Exploration of Active and Passive Infrared Thermography in Crime Investigation and Forensic Science

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ABSTRACT: At above absolute zero temperature, infrared (IR) rays will be radiated from an object while the ray itself is invisible to the naked eye. With the help of IR thermography equipment, the invisible thermal radiation transmitted from the object would then be converted to an image (thermo-image or thermogram), allowing the visualisation of invisible IR radiation. This exploratory study focused on the advantages of IR thermography as a rapid, non-contact and non-destructive detection method with the potential of passive and active IR thermography. The experiment simulated real-life situations encountered at a crime scene. The results suggested that passive thermal imaging, an imaging method driven by temperature differences, could assist in seeking and determining the number of suspects present. It could also highlight vehicles that were recently driven and guns that were recently shot and show cartridge cases left at crime scenes in dark environments. Furthermore, active thermal imaging with external energy input (light source, heat, etc.) was also assessed in this study. Its usefulness was limited in cases where an external light source was present when searching for bloodstains. Successful detection of bloodstains could be achieved in cases where the IR thermography equipment's temperature was reduced to –20°C for 60 min, followed by immediate use for detection after its removal from cooling.

Keywords: crime investigation; forensic science; thermal infrared image; bloodstain; non-destructive detection; thermography

Introduction

On-site investigation is not only information gathering but also case recording and exhibit collection and preservation. It is also an extremely crucial step in the entire crime investigation process [1, 2]. On-site inspection begins with a search using non-destructive light sources [3], followed by chemical tests, collection of exhibits and laboratory analysis, among others. This step marks the start of the investigation of a criminal case. The initial search uses light sources with different wavelengths within a broad spectrum of visible light. With the help of these light sources, the latent marks and hidden evidence could be visualised and easily identified. For instance, alternative light sources (ALS) with wavelengths of 300–700 nm (visible) are commonly used for latent evidence searching [4, 5]. Other light sources that are in use also include infrared (IR) with wavelengths of 700–14,000 nm, and IR is invisible to the naked eye, but has characteristics similar to those of visible light in reflection, refraction, absorption and radiation. IR could be further divided into five subgroups according to its wavelengths: near IR (NIR), wavelength 700–1,000 nm; shortwave IR (SWIR), wavelength 1–3 µm; mid-wave IR, wavelength 3–5 µm, longwave IR, wavelength 8–12 µm and far IR, wavelength 12–1,000 µm.

Given its excellent penetrating ability, NIR and SWIR with wavelengths ranging from 750 to 1,200 nm have been commonly used in crime scene investigation involving forged documentation and certificates [5], gunshot residue [6], bloodstains [7] and skin tattoos, among others. Bloodstain evidence deposited on dark-colour substrates can be visualised and recorded because of the differences in IR absorption between the bloodstains and the background substrate: bloodstains would absorb IR, whereas background substrates would not, thus generating an image with an obvious contrast. Modifications of different IR photography equipment also helped with bloodstain detection [8-11]. Additionally, photogrammetry can help produce virtual 3D models of objects and scenes. The application of visible light, IR, hyperspectral and thermal images has also been integrated in simulated crime scenes, demonstrating the advantages and practical challenges of their use in forensic practice [12].

The first IR thermography (IRT) was developed in Sweden in 1958. At above absolute zero temperature, IR rays will be radiated from an object. Then, the thermal radiation transmitted from the object would be received and converted to an image, which is a process known as IR imaging, thermal imaging or thermogram. The invisible IR used in IRT is the thermal IR with a longer wavelength of approximately 3–12 μm. Because IR could be absorbed in the air, a higher transmittance was observed mainly at wavelengths 3–5 and 8–12μm (referred to as the atmospheric absorption window). Therefore, most IRTs use these two ranges for detection [13-15].

IRT works similar to that of an ordinary camera. IR rays could pass through the optical lens and focus on the thermal imaging detector. Then, energy is transformed into electric power, and the thermal distribution on the surface of the object would then be calculated. Focal plane array (FPA) IRT sensors include photon and thermal detection. The photon detection sensor is highly sensitive; however, its manufacturing process is sophisticated because a low temperature is required to reduce noise. Hence, a photon sensor is commonly used in national defense because it is of large system volume, high cost and very power-consuming. A thermal sensor absorbs heat from IR and then alters the characteristics of its electrical elements to detect IR. It is made of Bolometric materials and manufactured as semiconductors. With a significant reduction in cost, the lack of need for cooling and a much more portable size, a thermal sensor is considered advantageous and widely commercialised. As mentioned, IRTs were initially used for military purposes because of the heavy cost of equipment and highly confidential technologies. Nevertheless, as the technology improves, IRTs were then gradually applied in the field of medical diagnosis [16], construction analysis [17], food product screening and pest inspection [18], algor mortis temperature determination [19, 20], bloodstain detection [19], temperature determination of shot bullet and cartridge cases [20-22] and other research and applications [23].

IR sources detected by IRT for imaging are closely related to the surrounding environment and air: a) the object directly emits IR rays that penetrate the air, b) IR rays from the surrounding environment reflected by the object then penetrate the air, c) IR rays from the surrounding environment that penetrate the air and d) IR rays directly emitted from the air. The aforementioned four IR sources would all be detected by IRTs and thus have various impacts on the resultant imaging and temperature measurement [13]. Crime scene investigators should be equipped with professional knowledge and proper training to ensure the precise measurement of temperatures and accurate interpretation of the thermal imaging using IRT [15].

This exploratory study focused on the advantages of IRT as a rapid, non-contact, and non-destructive detection method, discussing its application in crime investigation, particularly in dark/night environments where investigations must be conducted covertly. Compared with night vision goggles (which require the presence of a light source to function), IRT could function even in the absence of a light source and allow the observation of objects invisible to the naked eye. Therefore, it has great potential as a forensic tool in criminal investigation.

Materials and Methods

Equipment and Instruments

FLIR T420 (FLIR Systems Inc.; OR USA) IRT with an FPA sensor was used in the study. An ordinary digital camera was also used. Both thermal images and photographs could be obtained, as shown in Figure 1 and Table 1. Additionally, there were also various imaging modes. For instance, multi-spectral dynamic imaging (MSX) offers enhancement in thermal imaging details by combining the visible light image at the edge of the object; picture-in-picture provides results with its IR imaging frame overlapping with its visible light imaging. This study mainly focused on the results processed by the MSX mode together with iron or rainbow scale. However, the results processed by all other modes (MSX, arctic, grey, lava, iron and rainbow scales) were also recorded with photographic results. The results were generated on FLIR Tools® as required, saved as different pictures with temperature labelled at the predicted location.

In this study, the rate of human skin emittance [24] was set as 0.98 (while others were set as 0.95), and the reflection temperature was set as 25°C. FLIR ONE attaches to mobile phones and displays thermal images on the device's screen. The Lepton sensor—FLIR's smallest thermal camera module and a visible CMOS camera—enabled FLIR's patented MSX technology, as shown in Table 1.

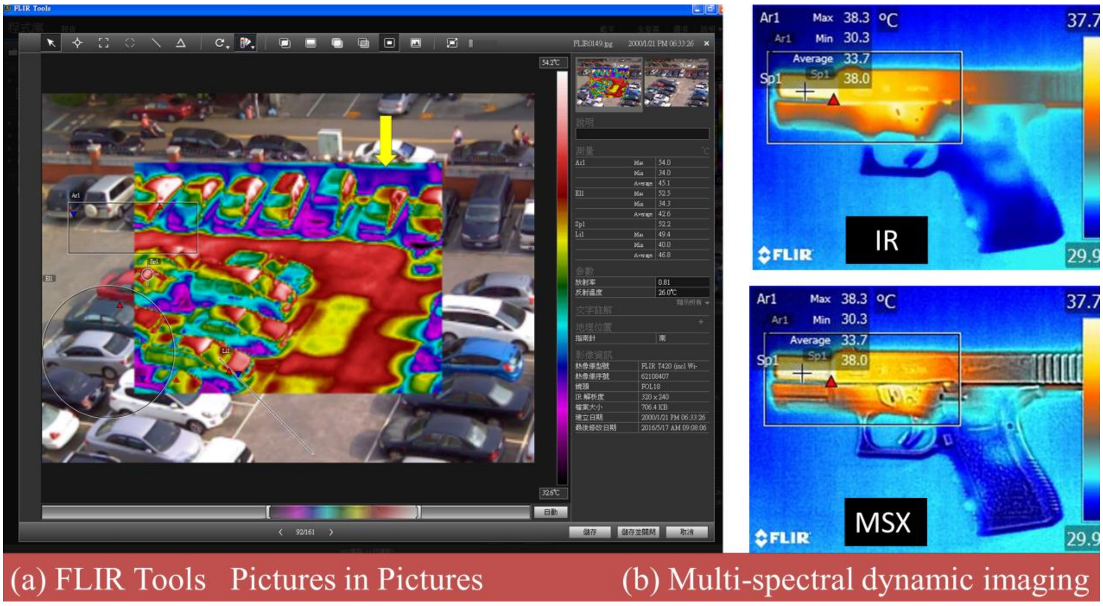

Figure 1: Infrared thermography of picture-in-picture with FLIR Tools® (left). Multi-spectral dynamic imaging (MSX) has a clearer edge than IR thermal image (right).

Table 1: Parameters of two IRT equipment specifications.

Instrument hardware and conditions	IRT (FLIR T420)	Mobile IRT (FLIR ONE)
Wave band	Longwave IR 7.5–13.0 μm	8–14.0 μm
Sensor type	FPA, Microbolometer	Lepton
Pixel pitch	320 × 240	160 × 120
Calibration range	−20°C to 650°C (set as −20°C to 120°C)	−20°C–120°C
Visual camera	3.1 megapixels (640 × 480)	3.1 megapixels (640 × 480)

Simulated Sample Preparation

We simulated a situation that on-site personnel may face and used IRT to take thermographs.

- First, people hide in cars during drug dealings. They may open the windows to conduct transactions or do so in dark places. Second, investigators observe whether vehicles are occupied and the number of people from a distance. Finally, in a dark environment, suspects may slightly wind down the car windows during drug deals. One minute after walking barefoot on floor tiles, IRT thermographs were acquired and recorded.
- After driving for 10 min at approx. 60 km/h, the car was parked next to several others. Thermographs were immediately acquired and recorded using IRT. FLIR ONE on the mobile phone was also used to acquire thermographs.
- Ten rounds of 9 mm Luger were fired at the target, and the condition of the shells and gun status were immediately observed and recorded with IRT.
- A few drops of blood were placed on a dark blue vest and left to dry overnight. Such bloodstains could be observed under visible light. In that scenario, we acquired and recorded IR thermographs in the presence of an external light source, heat and other forms of energy input.

Experimental Methods

The experiment simulated the real-life situations encountered in the crime scene. The results from two types of methods (passive and active IR thermography) were recorded [17, 18].

Passive IRT Method [17]:
IRT was simply used to measure and record the temperature of the target. For example, when tracing the heat of an object or subject, particularly the human body (as it is a good radiator of heat), in a dark environment (without any light source), this IRT could allow investigators to visualise the IR image of the object that was invisible to the naked eye. Various simulated samples were used to assess whether this IRT was suitable for application or whether it would be of assistance.

Active IRT Method [18]:
IR thermographs were measured and recorded in the presence of external light source, heat and other forms of energy inputs. In this experiment, Australian Rofin Polilight® PL400 ALS with wavebands 350, 415, 430, 450, 470, 480, 490, 505, 515, 530, 550, 560, 570, 590, 620 and 650 nm was used. In addition, if temperature increases or decreases by 30ºC, the temperature of the evidence sample will be 0 or 60ºC. Therefore, considering the impact on the evidence, a low temperature is recommended for active IRT. Therefore, the cooling process was completed first using refrigerator (Type: TR6601, Tatung Company, Taiwan).

Results and Discussion

The original thermal image data of FLIR T420 IRT were 12 or 14 bits, which were then converted to 8-bit grayscale or pseudo-colour image. As the conversion of 8-bit grayscale from 12 or 14 bit will reduce the colour layer to 256 (28) colours and result in loss of details, excess colour levels were automatically discarded; however, showing high- and low-temperature regions and any changes in temperature was easier. Pseudo-colour images would retain all details; however, observing the differences in temperature was much more difficult. The results were presented in different forms of images for the purposes of discussion. As mentioned, the results processed by all other modes (MSX, arctic, grey, lava, iron and rainbow scales) were also recorded with the photography results. In this study, the results generated on FLIR Tools with temperature labelled at the predicted location were selected and presented for discussion.

Passive IRT for Heat Tracing

Passive IRT was used for real-life simulation of heat tracing. The thermal image (temperature recording) was processed based on the IR rays emitted from the target object/subject, particularly the human body, because it is a good radiator of heat. Several materials, such as glass that are transparent to the human eye, are impermeable to long-wavelength infrared rays. Variations are observed in the ability of glass windows to block the transmission of infrared rays from human bodies [25].

It allowed the investigators to visualise the IR imaging that was invisible to the naked eye in a dark environment (without any light source), as shown in Figure 2. An image was taken upon arrival at the scene for barefoot heat tracing, shown in Figure 3. However, the temperature differences would no longer be easily observable after a short time (about 5–10 min) because the thermal energy conducted through human contact was relatively low, and heat exchange between the object and ambient environment would soon make it reach the thermal equilibrium.

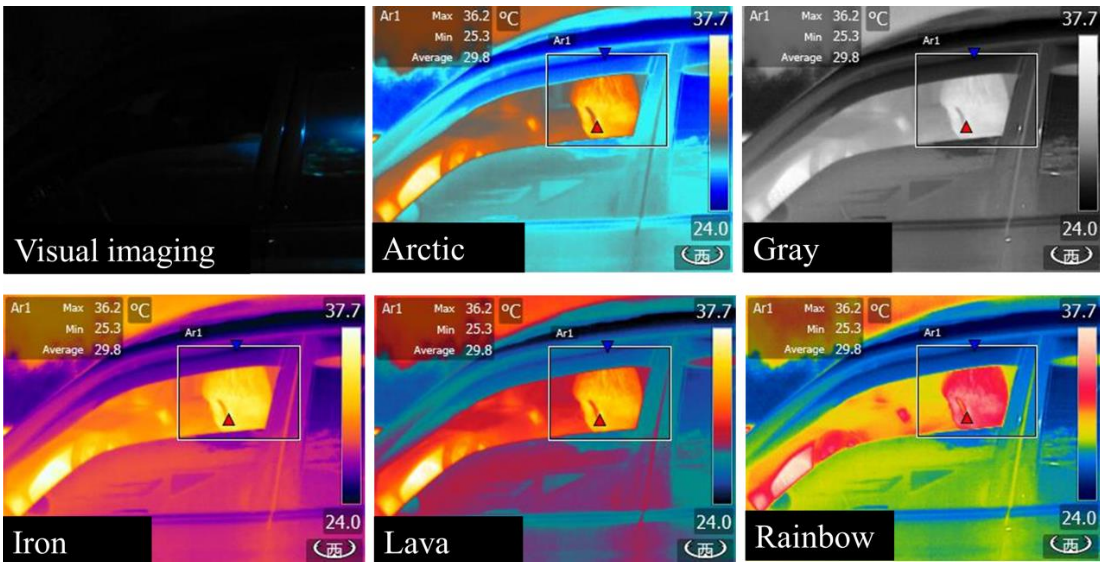

Figure 2: Different scales of IRT. A radiation rate of 0.98 and reflection temperature of 25℃ were set when observing and monitoring individuals inside the vehicle at night. A limitation was that the glass windows would block the transmission of IR rays.

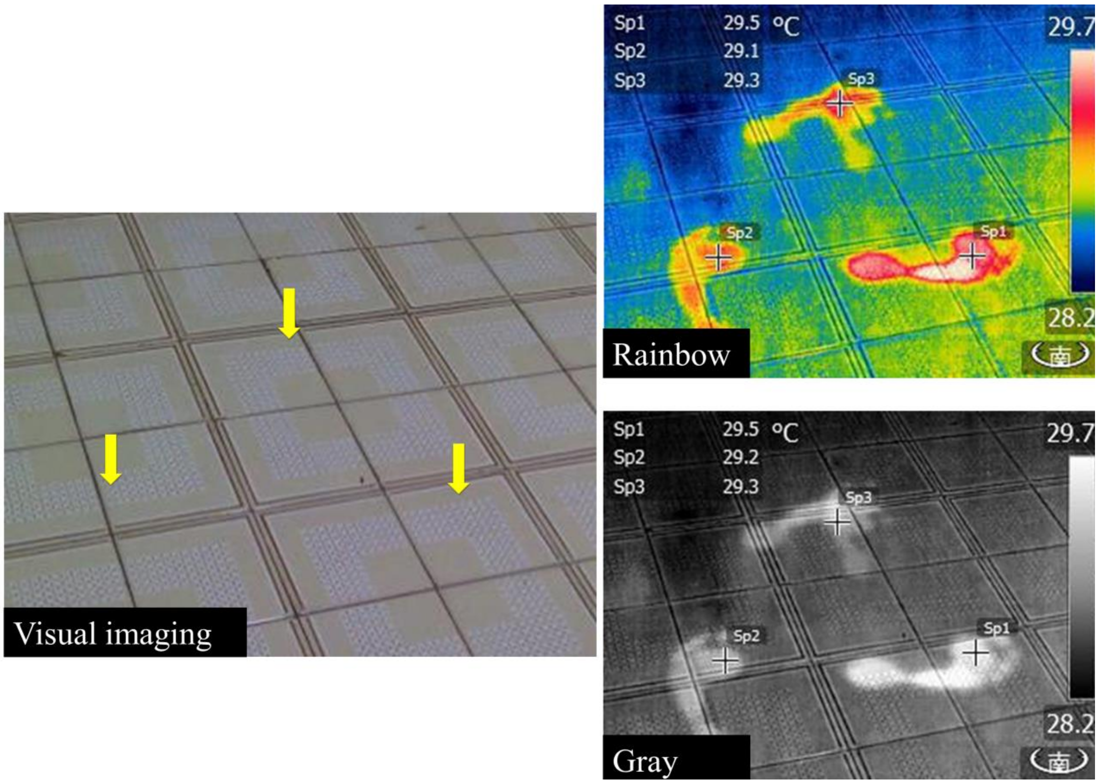

Figure 3: Visual imaging (left), and IR thermal imaging in rainbow scale at a radiation rate of 0.98 and reflection temperature of 25°C (right) for barefoot heat tracing at a crime scene.

When monitoring and observing in a dark environment lacking a light source, getting close to the target vehicles or using a torch was almost impossible for the investigators because these methods would expose the investigators to the scene. Using IRT, the heat of the vehicles parked at the roadside could be traced, and suspicious vehicles that were recently driven and parked could be identified, as shown in Figure 4. Increased heat in the gun barrel or cartridge case were easily observable (Figure 5).

In Taiwan, firearms and ammunition are strictly regulated. Every casing must be located after firing to ensure proper control. This system can be implemented in shooting ranges for real-time monitoring and to streamline the search for used casings, thereby reducing processing time. In addition, many objects are outdoors or in the grass. Therefore, the outdoor temperature is lower than the freshly fired cartridge casing, making it easy to observe when IRT searches scenes [26].

As a non-contact, non-destructive detection strategy, IRT has many advantages for crime scene investigation. Additionally, recent improvements have made IRT more portable as well. For example, IRT can now be connected to external smartphone devices, and FLIR ONE could be used for tracing in an investigation. Increased temperature in vehicles could be observed at the headlights and brake lining but not at the engine hood or wheels after driving (Figure 6). Such improvements increase the opportunities for IRT applications.

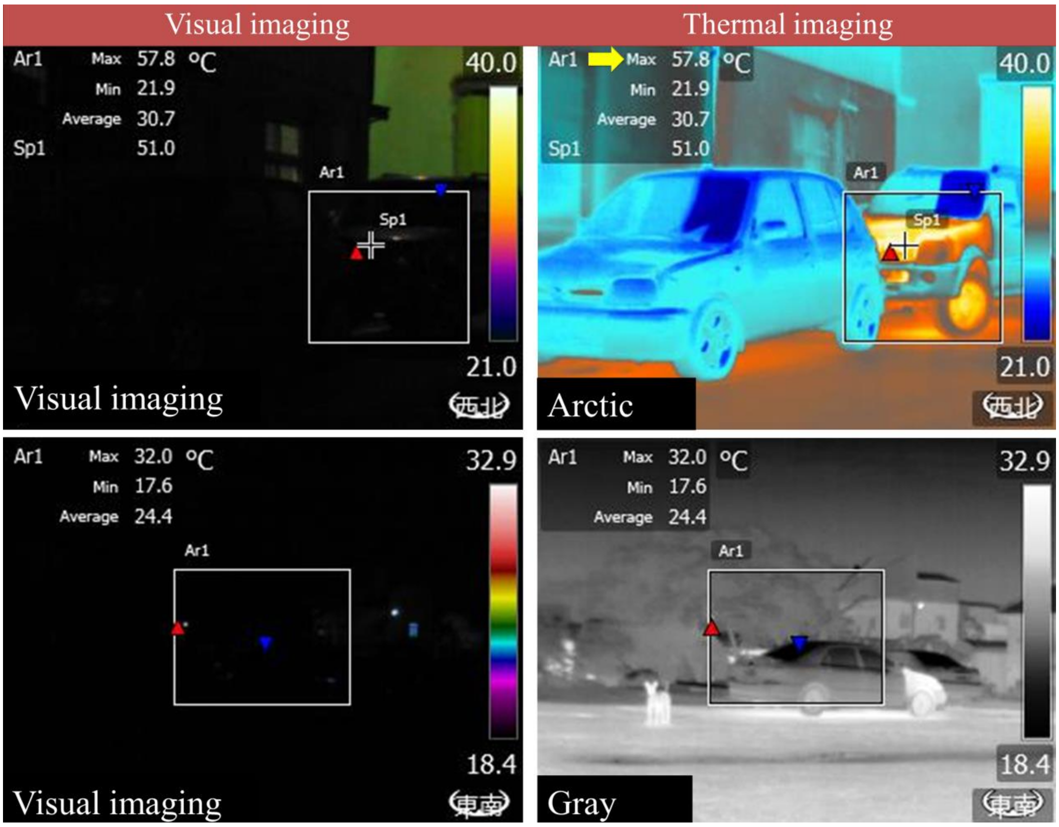

Figure 4: Heat tracing for vehicles at the roadside and targeting suspicious vehicles that just parked. The highest temperature of the vehicle hood could be up to 57.8℃, which was easily observable (above). Living animals would also be easily seen (below).

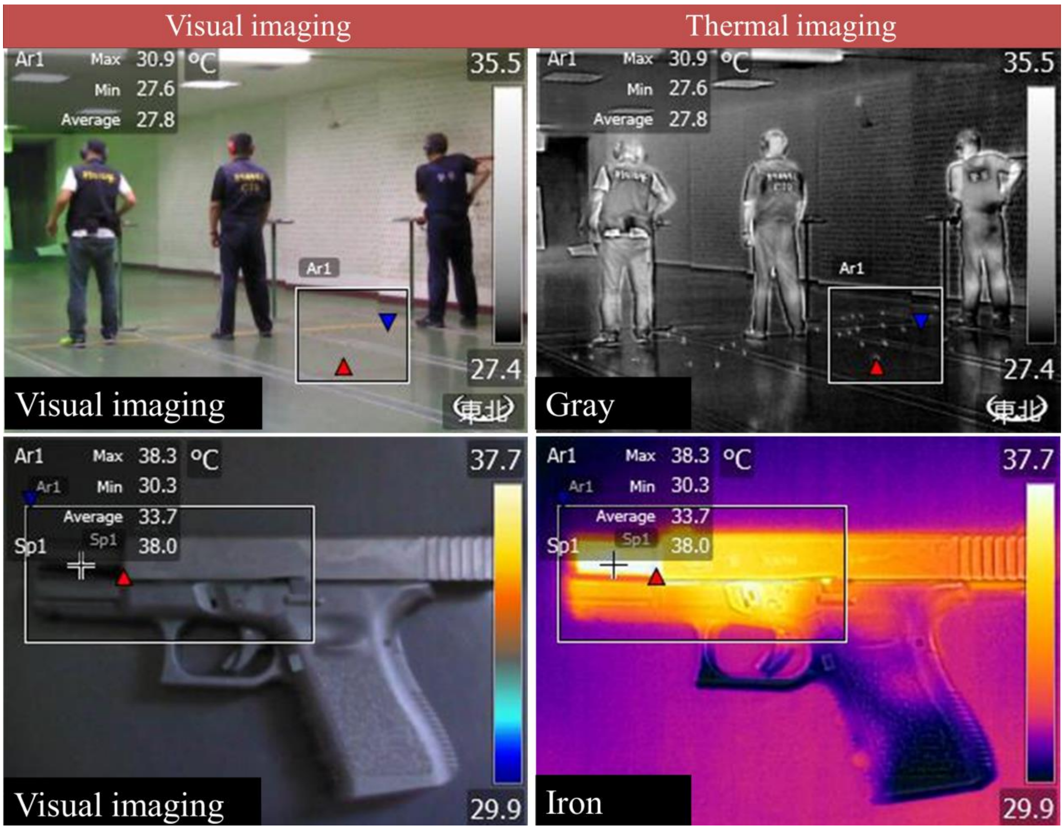

Figure 5: Heat tracing of the cartridge cases (above) and gun (below) after shooting using IRT in iron scale at a radiation rate of 0.98 and reflection temperature of 25℃.

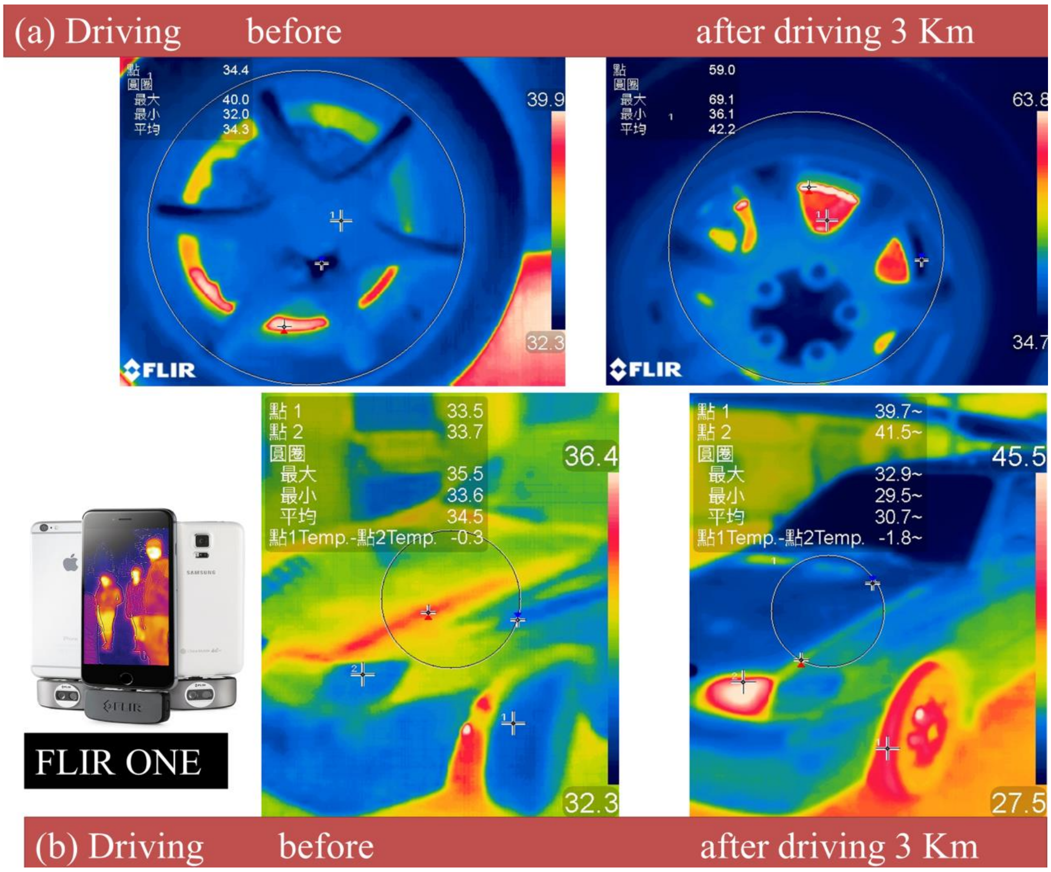

Figure 6: Thermographs processed using FLIR ONE connected to smartphone devices. (a) The wheel temperature was 32℃–40℃ before driving and was 36℃–69℃ after driving, with the highest temperature found at the brake lining. (b) The temperature nearby the hood before driving was 34.5℃–35.5℃; the highest temperature after driving was 41.5℃, which was found at the headlight.

Active IRT for Detecting Temperature Differences

Light sources of different wavebands and temperature control were initially introduced. Rofin Polilight® PL400 ALT with 16 wavebands was used for 3-min irradiation, and observations were made simultaneously. However, distinguishing bloodstains from the clothing fibre was difficult. No bloodstains were found on dark clothes.

Experimental exhibits were removed from the refrigerator (temperature, −20℃). Then, visual and thermal images were recorded, and observations were made at room temperature (30℃) and relative humidity of 50 RH. After cooling the exhibits, they were placed at room temperature and IRT photography immediately performed. As a result, the differences in the thermograph would no longer be easily observable. The results indicated that significant temperature differences would shorten the time to reach thermal equilibrium. Therefore, an immediate and successful imaging process is required, or the entire process would need to be repeated from the cooling step. It was found that different objects (bloodstains and fibres) had a different thermal equilibrium, and that thermography could be useful for searching bloodstains on dark-coloured clothes, as shown in Figure 7 and Table 2.

Several limitations remained when determining temperature through IRT. Note that thermography might represent reflected IR, instead of the location from where the real object and its IR originated (Figure 8). As the typical human body temperature is 36ºC, a temperature of 26ºC also causes similar problems. The image cannot show an actual human being, possibly a reflected image. The amount of energy radiated from an object was closely related to the material structure, material temperature and radiation temperature of the surrounding environment. The surrounding environment and the setting would have huge impacts on the temperature detected. As for the relationship between the reflection temperature and radiation rate, a rate of the object at the scene below 0.5 means that a huge proportion of the IR radiation came from the surrounding environment. Hence, the temperature detected may not accurately reflect the true temperature as the measurement may be affected by IR reflection.

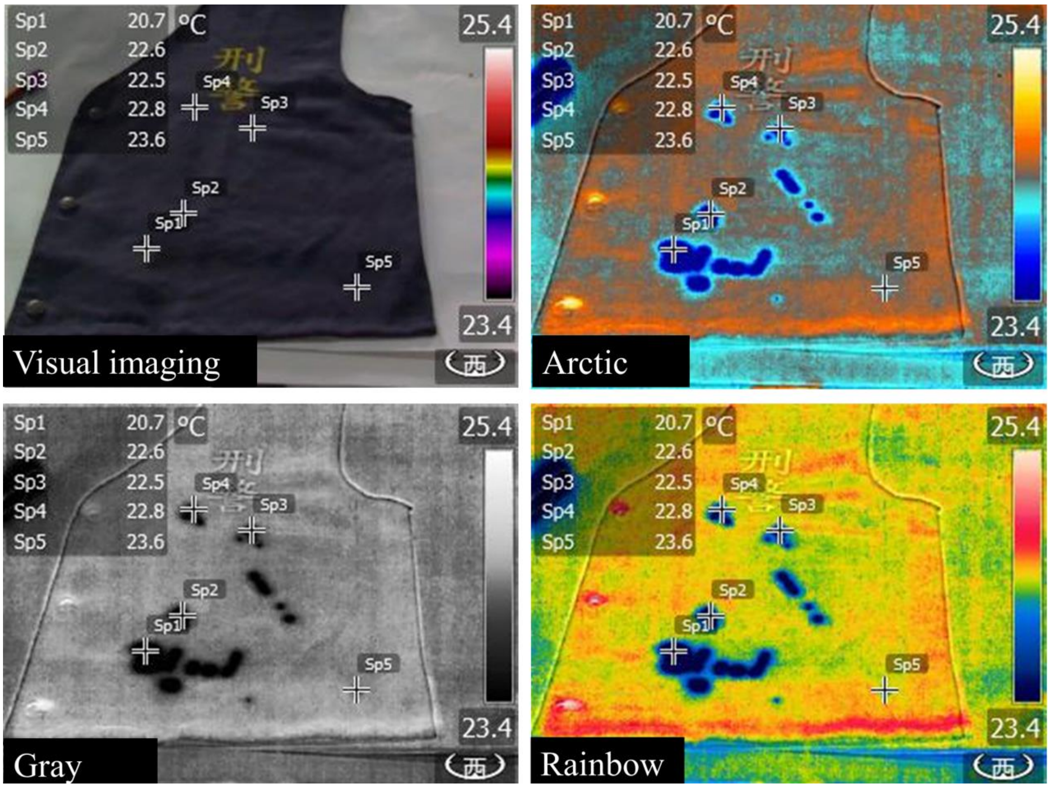

Figure 7: Identification of the suspicious marks (bloodstains) in different scales.

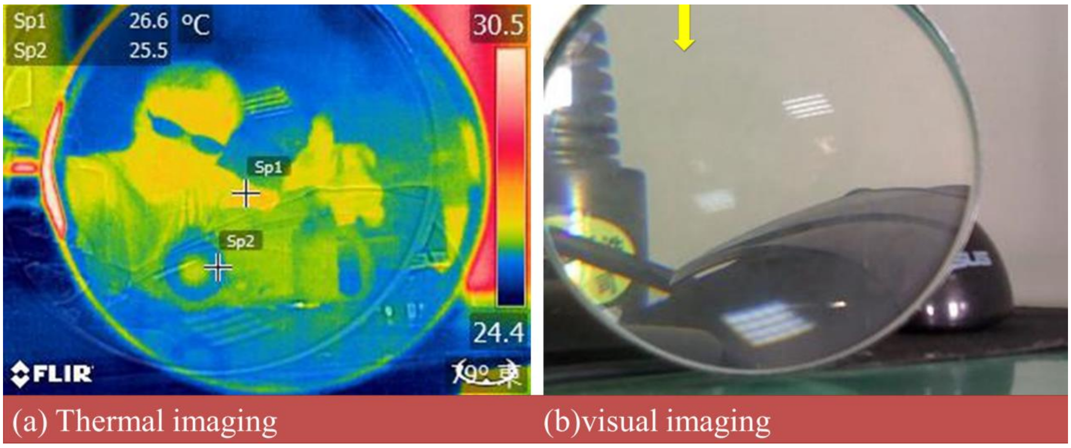

Figure 8: Thermograph (left) detected portrait versus its visual imaging (right) of the same spot. The thermograph might not accurately represent the real location of the individual.

Table 2: Comparison between ALS and temperature on bloodstains on dark-coloured clothes.

	Alternative Light Source	**Temperature**	
Conditions and Time	350–650 nm wavebands each for 3-min irradiation	Cooled at 8°C for 60 min	Cooled at –20°C for 60 min
Under daylight	Bloodstains could be identified at 415 nm	Only allows immediate observation Unable to record visual images	Bloodstains could be visualised within the first 3 min
IRT	No significant differences were observed. Unable to identify bloodstains		Bloodstains could be recorded, shown in Figure 6

Recommendations for successful detection duration

If the detection is related to the thermal radiation emitted by the human body, the duration can be measured at any time as long as the human body is detected. However, suppose it is a temperature difference (barefoot heat tracing and casing temperatures tracing) with the environment. In that case, it is considered temporary evidence on-site and must be recorded as soon as possible. Otherwise, it will reach equilibrium anytime and cannot be observed. Suppose small bloodstains on dark-coloured clothing, objects, or tyres are suspected to be at the scene in the future, and the initial ALS examination yields no obvious results or is unclear. In that case, it is recommended to use active IRT to examine the evidence. Active IR detection can determine temperature differences and enhance observational power.

Conclusion

The results from this simulation study suggested that passive IRT, which mainly focused on temperature differences, could help monitor and detect the number of suspects in a dark environment and search for vehicles driven and guns and cartridges shot recently. However, various objects present in the crime scene require the investigators to pay special attention to temperature measurements. An object with a measured radiation rate of <0.5 (rate of environment reached 0.5) should not be considered a reliable result; however, its thermograph might still be valuable and help with on-site investigation. Owing to the improvements made on IR sensors and on the manufacturing of equipment, which made it much cheaper and more portable, IRT has become a useful tool in forensic science and crime detection. Additionally, with external energy (light, heat, etc.) input, active IRT was found to be less useful in searching for bloodstains. Nevertheless, if the same exhibits were first cooled to –20°C for 60 min, followed by immediate IR imaging, the bloodstains would be observable. Furthermore, because of thermal exchange, detecting bloodstains on thermographs should be immediately performed. The appropriate protocol for stable visualisation still requires further investigation.

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