Woodland Burial Ground' identifying separate areas where visually known graves from between 2000 – 2017 were located.*

Figure 5: *DJI Phantom 1 (a) with GoPro Hero 3 mounted beneath flying over the natural burial site (b) used for the research.*

Figure 6: *Original visual lens distorted image showing Area 1 (a) and output image after lens correction (b).*

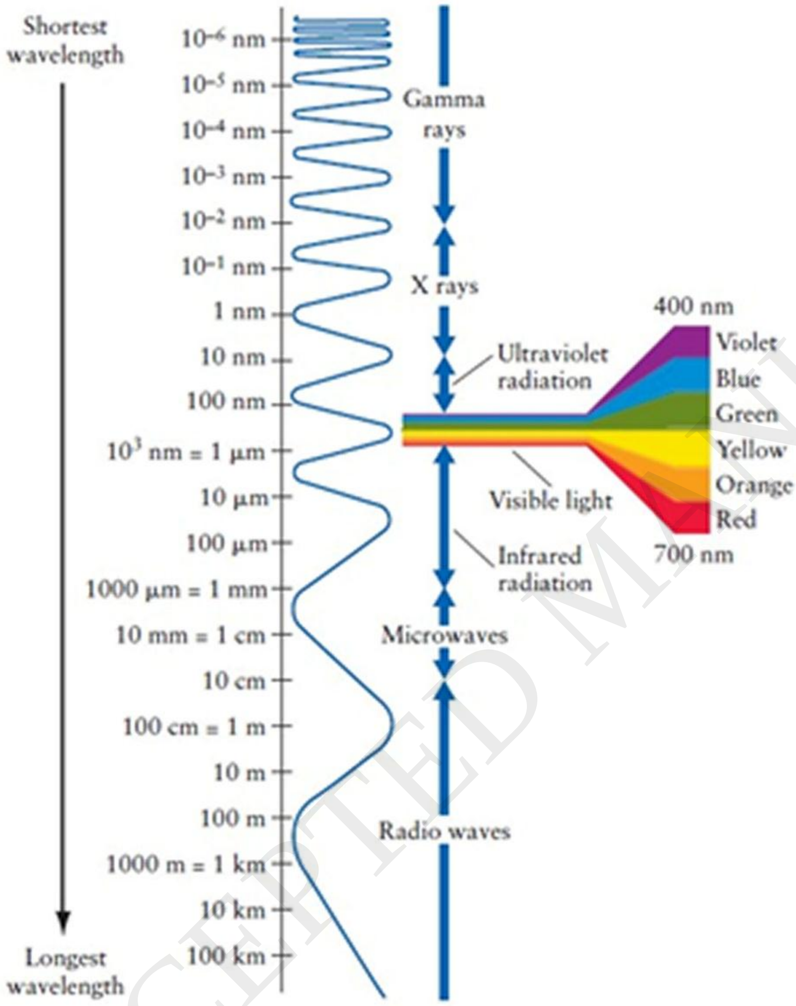
Figure 7: *Contrast enhancement (A2 and B2) of the original visible (A1) and NIR (B1) images respectively from the calibrated GoPro Hero 3 shows rectangular grave features are noticeably more conspicuous against the environment in the NIR.*

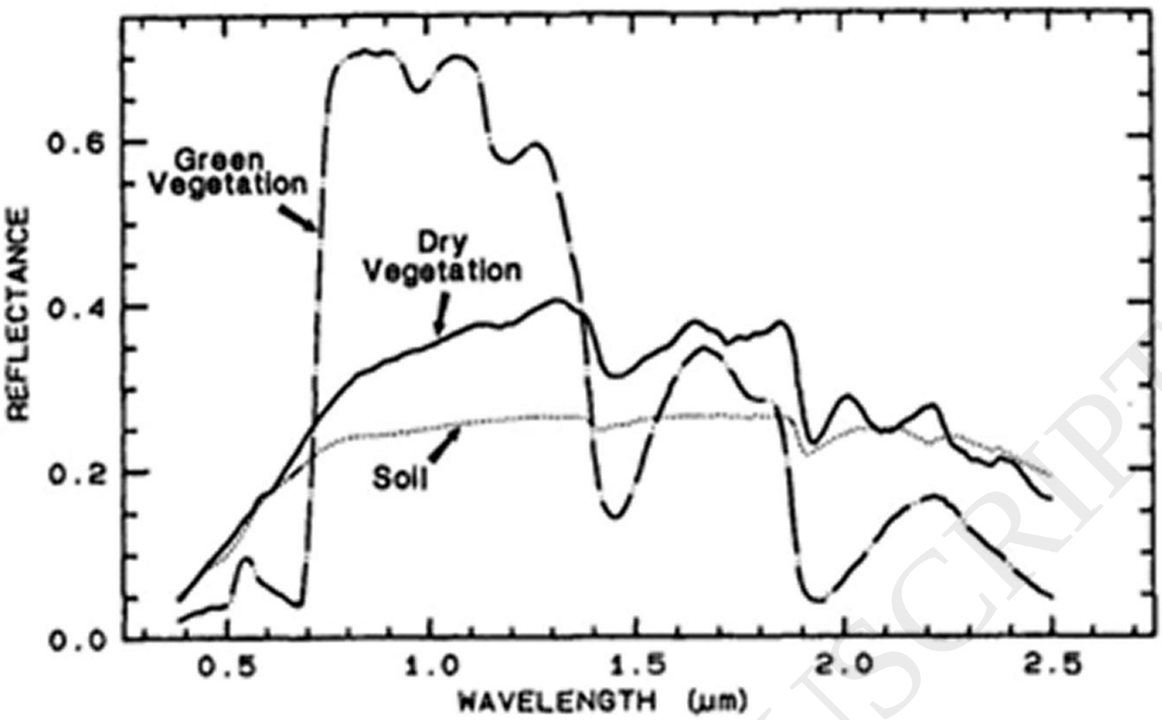
Figure 8: *Contrast enhanced versions of normal (a) and NIR (b) images with enlargement of Area 5, showing the advantage of colour images for identifying spoil heaps over graves.*

Figure 9: *Greyscale 3D models of the research site using all the visual (a) and NIR (b) images taken with the GoPro camera showing all areas of the site. 3D models created in Agisoft Photoscan Professional.*

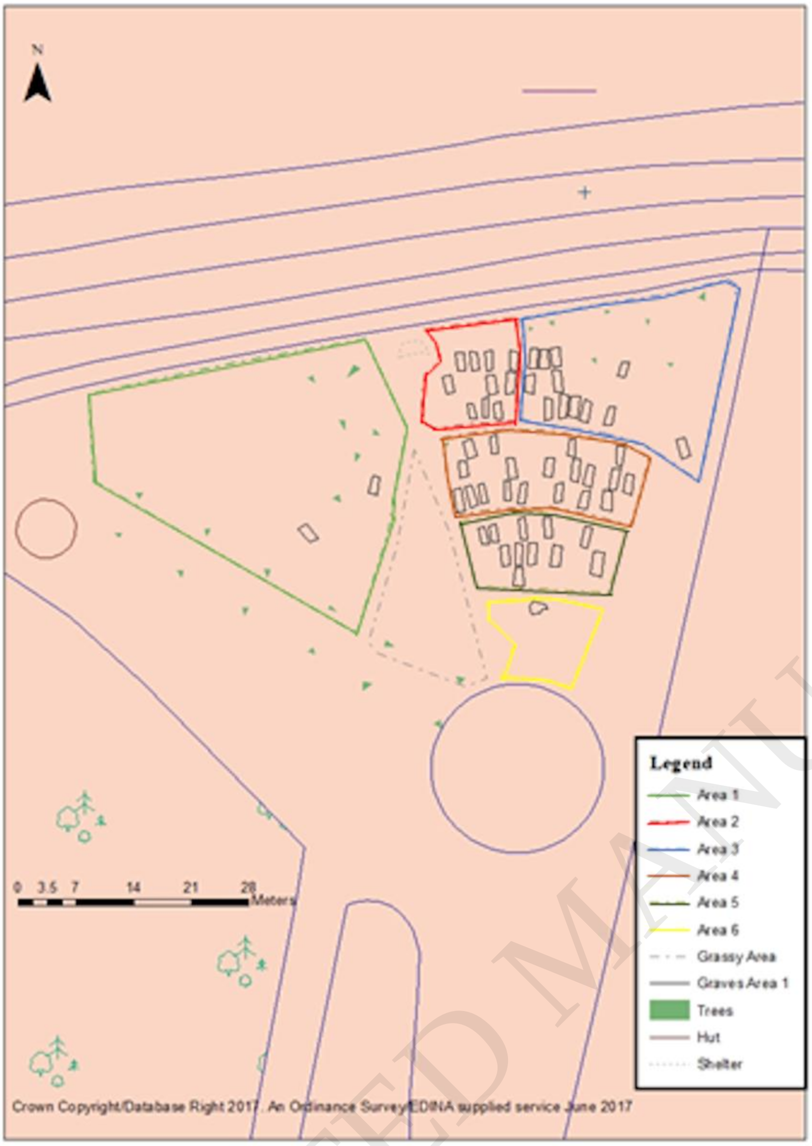
Figure 10: *Sobel edge detection filter (A2 and B2) added to the grayscale contrast enhanced colour (A1) and NIR (B1) images respectively show graves are easier to detect in the latter as illustrated by numbered examples.*

Figure 11: *Trace images of identifiable grave features from two contrast enhanced visual and NIR images (a) and a second trace of the Sobel edge detection visual and NIR images (b).*

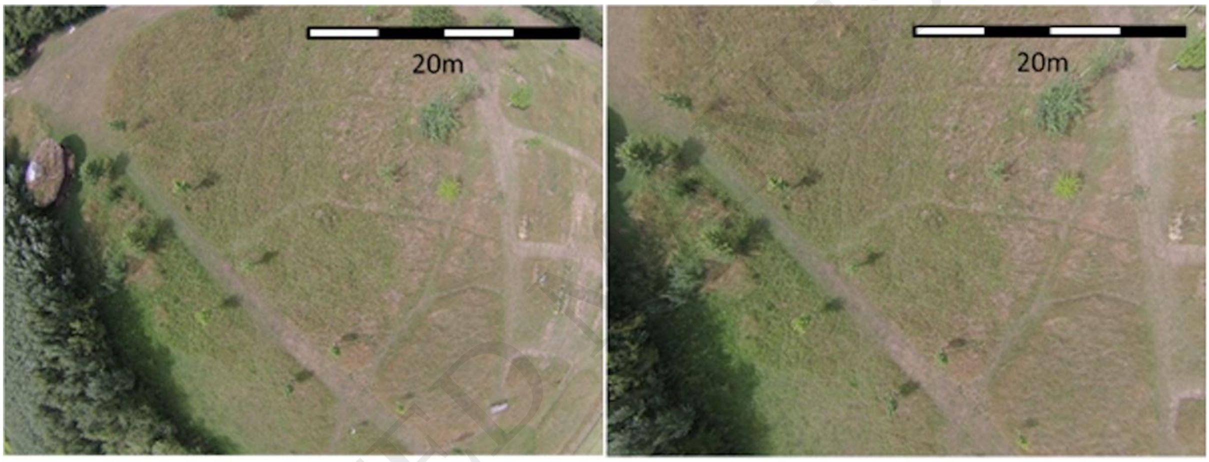


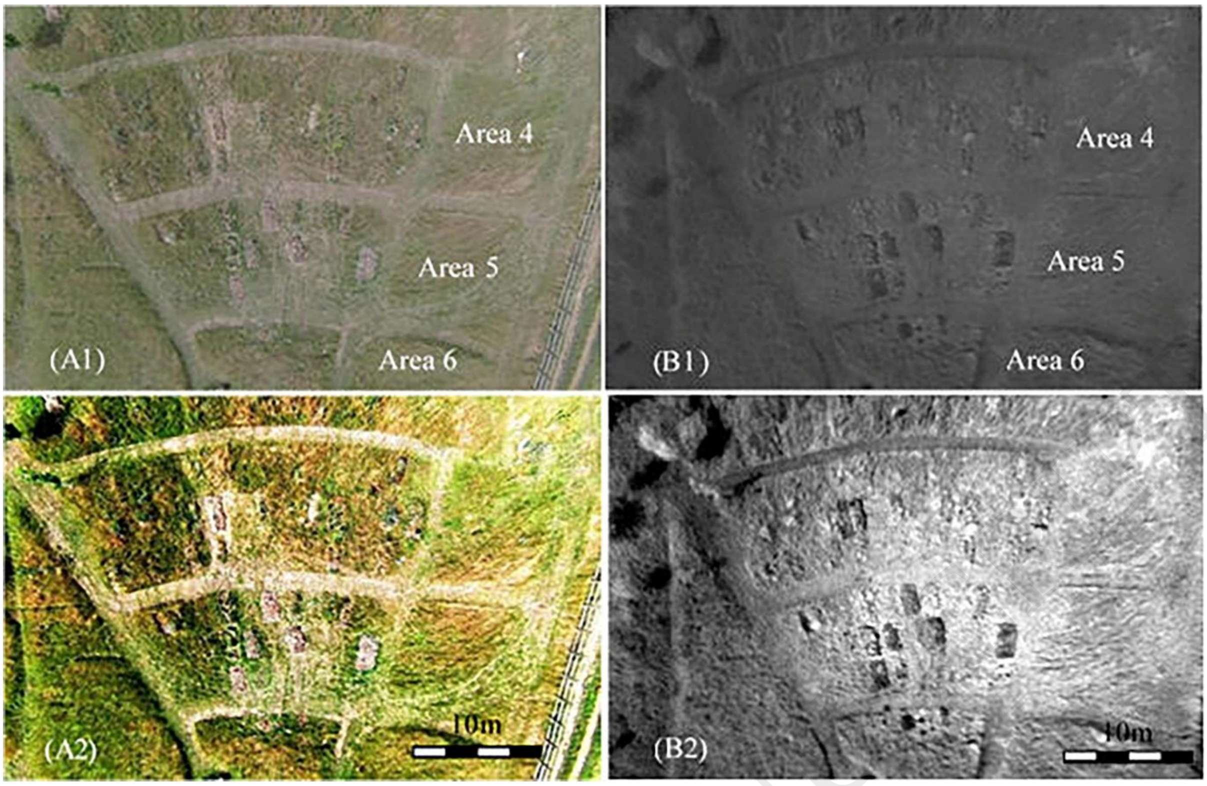

Green Vegetation
Dry Vegetation
Soil
REFLECTANCE
0.0
0.2
0.4
0.6
0.5
1.0
1.5
2.0
2.5
WAVELENGTH (µm)


N
ENGLAND
Coventry
Cambridge
Ipswich
Colchester
The Cotswolds AONB
Oxford
Swindon
London
Reading
Bristol
Bath
Canterbury
South Downs National Park
Southampton
Portsmouth
Brighton
Bournemouth
Exeter
Torquay
Plymouth
Newquay
Truro

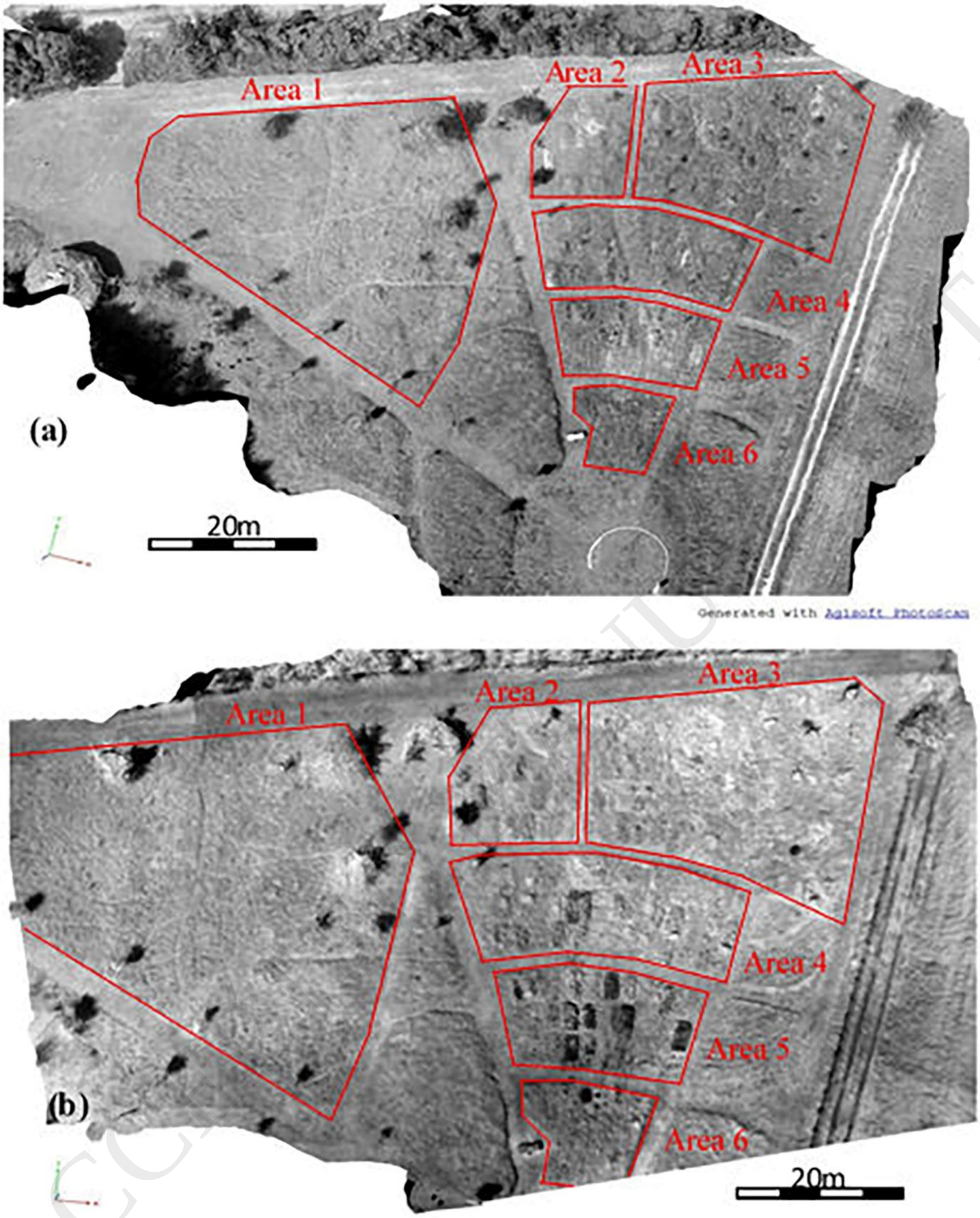

N
Legend
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
Grassy Area
Graves Area 1
Trees
Hut
Shelter
0 3.5 7 14 21 28
Meters
Crown Copyright/Database Right 2017. An Ordinance Survey/EDINA supplied service June 2017

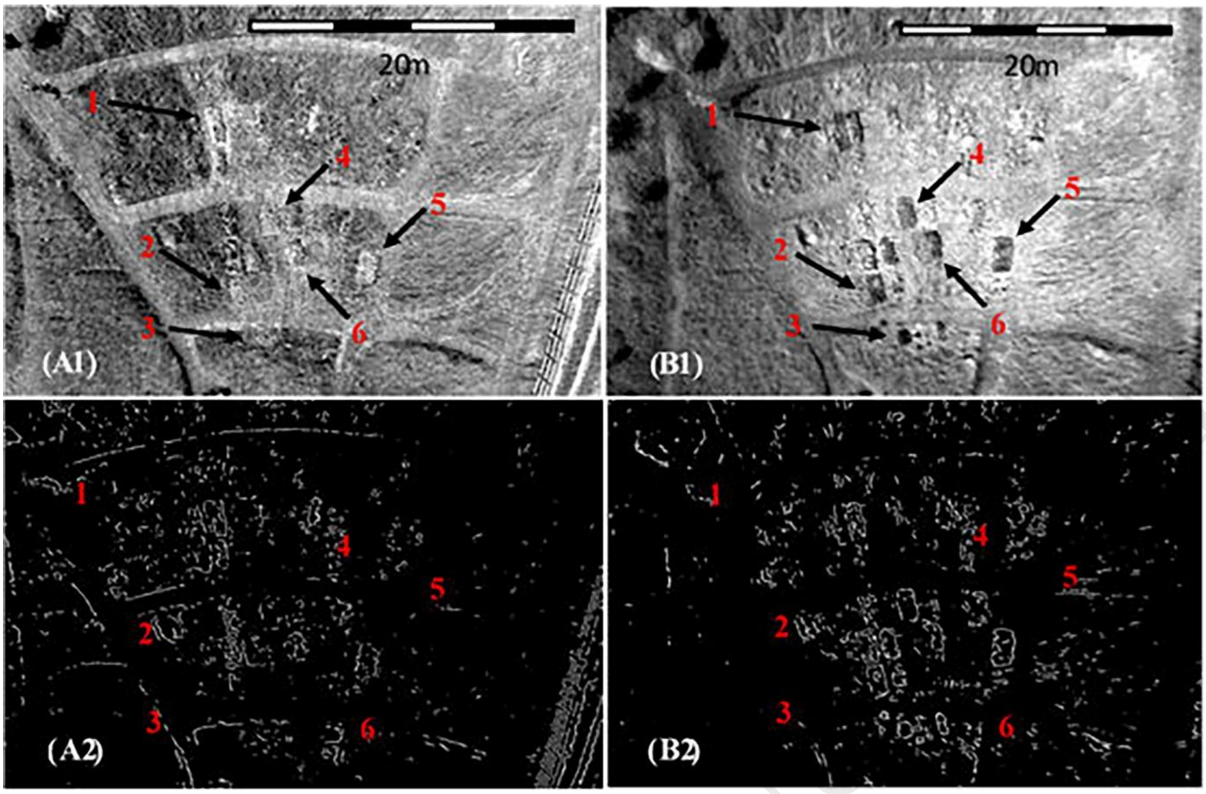

(a)
(b)


20m
20m


Area 4
Area 5
(A1)
Area 6
Area 4
Area 5
(B1)
Area 6
10m
(A2)
(B2)
10m


2m
(a)
2m
(b)


Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
(a)
20m
Generated with Agisoft Photoscan
Area 1
Area 2
Area 3
Area 4
Area 5
Area 6
(b)
20m


20m
20m
1
2
3
4
5
6
(A1)
(B1)
(A2)
(B2)


Legend
Area boundaries
Near-infrared features
Visual features
20m
20m

Table 1: *Specifications for the DJI Phantom 1 UAV used in the study*

Components	Specifications
Flight Control	Naza-M Transmitter
Operating temperature	-10 ~ 50°C
Take-off Weight	<1200g
Power consumption	3.12W
Battery	20W Lipo
Max Ascent/Descent Speed	6m/s
Max Flight Velocity	10m/s
Max flight time	~ 10mins