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TECHNICAL NOTE

Anthropology; General

The detection of clandestine graves in an arid environment using thermal imaging deployed from an unmanned aerial vehicle

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Abstract

The Middle East is one of the world regions that has frequently suffered from armed conflicts that resulted in mass burials. However, the detection of clandestine graves in such an arid environment by deploying remote sensing payload on unmanned aerial vehicles (UAVs) has received little attention. The present study used a UAV equipped with a thermal sensor aimed at narrowing down the search area of possible gravesites in the arid climate of Kuwait. The enclosed research area, which includes both control and experimental mass graves, was imaged for 18 months. The variation in topsoil temperature and soil moisture between the graves and their surroundings was evaluated. The results of the analysis demonstrated the effectiveness of thermal imaging techniques in detecting heat produced from buried sheep carcasses and detecting the change in grave soil moisture for our research environment for 7 and 10 months, respectively. The buried animals significantly influenced the topsoil temperature ($p = 0.044$), while the height from which the images were captured had an insignificant effect on the measured temperature within the range tested ($p = 0.985$). Furthermore, there was a negative correlation (−0.359) between grave temperature and the calculated soil moisture. The results from these cost- and time-effective search methods presented in this study confirm their potential for the detection of burial sites in an arid environment.

KEYWORDS
burial detection, drone, forensic anthropology, forensic archeology, mass graves, remote sensing, thermal imaging, UAV

Highlights

- The temperature variation between the mass grave and its surroundings is detectable for 7 months.
- Soil moisture can be used to aid the detection of mass graves for 10 months in an arid climate.
- The height of the UAV has an insignificant effect on the detection of grave temperature.
- This is the first research on grave detection in a desert environment to use these methods.
- The results are promising and can lead to further research despite some limitations.

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JOURNAL OF FORENSIC SCIENCES

1 | INTRODUCTION

Current practice in forensic archaeology suggests a phased approach in detecting burials in which the search moves from large-scale remote sensing methods [1] to the application of medium-range geophysical technologies [2] and finally, a ground search for a specific and defined area of interest [3]. On-foot coverage of a large land area and a thorough search for a possible burial site place a significant demand on both human and financial resources. Therefore, successfully implementing drone technology for image capturing in an arid climate would be highly beneficial to all the agencies involved in the detection of burial sites. The advantage of remote sensing deployed using drone technology lies in its non-invasive nature that covers a large area of interest in a short amount of time with minimal human and non-human resources [4]. In forensic science, remote sensing has been used in various cases to aid criminal investigation [4–9]. Past research has demonstrated that optical remote sensing can detect burial sites in tropical forests [1], rural landscapes [10], mountainous terrain [11], and woodland [12]. On the other hand, very little research has been conducted on grave detection in arid environments [9, 13]. The importance of detecting such burials arises from the fact that several countries in the Middle East have suffered from armed conflicts that resulted in many clandestine mass graves [14]. More precisely, there is an area which has received limited attention in the past and that is the detection of the heat produced by the decomposition process of the carcasses and the change of soil moisture in a burial site in an arid climate. The goal of the research presented here was to assess the effectiveness of using a commercially available UAV equipped with a thermal sensor in narrowing down the search area of gravesites by assessing the heat and soil moisture of the gravesites.

2 | MATERIALS AND METHODS

Kuwait is a country located in the north-western corner of the Arabian Gulf in the Middle East. It is known for its arid climate with a verified recorded temperature of 53.9°C in July 2016, making it the highest recorded temperature in Asia and the third hottest temperature ever recorded in the world [15]. A measured 30 m × 30 m plot of land in Jahra Pools Nature Reserve, an 18 km^2 nature reserve located at Jahra town in the north of Kuwait, was used for the research. At the time, the site consisted of dry soil with uniform roughness, no vegetation cover and was flat, with no significant slope (Figure 1). This site was chosen because it resembles the landscape of previously excavated mass graves in Kuwait dating to the Gulf War [16]. It also follows the description of Schuldenrein and co-authors on mass grave location and features in Iraq. They state that mass graves are usually located in remote places with minimal susceptibility to degradation, erosion, and exposure [14].

Two graves were simulated, 5 m apart to avoid cross-contamination or interference from the buried animals' decomposition fluids [17]. The graves were dug using a backhoe and had the same dimensions: 5 m by 2 m and 1.5 m in depth. Although it is expected that old mass graves that were dug more than 30 years ago, such as the ones from the 1990 Gulf War, would not be detectable using this technology, the depth of the graves at 1.5 m (Figure 2) was chosen to resemble similar conditions. This would aid in the determination of the useful timeframe to detect changes by using this technology in these specific conditions [16]. One grave served as a control (G1) and had no buried carcasses in it. This serves to simulate soil disturbance caused by other factors such as construction rather than a burial site. The experimental grave (G2) contained eight sheep and had some added content such as clothing and 9 mm handgun shell casings to make them resemble a real-life scenario. It is not the first time that mammals other than pigs have been successfully used when conducting such experiments [1]. The sheep used were purchased from the local abattoir with an average weight of 32 kg, which is within the recommended carcass weight for experimental studies when a human analog is used and within the average weight of an adult human torso of 22–35 kg [1, 18, 19]. The use of animals in this research was conducted in compliance with Liverpool

FIGURE 1 The research area and the two graves captured the day after the burial.

FIGURE 2 The grave's depth was checked using a measuring tape while digging the mass grave by the backhoe loader.

John Moores University's ethical guidelines for the use of animals in research.

A Parrot Anafi Thermal, a quadcopter (four propellers) UAV equipped with a forward-looking infrared (FLIR) Lepton 3.5 microbolometer (radiometric) sensor was used to capture the thermal images within the enclosed research area. In addition to the airspace restriction around the area, image capturing was limited to the enclosed experimental area in accordance with the obtained permission to fly the UAV from the Ministry of Interior of Kuwait. Previous literature suggested that heights of 50 ft (approximately 15 m) and 100 ft (approximately 30 m) are ideal to aid the investigation of a potential gravesite when a thermal UAV is used [20]. Hence, images were captured at different heights to explore the ultimate height for our research environment that covers the most area possible in a single flight while maintaining the on-ground details of the captured images which is known as Ground Sampling Distance (GSD). The lower the GSD, the more details and information can be obtained from the image. The heights used in this research were 10, 30, and 50 m. A total of 18 sets of thermal images were captured throughout the experiment period, which lasted for 18 months. The first images were captured 1 day before the burial, the day of burial, and then 1, 3, and 7 days after burial. Thereafter, images were captured weekly for 3 weeks. Next, a periodic (monthly) set of images were captured until 1 year after burial except for the fourth, fifth, and eighth months due to government restrictions related to the COVID-19 pandemic. Lastly, images were captured in the fifteenth and eighteenth months.

The captured images were then transferred to the photogrammetry software Pix4Dmapper to generate different orthorectified outputs [21]. FLIR and ArcMap were used to explore the temperature and soil moisture variations, respectively. The focus of the examination was the variation between the graves and their surroundings. These specialized software tools aid the process of detecting possible burial sites in an arid environment by highlighting the differences between G1 and G2.

The topsoil surface temperature of the enclosed research area was recorded using the commercially available Parrot Anafi Thermal UAV which is equipped with a FLIR radiometric thermal-imaging camera. The temperature variation between the graves and the undisturbed research area within the enclosure was analyzed using the FLIR tool software [22].

Soil moisture was calculated for both graves using the temperature vegetation dryness index (TVDI) formula:

$$\mathrm{TVDI} = \frac{Ts - Ts_{min}}{Ts_{max} - Ts_{min}}$$

where Ts is the temperature at a specific pixel, Ts_{min} is the lowest temperature of the area of interest and Ts_{max} is the highest temperature of the area of interest.

TVDI ranges from 0 to 1, where 0 represents the highest water content point and 1 the lowest water content point. For the captured thermal image of the research area, Ts was extracted for each pixel utilizing the *Spatial Analyst Tools – Extract by Mask feature* available in geospatial processing software *ArcGIS Desktop v.10.8.1* using its *Esri ArcMap application v.10.8.1.14362* [23]. Thereafter, the TVDI for the extracted points was calculated using the relevant formula mentioned above.

3 | RESULTS

The initial analysis demonstrated that the ultimate height which maintained a clear GSD, was 30 m. Henceforth, all aerial analyses listed will represent the obtained results at 30 m. There was a visible difference between the G1 (control grave) and G2 (experimental grave) when analyzing the captured images. The temperature of G2 was always higher than G1 up until the tenth month after burial when G1 got higher. The highest temperature difference was recorded in the seventh month, when G2 was 3.3°C warmer than G1. The temperatures of G1 and G2 were consistently lower than the temperature of the surrounding area, except for the third month after burial when G2 was higher than both G1 and the surrounding (Table 1).

The effect of UAV height and the buried carcasses on the temperature of the graves was tested using a two-way ANOVA. Within the range of heights tested, it was found that there is an insignificant effect of height ($p = 0.985$) when tested against the grave temperature. The captured temperature is not affected by the three different heights at which the UAV was flown in this experiment. On the other hand, buried carcasses showed a significant effect on the measured temperature ($p = 0.005$). Hence, having buried animals in the grave does influence the topsoil temperature.

There was a difference in soil moisture between the graves and the surrounding area, which lasted up to the tenth month. A noticeable color difference between the marked graves (blue) and their surrounding (yellow/red) is evident when examining the map. This indicates a difference in soil moisture between the graves and the surrounding areas (Figure 3). Some areas immediately around the graves also appear to have a higher soil moisture and this is the result of the soil disturbance by the backhoe loader during the

TABLE 1 A comparison between the captured temperature of the control mass grave (G1), experimental mass grave (G2) and the surrounding area throughout the experiment.

Measured	G1 aerial temperature (°C)	G2 aerial temperature (°C)	Surrounding temperature (°C)
Same day	36.4	36.2	43.3
1 day PB*	36.8	37.1	38.8
3 day PB	35.9	36.2	38.4
1 week PB	27.6	28.8	29.2
2 weeks PB	29.1	30	31.4
3 weeks PB	29.3	29.9	31.2
1 month PB	22.8	22.9	23.2
2 months PB	21.5	21.9	23.4
3 months PB	23.5	25.4	23.1
6 months PB	5.8	7.9	5.4
7 months PB	9.5	12.8	9.2
9 months PB	23.2	23.6	24.1
10 months PB	29.4	29.1	30.4
11 months PB	32.7	32.5	33.2
12 months PB	30.1	30.3	31.1
15 months PB	9.1	8.8	8.7
18 months PB	2.9	3	2.9

Abbreviation: PB, post-burial.

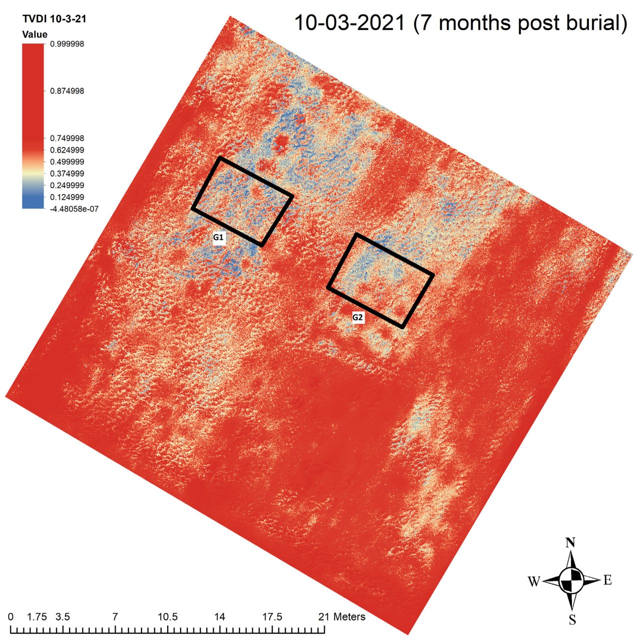

FIGURE 3 Calculated index map of the TVDI for the research area in the seventh month. Soil moisture is evident in both the control (G1) and experimental graves (G2).

construction of the graves. When calculated, soil moisture in both graves was higher than in the surrounding area, having a TVDI closer to 0. Table 2 illustrates the values extracted from the TVDI map for G1, G2 and the surrounding area.

When tested, the topsoil temperature and the calculated soil moisture of the graves showed a statistically significant correlation between them ($p < 0.001$). The correlation between aerial temperature and soil moisture is −0.359, which means that there is a moderate negative relationship between them. Hence, an increase in temperature would result in a lower soil moisture, and vice versa.

4 | DISCUSSION

In line with previously published literature [5, 8, 20], a distinguishable surface temperature difference between the control and experimental graves was detected when analyzing the findings of the research area. The total weight of the buried carcasses and the grave depth of the present study were almost the same as those in previously reported experiments. Furthermore, it is noticed that the temperature of the experimental grave was higher than both the control grave and the surrounding area in the third month after burial, and this temperature rise can be explained due to the process of decomposition that was taking place at that time. This is similar to previous research in detecting buried remains in a similar environment, where a better detection performance was observed 3 months after burial [13]. However, after the seventh month, this temperature variance between the graves was not detectable. A reason for this could be a result of the completion of the process of putrefaction. On the other hand, the experimental grave was moister than the control grave for 10 months and eventually leveled up.

The missed data on the fourth, fifth, and eighth months post-burial were due to government restrictions related to the COVID-19 pandemic. For the soil moisture, the results have not been affected as we were able to detect changes for up to 10 months. When it comes to the temperature variation between the graves and their surroundings, differences were detectable up to 7 months but not at 9 months. It is therefore unknown whether or not the temperature variation would have been detectable at 8 months.

All the aforementioned results are promising, as they are suggestive of the effectiveness of using a commercially available UAV equipped with a thermal sensor in narrowing down the search area of relatively recent gravesites in an arid climate. This method has shown to be effective under the given conditions for about 7 months when analyzing the temperature and 10 months when analyzing the soil moisture of the graves. It should be noted that the results might differ based on the total body weight of the buried carcasses, the nature of the environment where they were buried, the depth of the grave, and for how many days/months post-burial the data were collected. The present study used a small number of carcasses and it is encouraging that changes were detectable after 10 months. One can assume that if it was a larger grave containing more individuals, the grave would have been even more visible and for a longer period of time. Hence, such technology is largely dependent on the given grave characteristics and is considered an exploratory search method which aims to reduce the area under examination for a suspected burial site.

TABLE 2 The minimum, maximum, range and mean TVDI values of the graves and the surrounding area.

	Minimum TVDI	Maximum TVDI	Range TVDI	Mean TVDI
Control mass grave (G1)	0.04	0.57	0.53	0.24
Experimental mass grave (G2)	0.02	0.58	0.56	0.25
Surrounding area	0.44	0.99	0.95	0.33

Abbreviation: TVDI, temperature vegetation dryness index.

All UAVs are designed and operate in a manner that makes each a unique machine, in the sense of whether or not it can be flown in the rain, its resistivity to the wind, battery life, and many more features. Regarding the limitations of the Parrot ANAFI thermal used in this experiment, the maximum temperature it can be flown at is 40°C and a maximum humidity of 93%. Additionally, it can only handle a wind resistance of 50 km/h, wind gust resistance of 80 km/h and fly for 26 min per battery [24].

The present study is not free of limitations. For example, conducting the first few months of this experiment in the summer prevented us from being able to test the effect of the ground temperature variance at the desert. This is because the optimum time for conducting thermal imaging is when the temperature variance between the burial site and its surroundings is detectable, which is most likely to happen during sunrise and sunset. During these times of the day, the temperature of the surrounding environment would be lower than the grave containing the decomposed body, which produces heat that is easily captured [7]. However, the temperatures recorded for the first 2 weeks, around sunrise and sunset, were just below 40°C, the maximum temperature to operate a UAV. Hence, the temperature was only captured at sunrise, which limited the possibility of testing any temperature variance that might have been available. A future study could test this temperature variance usually shown during fall/winter seasons in a desert environment when temperatures are measured and compared at sunrise and sunset. Additionally, blind testing of the index maps by different observers who do not have any prior knowledge about the location of the graves would strengthen the validity of these methods when applied in an arid environment. It should be noted that some knowledge of the software used and its output is required by the observer, but this is true for the vast majority of specialized image processing programs.

It is known that in most search missions for mass graves, the work requires thoroughly covering a large land area. Nonetheless, our research area was relatively small, and images were only captured in the assigned plot of land, following the permission obtained. Hence, the commercially available UAV used in this research is suitable only for our experimental research conditions. Therefore, to implement it in real-life scenarios, the UAV would require flying at a greater height for longer time periods and still being able to capture high-resolution images. This would require a longer battery lifetime, a feature currently found on affordable commercially available fixed-wing UAVs that can fly for longer and cover large areas. Additionally, capturing images in larger areas than our limited research plot of land would allow us to further test the validity of these methods of grave detection.

5 | CONCLUSION

Optical remote sensing, using the inexpensive and time-effective passive sensors mounted on a multirotor UAV, performed well in narrowing down the search of the graves in an arid environment. Evaluating temperature and soil moisture variation provided satisfactory results to distinguish between the mass grave and its surroundings. The results obtained from analyzing the thermal images aided the assessment of the temperature and soil moisture of the graves and the effect of the buried carcasses on such features. Therefore, implementing this technology in such environmental conditions is considered a new approach that is hoped to serve as a cost- and time-effective search method. Furthermore, it will have a definite humanitarian impact as it can help to locate human remains and give closure to the families of the individuals who are missing and presumed dead in many countries.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

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