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Spectral analysis of blood stains at the crime scene

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8 - INFRARED IMAGING OF THE CRIME SCENE: POSSIBILITIES AND PITFALLS

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All objects radiate an amount of infrared energy invisible to the human eye, which can be converted into visible images by infrared cameras, visualizing differences in temperature and/or emissivity of objects. As a result of improvements in technology and a decrease in costs infrared imaging is an emerging technique for law enforcement and forensic investigators. The rapid, non-destructive and non-contact features of infrared imaging indicate its suitability for a wide range of forensic applications, which can be divided into two approaches; passive and active infrared imaging. The passive approach, referring to infrared imaging without using an external energy source, is useful for non-contact radiation measurements, e.g. for the estimation of the time of death, which is currently often based on invasive rectal temperature measurements. Passive infrared imaging of objects at the crime scene can provide new investigative leads, e.g. an indication of recent human contact or the time since a device was used. Active infrared imaging requires external heating or cooling of the target prior to imaging. Using this approach, contrast can be visualized between traces and their surroundings due to differences in thermal response, e.g. blood stains on red carpet. This chapter provides an overview of the principles and instrumentation involved in infrared imaging. Difficulties concerning the image interpretation due to different radiation sources and different emissivity values within a scene are addressed. Finally, reported forensic applications are reviewed and supported by practical illustrations.

8.1. INTRODUCTION

Infrared cameras, also known as thermal cameras, convert invisible infrared radiation into visible images. This technique was originally developed for military use but has since found application in such diverse fields as medicine¹⁴⁸, agriculture and the food industry^{149, 150}. As a result of improvements in technology and a decrease in costs infrared imaging is an emerging technique for law enforcement and forensic investigators. Previous work showed that infrared imaging of crime scenes has serious potential for aiding forensic case work¹⁵¹⁻¹⁵⁴. It is a non-destructive technique, which can reveal information invisible to the naked eye.

Infrared imaging is suitable for a wide range of forensic applications, and can be divided into two approaches; passive and active infrared imaging. The passive approach, referring to infrared imaging without using an external energy source, is useful for non-contact radiation measurements. As all objects radiate an amount of infrared energy, increasing with temperature, the radiation detected by infrared cameras can be used to measure temperatures and visualize temperature differences. However, the amount of infrared radiation emitted by an object is also influenced by the emissivity value, which should be taken into account when temperatures or temperature differences are measured. An interesting forensic application of passive infrared imaging is the estimation of the post mortem time interval, which is currently often based on invasive rectal temperature measurements. Using passive infrared imaging, a post mortem body temperature can be recorded non-invasively, without the risk of contamination¹⁵¹. Additionally, passive infrared imaging of objects at the crime scene can provide new investigative leads, e.g. an indication of recent human contact or the time since a device was used¹⁵².

Active infrared imaging requires external heating or cooling of the target prior to imaging. Using this approach, surface inhomogeneities can be visualized, due to differences in thermal response. When heated with an external source, e.g. blood traces on similarly coloured backgrounds and invisible to the human eye may be highlighted on infrared images. The external

heat source can be part of the active thermal imaging system, but may also be a human body, a domestic heating or an air-conditioning system.

External heat sources also complicate the interpretation of infrared images of a crime scene, as the image of a target object is influenced both by the surrounding objects, and by the presence of the investigators who emit infrared radiation. Infrared radiation that enters the camera lens is a combination of emitted, transmitted and reflected radiation, and comes from three different sources: the target object, its surroundings, and the atmosphere. To guarantee a correct interpretation of infrared images, investigators should be trained and educated, and standardized protocols for image capture and analysis are needed.

In this chapter we describe the possibilities and pitfalls of thermal imaging for crime scene investigation. Although this topic is scarcely covered in forensic literature, we review the existing literature and elaborate on some of the proposed applications using practical illustrations. While infrared imaging can also be useful in the forensic laboratory^{155, 156} and for surveillance purposes¹⁵⁷, this chapter is confined to crime scene purposes only. Next to a theoretical background, recent advances in infrared imaging technology are described, which reduce the size and costs of the equipment and thus enable future applications at the crime scene.

8.2. THEORETICAL BACKGROUND

8.2.a INFRARED EMISSION

All objects with a temperature above the absolute zero emit infrared radiation. The amount of energy emitted by an object increases with temperature, as described by Stefan-Boltzmann's law:

$$W = \sigma \epsilon T^4,$$

where W is the total amount of energy emitted by an object per square meter (Wm^{-2}), σ is Stefan-Boltzmann's constant ($5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$), ϵ is the

emissivity of the object and T its temperature (K). This relation between emitted energy and temperature is the basis of infrared imaging. It shows that the temperature of an object can be determined by measuring the radiated energy if the emissivity of the object is known, which is defined as the energy emitted by an object relative to the energy emitted by a blackbody at the same temperature.

A blackbody is a theoretical object with an emissivity of 1. In practice, the emissivity of an object can vary from 0 to 1, and depends on temperature, wavelength, material and the surface texture of an object. Objects with glossy surfaces have a lower emissivity than objects with matt surfaces, e.g. aluminum foil has an emissivity of approximately 0.1, water and human skin of 0.98¹⁵⁸⁻¹⁶⁰. Emissivity values for common materials and surface characteristics can be looked-up in tables or estimated experimentally, e.g. by comparing infrared images of an object at two distinct known temperatures¹⁶¹. Although a perfect blackbody absorbs all infrared radiation, all real objects react to incident radiation from their surroundings by absorbing, reflecting and transmitting a portion of it. The sum of the object's incident energy absorbance (α), reflectance (ρ), and transmittance (τ) equals one:

$$\alpha + \rho + \tau = 1.$$

At thermal equilibrium, the amount of absorbance will equal the amount of emission (Kirchhoff's law):

$$\alpha = \varepsilon. \tag{8.1}$$

Combining these equations shows that the emissivity of an object can also be estimated by measuring the reflectance and transmittance at thermal equilibrium and using the following equation¹⁶²:

$$\varepsilon = 1 - \rho - \tau.$$

8.2.b INFRARED IMAGING SYSTEMS

Infrared imaging systems detect infrared radiation and convert this to an image, similar to a common camera that forms an image using visible light. A typical infrared imaging system comprises an optical system, an infrared detector, a signal processing unit and an image acquisition system. Many characteristics of infrared radiation are similar to visible light; infrared radiation can be focused, refracted, reflected and transmitted. However, infrared cameras cannot use regular glass lenses, as glass will reflect infrared radiation rather than allowing the radiation to pass through the lenses. Commonly used materials for infrared lenses and their respective transmission windows are Germanium (Ge, 2-11 μm), fused Silica (IR grade SiO_2 , 0.2-4 μm), Zinc Selenide (ZnSe , 0.5-11 μm) and Zinc Sulfide (ZnS , 3-10 μm).

These lenses are used to focus the infrared radiation onto a focal plane array of detectors, which in turn convert the radiant energy into electrical signals proportional to the amount of radiation. Two types of detectors are known¹⁶³: thermal detectors and photon detectors. In classical photon detectors (e.g. HgCdTe (0.8-25 μm), InGaAs (0.7-2.6 μm)), photons are absorbed and generate free carriers which produce a current, voltage or resistance change of the detector. Photon detectors are highly sensitive, but require cooling, which implies a significant increase in cost, weight and size. In thermal detectors (e.g. microbolometers), infrared radiation causes a temperature rise of a thermally isolated detector element, which is a measure of the amount of radiation. These detectors do not require cooling, but are in general less sensitive than photon detectors. However, recent technological advances enable higher performance of uncooled thermal detectors, as well as low power lightweight detectors, proficient for helmet mounted systems, robotic systems and micro-air vehicles¹⁶⁴.

When selecting an infrared imaging system, an important aspect is the operating wavelength range. Most infrared cameras operate in the wavelength range from 3 to 5 μm or from 8 to 12 μm , because the absorption of the atmosphere is minimal in these windows (Figure 8.1). The required

temperature range is an important selection criterion, as the emitted wavelengths are temperature dependent, a relation described by Planck's law:

$$B(T) = \frac{2hc^2}{\lambda^5} \left(e^{\frac{hc}{\lambda k_B T}} - 1 \right)^{-1}, \quad (8.2)$$

where B is the spectral radiation, T is the absolute temperature of the black body, k_B is the Boltzmann constant ($1.3806488(13) \times 10^{-23} \text{ JK}^{-1}$), h is Planck's constant ($6.62606957(29) \times 10^{-34} \text{ Js}$), and c is the speed of light ($2.99792458 \times 10^8 \text{ ms}^{-1}$).

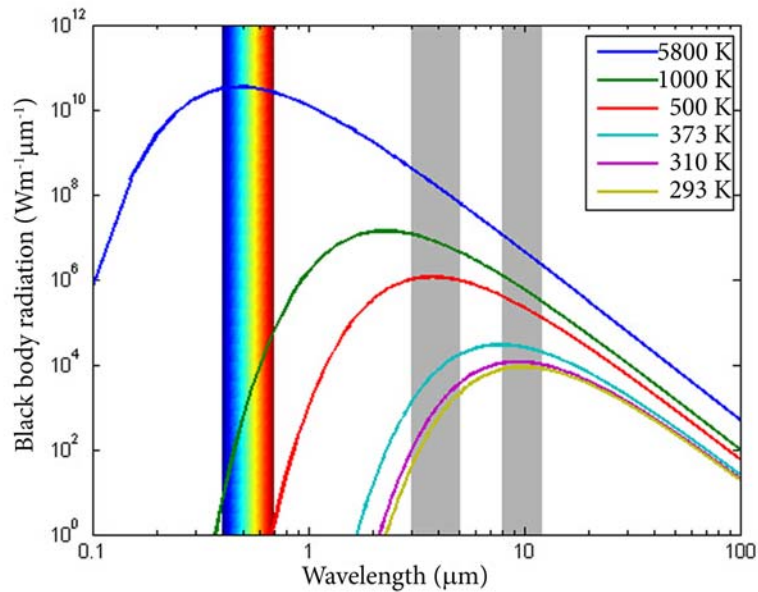


Figure 8.1. Wavelength dependent radiation emitted by a perfect black body at different temperatures, calculated using Planck's law (formula 8.2). The visible wavelength range is depicted by the coloured bars. Grey bars illustrate the atmospheric infrared transmission windows in which most cameras operate.

The resulting radiation for a blackbody at several temperatures is depicted in Figure 8.1, which shows that the wavelength of the emission peak is lower for hot objects. The peak wavelength (λ_{\max} (μm)) can be calculated using

$$\lambda_{\max} = b / T,$$

in which b is Wien's displacement constant, equal to 2.89×10^{-3} mK, and T the absolute temperature (K). This formula shows that the sun, with a temperature of approximately 5800 K, has a peak emission around 500 nm, which lies in the visible wavelength range. Objects at room temperature and human body temperature emit peak radiation around 10 μm , in the far infrared.

8.2.c IMAGE INTERPRETATION

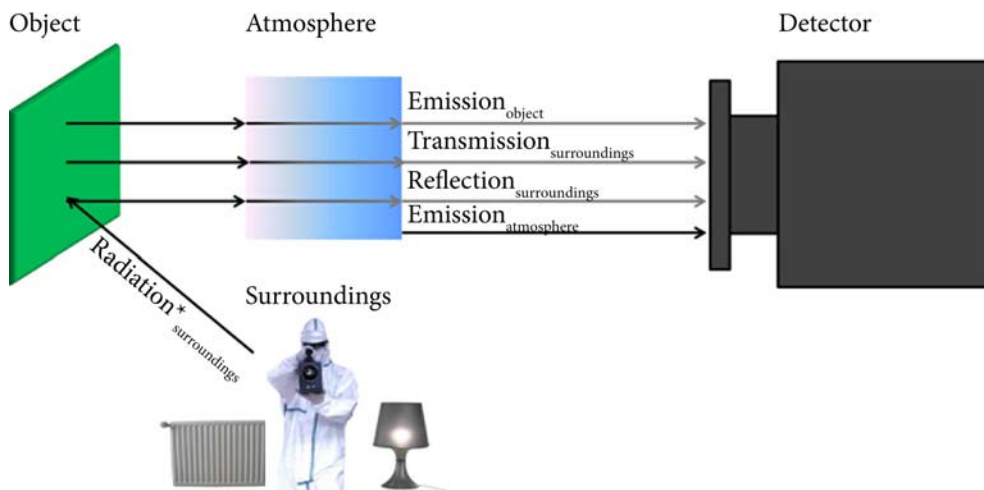


Figure 8.2. Schematic showing the contributions of the target object, its surroundings, and the atmosphere to the total radiation detected by an infrared camera.

An infrared camera converts infrared radiation to an image, displaying variations across an object or a scene. Interpreting these infrared images is not straightforward, as the camera receives radiation emitted from the target object, plus radiation from its surroundings that is transmitted through or reflected by the object (Figure 8.2). All these radiation components become

attenuated when they pass through the atmosphere. Since the atmosphere absorbs part of the radiation, it will also emit some itself (Kirchhoff's law, formula 8.1). Consequently, the radiation that impinges on the camera lens comes from three different types of sources: the target object, its surroundings, and the atmosphere. Differentiating between emitted, transmitted and reflected radiation is not possible (Figure 8.3), which is a probable cause of misinterpretation.

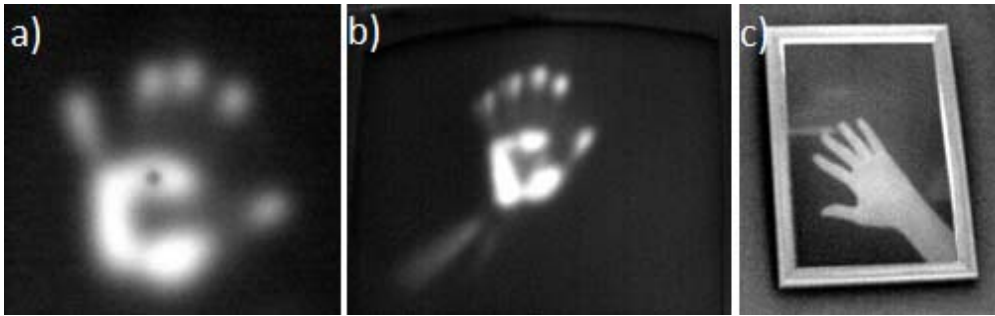


Figure 8.3. Infrared images depicting: a) Emitted radiation of body heat left by a hand pressed shortly against the wall, prior to recording the image. b) Transmitted radiation of the body heat of a hand through the door of a closet. c) Reflected radiation of body heat, reflected by the picture frame.

To calculate the temperature of the target object, infrared camera software requires input for the emissivity of the object, the atmospheric transmittance, the object distance, atmospheric temperature, and ambient temperature. Consequently, for images showing objects with different emissivities the input parameters should be adjusted for each material in order to compare the temperature of different objects. Thus, false-colour infrared images and temperature scale bars usually provided by infrared imaging software must be interpreted with caution (Figure 8.4).

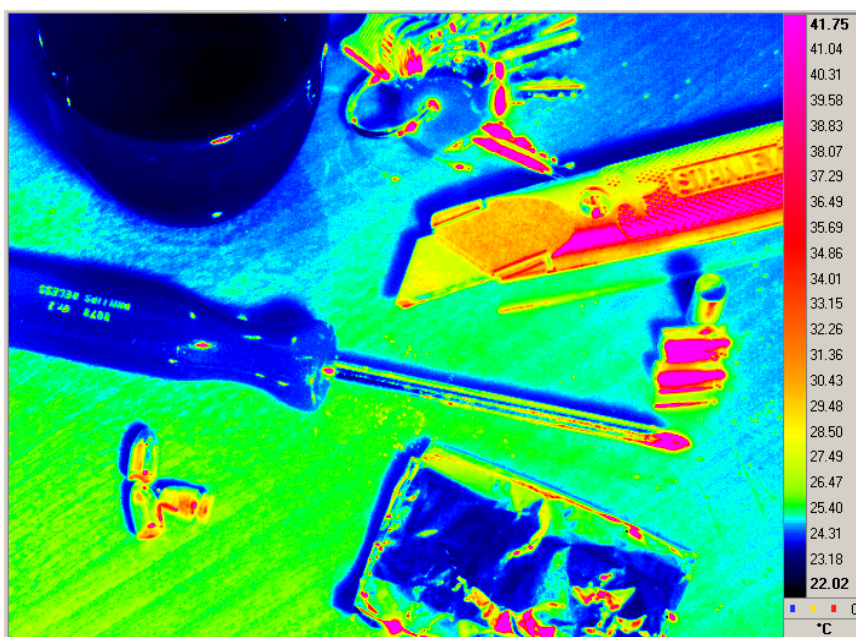


Figure 8.4. False-colour infrared image of a cup of water, keys, a knife, a screw-driver, bullets, bullet cases and aluminum foil on a table. All objects have room temperature. The scale bar on the right is based on an emissivity value of 0.98, and thus only shows the right temperature for the water (room temperature) in this scene.

To guarantee a correct interpretation of infrared images, investigators should be trained and educated, and standardized protocols for image capture and analysis are needed. Measurements of objects with low temperatures or low emissivities are most critical, since the relative contribution of external radiation is high in those cases.

8.3. APPLICATIONS

Several applications of infrared imaging for crime scene investigation have been proposed in conference proceedings^{152, 165} and scientific journals^{151, 153, 154}. In this section we elaborate on the theoretical background of possible applications, illustrated with some practical examples. Difference is made between applications using passive and active infrared imaging. Passive

infrared imaging can be used to investigate heat traces, which cause contrast because of temperature differences. Active infrared imaging can be used to visualize differences in thermal response, by using an external heat source.

8.3.a PASSIVE INFRARED IMAGING

Because the human body temperature is usually higher than the environmental temperature, people leave heat traces invisible to the human eye, which can be observed with an infrared camera. Consequently, infrared imaging can give insight in the recent presence of people and recently handled objects. As it is frequently possible to obtain DNA from an individual who has simply touched an object¹⁶⁶, this is highly important information supporting crime scene investigators in their search for trace evidence. Additionally, information about the presence of people and recent activities is useful for crime reconstruction purposes and for the verification of statements.

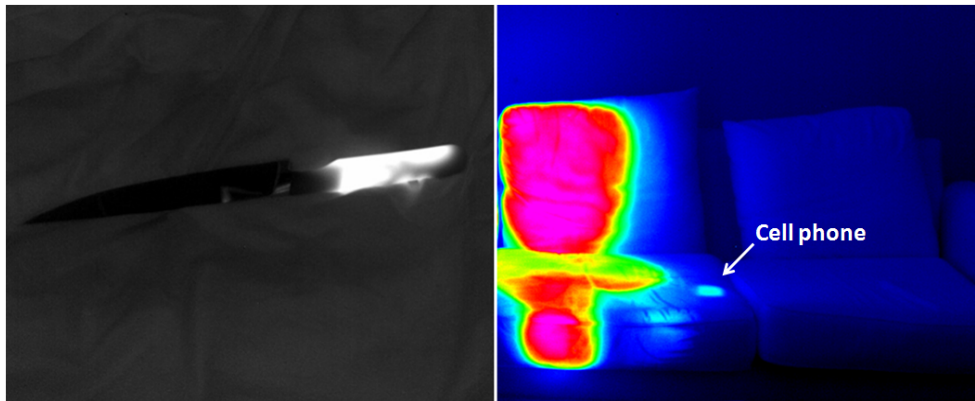


Figure 8.5. Heat traces of human contact with a knife (left) and a couch (right), visualized in greyscale and false colours respectively. Additionally, a heat trace of a cell phone is visible on the couch.

Figure 8.5 shows two examples of human heat traces visualized by an infrared camera, indicating the handle of the knife and one side of the couch were recently touched. As described above, these images should be interpreted with caution, but can give valuable qualitative information. In case contrast changes

are observed in time, this indicates the contrast will be due to temperature differences instead of emissivity differences. The time traces stay visible depends on the temperature difference, the material properties and the environmental conditions, e.g. the heat on the knife was visible for a few minutes, the heat on the sofa for an hour.

Apart from the human heat trace, Figure 8.5 shows the heat trace of a cell phone. Van Iersel et al showed the visibility of heat traces from cups of fluid and electronic devices, e.g. a computer screen¹⁵². These traces may also provide information useful for reconstruction purposes. Heat traces may lead to an indication of the time since an object was used. For instance, if the barrel of a gun is still warm, experiments can be performed to measure a cooling curve specific for the gun after firing in similar environmental circumstances. By comparing the cooling curve with the heat measured at the crime scene, the time since firing can be estimated.

The post mortem cooling curve of a body can also be recorded by infrared imaging^{151, 154, 165}. Currently, the Henssge nomogram is the gold standard for the estimation of the post mortem interval; the time since the death of a person. Henssge's nomogram is based on empirical data of human body cooling and requires the ambient temperature, the rectal temperature, the weight of the body and a clothing parameter to be able to lookup the estimated post mortem interval¹⁶⁷. Rectal temperature measurements are not favorable in a forensic setting because of the high risk of contamination and possible loss of traces of sexual assault. Since infrared imaging is non-invasive it is highly profitable to explore the possibilities of this technique for post mortem temperature measurements.

However, as infrared imaging systems measure the skin temperature instead of the core temperature, new models are required to determine the post mortem interval based on skin temperatures. Before application in forensic practice, new models need a thorough validation. Several promising studies have been performed on the post mortem cooling of the human head^{151, 168}. Figure 8.6 shows an infrared image of a body and the postmortem cooling curve. Based on such measurements, a model for postmortem skin cooling can be developed. Mall et al¹⁶⁸ stated that changes in ambient temperatures highly

influence the skin temperature, and thus need to be taken into account in a model for postmortem skin cooling. This is confirmed by the cooling curve in Figure 8.6, where fluctuations in the ambient temperature, caused by the cooling system, are clearly visible in the temperature measurements. A disadvantage of using infrared imaging for post mortem interval estimation is that the temperature of the skin decreases more quickly to the environmental temperature than the core of the body. A benefit is the high emissivity value of the human skin (0.98), which implies that reflections of surrounding heat sources are minimal. However, the skin is not always directly visible. Measurements on clothing are possible, but this severely complicates the interpretation.

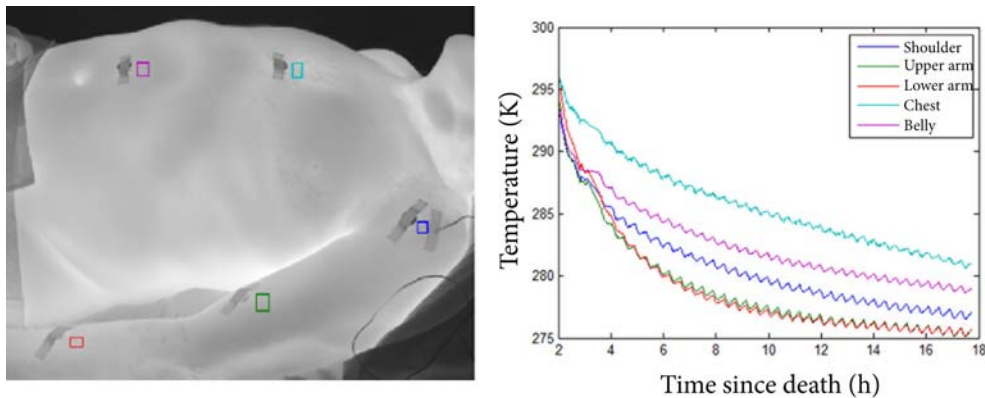


Figure 8.6. Infrared image of a body (left) and the cooling curves of regions of interest (indicated by the rectangles) on the shoulder, upper arm, lower arm, chest and belly (right).

Infrared imaging of a human body may lead to additional information relevant to forensic medical examiners, as reviewed by Ammer¹⁵⁴. Blunt traumas without skin damage may be detected using infrared imaging, due to an inhomogeneous temperature distribution. Similarly, hematomas due to strangulation may become visible using infrared imaging, which helps investigators in their search for crime-related DNA traces.

Apart from heat traces, wet traces are also easily visualized using infrared imaging. Figure 8.7 demonstrates an infrared image of a wet blood

stain hardly visible to the human eye. The infrared image shows high contrast between the wet blood stain and its background. This may be due to evaporation, which causes cooling of the blood stain, combined with the high absorption of infrared radiation by water. Regardless the physical explanation, it is clear that infrared imaging can be used to visualize fluids. After drying, in general less contrast is observed between stains and their backgrounds. In these cases, active infrared imaging can be applied, which is described below.

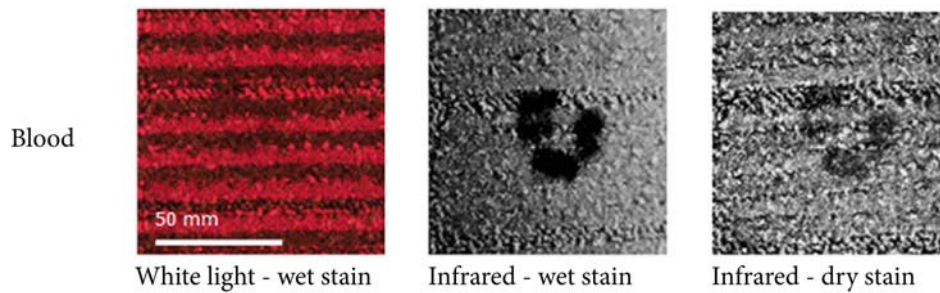


Figure 8.7. Photograph taken with white light (left) and infrared images of blood stains on carpet. The first infrared image (middle) was created passively while the stain was wet. The second infrared image (right) was created actively after drying. More contrast is observed for the wet stain. This may be due to evaporation, which causes cooling of the blood stain, combined with the high absorption of infrared radiation by water.

8.3.b ACTIVE INFRARED IMAGING

Even traces in thermal equilibrium with the environment can be visualized using infrared imaging, if the thermal response is different from its surroundings. The thermal response of a material is influenced by many physical properties including the conductivity, diffusivity, specific heat and radiative properties (emissivity, absorbance, reflectance and transmission). Inhomogeneities in the thermal response become evident when an external source causes a temperature change. This external source can be part of the active infrared imaging system, but may also be a human body, a normal building heating or an air-conditioning system (Figure 8.2)¹⁶⁵. By recording the

heating and cooling process of an object, inhomogeneities can be visualized (Figure 8.8).

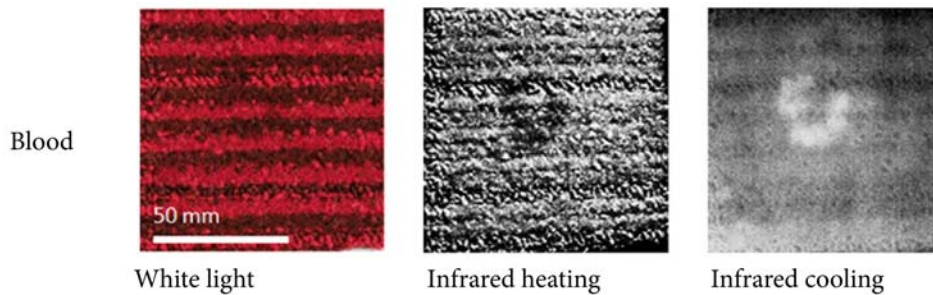


Figure 8.8. Photograph taken with white light (left) and infrared images of blood stains on carpet. The first infrared image (middle) is created using an external heat source. Contrast is observed because more heat is absorbed by the blood stain than by the background, which makes it appear darker. The second infrared image (right) is created after removal of the external heat source. In this case, contrast is observed because the absorbed heat is reemitted by the blood stain, which makes it appear brighter.

Based on this principle, drag traces may be visible long after thermal equilibrium is reached, because of an abraded surface, which causes a different heat flow^{152, 154, 165}. Another application is the visualization of body fluids. Brooke et al used active infrared imaging for the detection of blood on a dark, acrylic fabric¹⁵³. They reported contrast differences between the clean fabric and the fabric stained with blood diluted as low as 1:100. Additionally, they were able to discriminate between a blood stain and four common interfering agents (bleach, rust, cherry soda, and coffee) to other blood detection methods.

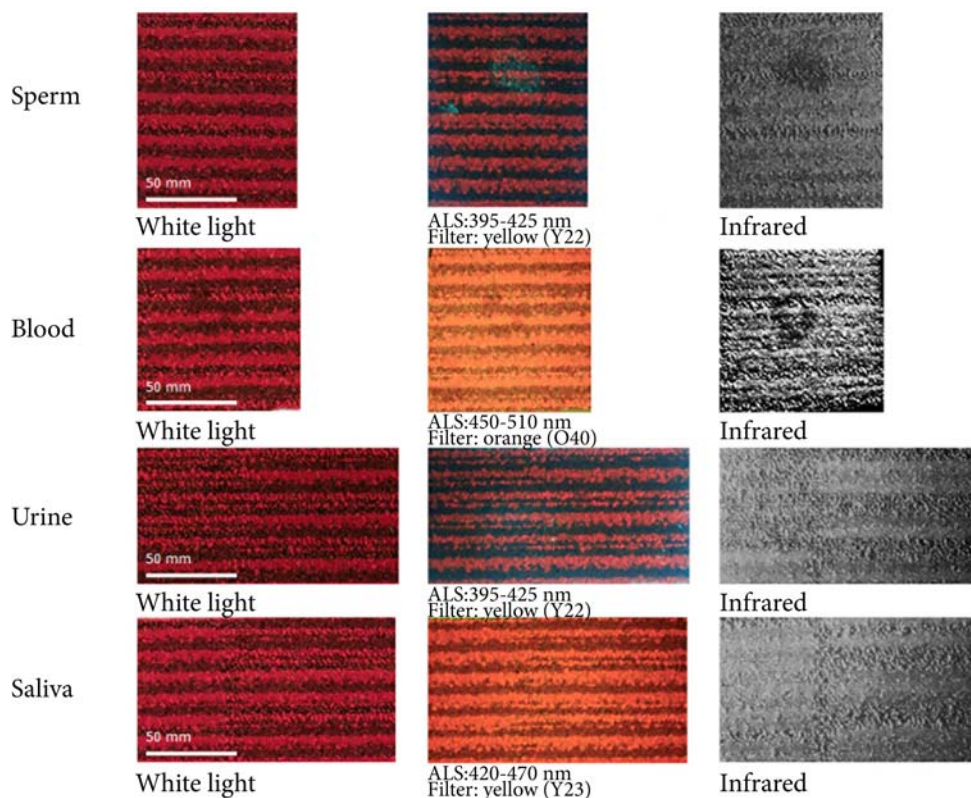


Figure 8.9. Photographs taken with white light (left) and alternative light sources (middle) and infrared images (right) of sperm, blood, urine, and saliva on floor tiles. Infrared images are created using an external heat source.

To explore the value of infrared imaging for the detection of body fluids, we compared the results with photographs taken using alternative light sources and filters. Sperm, blood, urine, and saliva stains were deposited on red/brown floor tiles and photographed using white light and a combination of alternative light sources and filters. The best results are shown in Figure 8.9, next to the infrared images of the floor tiles. This figure demonstrates that urine and sperm are highly fluorescent, which make them ideal candidates for visualization with alternative light sources. However, infrared imaging of sperm also revealed contrast on this background, in contrast to the urine stains, which could not be visualized using infrared imaging. On the other hand, blood stains

hardly visible to the naked eye became evident using active infrared imaging, while alternative light sources did not generate much contrast between the stain and its background. Saliva stains were not visible using either method. Success or failure of both methods highly depends on the background; the use of alternative light sources is hampered by highly absorbing (dark) backgrounds, infrared imaging is more difficult when stains are deposited on inhomogeneous structures or when there is a lack of thermal contrast.

8.4. DISCUSSION AND CONCLUSION

Infrared imaging of crime scenes has serious potential for aiding forensic case work. It is a non-destructive technique, which can reveal information invisible to the naked eye. Both temperature differences and differences in thermal material properties can induce contrast in infrared images. The use of passive or active infrared imaging at the crime scene can provide both investigative leads and evidence in court (provided the used technique is properly validated and accepted). Applications described range from the estimation of the post mortem interval to the visualization of blood traces on dark backgrounds.

We demonstrated the post mortem cooling curves of several parts of the human body (Figure 8.6). These curves were measured non-invasively using passive infrared imaging, which minimizes the risk of contamination and possible loss of traces of sexual assault. After a thorough validation and development of an appropriate mathematical model, this technique may be able to replace the current standard: Henssge's nomogram, an empirical model based on core body temperature measurements. Apart from measuring post mortem temperatures, infrared imaging can be used to detect heat traces caused by human contact (Figure 8.5). These traces indicating human presence or the recent use of objects can help investigators in their search for DNA or other relevant crime-related traces in those cases the incident recently happened.

The amount of time it takes until thermal equilibrium is reached depends on the temperature difference and the object properties; while a human heat trace on a knife may only be visible for a few minutes, a human

body can stay warmer than the ambient temperature for more than 24 hours after death. Consequently, heat traces are only temporarily available, and therefore crime scene investigators are advised to start the crime scene survey with infrared imaging. However, to preserve heat traces only shortly visible, it may be possible to provide first responders with a helmet mounted infrared camera (preferably combined with a normal video camera), as currently already available for firefighters. Infrared camera systems used for forensic purposes are ideally wireless, portable, waterproof, and sealed (to avoid contamination). Due to recent developments infrared imaging becomes more sensitive, user-friendly and cost effective. Consequently, an increased adoption of this technology by forensic investigators is highly likely.

When used actively, i.e. with an external heat source, infrared imaging can be used for the detection of traces not or hardly visible to the naked eye. We compared images of several body fluids on carpet created using alternative light sources (ALS, the current standard) with the corresponding infrared images (Figure 8.9). This comparison demonstrated that the success rate of both ALS and infrared cameras highly depends on the type of trace and its background. The well known expression “Absence of evidence is not evidence of absence” is certainly in place. Viewed from the perspective of a forensic investigator at the crime scene all information gained with different techniques used on the crime scene can be useful, provided they are correctly interpreted. Due to the fact that no single technique is capable to detect and identify all types of traces at the crime scene without the need of further confirmation, we can combine different techniques to search for all kinds of traces. To conserve traces for further analysis, non-destructive techniques are preferable.

In conclusion, we showed several potential applications of infrared imaging for crime scene analysis. Many of the applications discussed are still at an experimental stage. Initial experiments for the estimation of the time of death using infrared imaging are promising. Additionally, as it can help in the search for crime related traces, infrared imaging can be a good addition to the resources of the crime scene investigator. However, before infrared imaging can be used as evidence in the courtroom, several (key) steps have to be taken; are refining and validation of the technique to meet the needs of the legal and

scientific communities. Prior to that, infrared images may be used indicatively to lead the further investigation. When introduced in forensic casework, infrared imaging can help investigators detecting, visualizing and identifying useful evidence non-destructively.

8.5. ACKNOWLEDGEMENTS

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