

Article

A 3D-Printed Portable Episcopic Coaxial Illumination Device for Fingerprint Enhancement at Crime Scenes

*Zacchary Williams*¹

*Val Spikmans*¹

*Robert Ebeyan*¹

*Brenden Riley*¹

Abstract: Crime scene investigators have limited non-destructive optical techniques available for use at scenes for fingerprint enhancement on flat and reflective surfaces, such as glass, metal and plastic. If standard optical techniques, such as diffused reflection photography, fail, investigators are generally left to employ destructive techniques, including the application of fingerprint powders or chemical reagents. Episcopic Coaxial Illumination (ECI) is an alternate optical technique for flat, reflective surfaces that produces a contrasting dark fingerprint impression against a light background without the need for physical or chemical treatments. ECI is a common technique employed in laboratory settings and, although commercial portable ECI devices have recently become available, they are not designed for use with generic photographic equipment that is carried by crime scene officers as part of their standard kit. This research developed a portable and cost-effective ECI device that is 3D-printed and can be attached to any camera lens. The portable ECI (pECI) device was evaluated in a proof-of-concept, pseudo-operational environment, where the pECI was compared to conventional diffused reflection photography by photographing latent fingerprints and white powdered fingerprints. Overall, the pECI was able to record the same or more ridge detail compared to conventional diffused reflection photography on a range of pseudo-operational substrates. The pECI device therefore shows promise for enhancing fingerprints on non-porous surfaces at crime scenes and should be considered alongside routine diffused reflection enhancement. The developed pECI device can not only be used at routine crime scenes, but also in a laboratory environment, allowing flexibility in operation

¹ Western Sydney University, School of Science, Penrith, Australia

Introduction

Latent marks from the hands and feet are composed of residues that are transferred from a finger, palm, or foot to an item or surface upon contact. Such traces are important for forensic investigations as they can be used to identify individuals [1]. Latent marks can be found on a wide variety of surfaces at crime scenes including non-porous surfaces such as glass, plastic, and metal; and porous surfaces such as paper and cardboard. Semi-porous surfaces can also be encountered, including polymer bank notes and wax paper [2]. The detection of latent marks typically commences with non-destructive optical techniques, followed by destructive chemical or physical methods [3]. This study concentrated on optical techniques used for flat, reflective, non-porous surfaces, that rely on differences in light interactions between transferred residues and surfaces to visualise the marks. The discussion that follows is therefore centred around these types of surfaces.

Crime scene investigators routinely process immovable surfaces at crime scenes, including windows, mirrors, doors, and walls, for the presence of latent marks. In-field optical techniques for the detection of latent marks on non-porous, reflective surfaces are routinely limited to conventional diffused reflection (hereafter referred to as diffused reflection) [1]. Whilst forensic light sources may be available for latent mark detection at major or severe crime scenes, diffused reflection is frequently available for use, regardless of the severity of the crime. Diffused reflection is quick, simple, and non-destructive [4] and therefore can be attempted first in any detection and enhancement sequence.

If diffused reflection fails, the investigator must rely on destructive techniques to detect and enhance latent marks at the scene. Powder processing is a physical technique that is routinely conducted at crime scenes, while chemical techniques are generally reserved for major crime scenes. Physical or chemical techniques can damage ridge detail and it is preferable to optically detect and record latent marks before applying these destructive methods [5]. For example, Figure 1 displays a fingermark on a window captured with diffused reflection photography before and after application of white powder (left and right, respectively). The white powder has reduced the overall clarity of the ridges and furrows in sections of the fingermark (e.g., above and to the left of the core), reducing the ability to trace the ridges and locate minutiae in this region.

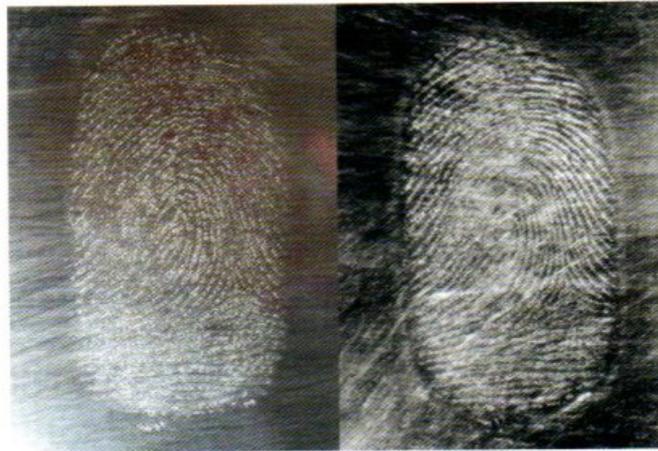


Figure 1

Image of a fingerprint deposited on a window, photographed using diffused reflection before powdering (left) and after white powder application (right).

In addition to the examination of fixed surfaces at scenes, investigators also collect moveable items of potential evidence from scenes to send to the laboratory for latent mark detection and enhancement. Laboratory examination for latent marks allows for the application of a wider range of detection and enhancement techniques under controlled laboratory conditions. In most instances, these laboratory methods are also more sensitive than in-field detection techniques [6].

Laboratory examiners may utilise episcopic coaxial illumination (ECI) for the detection and recovery of latent marks on flat, reflective, non-porous surfaces. ECI was first demonstrated by Pfister in 1985 [7] to be a reliable technique for latent mark enhancement. To perform ECI, a camera is placed directly above and perpendicular to the non-porous surface that is being examined for latent marks. A semi-transparent mirror is placed between the surface and the camera at a 45° angle. Incident light is then directed parallel to the surface plane where it passes through a diffuser towards the semi-transparent mirror. The semi-transparent mirror splits the incident light, with some of the light transmitting through the mirror and being absorbed, and some of the light being specularly reflected at a 90° angle down towards the latent mark and surface. The non-porous surface reflects the light back up through the mirror to the camera, whilst any latent mark residues on the surface will diffuse the light away from the camera, revealing a dark latent mark on a white background. The ECI components are typically housed inside a box to maintain the correct alignment of the diffuser, semi-transparent mirror, light source in relation to the camera [7, 8].

Whilst some commercial devices are available that allow for the use of ECI at crime scenes [9, 10], these devices are not compatible with the photographic equipment commonly available to crime scene investigators, as they require these examiners to carry more equipment into the scene. Other devices exist that are functional with crime scene photography equipment but are too cumbersome for use in field or would require an external power source [11, 12]. Although these devices might be considered suitable for major crimes, a solution is required that facilitates the use of ECI for routine scene investigations.

The aim of this study was therefore to design a cost-effective portable ECI device (pECI) for latent mark enhancement at crime scenes. A range of optical components for use inside the pECI were tested to evaluate which combination of components recorded the greatest amount of ridge detail at the lowest cost. The most successful combination of optical components was then integrated into the final pECI design and evaluated in a proof-of-concept pseudo-operational crime scene environment. The performance of the pECI was compared to diffused reflection photography, both for natural (un-powdered), latent mark enhancement and the enhancement of powdered marks. Diffused reflection and powdering are the most common techniques for latent mark recovery at crime scenes, hence this project has focused on comparisons to these routine techniques. These comparisons aimed to determine if the pECI device provided any additional ridge detail or contrast in comparison to these routine techniques.

Materials and Methods

Given that this study was largely a proof-of-concept investigation, the recommendations under Phase 1 (Pilot Studies) of the International Fingerprint Research Group (IFRG) Guidelines for the Assessment of Fingerprint Detection Techniques were followed during experimental design [13]. However, some elements of Phase 2 (Optimisation and Comparison) were also included.

The pECI Casing

The pECI casing was designed using Blender v3.0.1 software and 3D printed on a FlashForge Adventurer 3 3D printer

(FlashForge, China) using 1.75 mm black polylactic acid (PLA) filament. The pECI casing measured 80 (h) x 90 (l) x 90 (w) mm and consisted of two parts: (1) a base housing the optical components and (2) a removable lid. The base part contained integrated structural supports to ensure correct alignment of the optical components (semi-transparent mirror and diffuser). The removable lid allowed optical components to be swapped, replaced, or cleaned, whilst also functioning as an anchor to keep the components in place. A lens adaptor ring was glued to the top of the lid to allow the device to be attached to a digital camera lens. The design of the pECI case and components are shown in Figure 2.

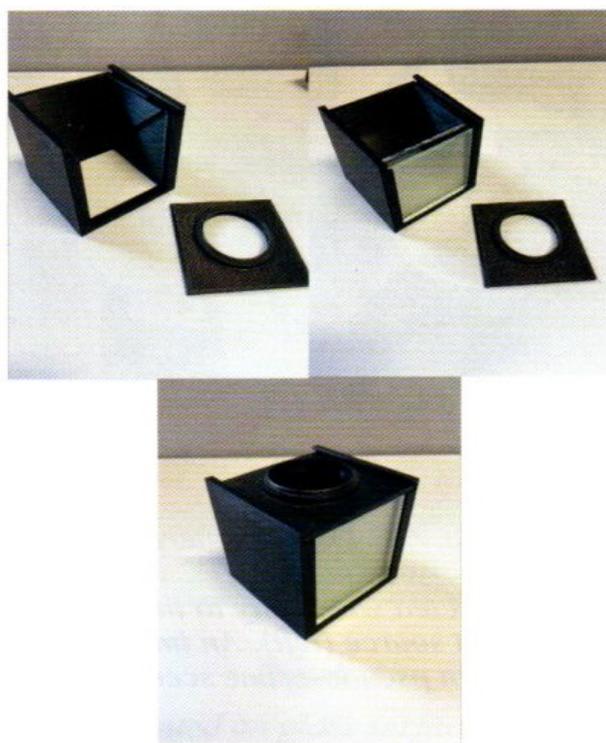


Figure 2

3D printed pECI case with removable lid (top left); diffuser and semi-transparent mirror slid inside pECI (top right); pECI case, removable lid and components combined (bottom). The ring adaptor that connects the pECI to a camera lens can be observed on the top of the device.

Camera Equipment

A Canon 90D Digital Single-Lens Reflex (DSLR) camera, equipped with a Canon EF-S 60mm F/2.8 Macro USM Lens and a Canon Speedlight 550EX flash unit connected wirelessly to a Canon Speedlight Transmitter ST-E2 was used for both pECI and diffused reflection photography. Figure 3 displays the pECI

attached to the Canon DSLR camera. The Canon Speedlight was used as the incident light source for the pECI. The camera was operated in manual mode using f -stop 22, ISO 100, a shutter speed of 1/125th sec and spot metering. The same camera equipment was used for both the pECI and diffused reflection photography to ensure that any differences in ridge details were not related to differences in selection of photographic equipment.

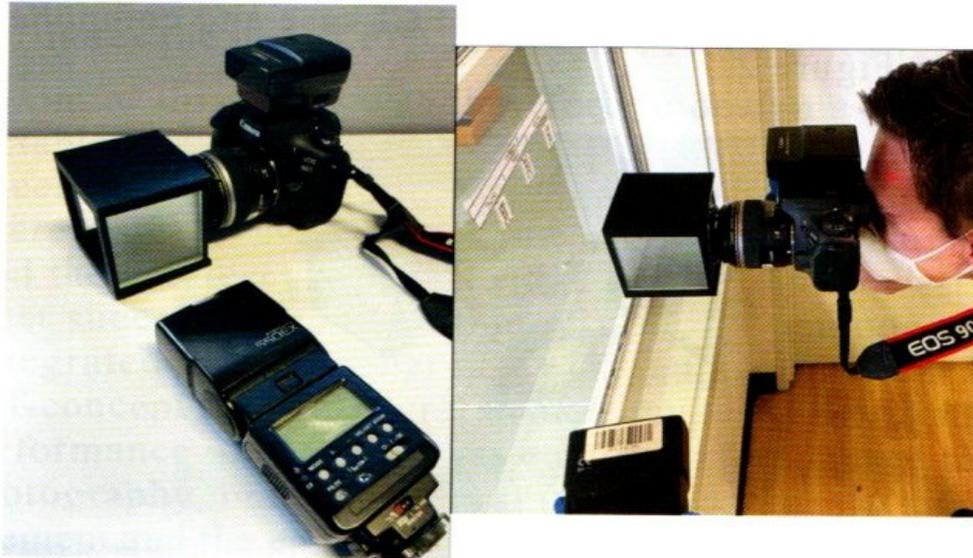


Figure 3

The pECI attached to a Canon 90D DSLR camera with a Canon EF-S 60 mm lens. The Canon Speedlight Transmitter ST-E2 was attached to the camera hot shoe, and this was connected wirelessly to the Canon Speedlight 550EX flash unit as the incident light source (left). An image of a user with the pECI and camera equipment in pseudo-crime scene environment (right).

Post-processing of Images

The surface to camera distance for pECI photography was found to be longer than for diffused reflection photography. Diffused reflection photography could be performed using a 1:1 magnification, whereas pECI photography required a 1:3 magnification to ensure that there was sufficient distance between the pECI device and the surface to prevent light from the flash unit reaching the fingerprint without going through the ECI device. Stray light reaching the surface without going through the pECI system would decrease the contrast between the ridge detail and the surface in the final image, reducing the quality of the recorded latent mark. Modifications to the device could be made to reduce stray light interference from the flash unit

but this would likely come at a cost of the device's portability or cost effectiveness.

The images obtained at 1:3 magnification were cropped using Adobe Photoshop® v23 to remove empty space from the final images. Once the images were cropped, contrast adjustments (levels, curves, and sharpness) were applied in Adobe Photoshop®, followed by a black and white filter. These adjustments mimic common adjustments completed by technicians or examiners during a latent mark identification workflow [14, 15]. Contrast adjustments and the black and white filter were applied to all images obtained using both the pECI and diffused reflection photography. Figure 4 displays a fingermark on a glass surface before and after digital image processing (left and right, respectively).

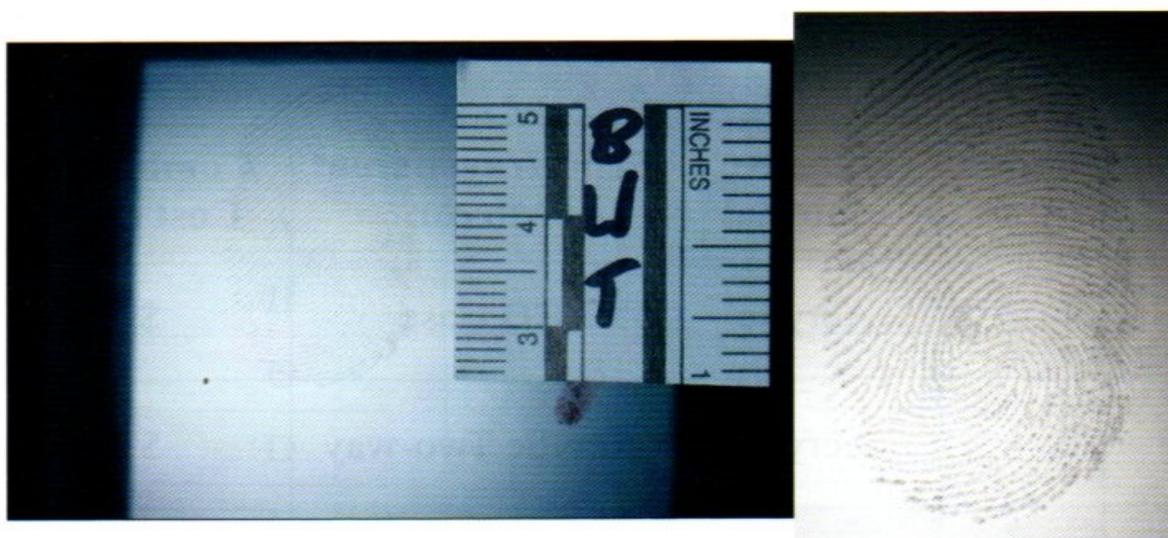


Figure 4

Image of fingermark deposited on glass surface photographed using pECI device. Unadjusted image (left), adjusted image (right) with levels, curves, and sharpness as well as a black and white filter applied using Photoshop®.

Optimisation of Optical Materials in the pECI

As previously discussed, an ECI device consists of a semi-transparent mirror and a light diffuser. A range of mirror and diffuser materials were tested to determine which materials were the most suitable optical components based on the balance of price, weight, and the amount of ridge detail present in the latent marks.

Three materials were tested for the semi-transparent mirror: (1) polystyrene plastic (clear cover of a CD case) with unknown

reflectance/transmission (R/T) ratio; (2) a two-way acrylic mirror with a 75/25 R/T ratio; and (3) a beam splitter with a 50/50 R/T ratio. The CD cover represents the cheapest and lowest-quality option, the beam splitter represents the most expensive and highest-quality option, and the acrylic two-way mirror is moderately priced and of intermediate quality.

Two materials were tested for the diffuser: opaque plastic and frosted glass. Both materials are relatively cheap, but differ in weight and durability, with the frosted glass being slightly heavier and more fragile.

The various materials were evaluated in pairs to determine which combination produced the greatest amount of ridge detail at the lowest cost. The most successful pairwise combination of mirror and diffuser materials were integrated into the final pECI design. Overall, six different diffuser and semi-transparent material combinations were tested as listed in Table 1.

Combination (C#)	Diffusive Material	Semi-transparent Mirror	Combination Cost (AUD)
C1	Acrylic	CD Case	\$22
C2	Acrylic	Acrylic Two-way	\$32
C3	Acrylic	Beamsplitter	\$412
C4	Glass	CD Case	\$24
C5	Glass	Acrylic Two-way	\$34
C6	Glass	Beamsplitter	\$414

Table 1

Combinations of materials tested for the diffuser and semi-transparent mirror, and the cost of each combination of materials in Australian dollars (AUD).

Fingermark Donations

The collection and processing of fingermark specimens for this study were approved by the Western Sydney University Human Research Ethics Committee (Ethics approval number H13684, subproject H13683).

To establish the most suitable combination of materials for the semi-transparent mirror and the diffuser, six different fingermark donors of varied age and gender deposited fingermarks on three different surfaces: glass, aluminium, and transparent plastic. The surfaces were chosen as they replicated common types of non-porous surfaces encountered at crime scenes. Table 2 displays the ages and genders of the six donors. Fingermarks were aged 24 hours before being captured.

Donor ID	Age	Gender
A	33	M
B	46	M
C	31	M
D	28	F
E	27	F
F	36	M

Table 2

The variance of the donor pool with regards to age and gender.

Each donor deposited a single natural fingermark on each of the three surfaces: glass, metal, and plastic. This resulted in six natural fingermarks per surface and eighteen fingermarks in total.

Fingermark Grading and Data Analysis

The University of Canberra (UC) comparative scale was used to compare fingermark ridge details and contrast between the different combinations of materials for the semi-transparent

ent mirror and diffuser [13]. Because ECI is a non-destructive technique, the same 18 fingerprints that were deposited by the fingerprint donors were recorded using each combination of materials C1 to C6 as listed in Table 1. Pairwise comparisons (270 in total) of fingerprints were performed to establish which combination of materials provided the greatest amount of ridge detail or contrast.

The UC comparative scale functions by comparing the performance of two fingerprint enhancement techniques on a scale from +2 to -2 when developing the same fingerprint. A positive grade (+2, +1) indicates technique A produced better enhancement quality than technique B, a negative grade (-1, -2) indicates technique B produced better enhancement quality, and a UC grade of 0 indicated little to no difference in enhancement quality between the two compared techniques. Table 3 provides the UC grades and descriptors. Each pair of images were graded using the UC scale independently by three assessors as a blind study (graders were unaware of the combination of pECI components they were assessing). The average UC grade for each pairwise comparison was calculated from the three assessors' grades.

Assessor Grade	Description
+2	Technique A resulted in greatly improved contrast/detail compared to technique B
+1	Technique A resulted in slightly improved contrast/detail compared to technique B
0	No significant difference in the results obtained by techniques A and B
-1	Technique B resulted in slightly improved contrast/detail compared to technique A
-2	Technique B resulted in greatly improved contrast/detail compared to technique A

Table 3

UC comparative scale for the assessment of two different enhancement methods A and B, adapted from the IFRG Guidelines [13]. In this research, techniques A and B refer to two different combinations of materials for the semi-transparent mirror and the diffuser.

Comparison of the pECI Device to the Routine In-Field Methods

Once the optimal combination of materials for the semi-transparent mirror and diffuser were determined, the performance of the optimised pECI was compared to that of routine methods for latent mark enhancement at crime scenes on non-porous surfaces. Both natural fingerprints (un-powdered) and powdered fingerprints were photographed using pECI and the routine method (diffuse reflection). The resulting fingerprints were compared to assess the quality of the ridge detail.

Fingerprint Donation Procedure

Given the proof-of-concept nature of this study, just three fingerprint donors were utilised, being three males aged 31, 33 and 36. All three donors deposited three natural fingerprints on six different surfaces: glass window, conventional mirror, clear plastic information sheet holder with white background, whiteboard, white refrigerator, and metallic grey filing cabinet. Hence, nine fingerprints were donated per surface, resulting in 54 fingerprints in total. These surfaces were chosen to represent typical surfaces that would be encountered at real crime scenes. Because the pECI was tested for its ability to enhance the fingerprints and not as a search tool, the location where donors were required to deposit their fingerprints was explicitly directed.

Fingerprint Detection and Enhancement Sequence

Fingerprints were detected by first searching for the fingerprint in the marked location followed by photography of the fingerprint. An attempt was initially made to detect the fingerprint through diffused reflection, using a 1000 lumen LedLenser P7R white light torch (LedLenser, Australia). Whether or not a fingerprint was observed at this point, a subsequent detection attempt was made using the pECI with the same LedLenser P7R torch as the light source. A torch is required for detection using the pECI, given that the flash unit cannot be turned on continuously. The operator used the live view finder on the camera to determine the presence of a fingerprint. While the location of each fingerprint was known, detection attempts were still made to compare the detection capabilities of the pECI against diffused reflection. This is not to be confused with the ability to search for fingerprint using the pECI, which was not the

aim of this step as previously indicated. If a fingerprint was visually detected using either technique, then diffused reflection and pECI photography was attempted. Figure 5 illustrates the sequence of steps followed for each area where a finger contacted surface, presumably leaving a fingerprint.

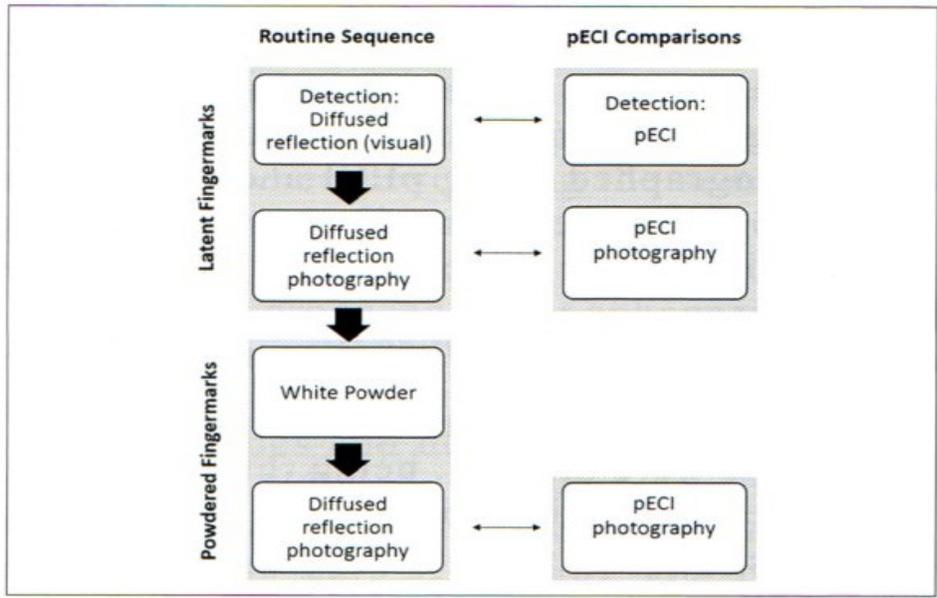


Figure 5

Flow chart of the routine detection and enhancement sequence of latent marks on non-porous, flat, reflective surfaces. The comparison of the routine method to the pECI has been indicated.

Any detected fingerprints were then powdered and re-photographed using the pECI and diffused reflection. Opti-Hadonite white fingerprint powder (Optimum Technology, Australia), was applied to fingerprints using a No. 6 squirrel-hair brush (Optimum Technology, Australia). A clean out brush was used to remove excess powder from the fingerprints, where required, before being photographed using either technique.

Only white powder was used in this experiment, regardless of the colour of the test surface. In casework, it is common practice to apply a powder that provides the best contrast between the latent marks and the surface. On white surfaces, black powder would be preferred; however, diffused reflection tends to work best with a white powdered latent mark. Given the aim of this research was to compare the performance of diffused reflection and pECI, white powder was applied to all detected latent fingerprints.

Fingerprint Grading and Data Analysis

Three direct comparisons were made in this pseudo-operational study. The first comparison was based on the visual detection of natural fingerprints using diffused reflection and the pECI. Each fingerprint was categorically assessed as 'detected' or 'not detected' based on the visual presence/absence of ridge detail.

The second and third comparisons involved grading fingerprint photographs to assess the amount of ridge detail and contrast of fingerprints: (1) the comparison of natural fingerprints photographed using diffused reflection and the pECI; and (2) the comparison of powdered fingerprints photographed using diffused reflection and the pECI device. For these comparisons, the UC comparative scale was used along with the same three graders previously discussed. Across the 54 fingerprints that were originally donated, 47 were detected using either diffused reflection or pECI or both, resulting in 94 UC comparisons (47 natural and 47 powdered comparisons).

The Centre for Applied Science and Technology (CAST) grading scheme was utilised to compare the quality of the features in the fingerprints enhanced with the pECI to the same fingerprints enhanced using diffused reflection photography. The CAST grading scheme is a categorical scale ranging from 0 to 4 that can be used to score the overall quality of a fingerprint that results from a particular enhancement process [13]. Table 4 provides the CAST grades and descriptors.

CAST Grade	Grade Definition
0	No evidence of a fingerprint
1	Some evidence of a fingerprint
2	Less than 1/3 clear ridge detail
3	Between 1/3 and 2/3 clear ridge detail
4	Over 2/3 clear ridge detail

Table 4

Centre of Applied Science and Technology (CAST) grading scheme, adapted from the IFRG Guidelines [13].

If a fingerprint was detected and the enhancement sequence was completed, four images were acquired: (1) diffused reflection image of the natural fingerprint; (2) pECI image of the natural fingerprint; (3) diffused reflection image of the powdered fingerprint; and (4) pECI image of the powdered fingerprint. Each image was graded using the CAST scheme by three assessors and the average CAST grade for that image was calculated. As previously mentioned, 47 fingerprints were detected, resulting in 188 CAST graded fingerprints.

Results and Discussion

Comparison of pECI Optical Components

Figure 6 and Figure 7 show the results of the comparison of the six different combinations of materials used for the semi-transparent mirror and diffuser (C1 to C6) when scored using the UC scale. As shown in Figure 6, frosted glass was observed to be the most suitable material for the diffuser. By comparing C1 to C4, C2 to C5, and C3 to C6 (where the semi-transparent mirrors were the same in each comparison, but the diffuser was either acrylic or frosted glass), it was consistently observed that the glass diffuser provided higher quality fingerprint images.

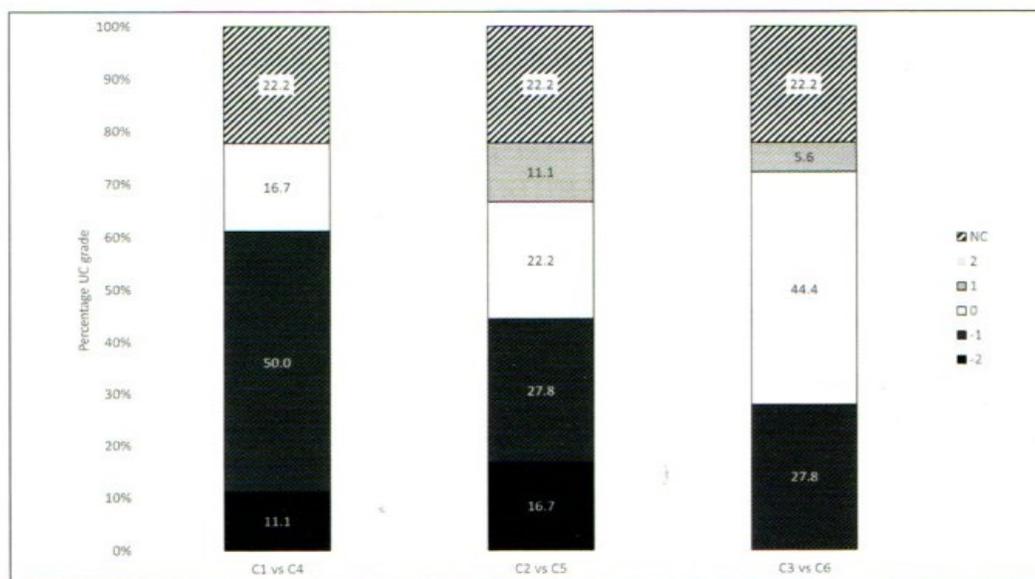


Figure 6

Comparison of fingerprint image quality obtained for each pECI containing an opaque acrylic diffuser (C1, C2, and C3) versus each pECI containing a frosted glass diffuser (C4, C5, and C6). Pairwise comparisons were conducted on the devices that used the same semi-transparent mirror, with C1 vs C4 using the CD cover, C2 vs C5 the acrylic mirror, and C3 vs C6 the beam splitter.

Using the frosted glass as the diffuser, the materials for the semi-transparent mirror were compared. The CD cover underperformed as a semi-transparent mirror compared to the acrylic mirror and the beam splitter. C4, which contained the CD cover, provided lower quality fingerprint images compared to C5 and C6, as shown in Figure 7. Although the CD cover did behave as a semi-transparent mirror and was able to provide fingerprint enhancement, it was flimsy, not entirely flat, and visually contained impurities. These issues resulted in poor contrast between the fingerprint and surface.

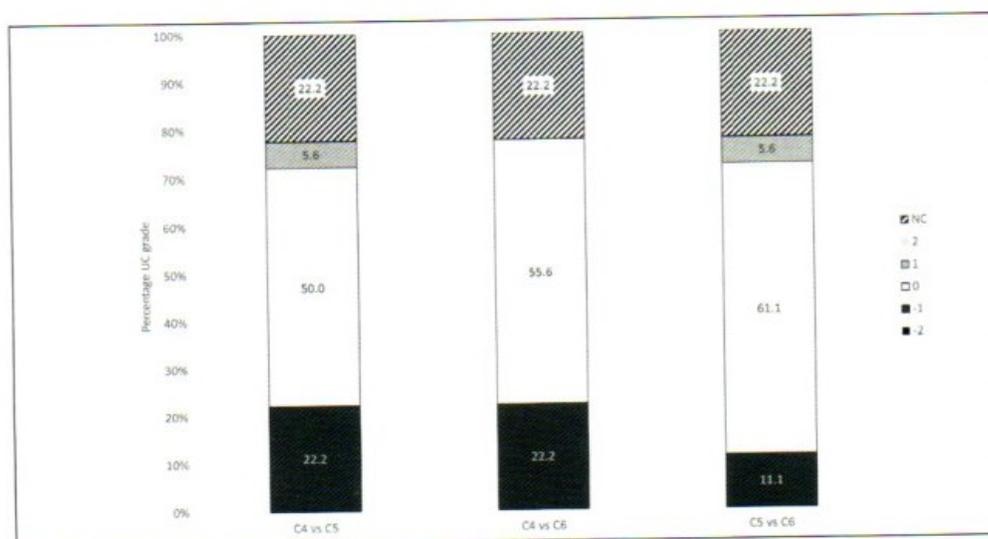


Figure 7

Comparison of fingerprint image quality obtained for pECI devices containing different semi-transparent mirrors (C4 contained the CD cover; C5 the acrylic mirror; and C6 the beam splitter). All three devices used the frosted glass diffuser.

As shown in Figure 7, C5 (acrylic mirror) and C6 (beam splitter) demonstrated very similar performance, with most fingerprints enhanced to a similar quality (61%). While C6 provided better enhancement for 11.1% of fingerprints (which equated to two fingerprints), C5 provided better enhancement for 5.6% of fingerprints (one fingerprint). Differences in these comparisons were related to minor differences in contrast; however, and more importantly, the same amount of detail was observed in both impressions which is of most relevance operationally.

C5 performed well against every combination that was tested and almost performed to the same quality as C6, even though the pECI using C5 was \$380 AUD cheaper. In addition, the pECI device based on C5 was found to be sufficiently light-weight

to allow for extended handheld operation. The frosted glass diffuser in combination with the acrylic mirror was therefore identified as the most suitable combination (best compromise between price and performance). The optimisation of the pECI was performed under laboratory conditions, demonstrating that the pECI is suitable for laboratory application.

Comparison of the pECI Device to Diffused Reflection in a Simulated Crime Scene Scenario

Natural Fingerprint Detection

In the context of this research, fingerprint detection was conducted on fingerprints in designated locations on the tested surfaces. The aim was not to assess the search capability of the pECI device, but instead to assess the ability of the pECI to visualise natural fingerprints when using a torch as the incident light source instead of the flash. This was compared to diffused reflection using a torch, which is the current standard for initial fingerprint detection at crime scenes. The purpose of this test was to determine whether pECI could detect any additional ridge detail compared to diffused reflection. If pECI could detect ridge detail that was missed by diffused reflection, then the addition of pECI alongside diffused reflection at crime scenes may be warranted.

Of the 54 fingerprints deposited across the six different surfaces (9 fingerprints per surface), 47 natural fingerprints were detected by pECI, as shown in Table 5. The seven undetected natural fingerprints were deposited on the white refrigerator (1 fingerprint) and metallic grey filing cabinet (6 fingerprints). Diffused reflection showed similar reduced fingerprint detection capabilities on the metal filing cabinet, demonstrating that this surface was a challenge for fingerprint detection by this method. The metal filing cabinet was not further included in the discussion as it did not allow for suitable comparison between the two optical techniques other than that both techniques had limited detection capabilities for this surface type.

	Window	Mirror	Clear plastic with a white background	Whiteboard	White fridge	Metallic grey filing cabinet
Diffused Reflection	9	9	9	8	8	1
pECI	9	9	9	9	8	3

Table 5

Number of detected natural fingermarks using both diffused reflection and pECI across six surfaces under pseudo-operational conditions. Nine fingermarks were deposited on each surface.

Diffused reflection was able to detect 44 natural fingermarks. The pECI was therefore able to detect three more fingermarks than diffused reflection (two on the filing cabinet and one on the whiteboard). Although the location of each fingermark was known, this finding demonstrates that pECI may provide additional information for latent marks if applied alongside diffused reflection at crime scenes.

Whilst the pECI was more effective than diffused reflection for detecting fingermarks, initial detection was faster and more practical using diffused reflection compared to the pECI device. If pECI is incorporated into the operational workflow, its use is only recommended when diffused reflection struggles to detect a fingermark.

Natural Fingermark Enhancement

The 47 detected natural fingermarks were each photographed using diffused reflection and pECI photography. Fingermark enhancement was compared between the two techniques using the average CAST grades and UC comparative scores. Figure 8 and Figure 9 show the results of each grading scheme.

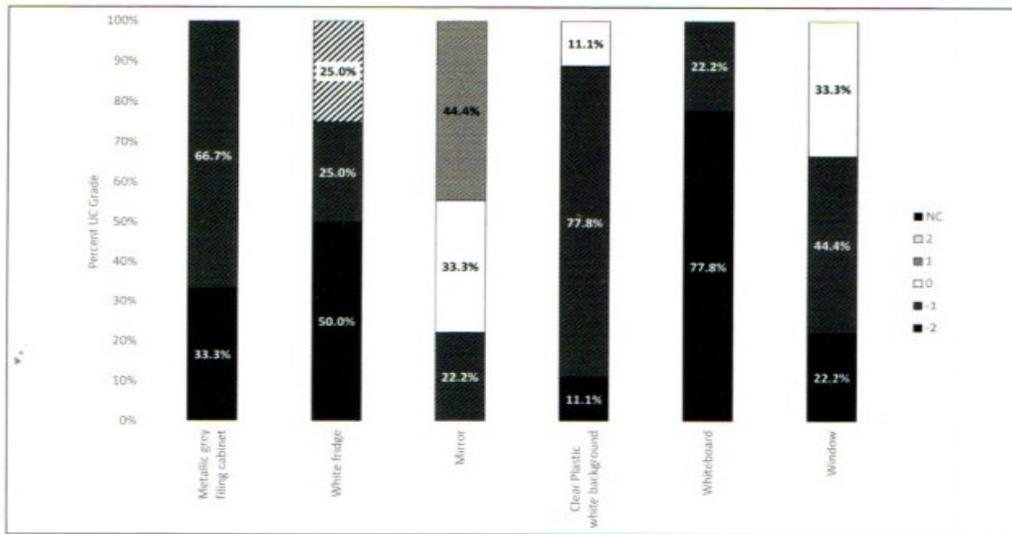


Figure 8

Comparison of diffused reflection and pECI photography of natural fingermarks on simulated crime scene surfaces using the UC grading scale. Positive grades indicate better fingermark image quality for diffused reflection photography over pECI photography and vice versa.

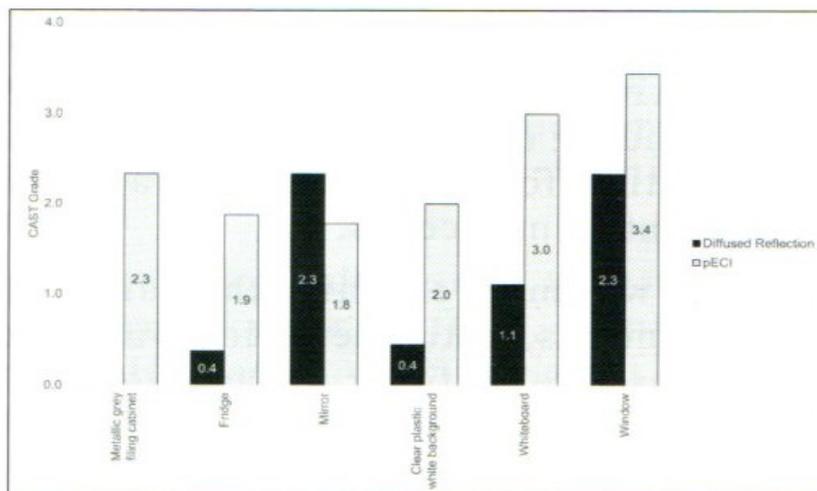


Figure 9

Comparison of diffused reflection and pECI photography of natural fingermarks on simulated crime scene surfaces using average CAST grades.

Arguably, the average CAST value itself has no meaning and is an arbitrary value, given that it represents a categorical scale. Nevertheless, the average CAST grade can provide information on whether one technique generally provides more ridge detail than another technique, although it cannot quantify how much better that technique is compared to the other technique. The average CAST grade was therefore considered suitable in this context. Whether one technique generally provided better ridge

detail than the other technique was determined using the UC comparative scale.

Based on the observed UC grades, the pECI device provided better enhancement of natural fingermarks compared to diffused reflection photography on all surfaces except for the mirror. The CAST grades demonstrated that the pECI device also recorded additional ridge detail compared to diffused reflection photography on all surfaces, again except the mirror.

Focusing on natural fingermarks on the mirror, the pECI device enhanced fingermarks to an equal quality or better for 55.5% of the fingermarks recorded compared to diffused reflection photography. Due to the mirror's ability to reflect a high percentage of light back into the pECI system, it was found that most images were overexposed even when decreasing flash power and adjusting exposure settings. This overexposure resulted in reduced ridge detail. On the other hand, an advantage of the pECI when photographing fingermarks on the mirror was the removal of hot spots and reflections of the camera's lens that were apparent in diffused reflection images. Figure 10 shows a natural fingermark captured using diffused reflection and pECI. While the diffused reflection image on the left in Figure 10 shows better contrast, it is also partially obstructed by the reflection of the lens.

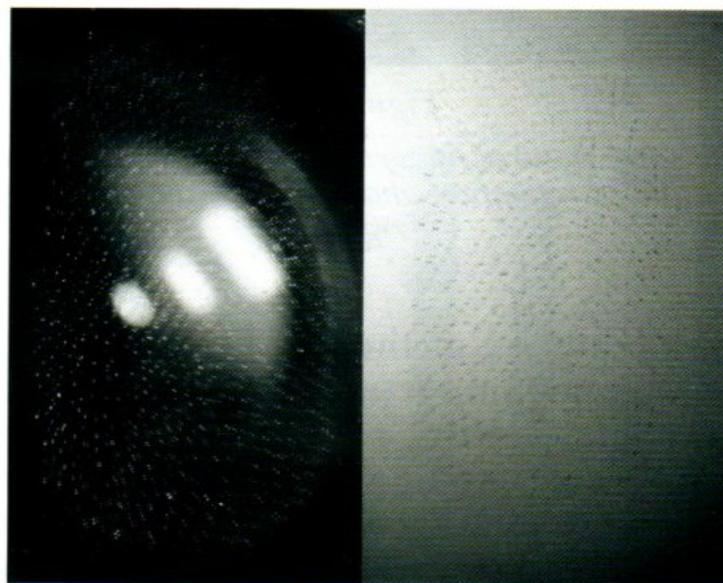


Figure 10

Images of the same natural fingermark deposited on a mirror, enhanced using diffused reflection (left) and the pECI device (right).

pECI photography outperformed diffused reflection photography on the remaining surfaces for two reasons, the angle of incident light and background color. Due to the angle of incident light in diffused reflection photography, any interferences (such as dust or debris in the latent residue) or any surface irregularities can create interfering shadows or other reflections. This effect is less apparent with the pECI device as the incident light is perpendicular to the surface, resulting in a clearer fingerprint image. In Figure 11, the diffused reflection image on the left displays ridges with more variable texture and outlined effect, inhibiting the ability to trace the paths of the ridges and locate minutiae.

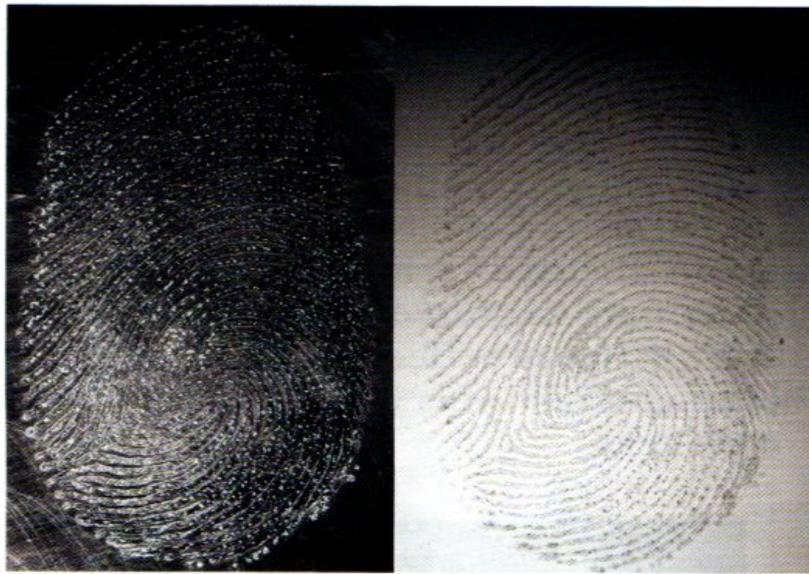


Figure 11

Images of the same natural fingerprint deposited on a glass window, enhanced using diffused reflection photography (left) and pECI photography (right).

The second advantage of the pECI device is that the colour of the surface was not important. Specifically examining the whiteboard and refrigerator, since they were white, diffused reflection photography struggled to not only detect but also photograph the ridge detail consistently. As shown in Figure 12, pECI capture of fingerprints on these surfaces resulted in images with dark ridges against a light background.

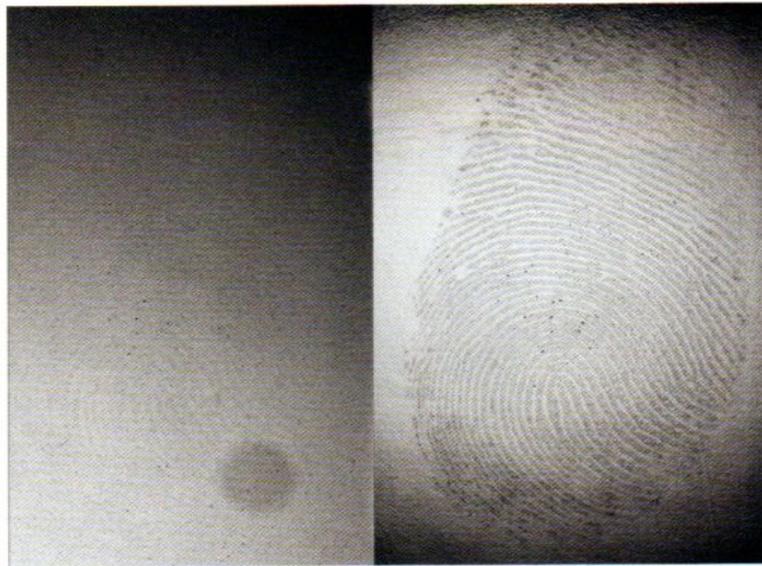


Figure 12

Images of the same natural fingerprint deposited on a whiteboard, enhanced using diffused reflection photography (left) and pECI photography (right).

Powdered Fingerprint Enhancement

Following optical recording of the 47 natural fingerprints, white fingerprint powder was applied, and the fingerprints were captured using diffused reflection and pECI photography. Fingerprint enhancement was again compared between the techniques using UC comparative scores and the average CAST grades. Scores from each method are provided in Figure 13 and Figure 14.

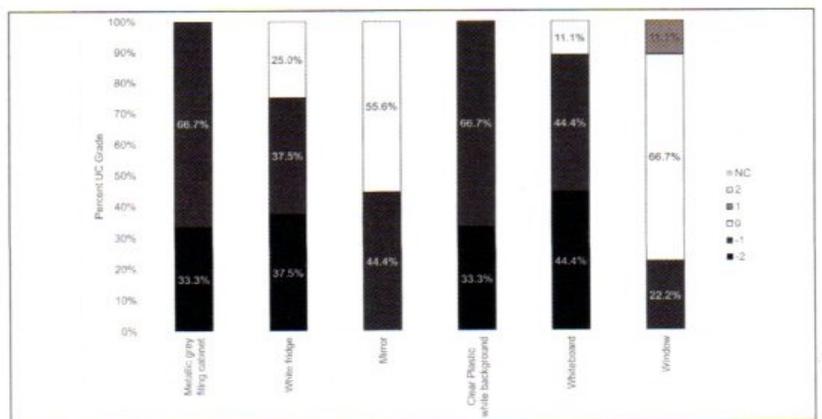


Figure 13

Comparison of diffused reflection and pECI photography of powdered fingerprints on simulated crime scene surfaces using the UC grading scale. Positive grades indicate better fingerprint image quality for diffused reflection photography over pECI photography and vice versa.

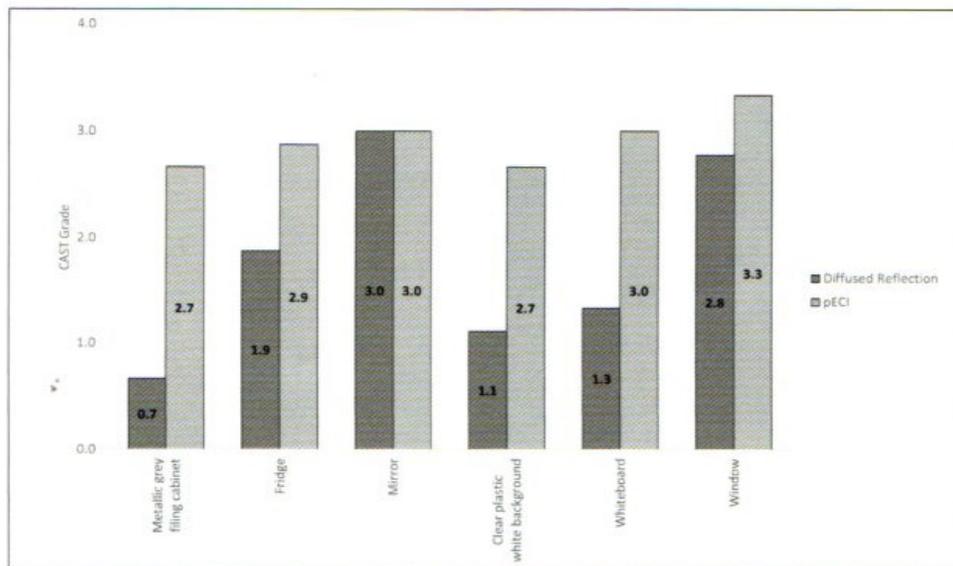


Figure 14

Comparison of diffused reflection photography to pECI photography of powdered fingerprints on simulated crime scene surfaces using average CAST grades.

The pECI device provided better contrast for powdered fingerprints on all surfaces compared to diffused reflection photography, except for the glass where both techniques performed equally. On average, the pECI device also recorded more ridge detail compared to diffused reflection photography on all surfaces, except on the mirror where both techniques recorded the same amount of ridge detail.

While both diffused reflection photography and the pECI device obtained, on average, similar amounts of ridge detail for the mirror, the pECI device obtained clearer ridge detail for 44.4% of comparable fingerprints due to the removal of hot spots and lens reflections as well as reduced occurrences of ridge duplicating. Ridge duplicating occurred when photographing fingerprints on the mirror as the reflection or shadow of the fingerprint on the mirror's reflective layer was observed and recorded along with the fingerprint itself on the mirror's top layer. Recording both the original fingerprint and the shadow created areas where the ridges appeared split or duplicated, causing a blurred effect. Ridge duplicating was difficult to avoid using diffused reflection photography due to the angle of incident light, compared to ECI where the incident light is perpendicular to the subject and thus was rarely observed. Figure 15 displays a powdered fingerprint on a mirror captured with diffused reflection (left image) and pECI (right image).

The duplicated or blurred ridges in the diffused reflection image reduced the overall quality of the ridge detail.

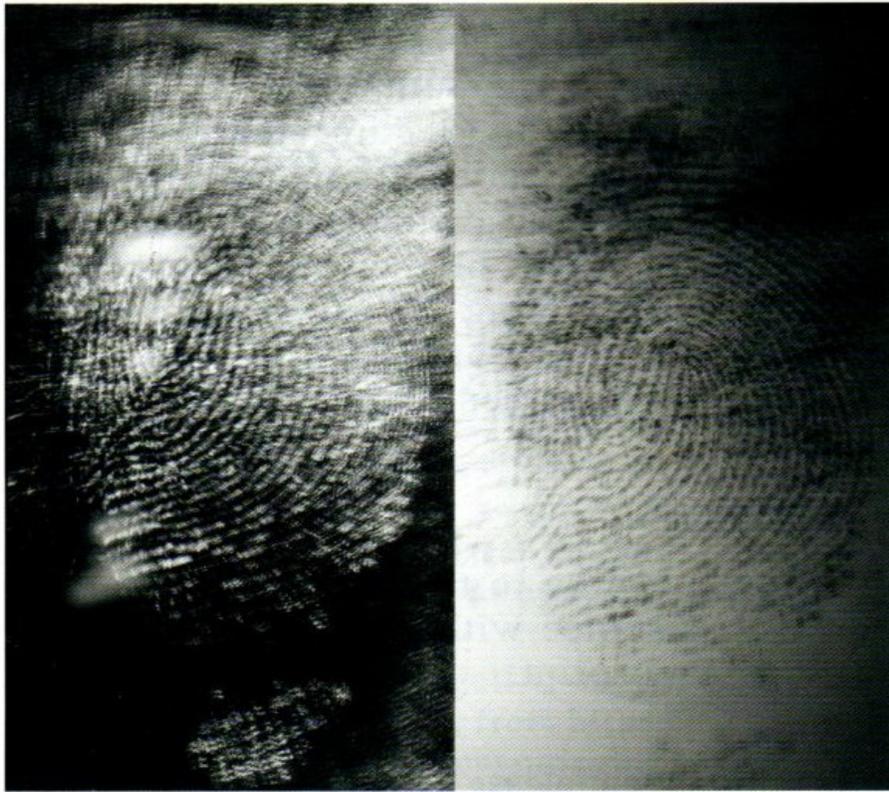


Figure 15

Images of a powdered fingerprint deposited on a mirror; enhanced using diffused reflection photography (left) and pECI photography (right).

Conclusions

A cost-effective, easy-to-produce and lightweight portable episcopic coaxial illumination device has been developed. The low cost of the device (approximately \$45 AUD) and its ability to integrate with routine camera equipment that is used by crime scene investigators is appealing. Implementation of the pECI is made easy by the ability to attach and remove the device from camera lenses, allowing investigators to switch between diffused reflection photography and pECI photography at the scene. In addition, the pECI could be re-sized appropriately for any lens diameter, further expanding its application, including in laboratory settings. This would, however, require additional research to assess the ease of use of different sized pECI devices.

This proof-of-concept study has demonstrated that the pECI can provide additional detection capabilities for latent marks on flat, reflective surfaces compared to the current in-field

approach of diffused reflection photography. The natural and powdered fingermarks that were photographed by the pECI have been shown to provide, on average, better contrast and ridge detail across multiple surfaces in comparison to diffused reflection photography, with the exception of natural and powdered fingermarks on a mirror. The authors do not suggest that the pECI should replace diffused reflection photography, but rather, the pECI shows promise as an additional optical detection and enhancement tool that may be available to investigators at crime scenes. Further research will be required to test the effectiveness of the pECI when detecting and enhancing a larger quantity of latent marks from a larger donor pool across a wider range of pseudo-operational environments and surfaces.

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For further information, please contact:

Brenden Riley
Western Sydney University, School of Science
Penrith, Australia
B.Riley@westernsydney.edu.au

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