




Article

A Low Cost Approach to Disturbed Soil Detection Using Low Altitude Digital Imagery from an Unmanned Aerial Vehicle

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Abstract: Until recently, clandestine burial investigations relied upon witness statements to determine target search areas of soil and vegetation disturbance. Due to this, remote sensing technologies are increasingly used to detect fresh clandestine graves. However, despite the increased capabilities of remote sensing, clandestine burial searches remain resourcefully intensive as the police have little access to the technology when it is required. In contrast to this, Unmanned Aerial Vehicle (UAV) technology is increasingly popular amongst law enforcement worldwide. As such, this paper explores the use of digital imagery collected from a low cost UAV for the aided detection of disturbed soil sites indicative of fresh clandestine graves. This is done by assessing the unaltered UAV video output using image processing tools to detect sites of disturbance, therefore highlighting previously unrecognised capabilities of police UAVs. This preliminary investigation provides a low cost rapid approach to detecting fresh clandestine graves, further supporting the use of UAV technology by UK police.

Keywords: forensic science; unmanned aerial vehicle; clandestine burial; grave detection; airborne; image processing; policing

1. Introduction

For the purposes of this study, a clandestine burial will be defined as the intentional concealment of complete or partial human remains, usually a victim of homicide [1]. With this in mind, the most common methods of body disposal include; covering (31.4%), burying (21%) and leaving in isolated places (14.2%) [2]. A study of 29 UK clandestine burial cases shows that clandestine burials are usually less than one metre deep and constructed using common garden tools [3]. Consequently, these fresh graves appear rushed, haphazard and visible due to characteristic disturbance of soils and vegetation [3–7].

Previous researchers of clandestine burials [8] have used a two-fold search process to determine grave location. A two-fold search process firstly relies upon crucial planning and intelligence to determine a target search area to locate visual anomalies. This is to ensure secondary search methods, such as line searches [9], cadaver dogs [10], probing [7] and geophysical techniques such as Ground Penetrating Radar (GPR) [11–17], are more efficient and cost effective [5,18].

Yet, current methods of clandestine burial searches remain costly as police resources are spent on determining grave location guided by witness statements [4,12,19]. Due to this, state-of-the-art remote sensing techniques such as aerial photography using Unmanned Aerial Vehicles (UAVs) are replacing

the reliance upon witness statements by determining the approximate grave location through the rapid detection of visual anomalies [18,20,21]. In this context, remote sensing is the acquisition of data about an object or scene without physically touching it [22].

Current remote sensing techniques used in the search for clandestine graves include the use of sensors mounted on-board satellites, manned aircraft and UAVs, for the purpose of capturing imagery or collecting other data for analysis [20]. Satellite imagery is the most traditional remote sensing technique used to detect ground disturbance [23], previously, satellite imagery has been used with success to detect burials in mass grave scenarios [19,24,25]. However, more suited for identifying single clandestine burials is the use of full-scale manned aircraft to provide real-time aerial photography due to the reduction of cloud cover compared to satellite imagery. Within an archaeological context, aerial photography from manned aircraft is an established technique used to record sites of disturbance and/or capture visual anomalies [26–28]. Common successful approaches include the use of invisible near infrared (NIR) photography to capture anomalies caused by potential buried material [29–31]. Although airborne hyperspectral imaging may be useful from a spectral point of view, the data still lack the necessary spatial resolution (4.7–5.2 m) to detect single targets [19]. However, whilst the image resolution obtained from full-scale aircraft is often much better suited compared to satellites, manned aircraft are still operationally costly and access is limited amongst law enforcement agencies. Despite these limitations, in an investigative context, airborne systems are still more commonly favoured over traditional geophysical techniques [32] as they limit unnecessary footfall, which minimizes crime scene alteration [20].

In contrast to this, UAV technology has gained popularity amongst law enforcement agencies as a low cost aerial support tool [33,34]. Due to its capability for fast deployment with limited demands upon police resources. While the literature surrounding the use of UAVs for clandestine burial detection is generally limited [20,21,35], questions have been raised regarding their practical usage in large scale homicide investigations, with regards to the detection of buried remains. As such, Murray et al. (2018) have written an exhaustive review on the use of the use of UAVs and multiple sensors for the detection of clandestine graves and surface remains [21]. With regard to this, current UAV clandestine burial detection methods only extend the reach of the traditional photographer without improving efficiency [33], as these approaches still require the manual analysis of every captured image or significant computation to undergo convolutional neural network or deep learning approaches. In addition, these previous approaches have required specific image capture devices and modified or custom UAV payloads, unlike the unmodified common commercial systems (e.g., DJI Mavic, Phantom, and Inspire Series) which have been purchased within UK policing. As such, the method outlined in this paper uses a standard commercial UAV system (DJI F550 Flame-wheel), equipped with an unmodified Red-Green-Blue (RGB) camera and video processing algorithm to determine whether an unmodified UAV, equivalent to UK police systems, can be used as a low cost tool for the aided detection of disturbed soil sites on shrub and grasslands, indicative of fresh clandestine burials. With the overall aim of improving operational productivity of shallow grave and clandestine burial searches.

Crucially, this approach uses a non-invasive visual based search method, that is comparably low-cost (£700) to other remote sensing techniques (e.g., hyperspectral imaging £5000–£100,000 or laser scanning £30,000+), with the ability to also adopt an exclusionary search approach [18,36,37]. The intention is not to replace the investigator or forensic professional, but to reduce demands upon resources and increase efficiency, by introducing new technology alongside established techniques. Ultimately, the physical analysis of the disturbed soil sites will remain the task of the practitioner, however; the proposed process used in this study highlights how the initial search process can become less resourcefully intensive.

2. Materials and Methods

2.1. Study Site

A large area of isolated grass and shrub land south of Chester, England was selected as the study site. This area of land consists of a clay rich soil covered by dense shrub land, trees and a small stream. The vegetation was over 1 m tall in some parts making the grave obscured from line of sight even at a small distance during a traditional foot search (Figure 1).



Figure 1. A photograph taken standing alongside the simulated grave position.

An approximate 1 m square patch of land was selected randomly within this test site and roughly dug over using a common garden shovel, to simulate the presence of a recent clandestine burial (Figure 2). No human or animal material was placed into the simulated grave due to the Human Tissue Act (2004) and restrictions from the landowner. The use of a common garden shovel and approximate 1 m² simulated grave was to replicate the visual appearance of clandestine burials outlined in analyses of 29 UK cases [3].



Figure 2. The simulated grave site partially recovered with disturbed vegetation. Approximately 1 m² in size.

2.2. UAV Platform and Data Capture

A DJI F550 Flame-wheel hexacopter equipped with an unmodified RGB camera controlled by a gimbal was used to capture all of the airborne video data (Figure 3). The DJI F550 Flame-wheel is a commercially available UAV kit measuring 550 mm diagonally across, with a frame weight of 478 g, and a maximum take-off mass of 2400 g [38]. The DJI F550 Flame-wheel was equipped with a DJI Naza M V2 flight controller connected to a global positioning system (GPS) module and power management unit (PMU). The propulsion system consisted of six DJI 2312E 920 kV motors and six DJI E420 electronic speed controllers (ESCs). The UAV was powered with a 14.8 V (four cell) Lithium Polymer battery and remotely operated via an FrSky Taranis X9D 2.4 GHz Transmitter bound to a FrSky X8R Receiver. The propellers fitted to the UAV were self-tightening DJI 9443 9-inch propellers.

A GoPro Hero 4 (Black Edition) was mounted to the UAV using a Tarot 2-axis brushless gimbal to ensure image stabilisation. The gimbal also allowed for the manual angular positional control of the camera during flight using the pilot's transmitter to obtain views from selected angles and orientations. During image acquisition, the gimbal was kept positioned parallel to the ground to obtain good coverage of the search area. For all data capture, the GoPro video footage was captured at 25 frames per second (fps) in protune mode at a 4 K (3840 × 2160) resolution and all the video footage was recorded in approximately four and a half minutes. Initially, a separate test flight was conducted to capture a calibration image of a disturbed soil site within the survey area, to obtain comparative threshold values to compare to potential visual anomalies discovered during data capture within the target area. To conduct data collection the UAV was manually flown at altitudes of approximately 2, 5, 10 and 20 m above ground level (AGL) in raster patterns over the search area to maximise the site coverage and capture data for analysis. Although in the UK the UAV could be flown up to 400 ft according to Civil Aviation Authority (CAA) legislation [39], these altitudes were selected to provide a broad dataset and examine the algorithm performance at different flying heights, whilst still being

able to cover large areas. The data capture was conducted during the British summertime in the late afternoon; weather conditions during the image acquisition were dry but overcast.



Figure 3. DJI F550 Flame-wheel drone with gimbal and camera used for data collection.

2.3. Video Processing

The data processing was performed using MATLAB version R2017b and functions from the image processing and computer vision toolboxes. An overview of the algorithm is included in Figure 4.

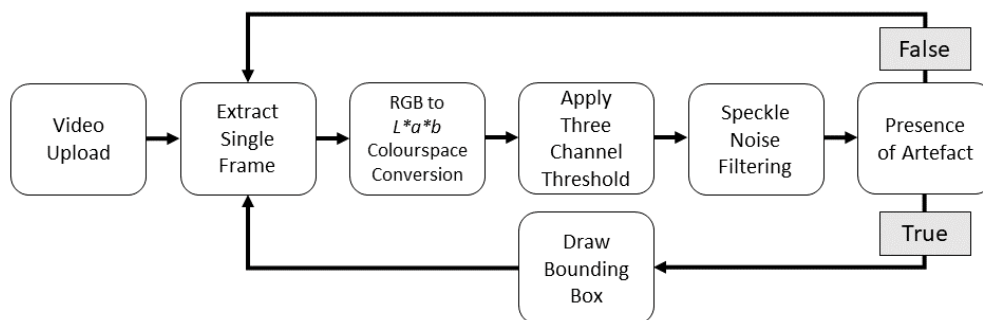


Figure 4. A basic overview of the video processing algorithm used for disturbed soil detection.

Before completing the workflow outlined within Figure 4, a still image was selected from the test flight to obtain comparative threshold values for all subsequent video processing, this process assessed and recorded the colour components of the CIE 1976 $L^*a^*b^*$ colourspace [40] within the test flight video frame. All subsequent analysis was then completed using these obtained threshold values as follows (Figure 4); the video was uploaded into the MATLAB workspace and a single image frame was extracted and stored in the workflow as a 2D array. Next, the motion blur was removed from the image by de-interlacing the single frame. The image colour space was converted from RGB to the CIE 1976 $L^*a^*b^*$ colourspace, which is a numerical colour representation of the image colour space where L^* is Lightness and a^* and b^* are respectively the green-red and blue-yellow colour components. The CIE 1976 $L^*a^*b^*$ colourspace was used as during development it distinguished the most difference between the simulated grave site and surrounding vegetation. The three-channel threshold determined from

the test flight data was applied to the image resulting in a binary (bit) mask. The resulting bit mask was then eroded (Speckle noise filtering, Figure 4) to remove any speckle noise of less than three pixels in diameter, this ensured only larger objects in the mask more likely to be graves remained and smaller noise artefacts were discarded. Then the size and position of any remaining objects in the bit mask were assessed and noted. If after filtering, no objects were discovered the next image was assessed. Otherwise, a red bounding box was drawn over the disturbed soil site in the original image. This entire process was encompassed within a loop to sequentially analyse images every 12 frames, a time interval equivalent to approximately 0.5 ms one after another.

3. Results

To ensure all results were equally comparable, the algorithm parameters were not changed during the course of the experiment and so the analysis of every image was identical. Consequently, the disturbed soil site was highlighted and detected successfully across the video where the simulated gravesite was present in the image frame. Figures 5–9 show this successful detection of the same grave location selected randomly from different perspectives and altitudes extracted at different points in the dataset. Use of a gimbal mounted underneath the UAV enabled the camera to be positioned facing downwards, to ensure that the gravesite was recorded directly from above without obstruction from tall vegetation and excessive motion blur. Erosion of speckle noise within the image was essential to lower the likeliness of false positives from small-misinterpreted objects in the camera view; consequently, no false positives were identified within the datasets.



Figure 5. An example algorithm output image with the disturbed soil site detected in the lower right region of the image. Recorded at an altitude of approximately 10 m above ground level (AGL). A stream can be seen on the left hand side of the image and a faint vehicle trackway running top to bottom across the image is visible on the left side of the disturbed soil site.



Figure 6. An example algorithm output image with the disturbed soil site detected within the centre of the image. Recorded at an altitude of approximately 15 m AGL. A stream can be seen on the left hand side of the image and a faint vehicle trackway running top to bottom across the image is visible on the left side of the disturbed soil site.



Figure 7. An example algorithm output image with the disturbed soil site detection in the upper region of the image. Recorded at approximately 20 m AGL. A stream can be seen on the left hand side of the image and a faint vehicle trackway running top to bottom across the image is visible on the left side of the disturbed soil site.



Figure 8. An example algorithm output image with the disturbed soil site detected in the lower right region of the image. Recorded at an altitude of approximately 10 m AGL. A stream can be seen on the left hand side of the image and a faint vehicle trackway running top to bottom across the image is visible on the left side of the disturbed soil site.



Figure 9. An example algorithm output image with the disturbed soil site detected in the lower left region of the image. Recorded at an altitude of approximately 20 m AGL. A faint vehicle trackway running top to bottom across the image is visible on the left side of the disturbed soil site.

4. Discussion

The results of this preliminary investigation show that a UAV equipped with an unmodified digital camera, can provide low cost soil disturbance detection when paired with a custom video processing algorithm. This approach uses systems equivalent to UAV devices currently owned by UK and international police departments, with the intention of improving the operational productivity of missing persons and homicide investigations, through the rapid, low cost and non-invasive detection of visual anomalies indicative of clandestine burials.

Aerial photographs have long been used to detect visual anomalies in an investigative and archaeological context [3,6,29–31] and the increasing incorporation of UAVs within policing, alongside the method outlined in this paper can further aid these investigations. The recent investment of UAV technology by UK and international law enforcement enables even the smallest law enforcement agencies to have constant aerial support [33]. With regard to this, the value of UAV technology within law enforcement is becoming increasingly realised worldwide with new capabilities including crime scene photography [33], scene reconstruction [34] and safety assessment [41] being reported frequently within academia and international media, despite some public privacy concerns [42].

With regards to clandestine burial detection all previous academic work has relied upon the use of custom or modified payloads, such as the addition of filters [35] or the modification of commercial cameras [29] to achieve positive results. As such, law enforcement is limited with implementing these approaches as these agencies lack the expertise or funding required to purchase or modify highly specific UAV devices. This is a more prevalent issue in the UK as many UK Police UAV systems use integrated payloads. With this in mind, the aim of this experiment was to use an unmodified UAV system equivalent to current Police UAV devices to develop any unrecognised capabilities without the requirement of in-house modification or the purchase of unique systems.

Even though aerial photographs have been assessed in the literature [18] as an effective tool for detecting unmarked and clandestine graves within rural areas, all remote sensing methods have limited capabilities in heavy woodland (with the exception of some laser scanning technologies able to penetrate vegetation, however, the ground plane can only be extracted during post processing [20]). With regard to this, UAV technology has advanced manoeuvrability compared to manned aircraft and National Police Air Service (NPAS) helicopters, which may make UAVs more suited to operate in some sparsely wooded environments. However, research suggests that body disposal is statistically more likely to be away from urban environments [43] and on diggable terrain away from rocks and trees [5,9].

While this shrub land dataset proved a successful environment for disturbed soil detection, the image-processing algorithm was reliant on the presence of light and a known soil comparison. This was to record the colour differences of disturbed soil anomalies on undisturbed shrub land. Although in this experiment a test flight was conducted to capture a comparative image of the soil colour, this approach could be replicated by manually digging a small area in proximity to the take-off zone to expose the soil colour and capture a comparative image upon take off using the same camera and settings on the UAV. In addition to these limitations, mechanical properties and environmental conditions may also limit some UAV operations. As for example, the low cost (£700) DJI F550 Flame-wheel used in this experiment cannot operate in high winds or heavy rain. Although, these operating conditions are similar to the fair weather DJI Mavic Series (£1349) popular amongst UK police. Other commercial systems better suited for adverse weather conditions are available but at a significantly greater expense (£65,000) [44]. In addition to this, the approach outlined in this paper only considers the detection of fresh clandestine graves through the detection of visual anomalies. As such, future work should be undertaken to assess the suitability of this algorithm on burials that have undergone significant taphonomic change as outlined within the literature [20].

The unique perspective offered by UAV technology from this approach allows investigators to interpret aerial spatial information and prioritise target search locations. This allows investigators to limit unnecessary footfall within any potential scene by pre-determining cordon limits and agreeing entry/exit points which may aid in the preservation of tyre marks, clothing and weapons that may have otherwise been destroyed or compromised during traditional foot searches [4]. Although soil disturbance captured via RGB aerial photography is not solely indicative of clandestine burials, as it can only provide spatial context and shapes of disturbances, this technology is much cheaper than more burial specific hyperspectral imagery [19]. While hyperspectral cameras are suitable for commercial UAVs, their cost and usability hinders their uptake amongst law enforcement and forensic practitioners. As UAV specific hyperspectral cameras are still an emerging technology and not widely available as

integrated payloads, their popularity is lacking in policing. Therefore, many commercially available hyperspectral cameras often require increasingly costly UAV systems which must be custom designed and built at great expense, unlike the systems owned by UK Police.

From this research, future technological considerations include the assessment of different flight paths through the use of automated flight thorough waypoint flying (a method of automated path planning based upon GPS coordinates), to increase automation in the system. Arguably future image processing could be completed in the field providing access to a laptop preinstalled with MATLAB, rather than processing occurring sometime later in a lab. In addition, this approach examined every 12 frames of the original video, in the future further research could down sample of the video data further to provide on scene real time results when working in the field. However, the use of RGB video footage over the site does provide full coverage of the environment with considerable overlap that can be used to create three-dimensional (3D) models of the crime scene, as is increasingly common within forensic science for reconstruction and evidentiary purposes [45]. With this in mind, to maintain full-site coverage future research could increase the camera resolution to allow the pilot to fly higher without the loss of image clarity whilst also using automatic sequenced photographing of the site rather than video to obtain a large site coverage without high computational load.

However, it is important to note that the detection of a disturbed soil site with RGB camera remote sensing does not guarantee the presence of a clandestine burial, and simply identifies a potential anomaly that should be investigated further. Notably, this process has further forensic implications beyond the detection of buried remains. For example, the same method could be implemented in large-scale crime scene searches for weapons, money, and other evidentiary items.

5. Conclusions

From this preliminary investigation, the use of RGB equipped UAVs as a method for aiding detection of disturbed soil sites seems promising. These initial results have highlighted the benefits of integrating UAV technology alongside traditional ground based search techniques to improve operational productivity. This study has highlighted how systems equivalent to UK police devices can be modified to enable rapid, low cost and non-invasive effective clandestine burial detection.

In the future, further studies should be conducted within areas of differing soil and vegetation types to highlight additional practicality improvements for clandestine burial investigations. Critically, this method adopts the exclusionary search principal which reduces operational costs and surveying time by quickly determining visual anomaly locations within large search areas. Beneficially, UAVs can assess hard to reach environments from above being deployed quickly without the expense of full-size aircraft and improved spatial resolution compared to satellite imagery. These capabilities and the rapid non-invasive approach outlined within this paper can significantly improve police operational productivity when searching for a clandestine grave.

Although this detection method is not burial specific and the algorithm performance is reliant upon daylight, the low cost and off the shelf accessibility of this method as opposed to other spectral imaging devices, make this technology easier to implement and low cost for efficient search results. Even though this approach currently only uses a low cost RGB camera similar to equipment owned by UK police, the image-processing algorithm implemented, would be as equally suited to other more expensive imaging devices which may be purchased in the future, which in turn may require larger more expensive custom UAVs. To conclude, this study has contributed to the advancement of current police UAV applications for the purpose of improving efficiency of clandestine burial investigations. This has been achieved without the requirement of in-house modification or the purchase of unique systems. This approach provides further evidence supporting the use of police UAVs internationally.

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