Preliminary hand-held thermal imaging results of sequential monitoring of a simulated deceased individual on terrestrial ground

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ABSTRACT

Thermal imaging is commonly used by forensic search investigators to locate missing persons, and can be used to detect thermal targets in darkness, but there is little research on its actual effectiveness to detect individuals after death. This paper aims to determine how long hand-held thermal imaging is effective to detect a naked body lying on the surface for and when is the optimal time to survey.

A simulated murder victim, using a freshly dispatched pig (*Sus scrofa*) carcass, was left on the soil surface of a test site and imaged three times a day until active body decomposition was complete (TBS of 35) which was 61 days. Images were quantitatively analysed to determine what the relative thermal response the cadaver had with respect to background site values, with results corrected for daily temperature variations (ADD) and decomposition stages (TBS scores).

Results evidenced the surface cadaver was detectable throughout active decomposition, but optimal survey time depended on decomposition stage. Morning surveys were found to be optimal up to 10 days PMI (0-90 ADD, 0-4 TBS), evening/dusk surveys optimal from 10 to 40 days PMI (90-400 ADD, 4-26 TBS), midday surveys optimal from 40 to 50 days PMI (400-530 ADD, 26-29 TBS) and then evening surveys to the end of the 61-day (530-680 ADD, 29-35 TBS) study period.

Implications suggest that thermal imaging is recommended to detect missing persons even after death and surveys should be undertaken at specific time periods during the day to improve search detection success if PMI can be estimated.

KEYWORDS: forensic science, thermal, search, surface remains, survey, missing persons

Highlights

- Study to quantify effectiveness of thermal imaging surveys for missing persons
- Decomposing cadaver thermally detected up to 61 days PMI (681 ADD, 35 TBS)
- Thermal anomaly low/high relative to background depending on survey
- When survey undertaken during the day also important
- Surveying needs to account for decomposition stage to optimise results

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Introduction

The use of forensic geoscientific techniques and methods in the search for missing persons is increasing; as locating them is of vital importance for their families and for criminal convictions to proceed (1). Current forensic search methods are highly varied and have been reviewed elsewhere (1,2), with best practice suggesting a phased approach, moving from large-scale remote sensing techniques (3) to ground reconnaissance and control studies before full searches are initiated (4). Full searches have involved a variety of methods, including forensic geomorphology (5), forensic botany (6,7), entomology (8) and scent-trained search dogs (9,10).

Remote sensing has commonly been used at both the large scale, where potential positions are identified, (see 2,11) and at smaller scales, such as using infrared imaging to capture blood spatter patterns at crime scenes (12), or diagnosing death by fire (13). Hyperspectral imagery is a common technique for detecting both explosive residues (14), trace evidence (e.g. 15) and even providing age estimations of blood stains (see 16). Originally adopted for military use in the 1950s, thermal detection has been utilised for the detection of landmines (17) and Improvised Explosive Devices (IEDs) (18). In forensics thermal imaging is commonly used to detect fleeing fugitives and heat by-products of illegal cannabis operations (19), and even facial analysis to detect intoxication (20).

Recent forensic research has used control studies to determine optimal body detection method(s) and equipment configuration(s). Results can be highly variable, depending upon a large number of factors, the most important being postmortem interval (PMI), body wrapping, local soil type, vegetation and climate (21-30). However, there has been little controlled research into the effectiveness of thermal imaging to detect surface remains after death.

Depending on climatic conditions, a body will cool after death, reaching ambient temperatures within ~24 h (31), thus providing no detectable thermal contrast. However, the human body has a higher specific heat capacity (~3,500 J/Kg ºC) (32), when compared to typical wet (~1480 J/Kg ºC) and dry (~800 J/Kg ºC) soil (33). Therefore, even when deceased, it will take longer for a human body to warm up and cool down, particularly at dawn and dusk when temperature changes are at their most rapid. Bone has a much lower specific heat capacity (~440 J/Kg ºC) and thus should also be able to be differentiated from background soil, with the contrast greatest in wet soil. It is also commonplace for necrophagous insects, particularly blowflies, to colonise a corpse immediately following death, given appropriate environmental conditions (34-37). Female flies will oviposit eggs on the cadaver, targeting natural orifices, wound sites and folds in clothing (38,39). These eggs will hatch after ~6 h - 40 h, depending on species and ambient temperature, and first instar larvae will immediately begin feeding on soft tissue (34). During this feeding phase larvae will aggregate, usually during second and third larval instar (34,35), to form a ‘maggot mass’. Masses, often composed of thousands of larvae, generate significant levels of heat as a result of feeding and fast metabolisms, particularly during active body decay. Controlled laboratory research has shown masses containing as few as 1,200 larvae producing significantly warmer than ambient temperatures (40), whilst field studies using animal proxies have recorded mass temperatures up to 50°C (36,41,42). Not only does mass size mass influence heat, but also density (43), species composition (44), stage of larval development (45), and sun exposure (46).

This paper’s aims are to investigate: (1) the length of time that a surface cadaver would be detectable for during active decomposition, using hand-held thermal imaging and (2) the optimal time of day for undertaking such a thermal imaging survey.

Materials and methods

Study test site

The test site at Keele University, Staffordshire, is situated in a restricted area of grassed semi-rural ground surrounded by deciduous woodland and hedges (FIG. 1). The site lies ~200 m above sea level. The local soil is a sandy loam with nearby borehole records (27) with a bedrock of Carboniferous (Westphalian) Butterton Sandstone bedrock present at ~2.5 m below ground level (bgl). This site has been previously used for forensic geophysical studies (27-29,47) but these are downslope of this investigation site so avoiding any soil contamination issues.

Surveying was carried out between the 10th April and 9th June 2017, when warmer temperatures would facilitate insect cadaver activity, and surveying continued until active decomposition was complete, i.e. when the Total Body Score (following (54) method) reached 35. Meteorological data was available from the weather station situated ~200 m east of the study site. Average monthly rainfall was 24 mm (April/May) and 70.2 mm (June), with average daily air temperatures varied from 6.6 °C to 23.6 °C and averaged 13.7 °C over the study period. Having temperature data allowed Accumulated Degree Days (ADD) to be calculated which corrects for local site temperature variations (see (21) for details).

Pig cadaver

The use of pig cadavers as human analogues is well established in forensic science studies as they have similar chemical compositions, body sizes, tissue-to-body fat ratios, gut fauna, skin/hair types, and emissivity value to humans (27,28,48-50). At the current research site their use has been approved by the Department for Environment, Food & Rural Affairs (DEFRA) and the School's Ethics Committees.

A single, naked, (~31 kg) pig (*Sus scrofa*) cadaver, sourced from a local abattoir and dispatched by a bolt gun to the temporal bone less than 6 h beforehand, was placed on the ground surface that was cleared of any vegetation (FIG. 1). Within 30 minutes of exposure adult blow flies identified as *Lucilia sericata* and *Calliphora vicina* were observed ovipositing eggs on the head, specifically in the eyes, ears, nose and mouth. Later that day the same species were observed in the region of the genitals. These two blow fly species are typical for the region and frequently observed at the research site from March through to September/October. During days 2-3, the eggs eclosed and first instar larvae emerged, aggregating to form two masses, one on the head and another in the genitals, each consisting of several thousand individuals. Exact larval numbers could not be determined, since the majority of mass fed internally, commencing at the head and genitals before progressing into the abdomen. The pig cadaver had a metal cage placed over the top after each survey to avoid/reduce scavenging activities.

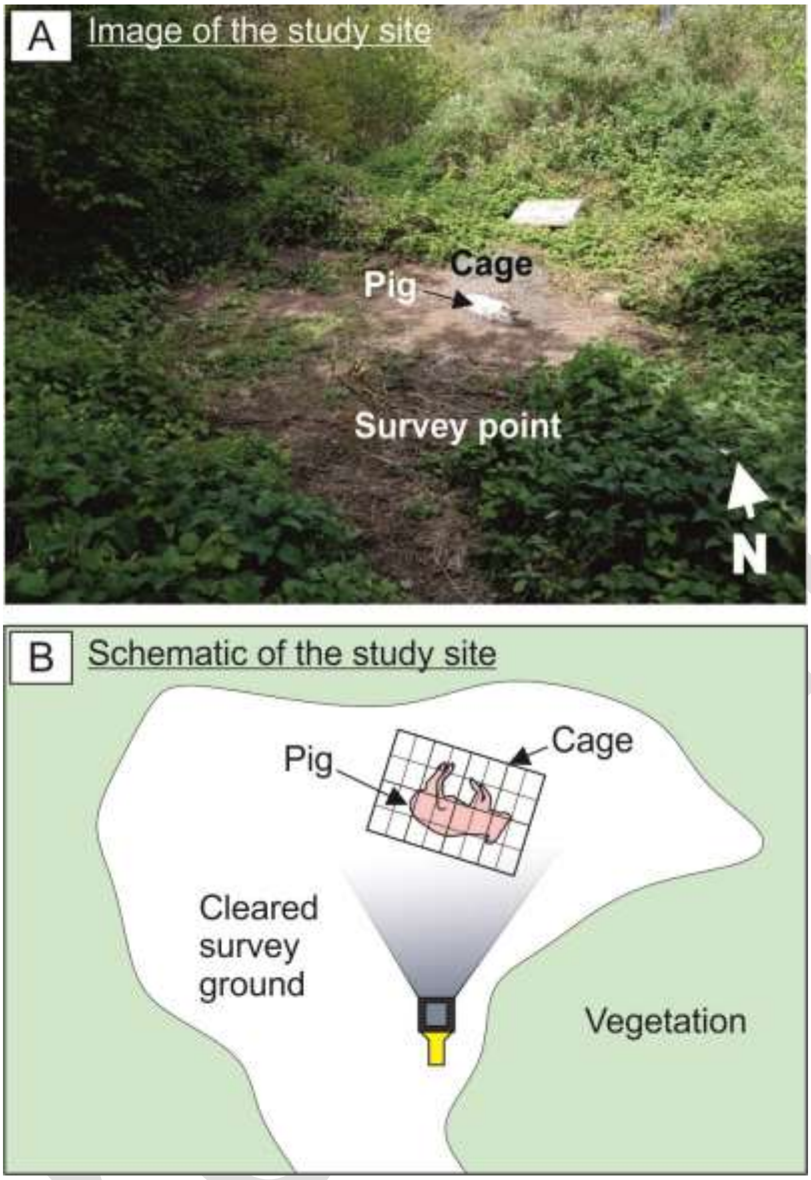

__FIG. 1.__ A) Image and B) schematic of survey site, survey point denotes location where all thermal image data were acquired (2.5 m from cadaver).

Thermal radiation

At temperatures above absolute zero all objects emit radiation (12) which can loosely be considered as 'thermal radiation' (51). At terrestrial temperatures thermal radiation, consisting primarily of self-emitted and secondarily of reflected radiation from other heat sources, is emitted predominately at a wavelength band of 3 µm - 14 µm of the electromagnetic spectrum (51) (see FIG. 2.).

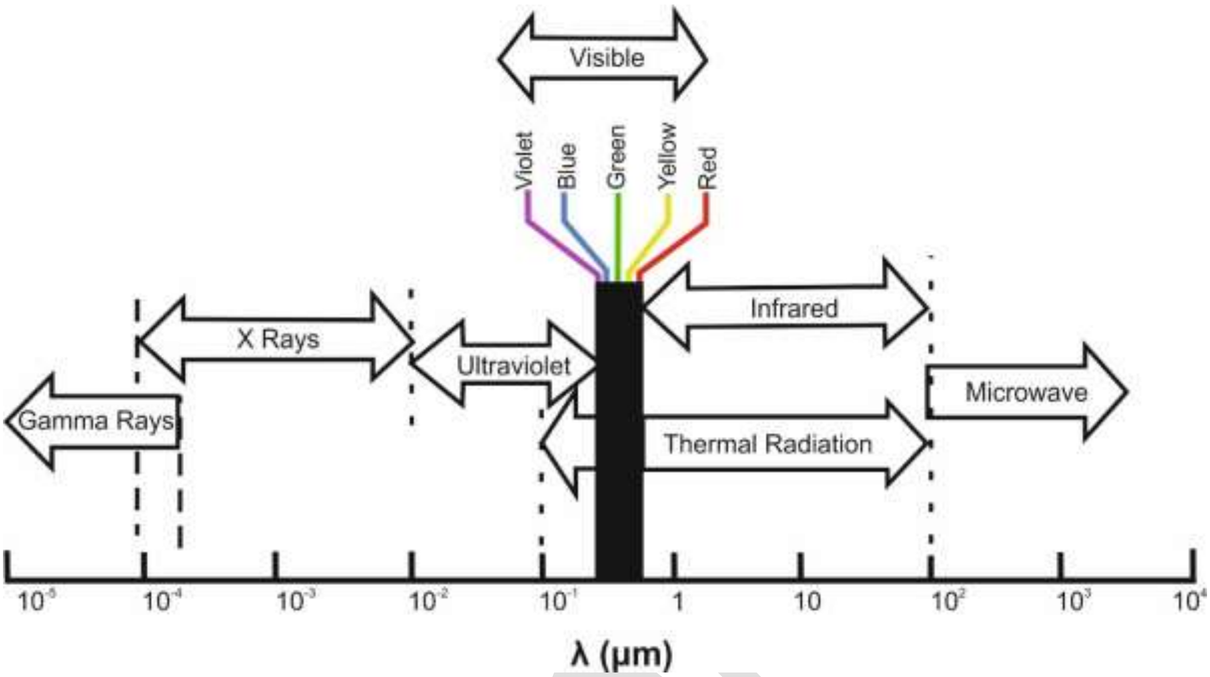

FIG. 2. *Electromagnetic radiation spectrum (after, (52).*

Although hypothetical in thermal radiation theory, a *blackbody* is an object that absorbs all radiant energy, thus appearing black at all wavelengths. A blackbody will also emit a continuous spectrum of wavelengths (53). Stefan–Boltzman's law (Eq. 1) describes the relationship between the total emission of radiant energy of a blackbody and its absolute temperature.

$$P_t = \sigma T^4 \qquad (1)$$

Where P_t = total power emitted by a blackbody (W/m^2), σ = Stefan–Boltzmann constant (5.67 × 10^{-8} W/m^2 K^4), and T = absolute temperature in K. However, since blackbodies do not exist in nature, Stefan Boltzman's law is modified to give (Eq. 2):

$$P_t = \varepsilon\sigma T^4 \qquad (2)$$

Here, ε = emittance of the surface (ε = 1 for a blackbody). The emissivity of a surface is defined as the ratio of the energy absorbed by the surface to the energy absorbed by a blackbody. Consequently, all surfaces will have an emissivity value between 0 and 1 (53). During day time surveys all measured radiation will include reflected radiation, with the major component being solar radiation (53). Other sources of radiation will also be detected i.e. if the target is self-heating (51). Most mammal skins have emissivities greater than 0.9, making them a good emitter/radiator, but a poor reflector of thermal radiation. Both human (54) and pig skin (50) have an emissivity of 0.98. In contrast, a shiny surface (e.g. ε = < 0.2) is a poor absorber and a poor emitter but a good reflector of thermal radiation (53).

A warmer/cooler object (*Po)* will continue to emit/absorb thermal radiation until it reaches equilibrium with its surroundings (P_b). Thermal imagers are able to distinguish between objects of the same temperature due to their contrasting emissivities. A thermal imager is only able to detect the differences between emitted powers (Eq. 1) and not absolute temperatures:

$$\Delta P = P_o - P_b \qquad (1)$$

The benefits of thermal imaging, compared to photographs, is that it does not rely on visible light, but instead thermal energy, making it possible to detect targets in total darkness, through low visibility (e.g. smoke and fog) and in low contrast situations.

Thermal imaging surveys

A Fluke™ TiR125 thermal imaging camera was used for this study that acquires quantitative temperature matrix data (*.IS2 format) over the surveyed area - this camera has an accuracy of 0.1 °C. This allows quantitative comparisons of repeat thermal image data to be calculated. A thermal emissivity correction of 0.98 was used for all the thermal images as 0.98 is emissivity of both pig/human skin (see 50, 54). After initial equipment testing, the instrument was used following the equipment manufacturers instructions, in particular, for the instrument to warm up for ~15 mins before each thermal imaging survey was undertaken to optimise results.

Immediately after the pig cadaver had been placed on the cleared ground surface on day 1, an initial thermal imaging survey was undertaken, with readings taken at 2 h - 3 h intervals over a 24 h period, in order to determine when optimal survey time(s) for the subsequent thermal imaging surveys should be undertaken. During the first 24 hours the thermal anomaly over the pig cadaver changed diurnally, from a relative high anomaly, with respect to background values, during midday and evening surveys to no thermal anomaly overnight and a relative low anomaly in the morning (see FIG. 3). Therefore, the best times for the subsequent thermal surveys over this pig cadaver were noted to be ~08:00-09:59 (morning), ~12:00-13:59 (Midday) and ~20:00 to 21:59 (evening) respectively, due to there being a good thermal response over the surface pig cadaver, when compared to background site values (FIG. 3).

The subsequent daily thermal imaging surveys over the surface pig cadaver, throughout the course of the survey period, were then taken at these three chosen time periods up to day 49; after this, daily surveys were only taken up to day 61 at evening survey times due to equipment availability. By day 61 the Total Body Score (TBS) of 35 was reached, which signifies the end of the active decomposition period (see 55) and thus this experiment. Vegetation regrowth had also meant thermal surveys were taking vegetation temperature by this point. Throughout the thermal survey experiment, each thermal image was taken from the same marked location (see FIG. 1) by the same operator at a set height of 1.4 m above the ground for consistency purposes.

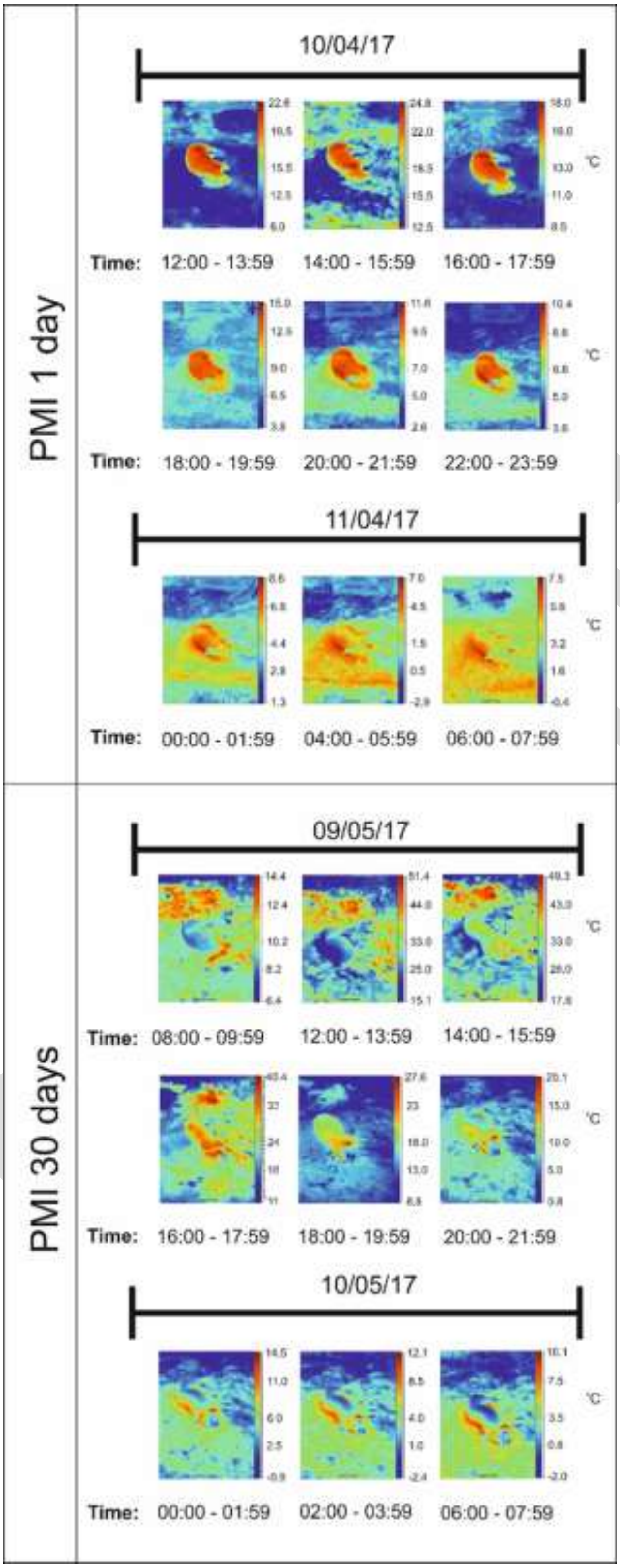

FIG. 3 -*Graphical summary of day 1 and day 30 thermal image surveys collected over the surface pig cadaver every 2-3 h, each over a 24 h survey period (times given).*

Thermal image data analysis

Fluke SmartView® 4.3 software was used for thermal temperature matrix image data processing. . Digital polygons were manually added on each digital thermal image matrix, which allowed the differentiation between the respective pig cadaver and background area, to obtain minimum/average/maximum thermal image temperatures (see FIG. 4 for example). The thermal difference data, between pig and background, from the study was treated separately, dependent upon the time of day it was collected. This data was then plotted against postmortem interval (PMI) and accumulated degree days (ADD; the latter correcting for daily temperature fluctuations). A simple 5-point moving average was then fitted to the thermal difference data so that single anomalous weather variations were minimised.

Total Body Scores (TBS) were also assigned during regular site visits; with TBS being the current standard forensic anthropology method used to quantify active decomposition (see 55). The PMI, ADD and TBS data were then summarised, and the type (positive or negative) of relative thermal anomaly, when compared to background values, that a surface cadaver would produce.

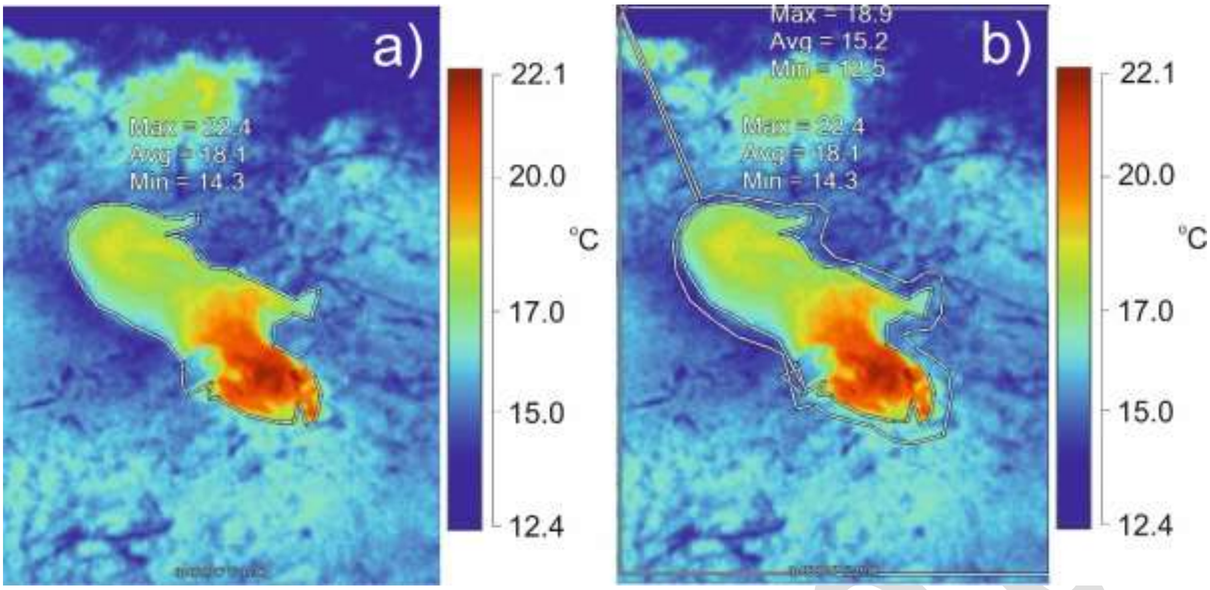

FIG. 4. Graphical summary detailing an example of thermal image data processing used in this study. A digital polygon was drawn around a) the surface pig cadaver and b) the background area, with minimum/average/maximum temperature values of both a/b areas (shown) extracted.

Results

The thermal signature associated with the pig cadaver, when compared to background thermal image values, varied as either a low, high or, in fact, no anomaly being imaged, when compared to background values. This variation was witnessed across each of the morning, midday and evening surveys (see FIG. 5 and FIG. 6 for respective thermal image data examples and graphical thermal summaries throughout the survey period).

For PMI days 1-10 (0 ADD - 90 ADD), morning and midday surveys generally had -1 ℃ to -2 ℃ anomalies, and evening surveys had +1 ℃ to +2 ℃ anomalies over the surface pig cadaver, when compared to background values respectively. Morning surveys determined to be optimal over this survey period.

For PMI days 10-20 (90 ADD - 170 ADD), morning surveys generally had -1 ℃ to 0 ℃ anomalies, midday surveys had -1 ℃ to +1 ℃ anomalies, and evening surveys had +1 ℃ to +2 ℃ anomalies over the surface pig cadaver, when compared to background values respectively. Evening surveys were determined to be optimal over this survey period.

For PMI days 20-30 (170 ADD - 270 ADD), morning surveys generally had -1 ℃ to 0 ℃ anomalies, midday surveys had 0 ℃ to +1 ℃ anomalies, and evening surveys had +2 ℃ to +5 ℃ anomalies over the surface pig cadaver, when compared to background values respectively. Evening surveys were determined to be optimal over this survey period.

For PMI days 30-40 (270 ADD - 400 ADD), morning surveys generally had 0 ℃ to +2 ℃ anomalies, midday surveys had +1 ℃ to +3 ℃ anomalies, and evening surveys had +2 ℃ to +4 ℃ anomalies over the surface pig cadaver, when compared to background values respectively. Evening surveys were determined to be optimal over this survey period.

For PMI days 40-50 (400 ADD - 530 ADD), morning surveys generally had +2 ℃ to +3 ℃ anomalies, midday surveys had +3 ℃ to +6 ℃ anomalies, and evening surveys had +2 ℃ to +3 ℃ anomalies over the surface pig cadaver, when compared to background values respectively. Midday surveys were determined to be optimal over this survey period.

For PMI days 50-61 (530 ADD - 680 ADD), evening surveys had +1 ℃ to +2 ℃ anomalies over the surface pig cadaver, when compared to background values respectively.

Table 1 summarises these key findings which, as well as including the PMI, also includes the Accumulated Degree Days (ADD) and Total Body Scores (TBS) of the target surface cadaver. Finally, it also summarises the perceived optimal time during the day for a thermal imaging survey to be undertaken as discussed here.

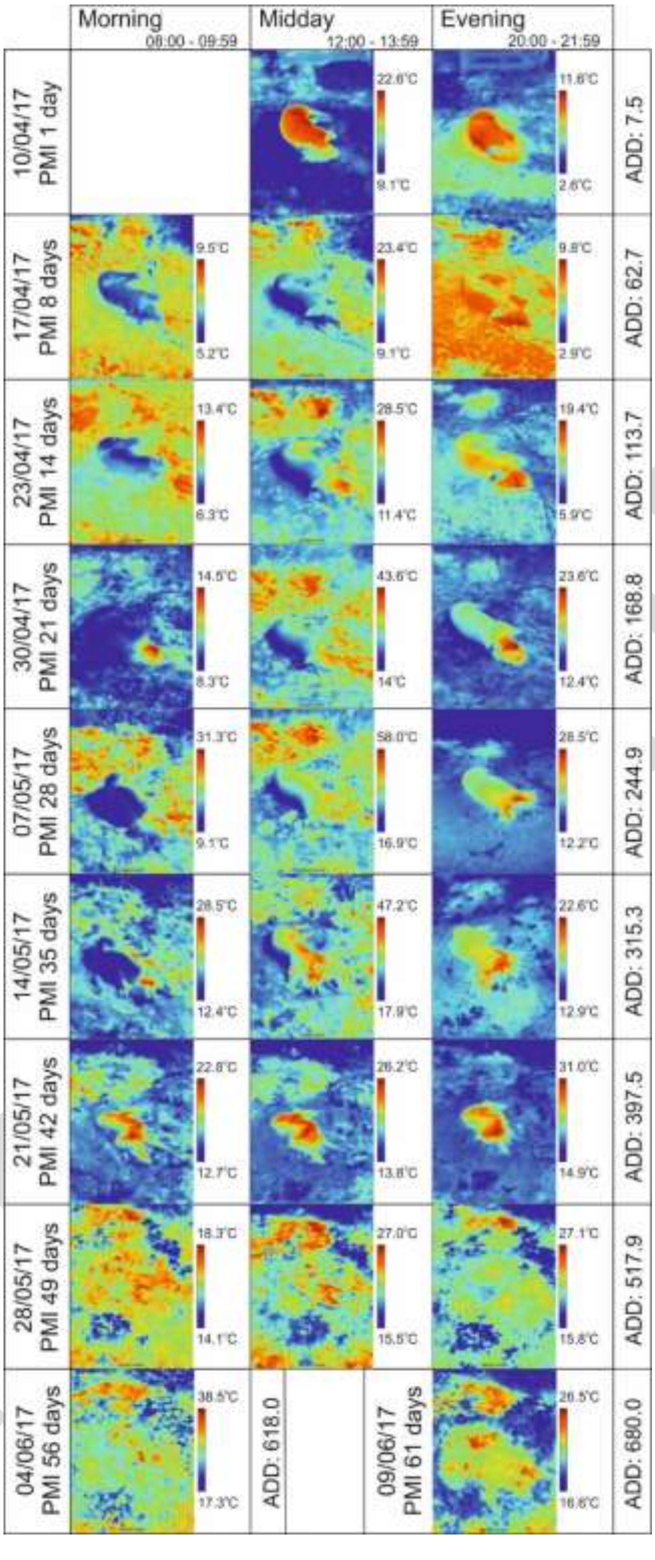

FIG. 5-*Thermal image survey examples taken over the study period (PMI/ADD shown for comparison). Note the morning, midday and evening surveys and thermal anomaly over the surface pig cadaver varies as either low, no anomaly or high anomaly with respect to background values.*

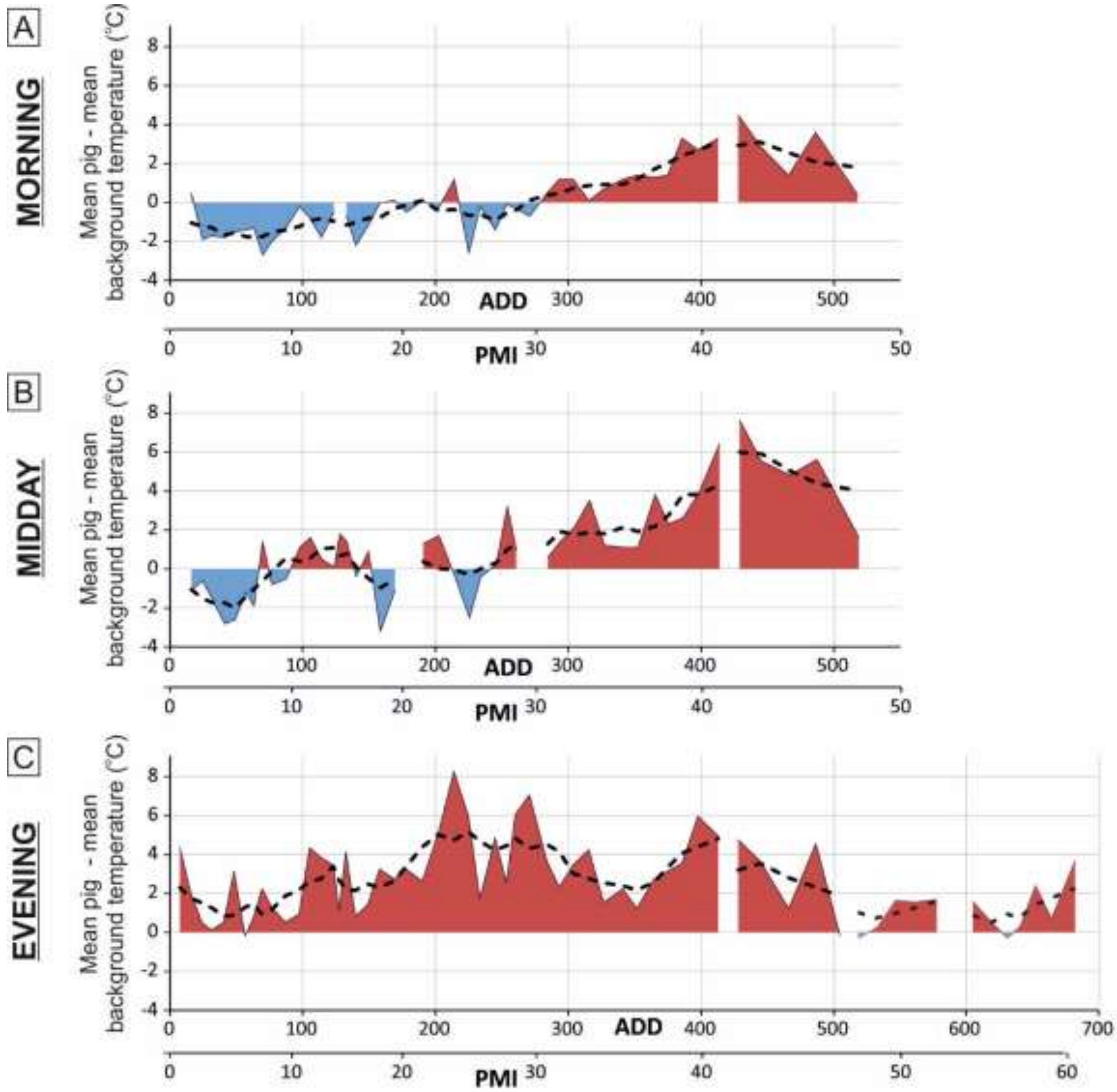

FIG. 6. *Graphical summary of thermal imaging data quantitative analysis, showing the relative thermal difference (average pig anomaly minus background values) for (a) morning, (b) midday and, (c) evening surveys respectively. Dotted line gives five-point running average values. Note bottom axes are both Post-Mortem Interval (PMI) and Accumulated Degree Days (ADD), see text for details.*

PMI (days)	ADD (℃)	TBS	Morning anomaly (°C)	Midday anomaly (°C)	Evening anomaly (°C)	Optimal time for thermal survey
0-10	0-90	0-4	-1 to -2	-1 to -2	+1 to +2	Morning
10-20	90-170	5-12	-1 to 0	-1 to +1	+2 to +3	Evening
20-30	170-270	13-20	-1 to 0	0 to +1	+2 to +5	Evening
30-40	270-400	20-26	0 to +2	+1 to +3	+2 to +4	Evening
40-50	400-530	26-29	+2 to +3	+3 to +6	+2 to +3	Midday
50-61	530-680	29-35			+1 to +2	Evening

Table 1. *Thermal imaging summary of relative average temperatures of surface pig cadaver minus background values. PMI = Postmortem interval (days), ADD = Accumulated Degree Days, TBS = Total Body Score, see (54) and text for details.*

Discussion

This paper’s first stated aim was ‘*the length of time that a surface cadaver would be detectable for during active decomposition*”. From the results of this study, thermal imaging surveys could detect the surface remains of the pig cadaver during active decomposition (61 days PMI / 681 ADD / 35 TBS). Two studies, using a ground-based study (56), similar to this study, and using airborne helicopter thermal imagery (57), have shown detectable [elevated] thermal signatures of maggot masses on pig carcasses, but only over more limited 14- and 21-day survey periods, respectively. This supports the findings reported elsewhere (58), following investigations into whether thermal imaging could successfully be used to detect thermal emissions on seven pig cadavers as they decomposed in woodland in New England, USA. Pig cadavers were detectable between 2- and 26-days PMI, largely due to the larval aggregations colonising the cadavers, which generated significant amounts of heat. By day 26 the cadavers had reached the advanced stage of decay, and the absence of any remaining soft tissues caused the larval masses to disperse away from the remains and all associated heat to be lost, signifying the end of their experiment (58). It is possible that the cadaver used in the current research was detectable for longer due to the cooler ambient temperatures recorded at Keele, slowing the rate of decomposition and allowing soft tissue to persist for longer, which would support the larval communities over an extended period of time.

The advantage of using the Fluke™ TiR125 thermal imaging camera was that the data can be saved quantitatively and analysed, particularly to calculate average temperature differences of the anomaly over the pig cadaver when compared to the background study site area. This is an important development for such thermal monitoring studies; rather than simply producing an image that could only be qualitatively assessed, and has other broad forensic applications, not just for thermal imaging, but perhaps for other search technique data types, for example electrical resistivity datasets (see (59).

This paper's second stated aim was '*to investigate the optimal time of day for undertaking such a thermal imaging survey*'. Surprisingly this was found to be important, with different times of day determined to be optimal for surveying, which seemed to depend upon the PMI and TBS values (Table 1). This should therefore be of great interest and use to forensic search teams if the PMI/ADD of the missing individual is known. If the thermal imaging survey is taken at the optimum time, then search teams should have the greatest chance of success at detecting the missing individual, which could potentially maximise any remaining forensic evidence, advance the case efficiently, reduce expenditure and provide more rapid closure for the victim's family.

As decomposition enters the active stage, the relative thermal anomaly over the pig carcass, with respect to background values became much more elevated. Initially following death, the remains will cool to ambient, a process known as algor mortis, making the pig less discernible from its surroundings. However, shortly thereafter temperatures will increase, likely due to a number of factors including larval aggregations, bacterial activity and heat loading (40). In regards to heat loading, the size of the carcass, the nature of the ground it is laid on, and its exposure to direct sunlight, can all have an effect on its temperature (60). As bodies begin to decompose the bacteria in the intestines proliferate as they break down the body further during putrefaction. Some researchers have proposed that bacterial metabolism plays a significant role in carcass thermogenesis, reporting that even in the absence of maggot masses and solar radiation, cadavers can peak at temperatures of 32 °C whilst ambient temperature remains a constant 23 °C (56).

Despite these factors, it is the heat generated by feeding larval masses that is believed to be the biggest contributor to increased localised temperatures recorded on cadavers. The increase in temperature from ambient correlates with the emergence of first instar larvae, usually during the bloated stage of decay, and continues to rise as colonising larvae increase in numbers, as well as in physical size, with temperatures peaking during the third larval instar and the active stage of decay (36,40,44,45). It would be during this time, when larval aggregations are at the hottest, that the use of thermal imagery in searches is most proficient (61). Once larvae consume the remaining soft tissues on the carcass, they cease feeding and migrate away from the body in search of a place to pupate and complete development. It is at this point where temperatures on the cadaver begin to decline, gradually returning to ambient (40). The thermal anomaly associated with the remains on day 61 is likely a result of heat absorption by the skeletal elements and bacterial activity in the soil. The latter was also suggested by a recent study which reported that carcasses were detectable during the advanced stages of decay using aircraft mounted thermal imaging due to the soils being contaminated with decompositional fluids and supporting larger than expected bacterial communities, resulting in slightly elevated soil temperatures (61). This is likely why all the later thermal imaging surveys had slightly elevated temperatures regardless of the time of day that the survey was undertaken.

Study limitations included using one and not multiple pig cadavers for replication purposes and of course this was undertaken on one study site, with unique soil compositions and local vegetation type. Surveying a wider area on this site may have shown the surrounding vegetation to be poisoned by the release of decomposition fluids from the cadaver during composition (62), killing the surrounding vegetation arounds the body and stressing vegetation further away, that may also be giving a heat signature; this is commonly used in satellite imagery analysis (63).

Since the current research has demonstrated that thermal imaging has the potential to be used as a search tool for missing persons who are presumed dead, further investigation should be carried out in order to test its capabilities in a range of scenarios that may be encountered in casework. This might involve researching its success at locating bodies wrapped in some form of covering, or drowned victims floating on the water surface (as below surface victims will not be detectable as water absorbs IR). Cadavers decomposing in both of these scenarios will be exposed to insect activity, however insect numbers are expected to be smaller and more localised as the water and coverings limit larval access. Some researchers have already investigated the use of aircraft mounted thermal imaging on locating decomposing remains (57,62), but with current policing budget cuts it may be worthwhile to look at drone-mounted thermal imaging as a cheaper alternative for police forces, focusing on their ability to detect remains at different heights, speeds and over different types of terrain.

Conclusion

This study aimed to answer fundamental questions on how effective thermal imaging surveys are to detect deceased individuals on the ground surface using a simulated individual of a pig (*Sus scrofa*) carcass. Thermal imaging could detect the carcass over the active decomposition period (61 day, 680 ADD, 35 TBS), with morning surfaces determined to be optimal from 0 - 10 days PMI (0-90 ADD), evening surveys optimal for 10-40 days PMI (90-400 ADD) and midday/evening surveys optimal from 50 days PMI to the end of the 61 day PMI (680 ADD) survey period.

Study limitations included using one and not multiple pig cadavers for replication purposes, one naked deposition style and of course this was undertaken on one study site, with unique soil compositions and local vegetation type. Replicating the study using replicate pig cadavers in different depositional styles (i.e. wrapped in carpet/plastic sheeting, clothed) will undoubtably have different thermal signatures and thus should be undertaken. Finally, this should be repeated using UAVs, or indeed helicopter-mounted thermal cameras as these are commonly used in Police active searches.

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