

Using Infrared Light to Visualize Tire Marks on Clothing

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Abstract: The value of trace evidence in a vehicle-pedestrian collision has been widely reported in forensic science. However, one evidence type that is routinely overlooked is tire marks (e.g., in traffic collision investigations). When an individual is run over by a vehicle, tire marks may be deposited on the clothing. These marks are generally unclear and difficult to visualize in natural light, yet very little research has focused on their enhancement. This work is one of the first to demonstrate the ability of infrared (IR) light to enhance tire marks on clothing. Various clothing items were driven over at a controlled speed and then visualized in IR using both the Video Spectral Comparator VSC6000/HS and the Crime-lite 82S. IR allowed visualization of numerous tire marks, 73% of which were not previously visible in normal white light. IR was also able to considerably improve the clarity of pattern details, even for marks that were visible in white light. The Video Spectral Comparator was compared to the Crime-lite 82S in its ability to enhance tire marks on clothing and was determined to have better visualization, more consistency, and less interference from shadows. This research has highlighted the ability of IR to improve visualization of this evidence type that may otherwise remain undetected.

Introduction

Traffic collisions are the leading cause of death for people aged 5 to 29 years, and the eighth leading cause for all age groups, with approximately 1.35 million annual deaths worldwide [1].

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Forensic investigation of these incidents can be challenging, with a huge reliance on physical evidence such as paint, glass, and tire marks [2, 3]. After contact with a vehicle, these types of evidence may be present on the clothing or shoes of a pedestrian, but can often be overlooked [2]. The lack of research on pedestrian clothing as a source of evidence in these cases is alarming; clothing is often the first to interact with a vehicle at the time of impact and could therefore be vital in identifying the vehicle and determining the circumstances of the incident.

Tire Marks on Clothing

Because motor vehicles are used so frequently in crimes, it is not surprising that tire marks are a common evidence type found at crime scenes. However, this vital evidence is often overlooked because examiners may focus on more traditional evidence such as DNA and fingerprints. Although latent fingerprints are a well-established type of evidence expected at most crime scenes, investigators may not always recognize the possibility that latent tire marks may be present [4]. A tire has class characteristics, such as manufacturer markings and tread patterns, as well as individual characteristics that include wear and damage. Both class and individual characteristics can be transferred to the surface when an impression is made [5] that can be used to identify the vehicle, providing great evidential value in a forensic investigation.

The focus of this research was tire marks on clothing that may be present after an individual has been run over by a vehicle [6]. These tire marks are generally unclear and difficult to visualize in natural white light and may be particularly difficult to see on darker material [3]. Therefore, improving the visibility of tire marks on clothing is desirable in forensic science. This can be achieved using alternate light sources. Lin et al. [7] used infrared (IR) light to visualize a tire mark on the dark blue clothing of a collision victim. This was the first known use of IR to examine tire marks on clothing, with very little research having been carried out in this area since. It is worth noting that tire marks may also be deposited on the inside surfaces of an individual's clothing following a run-over by a vehicle [6, 8], which may be caused by the rubbing of skin cells on clothing during contact with the tire [8]. For the purposes of this paper, the aim of the research was to look solely at tire marks on the outside surfaces of clothing. However, this could provide scope for further work.

Infrared Light (IR)

The use of alternate light sources is well established in many fields of forensic science. Infrared light is commonly used to view latent evidence such as fingermarks, bloodstain patterns, and inks. In a recent study, IR successfully detected bloodstains on fabrics, some of which were not able to be detected using only visual photography [9]. Bastide et al. [10] also used IR to reveal bloodstains beneath a dense layer of soot, demonstrating potential applications to fire scene investigation. In comparison to traditional methods of visualizing blood that involve fluorescent stains or chemicals, IR is an effective alternative as a noncontact and nondestructive technique [9]. IR has also been used to enhance bloodstains and black ink on black fabric that were not visible in white light [7]. In this work, IR did not reveal bloodstains and black ink on some fabric types, possibly because the dyes in the fabric absorbed and reflected IR at similar wavelengths to the bloodstains and ink. This should be considered when using IR to visualize latent evidence, because sufficient contrast between the evidence and background material is needed.

Materials and Methods

Instruments for the Application of Infrared Light

The emergence of alternate light sources in forensic examination has led to the development of specialized equipment that can apply light at different wavelengths to view latent evidence. Two light sources were used in this particular study, although many different light sources from different manufacturers are also available.

The Video Spectral Comparator (VSC) is an advanced scientific instrument developed by Foster & Freeman (Worcestershire, U.K.). Although it is intended and typically used for the examination of questioned documents, the range of illumination options, including visible light and IR, provide opportunity for use with other evidence types.

The Crime-lite 82-S, also developed by Foster & Freeman, is a handheld LED-based light source, with a range of models and wavelength ranges available to suit the examiner's needs.

Clothing

Various clothing items were acquired through donations. These were classified based on the type and material composition, using information from the clothing labels. For simplicity, this research was limited to t-shirts (100% cotton or a cotton-polyester blend) and denim jeans (100% cotton or a cotton-polyester blend). Each pair of denim jeans was cut in half to separate the legs, so that each leg could be treated as a separate item. Table 1 shows the composition of clothing items discussed in this research.

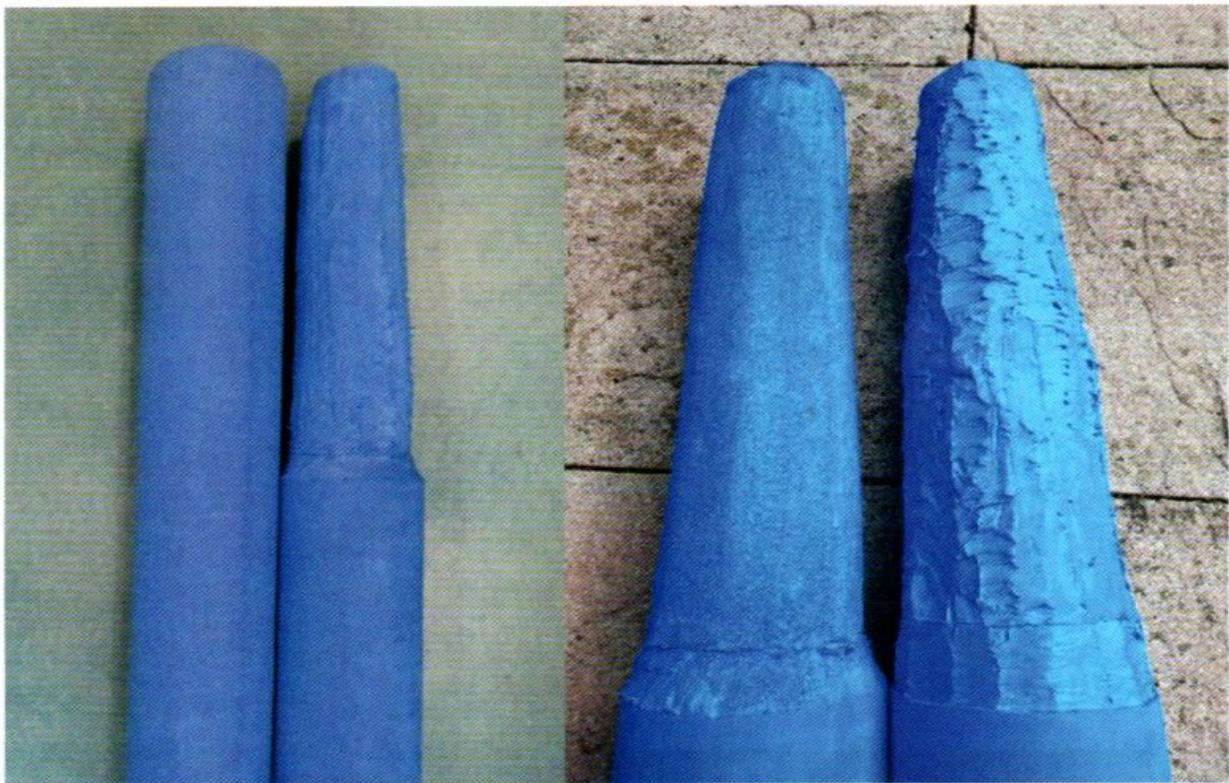
Item	Composition	Quantity
Denim jean leg	100% Cotton	8
Denim jean leg	Cotton / Polyester	4
T-shirt	100% Cotton	5
T-shirt	Cotton / Polyester	5

Table 1

Composition of materials and quantity of clothing items used for this research.

Foam Rollers

To replicate a dynamic, three-dimensional vehicle pedestrian collision, two Gonex foam rollers (Gonex Inc, Denver, CO) made from ethylene vinyl acetate were used to pad out the clothing items. These measured 90.4 x 15.2 x 14.8 cm each and weighed approximately 512 g and 604 g, though weight was not considered to be a significant factor in this research. The rollers had enough resistance to remain three-dimensional during impact from a vehicle, without being too sturdy to damage the vehicle or potentially cause injury to the driver. The rollers were tapered using a scalpel and electric sander to fit inside a trouser leg (Figure 1).



(a)

(b)

Figure 1

Images to show how Gonex foam rollers were modified: (a) unmodified roller (left) and roller tapered with scalpel (right); (b) roller fully sanded with an electric sander (left), alongside a nonsanded tapered roller (right).

Tire Mark Production

Tire marks were made by driving over various clothing items on a dry day at the Police Scotland College, with a high temperature of 15 °C and average humidity about 50% [11]. All tire marks were produced in a single day. The vehicle that was used was a rear-wheel drive 2004 BMW 116i, fitted with a Michelin Primacy HP tire on the front left side and a Sailun Atrezzo Z4+AS tire on the rear left side. Acetate lifts were later taken of the tread and various sidewall details of both the front and rear tires to enable future comparison with the marks. Clothing was positioned in line with the left-side tires and made no contact with either the front or rear right-side tire.

The same vehicle, driver, and road surface (asphalt) were used for each run to reduce extraneous variables. The speed of the vehicle was also kept as constant as possible, with a range between 38 and 42 mph according to the trained police driver.

The tapered foam rollers were inserted into denim jean legs and placed in the path of the vehicle. All jean legs were positioned with the lower leg pointing towards the underside of the vehicle. The same foam rollers were used for all clothing items, alternating between the two rollers to maximize efficiency of the process (one roller was positioned on the ground ready to be run over while the other was being set up with the next clothing item).

For the t-shirts, two foam rollers were taped together. All t-shirts covered the thicker, non-tapered part of the rollers and were positioned with the neck of the t-shirt towards the underside of the vehicle. A line was drawn in chalk to ensure that the roller was repositioned in the same place and angle for each run-over. Figure 2 shows how foam rollers were inside the clothing items and driven over by the vehicle.



(a)

(b)

Figure 2

Photographs showing foam rollers in: (a) a jean leg; and (b) a t-shirt while being driven over by the vehicle. For the jeans, one foam roller was used for one leg, whereas for t-shirts, two foam rollers were taped together.

Enhancement of Tire Marks with Infrared Light Using the VSC6000/HS

Tire marks were visualized using the VSC6000/HS at either 725 nm, 780 nm, or 830 nm, depending on which wavelength offered the best contrast and clarity for each mark and fabric type. The integration and iris settings within the VSC were also adjusted to maximize contrast with the background and to optimize the image. Each mark was photographed with a scale ruler in IR and in visible light.

Enhancement of Tire Marks with Infrared Light Using the Crime-lite82S

Tire marks were photographed in the same position and wavelength as on the VSC, but this time using the Crime-lite 82S as a source of IR light. Two wavelength ranges were used: 730 to 800 nm and 800 to 900 nm.

Photography

The photographs were taken with a Nikon D5 camera using a Nikon AF-S Micro NIKKOR 105 mm F/2.8G ED lens. The camera was mounted on a vertical stand and connected to a PC, and photographs were recorded using the Foster & Freeman Digital Capturing System DCS5. Figure 3 illustrates the set-up of the camera equipment. Longpass filters (supplied by Foster & Freeman) were attached to the camera lens to improve the performance of the light source. For the 730 to 800 nm wavelength range, a Schott longpass filter with either a 693 nm, 751 nm, or 793 nm cut off was used. For the 800 to 900 nm wavelength range, a Schott longpass filter with either an 815 nm or 895 nm cut off was used. The cut off filter was selected based on which one provided the greatest contrast between the mark and fabric. Simple image enhancement software in the DCS5 system was used to optimize the brightness and contrast of the marks.

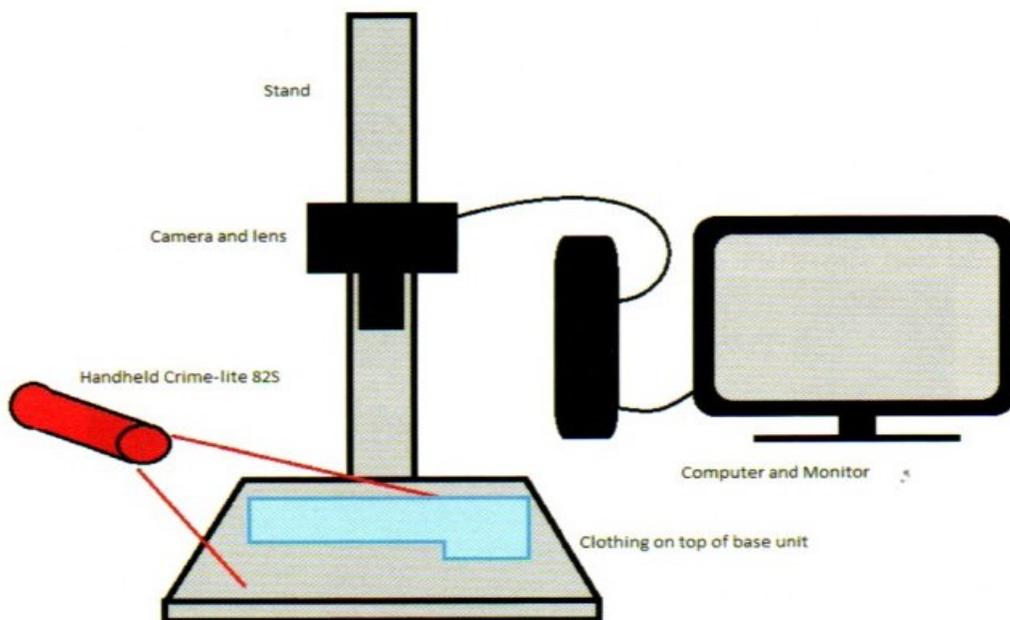


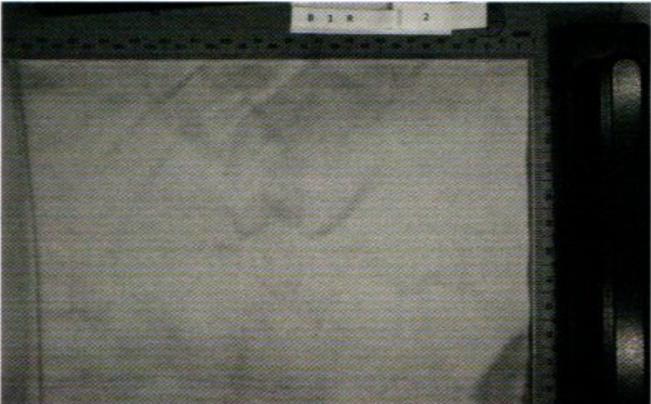
Figure 3

Diagram to show equipment set-up for photographing tire marks with the Crime-lite 82S.

Comparison of the VSC6000/HS with the Crime-lite 82S

To assess whether infrared light improved the visualization of tire marks on clothing and also to assess whether one infrared light source produced better results than the other, photographs of each mark in white light, IR using the VSC, and IR using the Crime-lite were shown to six footwear mark experts in the Scottish Police Authority Forensic Services (Chemistry and Documents section), who graded the marks based on the criteria described in Table 2. This grading system was produced solely for the purpose of this study and is not a system used in routine casework.

Three sets of photographs of 52 marks were shown to the experts in the form of a Google Survey, with each question being a photograph of a tire mark in either white light, IR using the VSC, or IR using the Crime-lite. To avoid direct comparisons, the marks were ordered so that photographs of the same mark under different light sources were not consecutive. The grading criteria was given in every question to remind the expert and ensure everything was clearly understood. For each photograph, the expert chose a grade from 0 to 5 from a drop-down menu.

Grade	Description
0	No mark visible 
1	Mark visible, no pattern elements (tread or sidewall), not identifiable as a tire mark 

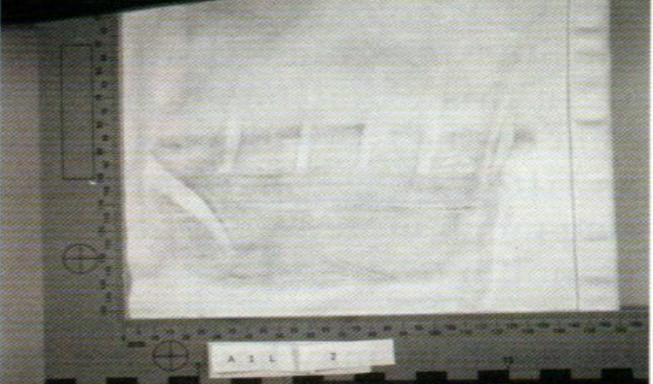
2	<p>Some pattern elements (tread or sidewall), may be heavily obscured</p> 
3	<p>Some pattern elements (tread or sidewall), may be slightly obscured</p> 
4	<p>Good quality tire mark, well defined edges and pattern elements (tread or sidewall), may have some interference from fabric</p> 
5	<p>Excellent quality tire mark, very clearly defined edges and pattern elements (tread or sidewall), little to no interference from fabric</p> 

Table 2

Grading system used by footwear experts to describe tire marks in white light, IR using the VSC, and IR using the Crime-lite. Examples were not shown to experts, but are included here to help illustrate the evaluation scale.

Results and Discussion

The outside surface of each clothing item was examined under white light and IR using the VSC6000/HS and the Crime-lite 82S. The vast majority of the tire marks visible in IR were not visible at all in white light, and the VSC improved the quality and clarity of almost all marks by removing interference from the background. Some examples of tire marks visualized in IR using the VSC are shown in Figure 4. These marks were able to withstand manipulation and movement of the clothing, suggesting they were not made with dust or dirt residue. However, more research would be needed to understand the composition and the mechanism by which they were formed.

Factors Affecting the Quality of the Mark

IR Absorbance by the Fabric

Although all items of clothing were driven over in the same manner, not all items contained identifiable tire marks, and some marks were better enhanced by IR than others. This could be due to the way different types of fabric interact with IR. Some clothing items absorbed IR and appeared much darker than other items that did not absorb IR. This caused the material to appear dark, which minimized contrast with any tire marks present. Other fabrics that absorbed IR to a lesser extent allowed light to pass through the material and be reflected, causing the material to appear lighter. This allowed much better visualization of the dark tire mark detail present on the fabric.

Creases, Folds, and Dark Smudges

Creases or folds in the fabric may also affect the quality of a tire mark because they may obscure pattern details. If an item of clothing is folded as a vehicle runs over it, the mark may be deposited irregularly and distorted once the clothing is unfolded. In this experiment, problems from creasing were more apparent on the t-shirts. This is likely because the t-shirts were not as fitted to the foam roller “dummy” as the denim jeans, leaving much more loose fabric to move around. Figure 5 shows an example of a tire mark on a t-shirt where detail has been obscured by creases. This may reflect casework in that looser fitting clothing may have more distorted tire marks after the wearer has been run over by a vehicle, compared to tighter fitting material such as denim jeans.

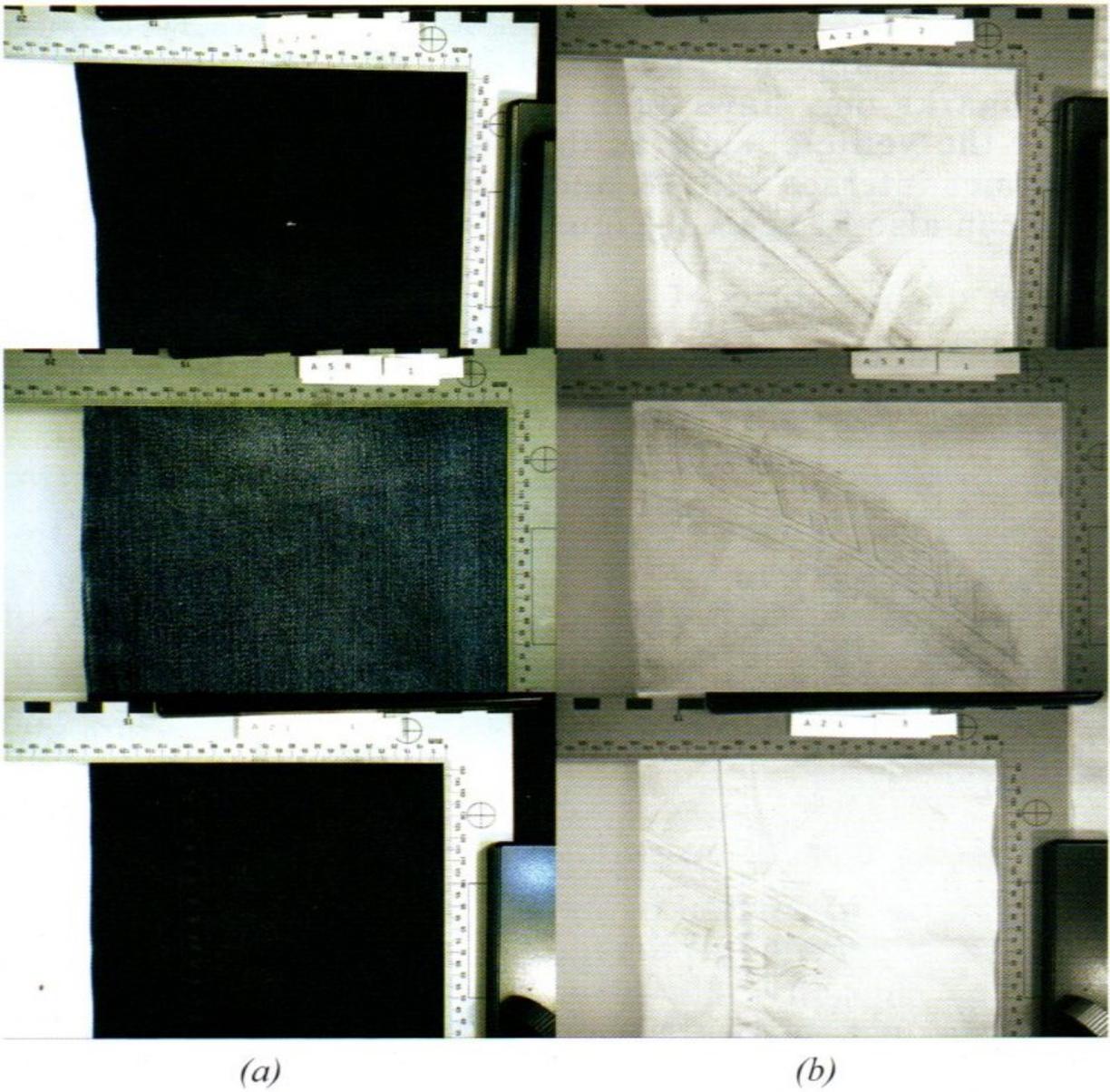


Figure 4

Three examples of tire marks visualized on clothing using the VSC:
 (a) clothing in white light; (b) clothing in IR.

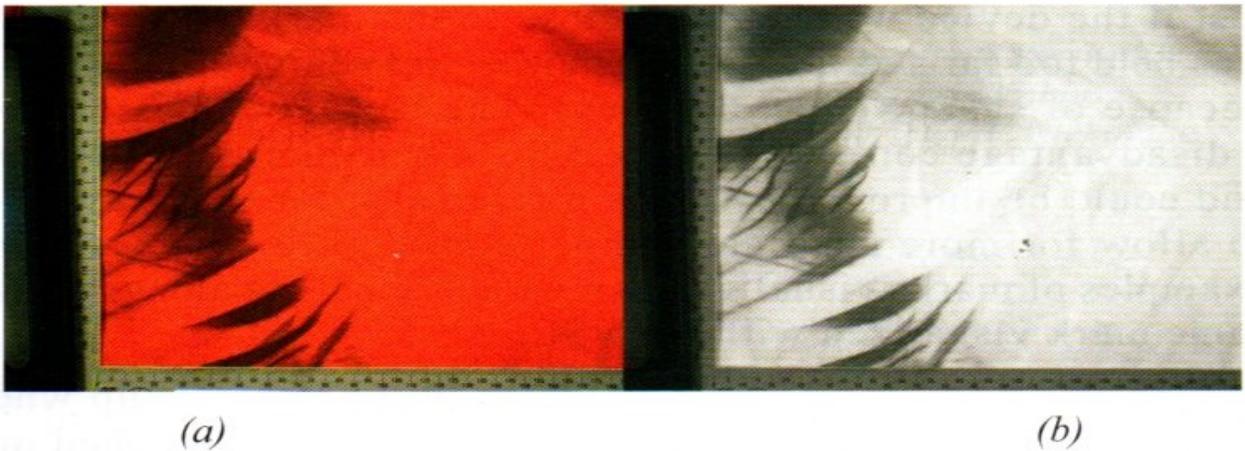


Figure 5

A tire mark visualized on a t-shirt using the VSC:
 (a) clothing in white light; (b) clothing in IR. Tread markings are visible but are heavily obscured by dark smudges and creases in the fabric.

Dark smudges were present on some of the clothing items, which did not appear to have any discernible tire mark details. These marks may have been caused by contact with another part of the vehicle, such as the underside. These marks may sometimes interact with IR and obscure any tire mark present, which can also be seen in Figure 5.

Color of the Fabric

On one occasion, IR actually worsened the quality of the mark. This occurred with a white t-shirt, where tread and sidewall details were visible in white light. The mark was still visible in IR; however, the edges and details were less defined.

Tire marks are often easier to see in visible light on light-colored clothing, and in these cases, IR may not be as useful in visualizing the mark as on darker fabric. However, in some cases, IR was able to enhance marks even on light-colored clothing by removing interference from the color of the fabric or by visualizing other parts of the mark that were not visible to the naked eye.

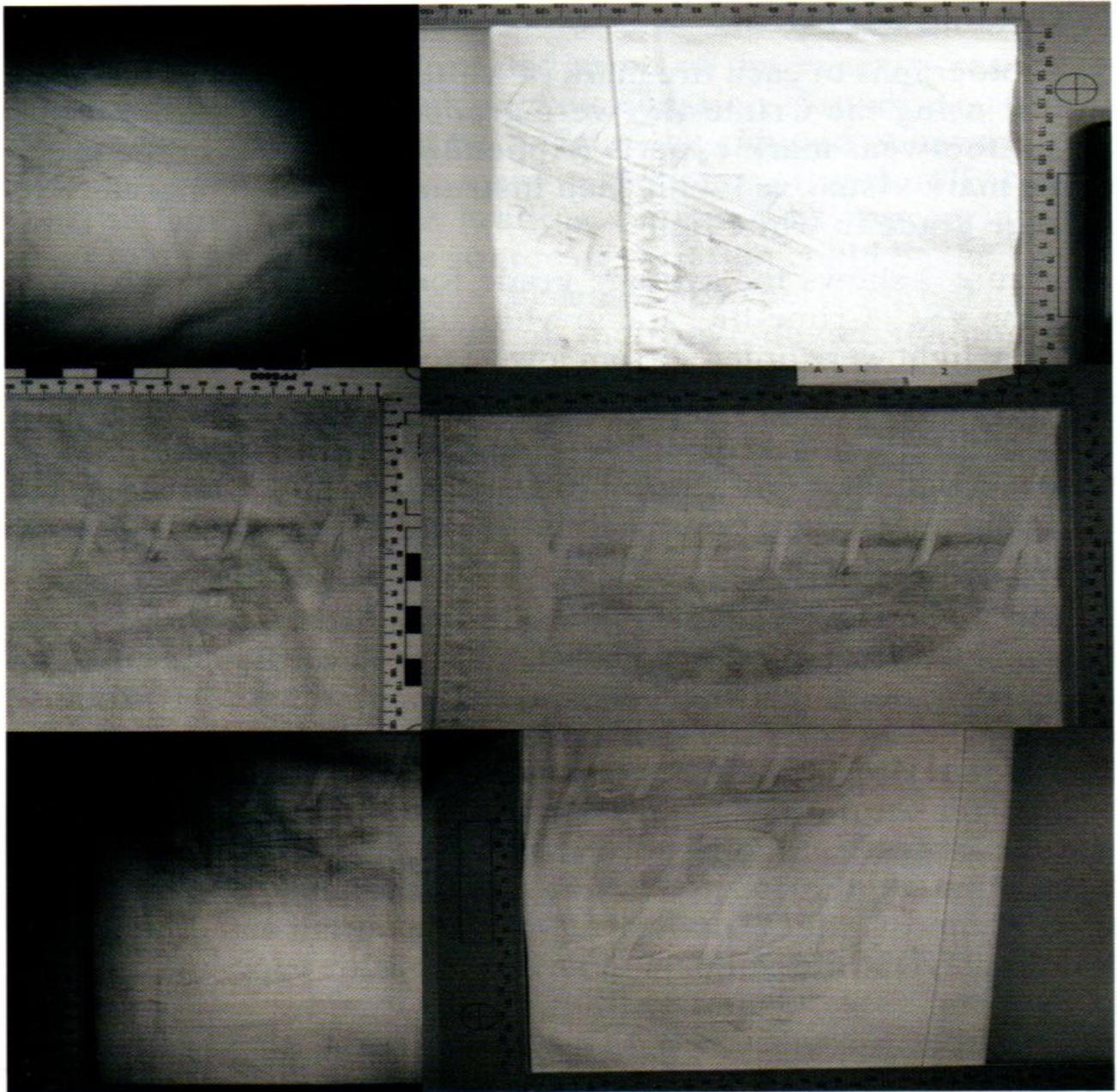
Comparison of the VSC6000/HS with the Crime-lite 82S

Tire marks identified using the VSC6000/HS were marked with a grease pencil and photographed at the same IR wavelength using the Crime-lite 82S. A scale ruler was positioned directly on the markings to ensure the same field of view was captured.

The Crime-lite photographs varied greatly in quality. Because the device is handheld, this added an extra variable of distance from the mark, unlike the VSC, which is a fixed light source.

The intensity of the spotlight resulted in some details being lost if the device was held too close to the mark. If the device was held too far away, detail was either very faint or not visible because of shadows and darkness. The lack of consistency is a disadvantage compared to the VSC when comparing images and could be improved by using a fixed arm for the Crime-lite to allow for more accurate comparison. Figure 6 shows some examples of marks visualized using the Crime-lite alongside the same mark visualized with the VSC.

Because of sizing constraints with the camera set-up when using the Crime-lite, the clothing items were photographed in a different orientation than on the VSC. However, the images have been rotated to enable appropriate comparison.



(a)

(b)

Figure 6

Three examples of tire marks viewed with: (a) Crime-lite 82S; (b) VSC. The quality of the Crime-lite images varied considerably, with many pattern details obscured by shadows or the intensity of the spotlight.

Grading Survey

Photographs of each tire mark in white light, IR using the VSC, and IR using the Crime-lite were graded on a scale from 0 to 5 by six footwear mark experts (Appendix A). The average grade of the mark visualized with each instrument was compared to its average grade in white light.

Figure 7 shows the average grade for each photograph taken with the VSC, Crime-lite, and in white light. The grades for marks in white light were ordered from lowest to highest to enable clearer comparison of each IR light source to the white light mark.

Overall, the marks in white light were of the lowest quality, followed by marks in IR using the Crime-lite 82S. Marks viewed using the VSC were consistently graded higher than the same marks in white light or using the Crime-lite.

Most of the marks (73%) in white light had an average grade between 0 and 1; either no mark was visible or the mark had no identifiable features to be considered a tire mark. All of these marks were successfully enhanced by the VSC, with none of the average grades for VSC images being below 1. This finding is crucial for the future of forensic casework. If the clothing of a vehicle-pedestrian collision victim is examined only in white light, almost three quarters of the tire marks may go undetected. IR can improve the visualization of tire marks considerably and should play an integral part in any case of this type.

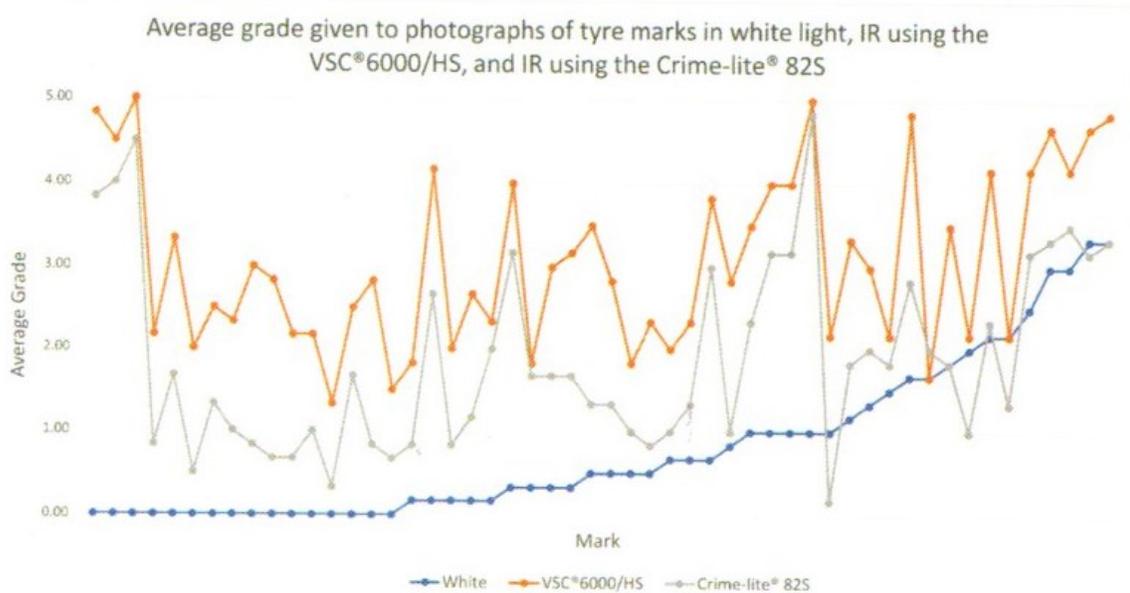


Figure 7

Graph to show the average grade given by experts to photographs of tire marks in white light (blue), IR using the VSC (orange), and IR using the Crime-lite 82S (gray). Each point on the x-axis refers to a photograph of a tire mark, with three corresponding points each on the y-axis for each of the three visualization methods.

Statistical Analysis

The mean and standard deviation of the experts' responses were calculated for each survey question. Some variation in responses was expected because of the subjective nature of an opinion survey. However, many responses were generally consistent, indicating that the grading criteria was appropriate and clear to understand. One source of variation could be the brightness of the computer screen, because the experts were sent a web link to complete the survey on their own device. Photographs of the marks may look different on different devices, depending on the screen brightness, type of screen or screen protector, and lighting conditions. These variables were not considered when designing the survey, and in the future, it may be more appropriate to have experts complete the survey on the same device.

Furthermore, although efforts were made to ensure that photographs of marks viewed with different light sources were as comparable as possible, the effects of the different photography techniques must be taken into account. The Crime-lite images were taken with a camera whereas the VSC images were produced by the VSC itself. Therefore, the parameters and settings that were used would not be exactly alike and may have influenced the perceived quality of the tire mark. To keep comparison as focused on the light sources as possible, photographs were taken using the same IR wavelength for both techniques, a scale ruler was used to ensure the same portion and position of the mark was captured, and some of the Crime-lite images were not used in the survey if the photo quality was particularly poor (e.g., too many shadows or poor framing of the mark).

Considering just the VSC and Crime-lite grades, a paired t-test was carried out to determine whether differences between the average grades were statistically significant. This type of test is used for experiments carried out on the same test subjects, resulting in paired "measurements", and is often used to compare two different methods [12]. This enabled determination of the differences between grades for the VSC marks and the Crime-lite marks, while ignoring variation in the tire marks themselves. The results of the paired t-test show that the two instruments did give significantly different results, suggesting that differences between the average grades were unlikely to be due to random variability.

Conclusions

This work has demonstrated the ability of IR to enhance tire marks on clothing by reducing interference from background colors and increasing contrast. Tire marks were visible on several different clothing types, with marks from both the front and rear tires. Both tread and sidewall patterns were transferred on some items. Some marks were obscured by creases or folds in the fabric and were not always visible because of dyes in the fabric interacting with IR.

Both the VSC6000/HS and the Crime-lite 82S were able to enhance tire marks with IR. However, some of the images taken with the Crime-lite were unsuitable for comparison because of excessive shadows or poor quality. Marks in white light, IR using the VSC, and IR using the Crime-lite were evaluated using a grading system to compare the abilities of each light source. Marks viewed using the VSC were consistently graded higher than the same marks viewed in white light or with the Crime-lite, with a statistically significant difference between the VSC and Crime-lite. Given the advantage of the fixed light source in the VSC compared to the Crime-lite, it may be worthwhile to consider comparison with other Crime-lite models that have a fixed arm.

This is the first known work to evaluate the VSC6000/HS for the examination of tire mark evidence on clothing and to begin to explore the factors affecting the formation of a mark. This research has highlighted the high probability that tire marks will be present on clothing after being driven over by a vehicle, and therefore the value of this evidence type should not be underestimated. With so little published research in this area, the findings described here have laid the groundwork for future work, with many other variables to consider other than clothing type. Further research could also be carried out into the formation and composition of tire marks on clothing in order to fully understand the interactions between the tire mark and IR.

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