INTERDISCIPLINARY PERSPECTIVES

How do passive infrared triggered camera traps operate and why does it matter? Breaking down common misconceptions

Dustin J. Welbourne¹, Andrew W. Claridge¹,², David J. Paull¹ & Andrew Lambert³

¹School of Physical, Environmental and Mathematical Sciences, University of New South Wales, Canberra, ACT 2610, Australia
²Office of Environment and Heritage, National Parks and Wildlife Service, Nature Conservation Section, Queanbeyan, NSW 2620, Australia
³School of Engineering and Information Technology, University of New South Wales, Canberra, ACT 2610, Australia

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Abstract
The use of passive infrared (PIR) triggered camera traps has dramatically increased in recent decades. Unfortunately, technical descriptions of how PIR triggered camera traps operate have not been sufficiently clear. Descriptions have often been ambiguous or misleading and in several cases are demonstrably wrong. Such descriptions have led to erroneous interpretations of camera trapping data. This short communication clarifies how PIR sensors operate. We clarify how infrared radiation is emitted and transmitted, and we describe the parts of the PIR sensor and how they detect infrared radiation and, by extension, fauna. Several problematic descriptions of PIR sensors are drawn on to highlight flawed descriptions and demonstrate where erroneous interpretations of camera trapping data occurred. By clarifying the language and the description of PIR triggered camera traps, this paper ensures that wildlife researchers and managers using camera traps will avoid flawed interpretations of their data. Avoiding flawed interpretations of data should reduce wasted effort and resources that would otherwise come about as researchers attempt to test flawed hypotheses. Furthermore, this paper provides a thorough technical reference for camera trapping practitioners, which is not present elsewhere in the wildlife research literature.

Introduction
The use of camera traps in terrestrial vertebrate research has grown rapidly in the past two decades (Cutler and Swann 1999; Burton et al. 2015). Much of the growth in camera trapping is derived from mammal related studies, with slower uptake seen in studies of birds, reptiles and amphibians (Burton et al. 2015). Camera traps are triggered in a variety of ways such as time-lapse triggers (e.g. Cochran and Schmitt 2009); microwave sensors (e.g. Glen et al. 2013); mechanical triggers (e.g. Guyer et al. 2012); active infrared (AIR) sensors (e.g. Karanth et al. 2006) and passive infrared (PIR) sensors (e.g. Welbourne et al. 2015). Although a plethora of camera trap brands are available (Trailcampro 2015), camera traps triggered by PIR sensors dominate the market and are used most frequently. Despite this, from a technical perspective PIR triggered camera traps appear to be the most misunderstood, as evidenced by existing published studies. Descriptions in the wildlife research literature of how PIR sensors operate are often ambiguous or misleading and in several cases plainly wrong. In the following examples, we have italicized problematic terms associated with their description and briefly outline why they are problematic. In the ‘Clarifying problematic descriptions’ section we expand upon these explanations. Swann et al. (2004) stated that PIR sensors ‘detect differences between ambient background temperature and the rapid change in heat energy caused by a moving animal’, which is ambiguous since ambient may refer to air temperature or the surface on which the animal is moving. Rovero et al. (2010) stated that PIR sensors detect ‘heat-in-motion’ and trigger the camera ‘when something warmer than the ambient temperature passes in front of the sensor’, which
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Infrared radiation

All objects above absolute zero (i.e. 0 K or −273.15°C) emit electromagnetic radiation (Caniou 1999). Emitted radiation is not distributed uniformly across the electromagnetic spectrum. The distribution of emitted radiation depends upon an object’s surface temperature and surface properties. Surface properties of an object are its transmissivity (τ), reflectivity (ρ) and emissivity (ε). Transmissivity is the fraction of electromagnetic radiation that passes through the object; reflectivity is the fraction of electromagnetic radiation reflected off of the object; and, emissivity is the ratio of an object’s radiance to a blackbody at the same temperature (Kaplan 2007). For electromagnetic radiation interacting with a body, these properties sum to one (i.e. τ + ρ + ε = 1). The ‘blackbody’ is a theoretical object that is a perfect emitter (i.e. ε = 1); that is it does not reflect (ρ = 0) or allow electromagnetic radiation to pass through (τ = 0) (Kaplan 2007). Using Planck’s Law the emittance distribution of a blackbody object at specific temperatures can be determined (Driggers et al. 2012). Hence, Figure 1 demonstrates that the peak emissions for a blackbody with surface temperatures between 0–60°C occur between approximately 8–11 μm wavelengths.

Real world objects such as animals, plants and rocks are obviously not blackbodies. Blackbodies do not explain how these components operate. In the penultimate section we directly address several common problematic descriptions, and then conclude the paper by suggesting a suitable way forward.

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produce energy internally. Through metabolic process, animals do, which adds to the absorbed and re-radiated energy of the body, which is affected by the surface emissivity. Furthermore, the surface of objects can be categorized as ‘blackbodies’, ‘greybodies’ and ‘non-greybodies’. The difference between these surfaces is that the emissivity of blackbodies equals one \( (\varepsilon = 1) \), whereas the emissivity’s of greybodies and non-greybodies is \(<1 (\varepsilon < 1)\) (Fig. 1). Greybodies differ from non-greybodies by having relativity high emissivities that are relatively constant with wavelength (Kaplan 2007). Although blackbodies ‘do not exist in practice, the surface of most solids are greybodies’ (Kaplan 2007). Emissivities of most objects in the natural environment are \( \geq 0.90 \) (Driggers et al. 2012). For example the emissivity of human skin is 0.98 (Driggers et al. 2012), human hair and bear fur is 0.91 and 0.95, respectively (Preciado et al. 2002), and reptile skin and geese feathers are 0.96 (Best and Fowler 1981; Tracy 1982). Therefore, for most objects in the natural environment whose surfaces are near ambient temperature \( (21^\circ C) \), peak emissions occur at approximately 10 \( \mu m \) (Fig. 1).

Passive infrared sensors work by detecting electromagnetic radiation emitted from objects. The amount of radiation that reaches the sensor depends upon the medium that the electromagnetic radiation is propagating through. In a vacuum, no energy is lost and all emitted radiation is received by the sensor. Yet, in Earth’s atmosphere not all wavelengths propagate equally since some molecules absorb electromagnetic radiation (Driggers et al. 2012). At sea level, water \( (H_2O) \) and carbon dioxide \( (CO_2) \) are the primary absorbers (Fig. 2). Although absorption is negligible over distances of tens of centimetres, absorption in specific parts of the spectrum becomes substantial over metres (Gerritsma and Haanstra 1970; Kaplan 2007). Fortuitously, there are two primary ‘atmospheric windows’ in which electromagnetic radiation is transmitted with little loss in energy; one between 3–5 \( \mu m \) and a second between 8–14 \( \mu m \) (Figs 1 and 2) (Gerritsma and Haanstra 1970; Driggers et al. 2012). Since bodies near ambient temperatures peak in emittance at approximately 10 \( \mu m \), and given the 8–14 \( \mu m \) atmospheric window, PIR sensors used in wildlife research are tuned to detect 8–14 \( \mu m \) wavelengths (Keller 2000).

**Components of PIR sensors**

The two key components of a PIR sensor, at least for wildlife research, are the Fresnel lens and the pyroelectric sensor (Fig. 3). The Fresnel lens focuses incoming electromagnetic radiation onto the pyroelectric sensor. The pyroelectric sensor contains a pair of pyroelectric elements and an infrared filter. The infrared filter allows only wavelengths of approximately 6–14 \( \mu m \) to reach the pyroelectric elements (Excelitas Technologies Corporation 2015). The pyroelectric elements use the pyroelectric effect to generate an electrical current when they are different temperatures to one another (Kaplan 2007). When used in a camera trap, the camera is triggered when the electrical current generated by the pyroelectric elements exceeds a given threshold. Due to differences in the Fresnel lenses and pyroelectric sensors installed in different camera trap models, different camera traps will vary in their efficacy for detecting particular species (e.g. Swann et al. 2004; Damm et al. 2010).

The Fresnel lens is the optics of the PIR trigger. The two types of Fresnel lenses used in camera traps are either single-zone or multi-zone lenses; and there are many versions of multi-zone lenses (Fig. 4). The Fresnel lens in Figure 3 depicts a single-zone lens; that is electromagnetic radiation from only a single area is focused onto the sensor. Figure 5 depicts a multi-zone Fresnel lens, representative of the Scout Guard SG550v Fresnel lens in Figure 4C. A multi-zone lens is analogous to an array of single-zone lenses stacked together. Each detection window focuses electromagnetic radiation onto the pyroelectric sensor. All detection windows taken as a whole is the camera traps ‘detection zone’. The Fresnel lens does not alter how the pyroelectric sensor functions as lenses are manufactured from polyethylene, which is highly transparent to 8–14 \( \mu m \) wavelengths (Kaplan 2007). The Fresnel lens simply alters where in the environment the pyroelectric sensor is ‘looking’.

**How PIR sensors operate**

As the name suggests, the PIR sensor is a passive device. That is the PIR sensor does not emit any radiation; it simply detects infrared radiation being emitted from the surface of objects in the detection zone. The pyroelectric
sensor triggers the camera when the pyroelectric elements produce a sufficiently large electrical current. The required magnitude of the current depends upon the programming and settings of the camera trap. The pyroelectric elements produce a current when they are different temperatures to one another. Pyroelectric elements change temperature in accordance with the electromagnetic radiation they receive from objects in the environment. To differ in temperature, the pyroelectric elements simply need to detect different wavelengths of electromagnetic radiation to one another. The pyroelectric elements normally detect different wavelengths of electromagnetic radiation to one another when two surfaces in the detection zone have different surface temperatures and the PIR sensor moves; or, when an object with a different surface temperature from background objects (i.e. the two objects are emitting different wavelengths of electromagnetic radiation) moves into the detection zone of the PIR sensor.

To understand this in practice, consider a simple system. In Figure 3, excluding reflected radiation, the pyroelectric elements would detect infrared radiation being
emitted from the surface of the wall. If the wall uniformly increased or decreased in temperature, both elements would receive identical levels of electromagnetic radiation and, therefore, would not differ in temperature to one another and the camera would not be triggered. Now, consider the macropod entering the detection zone from the near side in Figure 3 and assume its surface temperature is sufficiently different to that of the wall. The pyroelectric element on the near side (red) would receive a different level of electromagnetic radiation than the element on the far side (green). The difference in electromagnetic radiation would cause the pyroelectric elements to differ in temperature, which would produce an electrical current and trigger the camera. Whether the macropods’ surface temperature is greater or less than the wall is irrelevant to the trigger event. The process is the same for multi-zone PIR triggers. Imagine the macropod transiting from left to right in Figure 5A. As the macropod enters one of the detection windows, the left most pyroelectric element will detect a different temperature to the right element, subsequently triggering the camera.

The various environments that wildlife researchers encounter in the field are far more complicated than the simple system discussed above. In Figure 3 we represented the ‘background’ as a flat wall, which is normally absent in the field. In reality the ‘background’ environment would ordinarily consist of a thermally heterogeneous combination of objects such as trees, shrubs and rocks. For example Figure 6 is a thermogram of an area in which a camera trap might be placed. Despite possessing almost homogeneous air temperature and the exposed foreground receiving similar levels of solar radiation, the tree and grass exhibit different surface temperatures due to their different thermal properties (Kaplan 2007). Thermal heterogeneity in the environment can affect the efficacy of PIR sensors in several ways, with false-triggers (trigger events without an animal present) being the most obvious. Moving objects that are warmer or cooler than background substrates, for instance a branch or shrub, will cause the camera to be triggered. Equally, if a camera trap is mounted to something that moves, for example a pole that wobbles due to wind, false triggers can also occur. Although thermal heterogeneity can affect PIR sensor efficacy, it does not change how the PIR sensor functions.

Clarifying problematic descriptions

Although we have not formally categorized and quantified problematic descriptions, they generally relate to either the origin of infrared radiation or the process by which PIR sensors operate. We explained in the ‘Infrared radiation’ section that infrared radiation is emitted from the surface of objects. Hence, infrared radiation is emitted from an animal’s outer most surfaces whether that is bare skin, fur, feathers or scales. Therefore, any reference to an animal’s body temperature (e.g. Rovero et al. 2013) or core temperature (e.g. Meek et al. 2015) affecting a PIR trigger is ambiguous at best and technically incorrect at
worst. The term ‘body temperature’ is ambiguous since some authors use it to refer to an animal’s core temperature (Rovero et al. 2013), whereas other authors use body temperature to refer to an animal’s surface temperature (Lerone et al. 2015). Referring to an animal’s core temperature is erroneous since the core temperature of an animal is not necessarily its surface temperature, which is especially true for animals that are wet or covered in fur or feathers (Tregear 1965; Best and Fowler 1981; Best 1982; Raske et al. 2012; Lerone et al. 2015). When discussing PIR sensors in the described manner, we urge authors to consistently refer to an animal’s ‘surface temperature’.

Using the term ‘surface temperature’ is also advised when discussing the temperature of objects in the environment. Swann et al.’s (2004) reference to ‘ambient background temperature’ is ambiguous since ‘ambient temperature’ could mistakenly be interpreted as ‘air temperature’ (e.g. Clark and Orland 2008; Ariefiandy et al. 2013). In fact, Bennett and Clements (2014) recognized the ambiguity of this term when they stated “in the present case, ‘ambient’ temperatures mean tree trunk surface temperature”. A close reading of Swann et al. (2004) suggests they are referring to the surface temperature of objects and not the air temperature. Still, it is not clear that McGregor et al. (2015) is referring to surface temperatures when they state ‘cats would not be detected on any camera on warm days where ambient and cat temperatures are identical’. To avoid future confusion, again we recommend authors consistently refer to ‘surface temperature’.

The effect of air temperature on PIR sensors appears to have created some confusion in the camera trapping literature. Examples range from claims that PIR sensors detect a difference between the animal and the air temperature (e.g. Clark and Orland 2008; Ariefiandy et al. 2013), through to suggestions that PIR sensors ‘can be triggered by the movement of pockets of hot air’ (Rovero et al. 2013). These and other examples referring to air temperature affecting PIR sensor function are erroneous. As illustrated above, infrared radiation between 8 and 14 µm propagates with very little energy lost to the atmosphere (Fig. 2) (Gerritsma and Haanstra 1970). Since air has high transmissivity, its reflectivity and emissivity are very low. Put simply, regardless of the air temperature, PIR sensors in camera traps do not ‘see’ the air, but instead see through it. Consequently, unless authors are discussing how air temperature might affect surface temperatures and thus emitted radiation, there is no reason to refer to air temperatures when discussing the function of PIR sensors.

‘Heat-in-motion’ or ‘heat-and-motion’ are terms often used to describe PIR triggered camera traps (Rovero et al. 2013). These terms are misleading. Using this terminology implies that PIR sensors function only when warm objects or ‘something warmer than the…[background surface] temperature passes in front of the sensor’ (Rovero et al. 2010). As we have discussed above, objects with sufficiently higher surface temperatures than the surface temperatures of background objects, by virtue of their emittance will cause the PIR sensor to trigger the camera. But, likewise, objects with sufficiently lower surface temperatures than the surface temperatures of background objects will also cause the PIR sensor to trigger the camera. Although this terminology is regularly encountered in the popular literature, we urge authors to avoid use of this term in the scientific literature. Instead, reference should be made to differences between surface temperatures of objects, which should clarify that both warm and cool objects can be detected by PIR sensors.

Conclusion

The use of PIR triggered camera traps has dramatically increased in recent decades. As more researchers adopt the technology, our understanding of the limitations and advantages of camera traps compared to traditional detection methods grows. Unfortunately, technical descriptions of how PIR triggered camera traps operate has not been as clear as it might have been. Descriptions so far have often been ambiguous or misleading and in a growing number of cases are demonstrably wrong. Fortunately, there are hitherto relatively few instances of erroneous interpretations of camera trapping data due to these misunderstandings. Nevertheless, erroneous interpretations of data may cause researchers to waste effort and resources as they attempt to falsify flawed hypotheses. By clarifying how PIR sensors operate, practitioners will have a solid foundation for interpreting data collected by camera traps, and may also think more carefully about the deployment of such devices, thereby leading to improved research outcomes. When authors describe the function of PIR sensors in future research, it is best kept simple and consistent. Merely referring to ‘surface temperature’ and describing the PIR sensor as detecting a difference in said surface temperature seems sufficient. Put another way, PIR sensors detect the surface temperature of objects in the detection zone and trigger the camera when a rapid change in temperature is detected.

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