Optimisation and Development of a Portable Episcopic Coaxial Illumination Device for In-field Fingermark Enhancement

Thesis Presented by

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Submitted in fulfilment of requirements for the degree of,

Master of Research

Supervisors:

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Statement of Authentication

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

[redacted]

Acknowledgments

I would first like to acknowledge my supervisors, [redacted] as the project would never have existed without them, and to thank them for their continued guidance on the journey.

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Ethics Approval

All fingermarks donated in this project were utilised in accordance with ethics approved by the Western Sydney University Human Research Ethics Committee.

Ethics Approval Number and Title:

H13684, [H13483 subproject] Design and Development of an Episcopic Coaxial Illumination Attachment for a Digital Camera

Approved Researchers:

[redacted]

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List of Abbreviations

CSI	Crime Scene Investigator
DSLR	Digital Single Lens Reflex
ECI	Episcopic Coaxial Illumination
FLS	Forensic Light Source
FOV	Field of View
IFRG	International Fingerprint Research Group
NC	Non-Comparable
pECI	Portable Episcopic Coaxial Illumination

Abstract

Episcopic coaxial illumination (ECI) is an optical technique used in forensic laboratories for latent fingermark enhancement. ECI works best on flat and reflective surfaces such as glass, metal, and plastic, and will produce a contrasting dark fingermark impression against a light background without the use of prior treatments. This technique is currently limited to laboratory examinations due to the configuration of optical components normally required for the technique to work. Commercial ECI devices used in controlled laboratory environments are more likely to meet such requirements. Current commercially available ECI devices are not practical for in-field use due to their size, complexity, and price. This is a limitation for crime scene investigators as they are restricted in the number of non-destructive techniques for fingermark enhancement on flat and reflective surfaces in-field. If standard optical enhancement methods such as diffused reflection photography fail, investigators are left to employ destructive techniques such as fingerprint powders or chemical reagents.

This project aimed to develop and optimise a new prototype portable ECI (pECI) device designed to function as a lens attachment for a conventional digital single lens reflex (DSLR) camera, in conjunction with the camera flash unit as the light source. Commencing with the evaluation of this initial proof of concept pECI device, the project examined its capabilities and design to identify areas of improvement. This was done by comparing the pECI to the current standard approach to fingermark examination in-field on non-porous substrates and compared to a laboratory standard ECI device. As expected, due to the preliminary design of the pECI device, it was underperforming, but it was found to be functional and practical in its purpose allowing the project to continue.

The project then followed a development and optimisation process to redesign and refine the pECI into a 3D printable device that utilises relatively cheap but effective optical components, while still maintaining the initial design as a DSLR attachment. Optical components for the device were tested through comparisons examining their effect on the contrast created between fingermarks and test substrates but also their cost and practicality.

The final pECI device produced from the project was then compared against the current in-field approach to fingermark enhancement for non-porous substrates in a simulated crime scene environment. Here the optimised pECI device was found to improve the current in-field approach, as it was detecting and enhancing fingermarks to a higher quality than diffused reflection in most instances.

The pECI device is hoped to be utilised by any crime scene investigator, as an additional non-destructive enhancement technique for non-porous substrates in-field. With the addition of pECI in-field, fingermarks that would have likely been lost or damaged due to failed diffused reflection attempts or destructive techniques, could now be alternatively recorded using pECI prior to or after other techniques.

Chapter 1. Introduction

1.1 Fingermark Detection and Enhancement

When a substrate (surface) is touched with a fingertip, a pattern impression is left behind due to the transfer of secretions and contaminants from the finger to the substrate. The resulting impression is called a fingermark (Lennard, 2007). Fingermarks are generally of lower quality compared to fingerprints, which are collected directly from an individual in a controlled manner for reference or database purposes (Alberink et al., 2014).

Fingermark evidence is used to prove a person has touched an object or substrate (Lennard, 2007). When a fingermark is collected, it is analysed by noting visible minutiae. Minutiae are the fine ridge details of a fingermark that are used to compare crime scene fingermarks to reference fingerprints (Alberink et al., 2014). The detection, enhancement, and recording of crime scene fingermarks must be done methodically, as the quality of ridge detail is crucial for comparison. Fingermarks vary in quality depending on several factors, including the depositional pressure of the finger on the receiving substrate, and the physical properties of the receiving substrate itself. Some latent fingermarks can therefore be of high quality with clearer ridge detail, or they can be of poor quality and hence hold limited information, even after enhancement (Lennard, 2007). Fingermarks deposited at crime scenes or on evidence items can either be visible or latent. Visible fingermarks can be seen with the naked eye with little to no enhancement techniques applied. Latent fingermarks require the use of detection and enhancement techniques to visualise them (Christofidis et al., 2018).

Detection and enhancement techniques are categorised into three groups: optical, chemical, and physical techniques. Optical techniques are non-destructive, and they include lighting and photographic techniques. Chemical techniques are deemed destructive as they require the direct application of chemicals to the fingermark and substrate. Physical techniques can also be destructive, such as the application of powders or powder suspensions (Lennard, 2007). When comparing destructive and non-destructive techniques, destructive techniques may inadvertently destroy ridge detail or even destroy the substrate on which the fingermark was deposited, hence caution must be taken when using some techniques (Lin et al., 2006). Over-development is an example of ridge detail destruction, and it occurs when the substrate or background is developed to the same degree as fingermarks, causing marks to no longer be visible on the substrate. In contrast, non-destructive techniques will not affect the ridge detail or substrate at all. Due to this, non-destructive techniques are favoured and are usually performed before and after each chemical or physical treatment in an appropriate sequence depending on the evidence substrate type (Lennard, 2007; Lin et al., 2006).

Fingermarks can be found on various substrates at crime scenes. A substrate can be categorised into three groups based on porosity: porous, semi-porous and non-porous. Porous substrates are capable of rapidly absorbing fingermark residue through micro pockets. Some examples of porous substrates include paper and cardboard. Semi-porous substrates have micro pockets but absorb fingermark secretions at a much slower rate than porous substrate. Semi-porous substrates include waxed paper, glossy paper, or some plastic substrate such as polymer banknotes. Non-porous substrates do not absorb fingermark secretions as they do not have micro pockets in their structure. Consequently, fingermarks remain on the substrate rather than being absorbed. Examples of non-porous substrates include glass, some plastics and metal (Bossers et al., 2011). Substrates of differing porosity require the application of different detection and enhancement techniques to visualise latent fingermarks. The reason different techniques must be used on different substrate types is due to the interaction of fingermark residues with receiving substrates as previously mentioned.

This project focused solely on non-porous substrates and enhancement techniques for that substrate type, which would be used at crime scenes, touching on laboratory enhancement techniques as well.

1.1.1 Crime Scene Detection and Enhancement Sequences

In criminal investigations, fingermarks may be present on exhibits that can be collected from the crime scene and examined in a laboratory, or they may be detected at the crime scene itself on fixed/immovable substrate that cannot not feasibly be collected and sent to the laboratory. These immovable objects require the crime scene investigator (CSI) to perform detection and enhancement techniques in-field.

Crime scenes may be categorised loosely into two different types based on the severity of the crime: (1) major crime scenes; and (2) volume crime scenes (Adderley & Musgrove, 2001). Volume crimes are common crimes, such as break and enters or stolen motor vehicles, and CSIs at volume crime scenes have limited resources for fingermark detection and enhancement; they are often equipped with a standard digital single lens reflex (DSLR) camera, a white light torch, a 415 nm forensic light source (FLS), and a general powdering kit.

Major crimes are more serious, such as assault or homicide (Adderley & Musgrove, 2001). Major crime scenes are often more complex and time-consuming scenes to investigate, hence require the use of extensive resources. Due to this, CSIs will have more detection and enhancement techniques at their disposal. Like volume crime, CSIs have a standard DSLR camera and a powdering kit, but they also have a wider range of FLSs and chemical techniques that can be used for fingermark detection and enhancement at the scene.

The sequence followed for the detection and enhancement of fingermarks at any crime scene is similar in principle. The examination begins with optical techniques, then the application of a chemical or physical technique, followed again by optical techniques (Bossers et al., 2011).

When considering a fixed non-porous substrate at a crime scene, optical techniques are used first such as diffused reflection and photographs are taken of any visible fingermarks. Physical or chemical techniques are then applied to the target substrate. Following each physical or chemical technique, photographs are taken again. Fingermarks can also be lifted using adhesive material if a clear photograph is too difficult to produce (Birkett, 2018).

1.1.2 Laboratory Detection and Enhancement Sequences

When exhibits are collected from crime scenes for fingermark examination at a laboratory, they will have no prior detection or enhancement techniques applied. Knowing this, a sequence is used similarly to a crime scene sequence (non-destructive followed by destructive), but with the availability of a much larger and more sensitive range of detection and enhancement techniques. Refer to Figure 1.1 for a more specific recommended sequence for non-porous substrates as suggested by Lennard (2009).

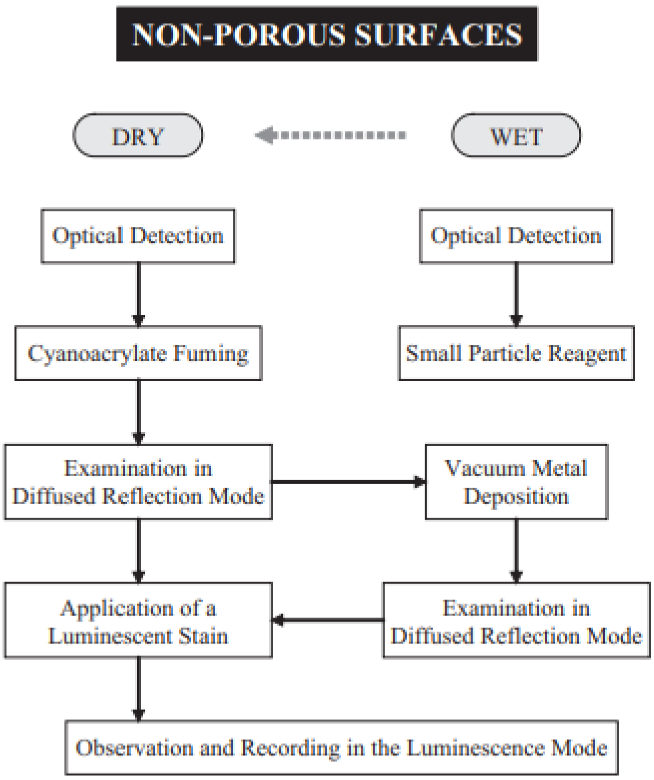


Figure 1.1; Recommended sequence of fingermark examination techniques on dry or wet non-porous substrates as suggested by Lennard (2007).

As mentioned, there are more detection and enhancement techniques available in a laboratory environment. An additional optical technique that is currently only available in the laboratory is episcopic coaxial illumination (ECI) and was the technique of interest for this project.

1.2 Optical Detection and Enhancement Techniques

As previously mentioned, when discussing the detection and enhancement of fingermarks in this study, the focus will remain on techniques used on non-porous substrates both in crime scenes and laboratories. Optical techniques especially, such as ECI, are of interest as CSIs are currently limited in the non-destructive techniques that they can use in-field on non-porous substrates.

Optical detection and enhancement techniques rely on the interaction of light with substrates and fingermark residues to achieve contrast. The two prominent optical techniques used for fingermark detection and enhancement on non-porous substrates are diffused reflection and ECI. To understand both techniques, some basic light theory must first be discussed.

1.2.1 Light Interactions with Non-porous Substrates

When incident light is directed upon a non-porous substrate, it will be reflected, absorbed, and/or transmitted (Figure 1.2). Transmitted light is electromagnetic energy that has passed through an object. The object or substrate does not need to be visually transparent to transmit light. The substrate only needs to be able to transmit certain wavelengths. For example, visually transparent objects transmit visible light, whereas opaque objects absorb visible light but may transmit longer wavelengths such as Infrared light (Born & Wolf, 2013).

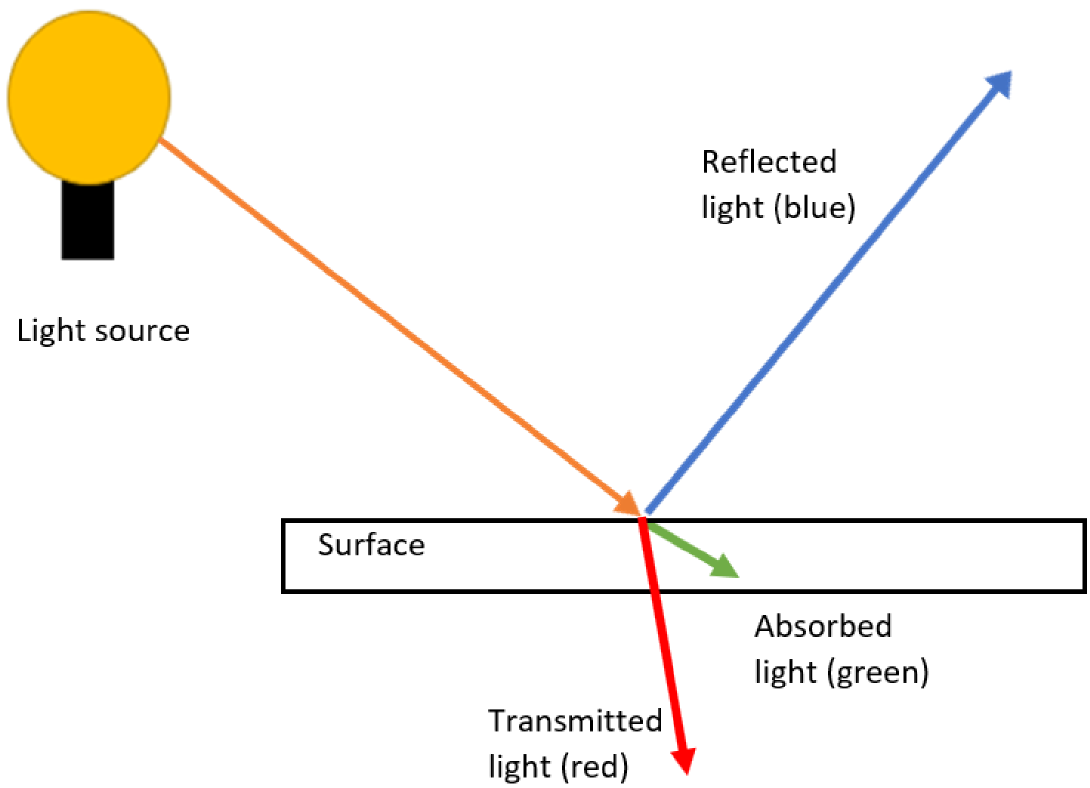


Figure 1.2; Diagram depicting the modes of interaction when light interacts with a substrate. Incident light interacting with a substrate either (orange) reflecting (blue), absorbing (green), and/or transmitting (red) light.

To the human eye, the visual appearance/colour of a substrate is dictated by its absorption, reflection, and transmission properties. For example, if a substrate is red then it is only reflecting red light (roughly between 650 and 700 nm), while absorbing/transmitting all other wavelengths in the visible region (Aumeer-Donovan et al., 2009).

There are two types of reflection: diffused and specular. Diffused and specular reflection refers to how incident light is reflected off a substrate based on substrate topography. A flat, smooth, and highly reflective substrate will reflect light at the same angle as the incident light but in the opposing direction. This is referred to as specular reflection (Figure 1.3a). This is the most common type of reflection on substrates with mirror-like properties, as a mirror reflects almost all the incident light due to high reflectivity. If the substrate is textured due to micro-indentations or micro-structures for instance, then the incident light is reflected in seemingly random directions determined due to these substrate irregularities. This phenomenon is referred to as diffused reflection (Figure 1.3b) (Stoilovic & Lennard, 2004).

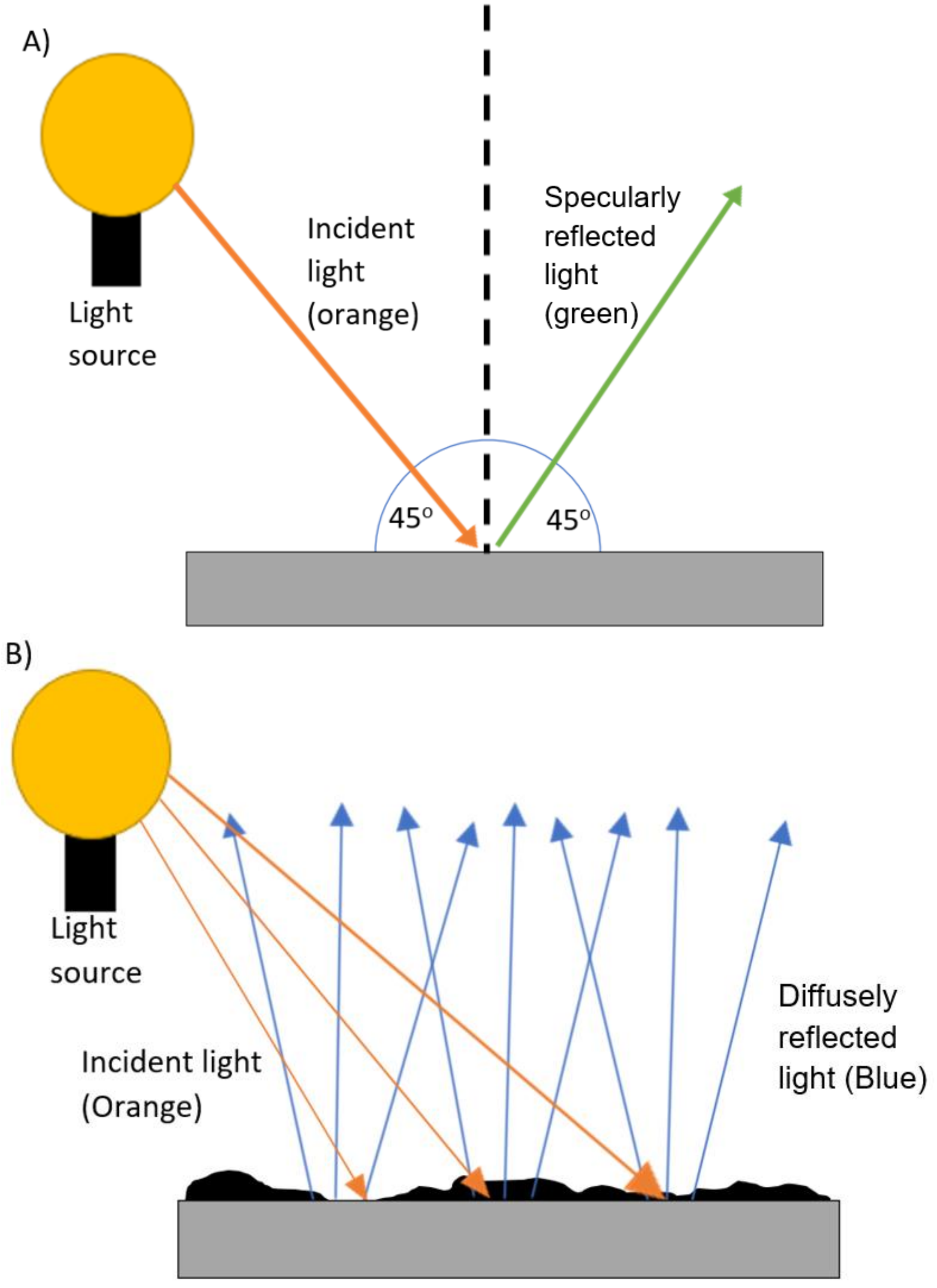


Figure 1.3; The reflection of light on different substrates: a) incident light (orange) interacting with a flat substrate, causing the specular reflection of light (green), and b) incident light (orange) interacting with a textured substrate, causing the diffused reflection of light (blue).

1.2.2 Diffused Reflection for Fingermark Detection and Enhancement

Given that flat, highly reflective, and non-porous substrates alone will cause specular reflection, when a fingermark is deposited on these substrates the residues will create a textured deposit that will cause diffused reflection. When applying incident light to the substrate and fingermark deposit, the difference in reflections produced from the fingermark and the substrate results in contrast (Stoilovic & Lennard, 2004).

This phenomenon is used for optical detection of fingermarks and is referred to as diffused reflection. Diffused reflection utilises highly directional lighting such as a handheld torch or flash unit and is applied to both the substrate and the fingermark. To document this phenomenon, a camera is placed directly above the substrate, with the lens perpendicular to the substrate bearing the fingermark. Incident light is applied at an oblique angle commencing at roughly 45° and is adjusted until a clear fingermark is observed through the camera. Since the angle of incidence is oblique, the substrate will specularly reflect light away from the camera sensor, while the fingermark will diffusely reflect light towards the camera sensor. The final image recorded will result in a contrasting light fingermark against a dark background (Figure 1.4) (Champod et al., 2016).

Diffused reflection photography is routinely performed both at crime scenes and in laboratories. In laboratories, it can be produced using any light source and camera but at crime scenes it is generally achieved using a DSLR camera and flash unit.

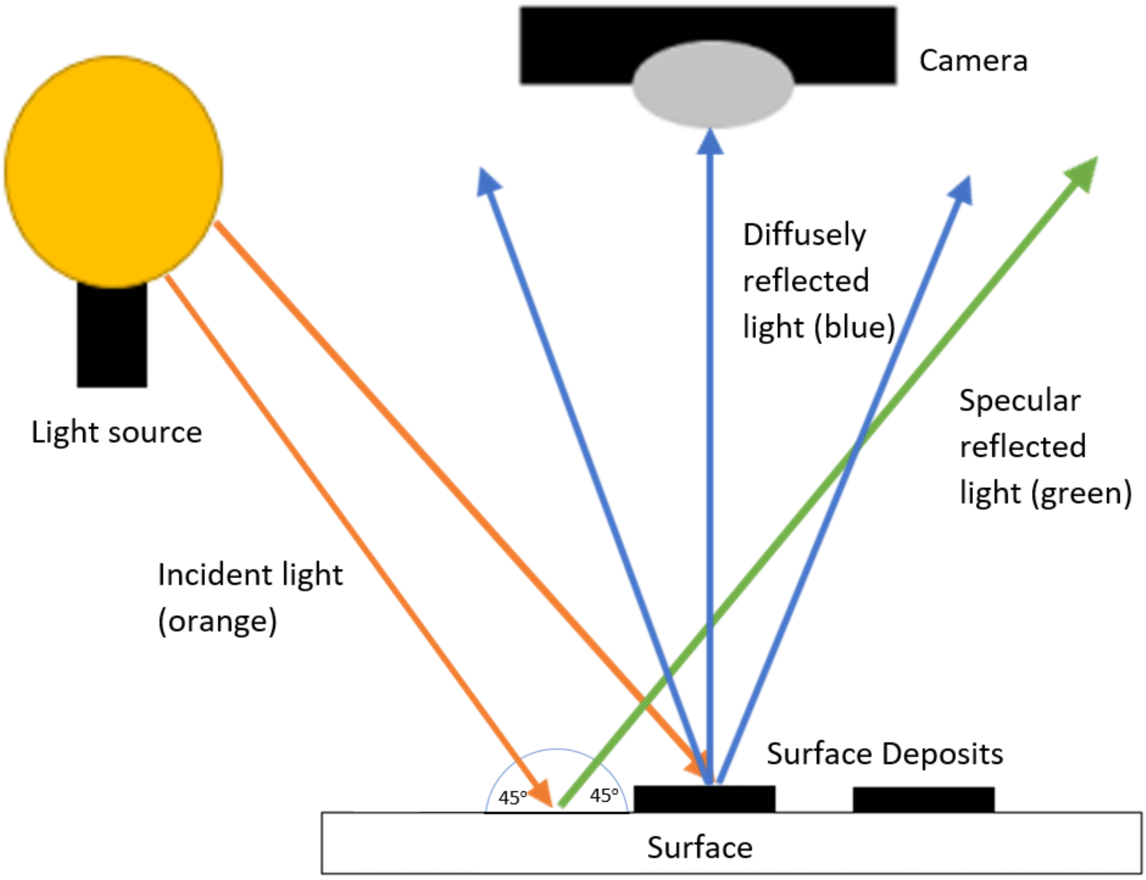


Figure 1.4; Diagram depicting diffused reflection photography. Incident light (orange) applied to a substrate deposit (black boxes) causing diffusely reflected light (blue) being detected by the camera while specular reflected light (green) is reflected away from the camera.

It is important to note that while non-porous substrates do not have micro pockets like porous substrates, this does not mean they are automatically flat and highly reflective causing specular reflection. Non-porous substrates can still be textured if they had many protruding microstructures which would cause diffused reflection. For example, a ceramic substrate is textured but still technically non-porous, hence diffused reflection photography will not function adequately.

1.2.3 ECI for Fingermark Detection and Enhancement

ECI, like diffused reflection, is an optical technique for non-porous, flat, and reflective substrates that also exploits diffused and specular reflection principles. The major difference is the re-direction of the incident light before it reaches the target substrate and fingermark. As discussed, the light will be angled towards the subject at roughly 45° for diffused reflection photography. Instead, ECI uses a semi-transparent mirror to re-direct the incident light onto the fingermark and substrate from directly above (i.e., episcopic), along the camera lens axis.

ECI can only function effectively using a specific camera set-up and ECI componentry. For ECI to work, the camera is placed directly above the substrate and fingermark needing to be photographed. Incident light is provided using a light source which travels parallel to the substrate plane. This incident light will initially transmit through a diffuser, designed to spread light, and soften it to prevent hotspots. The now diffused light will reach a semi-transparent mirror which is placed at a 45° angle between the camera lens and the substrate. The mirror (being semi-transparent) splits the light, ideally in equal proportions, with some light transmitting through the mirror and some light specularly reflecting towards the substrate and fingermark. The reflected light will then interact with the substrate and fingermark, with specular reflection and diffused reflection occurring respectively. The specularly reflected light from the substrate will return directly back towards the semi-transparent mirror, with the light being split again, with the transmitted light reaching the camera sensor beyond the mirror (Figure 1.5) (Robinson, 2016). The result will produce an image of a dark fingermark against a light background due to the camera sensor detecting reflected light from the substrate, while the fingermark diffusely reflects light away from the semi-transparent mirror and subsequently away from the camera sensor.

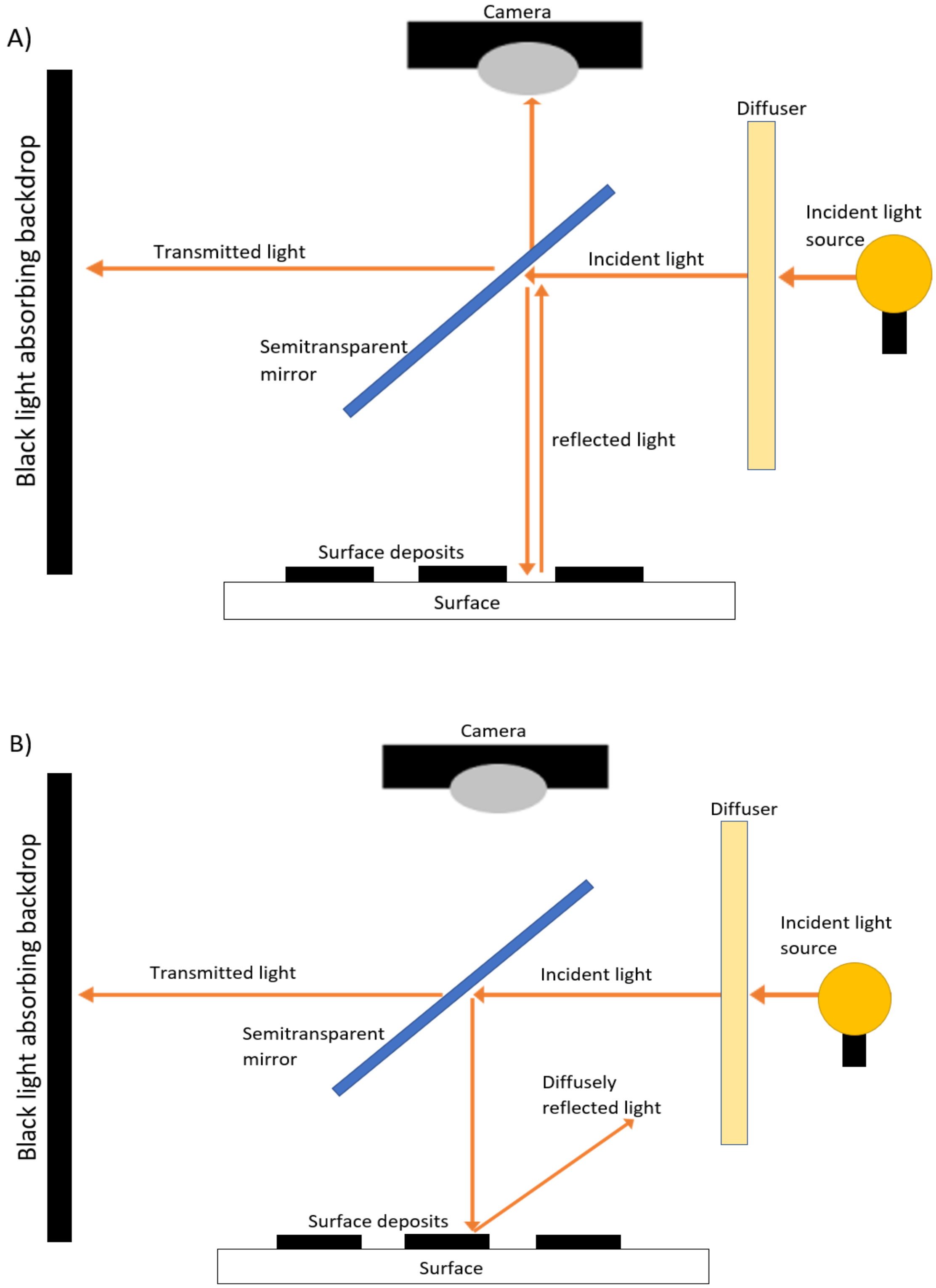


Figure 1.5; a) episcopic coaxial illumination diagram depicting light (orange) reflecting off the substrate into the camera lens using a semi-transparent mirror and specular refection; b) episcopic coaxial illumination diagram depicting light (orange) reflecting off substrate deposit (black square) causing diffused reflection away from the camera lens.

1.3 Current Application of ECI in Fingermark Detection and Enhancement

Roman Pfister (1985) first used episcopic coaxial lighting to record fingermarks on non-porous substrates with varying degrees of success. A noted advantage of ECI is that the substrate colour does not have a negative effect on the overall contrast produced; if the substrate is sufficiently flat and reflective then it will appear white in the final image. Some non-porous substrates that ECI has been shown to work on are summarised in Table 1.1.

ECI has photographic advantages compared to diffused reflection. Due to the re-direction of incident light to be directly above the fingermark, the subject appears without obstructions such as shadows, improving contrast. This allows finer detail to be visible and is of great benefit when photographing evidence such as fingermarks (Robinson, 2016).

While ECI has photographic advantages over diffused reflection, this comes at a cost of practicality, as ECI has more technical requirements. Due to the technical requirements of ECI, it is currently only available for use in forensic laboratories on small exhibits such as credit cards or knives and is not readily available to CSIs at crime scenes (Lennard & Margot, 1988, Bullock et al., 1994). While ECI is restricted to laboratories, it has proven effective when used throughout enhancement sequences and has been shown to work in conjunction with various chemical and physical techniques, including cyanoacrylate fuming (CA), gentian violet (crystal violet) and vacuum metal deposition (Ziv & Springer, 1993; Lennard 2007). Noting the versatility of ECI, portabilisation could be of great benefit to CSIs who need additional non-destructive techniques at the scene.

Table 1.1; Table summarising substrates ECI has successfully enhanced fingermarks in literature.

Substrate	Substrate properties	References
Glass	- Transparent - Reflective	Pfister, 1985
Stainless steel	- Metallic - Reflective	
Bakelite	- Multicoloured or monocoloured - Glossy - Partially reflective	
Porcelain	- Coloured - Glossy - Partially reflective	
Photographic paper	- Non-porous - Glossy - Partially reflective	
Garbage bags	- Commonly black but can be coloured - Glossy - Partially reflective	
Sandwich bags	- Transparent can be coloured - Glossy - Partially reflective	
Adhesive tape	- Transparent can be coloured - Glossy - Partially reflective	
Glossy cardboard	- Coloured - Glossy - Partially reflective	
Plastic	- Transparent can be coloured - Glossy - Partially reflective	
Credit cards	- Multicoloured - Glossy - Partially reflective	Lennard & Margot, 1988
Mirrors	- Metallic - Reflective	Sturelle, 2007
Gelatine lifts	- Partial transparency - Partially reflective	Attard & Lennard, 2018

1.3.1 ECI Laboratory Devices

For laboratories, commercial products have been designed to house all the main components of ECI internally including the semi-transparent mirror, the diffuser, and the lighting source. Some of the laboratory ECI devices that are currently available include the:

- *Coaxial Light guide and illuminator* manufactured by Arrowhead Forensics (United States of America). (Figure 1.6.a)
- *CAS2 SERIES – Uniform Mid Power Coaxial Illumination* manufactured by TMS-LITE (Malaysia). (Figure 1.6.b)
- *Coaxial illumination with beamsplitter* manufactured by Planistar (Germany). (Figure 1.6.c)

The arrowhead ECI device is the only device listed that is directly marketed for forensic use. The other two devices are marketed for other purposes but can be used for forensic applications.

b)

a)

c)

Figure 1.6; a) *Coaxial Light guide and illuminator* manufactured by Arrowhead Forensics (Arrowhead Forensics, n.d). b) *CAS2 SERIES – Uniform Mid Power Coaxial Illumination* manufactured by TMS-LITE (TMS-Lite, n.d.)**.** c) *Coaxial illumination with beamsplitter* manufactured by Planistar (Planistar, n.d.).

1.4 Progression Towards Portable ECI

ECI has shown to be an effective detection and enhancement technique in laboratory environments but the portabilisation of ECI has not been explored greatly. The laboratory ECI devices previously mentioned may be small and are capable of being carried, hence may be classified as portable, they are not feasible to be taken to a crime scene due to several factors.

A requirement for ECI to work is the need for the substrate to be completely flat and the camera axis to be perpendicular to the substrate. To allow for this requirement, a DSLR camera is usually mounted using a copy stand with either of the three devices mentioned supported underneath. The arrowhead ECI device is recommended to be supported by lab jacks and the TMS-LITE ECI device is designed to be mounted above the subject. It is unclear how the Planistar device is positioned for laboratory applications, but an assumption can be made that it would also require a platform or mounting set up. The issue with taking platforms or mounting devices to a crime scene is the increased possibility of contamination when using the same platforms at multiple scenes. Unlike a digital SLR camera which is also taken to multiple crime scenes, the stabilisation equipment will have to come into contact with the scene, while the camera remains handheld. Because of this, the stabilisation equipment will have to be regularly sanitised or disposed of which is a waste of resources and time. With the devices requiring platforms or mounting devices, this also limits the devices to only being used on horizontal substrate. This is a problem as fingermarks can be found on various substrates including vertical substrates.

Another limitation for all three devices is that they each require too much power for a simple battery pack to suffice. The TMS-LITE and Planistar ECI devices require 24 V (TMS-Lite, n.d.; Planistar, n.d.), and the Arrowhead ECI device comes equipped with only a 120-240 V power adapter (Arrowhead Forensics, n.d). In laboratories, this is not an issue as mains power points are available. At a crime scene, power may not be readily available. To counteract this issue, a portable power supply can be taken along with various power cords, but again this is impractical as this is another device needed to be carried, maintained, and monitored, slowing down CSIs and making tasks more cumbersome.

Even if the requirements of the aforementioned devices were met in-field, the impracticality of the devices would still outweigh the advantages. Portable ECI should be achievable and available to all investigators enhancing fingermarks in-field. This project seeks to demonstrate that portable ECI is achievable in a practical manner through the optimisation and development of a new device.

If successful, this new device would have the potential to be taken into future studies and possibly become another standard, non-destructive technique alongside diffused reflection photography for latent fingermark detection and enhancement at crime scenes. With the addition of portable ECI at scenes, this could increase the number of latent fingermarks recorded that might have otherwise been damaged or missed due to the failure of diffused reflection followed by destructive techniques.

1.4.1 Portable ECI Commercial Devices

There is currently only one product on the market, that could be found, that can perform portable ECI photography: *The Contactless Fingerprint System* developed by ForenScope (Hong Kong) (Figure 1.7). The ForenScope product is marketed for use at both crime scenes and in laboratories. It is also marketed to be used without the use of other enhancement techniques such as powdering.

Figure 1.7; *The Contactless Fingerprint System* developed by ForenScope (ForenScope, n.d.).

There are no scientific articles to date that have validated the performance of the ForenScope device. The ForenScope device comes as a single, large unit built onto a camera by the provider. The initial issue with the single unit device is the potentially high cost. The manufacturer has made it difficult to determine an exact price, but an assumption can be made that it is an expensive device, as you will be buying a new camera and the ECI unit as one. Another issue with the device being a single unit is the reliance on all parts functioning. If one component breaks, such as the camera, the entire system may then be useless in the field.

An issue faced with the ForenScope device, and any new portable ECI device, is the introduction of an entirely new system that CSIs will have to incorporate into their workflow. This is problematic for the ForenScope device as it is not small or compact in size. This would be cumbersome to be carried alongside the standard resources that a CSI uses, especially if the CSI is attending a scene alone. The ForenScope device also utilizes an entirely new camera that would require additional training to operate. Whilst the addition of any new ECI device will require further training, ideally a new device should not require specific camera or software training. The ForenScope would require training for any dedicated software used by the device but also to correctly use the hardware features built into the device which includes various light sources. It would be favourable to create a portable ECI device that is simpler in design and would require less training.

1.4.2 Improving the Portability of ECI

Given that each CSI is equipped with a DSLR camera that they are trained to use, it would be beneficial to have an ECI device that can be used in conjunction with the standard issue DSLR. This ECI device could be an attachment to the DSLR which would allow the CSI to continuously use only their DSLR. Considering the relatively simple components needed for ECI to work, the device can be small. With reference to laboratory devices such as the TMS-LITE and Planistar ECI devices, small ECI devices are possible, as these two devices house all components internally and are the smallest in comparison with other commercial products. Another problem faced is the weight of the device as to not harm the camera's lens (if affixed to the lens), but also so it is not strenuous to be handled by a CSI for extended periods of time. Lightweight components should be used where necessary to avoid this problem.

If a portable device were made that could be used as an attachment with a standard DLSR camera, then this would be beneficial for a few reasons. Firstly, the CSI would be able to quickly switch between standard photography and ECI photography with ease through attaching and detaching the device. Secondly, all the images collected would be saved to one device/SD card rather than across multiple locations. Finally, a simple portable ECI attachment also has potential to be used at both volume and major crime, greatly benefiting both.

In order to build a new ECI device/DSLR attachment, the components (semi-transparent mirror, diffuser, and light source) would have to be examined, based not only on the quality of fingermark enhancement they produce, but also their practically such as cost, weight, and usability.

1.4.2.1 Semi-transparent Mirrors

There are three different semi-transparent mirrors that could be used for ECI: beamsplitters, two-way mirrors, and non-conventional semi-transparent mirrors.

For scientific instruments, specially designed semi-transparent mirrors called beamsplitters are used. These mirrors are designed to split beams of light equally — or unequally depending on their purpose — into transmitted and reflected components.

Due to the diverse functionality of beamsplitters they are generally expensive and are used a wide variety of disciplines and experiments.

Another type of semi-transparent mirror that can be used for ECI is a two-way mirror. Two-way mirrors are common and are made using a transparent material with one side coated in a thin metallic coating used as the reflective side.

To use ECI effectively, the semi-transparent mirror does not have to be a conventional semi-transparent mirror. All that is needed is a flat, rigid piece of material that has both reflective and transparent properties, such as suggested by Robinson (2016), the use of a piece of glass. Rigid pieces of transparent plastic can also be utilised as non-conventional semi-transparent mirrors. There is a benefit to using a non-conventional mirror. Conventional semi-transparent mirrors, such as two-way mirrors and beamsplitters, are expensive; while non-conventional mirrors are inexpensive, they can be just as effective. Spring (2015) demonstrated ECI on a larger scale compared to using a smaller commercial device, using only glass as the semi-transparent mirror, and produced clear results.

1.4.2.2 Diffuser

An ECI diffuser is usually a transparent material that has light diffusing elements incorporated. These elements can be particles that will refract and disperse the incident light to achieve the even lighting required for ECI. When incident light is diffused, some light intensity is lost due to the refraction of light in directions other than forward. The refraction properties of a diffuser may vary as a result of the thickness of the diffuser as well as the concentration of diffusing elements inside. Some commonly found diffusing materials include frosted glass and a range of plastics.

An alternative to a diffuser would be a Fresnel lens. A Fresnel lens is a cost-effective lens that collimates light rather than dispersing light like a diffuser. First designed by Augustin-Jean Fresnel in 1822 for lighthouses, Fresnel lenses are lightweight and less-expensive alternatives to much larger lenses used to collimate incident light to focus on a single point or area, depending on the application (Davidson, 2010) (Figure 1.8).

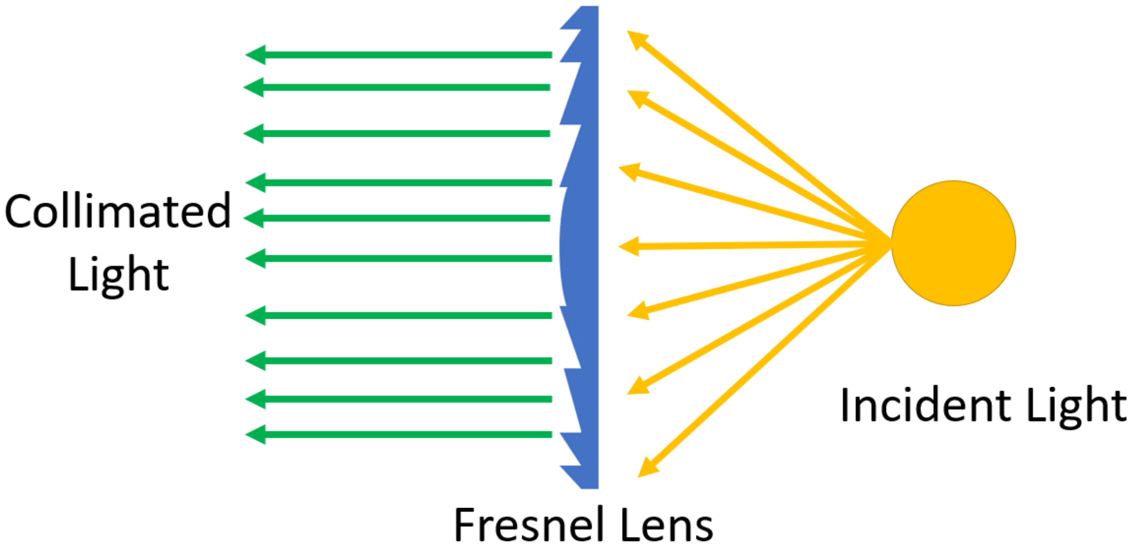


Figure 1.8; Spread incident light (Yellow) traveling through a Fresnel lens (blue) creating collimated light (green).

Normally, in order to collimate light, a bulky aspheric lens is required but a Fresnel lens achieves the same outcome as a standard aspheric lens without the need for bulky glassware, cutting costs and weight immediately. It achieves this through the refraction of incident light, using groves on one side of the lens rather than a larger aspheric curve. The only requirement is that the Fresnel lens, depending on the purpose, needs to be at the desired focal length from the focal point for it to be optimal. The focal length of a Fresnel lens differs depending on its design and purpose but this information can easily be sourced from the manufacturer (Davis & Kühnlenz, 2007) (Figure 1.9).

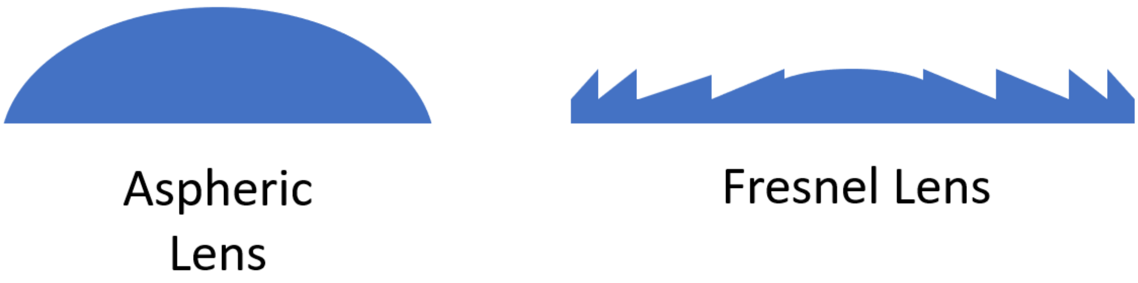


Figure 1.9; Curved aspheric lens (left) compared to a grooved Fresnel lens (right).

Theoretically, there are several benefits of using a Fresnel lens rather than a conventional diffuser for ECI. Firstly, the collimated light is immediately more powerful than diffused light as the Fresnel lens is ‘catching’ and directing any incident light into one direction, compared to a diffuser which will spread the light and cause it to bounce in different directions resulting in some minor loss of light. Secondly, when using a diffuser, depending on the quality, the light source needs to be roughly the same size as the diffuser or powerful enough to spread across the whole diffuser. In comparison, the Fresnel lens can function using a smaller light source. Fresnel lenses would theoretically be great for ECI as the user could take any light source and immediately collimate light to the same quantity. If the Fresnel lens was the same dimension of the desired semi-transparent mirror, then it can evenly illuminate the entire mirror with ease, with the only requirement being the focal distance of the Fresnel lens.

1.4.2.3 ECI Lighting

The use of different incident light sources may also be explored for portable ECI. For instance, the flash unit of the DSLR could be a useful source of incident light to achieve portable ECI. Flash units for DSLRs are handheld, battery operated, and are readily available to the CSI who already carries a flash unit to every scene. Another common forensic light source that can be used with a commercial ECI device is the

Polilight PL500 produced by Rofin (Australia). The PL500 has the ability to emit single-band (coloured) lighting within a range of 415 nm to 650 nm, with the inclusion of white light, ultraviolet and infrared modes (Vandenberg & van Oorschot, 2006). The PL500 is not restricted solely to laboratory usage; it is generally portable due to its design, as long as there is a mains power supply nearby (Figure 1.10.a). The *Polilight Flare Plus 2* (also manufactured by Rofin Australia) is a more portable lighting device as it is shaped like a general handheld torch and functions using a rechargeable battery. It was designed more specifically for crime scene usage and can also be used with an ECI setup. The flares are purchased in kits, with each torch producing one specific wavelength. In the kits, one of the torches produces white light which can be used with ECI (Figure 1.10.b).

Another form of light source is light emitting diodes (LEDs). Commercial ECI devices sometimes have lighting capabilities built into the device in the form of LEDs. LEDs are small light emitting devices that produce light through two semiconductors which cause electrons to drop orbital levels and release energy in the form of photons (Yeh & Chung, 2009). LEDs have many benefits including a longer life span and improved energy usage compared to incandescent and fluorescent lighting. They are also smaller in size, more cost effective, and can produce different electromagnetic energy outputs meaning they can produce different colours across the visible spectrum and can even emit infrared and ultraviolet light (Yeh & Chung, 2009).

a) 

b) 

Figure 1.10; a) The ‘*Polilight PL500’* Produced by Rofin Australia (Rofin Forensic (a), n.d.); b) ‘*Polilight Flare Plus 2*’ also manufactured by Rofin Australia (Rofin Forensic (b), n.d.).

1.5 Project Aim, Scope, and Limitations

This project aimed to further develop and optimise a proof of concept portable ECI (pECI) device (referred to throughout as ‘pECI v1’) that was developed prior to the commencement of this project by the Western Sydney University (WSU) Forensic Research Team.

The pECI device in question was designed as a DSLR camera attachment that functions with an external DSLR flash unit as the light source. This is a unique design and addressed most of the problems previously mentioned. To further develop and optimise the device, an array of differing components and materials were tested to determine which combination of materials provided the best quality of fingermark enhancement. Any components that were tested were also evaluated based on their cost, practicality, and availability. This ensured that the final optimised pECI device is cost effective and readily available to all CSIs.

This project followed the recommendations outlined in the International Fingerprint Research Group (IFRG) guidelines, initially under Phase 1 (Pilot Studies) and progressed into the early stages of Phase 2 (Optimisation and Comparison) as the project continued (Almog et al., 2014). While the project did follow the IFRG guidelines where possible, there were some limitations that could not be avoided. Firstly, the effects of aging on fingermarks could not be examined. While it would be ideal to examine the effects of aging, due to the 1-year time frame available for the research, aging the fingermarks longer than 24 hours was not feasible. Consequently, it was decided that fingermark age would not be examined but should be included in future work. Secondly, as the experiments continued towards the end of the project, less donors were available thus the opportunity to evaluate donor variability as one of the experimental parameters was limited.

1.6 Research Questions

The primary research questions of this study were:

1. How does the initial pECI device (pECI v1) currently perform?
2. How can the pECI v1 design be optimised so that it is more practical, cost effective and reproducible?
3. What would be the most effective optical components to be used in the optimised pECI device (pECI v2)?
4. How does the optimised pECI device (pECI v2) compare to the current standard for optical detection and enhancement in-field at crime scenes?

Chapter 2. Materials and Methods

2.1 Proof of concept: Evaluating the Capabilities of the pECI v1 Device

Prior to commencement of this research project, a proof of concept pECI device (pECI v1) had been developed. The pECI v1 consisted of a 3 mm thick aluminium frame, the dimensions of which were 80 x 80 x 90 mm (length x width x height). The frame was spray painted matte black and lined on the inside with black felt in order to diffuse any internal stray light and improve image quality. The semi-transparent mirror was made from a plastic CD cover (polystyrene). The diffuser was produced from 3 mm thick opaque acrylic sheeting purchased from a local hardware store. The device contained a removable lid with a built-in ring adapter to allow the device to be attached to any standard DSLR camera lens. The total weight of the device was 262 g. A Canon Speedlight 550EX flash unit was used as the light source as this was found to be sufficiently powerful to achieve good ECI results and flash units of this type are a standard accessory carried by scene examiners. In this study, the flash unit was used wirelessly through a Canon Speedlight Transmitter ST-E2 (Figure 2.1).

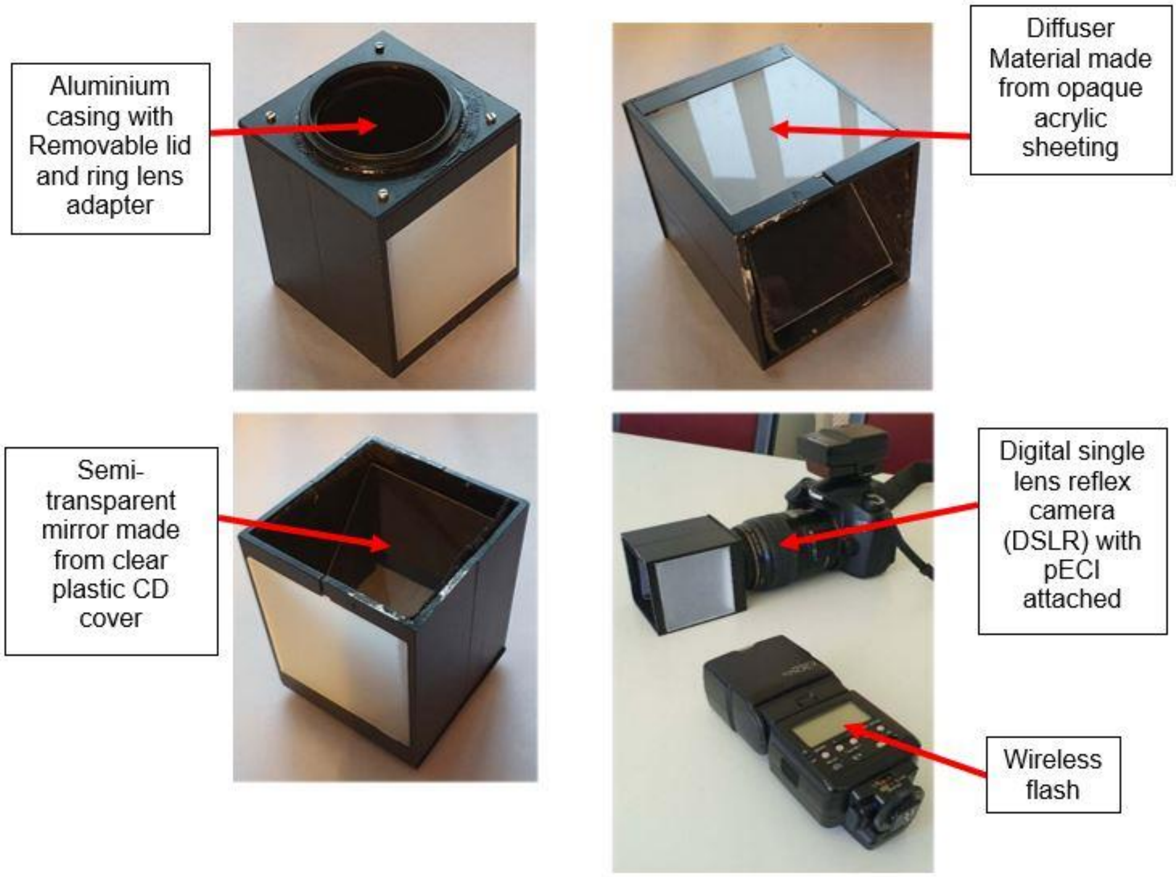


Figure 2.1; The pECI prototype design shown from various angles: (top left) removable lid of device with built in ring adapter for lens attachment; (top right) side of device showing diffuser; (bottom left) showing the inside of the device and the semi-transparent mirror; and (bottom right) device attached to a DSLR with a portable flash unit at the side.

Three experiments were conducted in the proof of concept stage: (1) fingermark images obtained in-field using pECI v1 were compared to fingermark images acquired using the current standard for optical detection and enhancement at crime scenes; (2) fingermark images obtained using the pECI prototype were compared to fingermark images obtained using a commercial laboratory based ECI device; and (3) a final comparison of images from the pECI v1 mounted on a copy stand compared to images captured handheld with the pECI v1.

2.1.1 Fingermark Donation Procedure

This proof of concept set of experiments followed recommendations in the Phase 1 (Pilot Study) section of the IFRG Guidelines for the Assessment of Fingermark Detection Techniques (Almog et al., 2014).

For these experiments, the fingermark donation process was the same, differing only in the substrates used. Each experiment utilised the same three anonymous donors, with each donor depositing natural fingermarks on the respective substrates for each experiment. Charged fingermarks were not utilised as these are not considered to be representative of the fingermarks typically encountered in casework.

Only three donors were utilised due to the preliminary nature of these experiments. The donors were categorised by only age and gender, representing weak, medium, and strong fingermark donors. The donors included: donor 1, female (27 years old); donor 2, male (44 years old); and donor 3, male (23 years old). Donors were instructed to rub their hands together to evenly distribute skin secretions just prior to placing their fingertip on each test substrate using moderate force.

All recorded images for all fingermarks were subjected to basic contrast enhancements that were completed using the latest version of Adobe Photoshop version (2022, Version 23.0 - 23.5). Image adjustments included the addition of a black and white filter, image cropping and adjustments to curves, levels, and sharpness.

2.1.2 Fingermark Grading System

To compare the fingermarks between devices or techniques, the University of Canberra (UC) comparative scale was used (Almog et al., 2014). The UC scale is used to assess the quality of a split fingermark impression, by comparing either two different enhancement techniques or comparing the same enhancement technique but with a change in variables (Table 2.1).

Table 2.1: UC comparative scale for the assessment of two different enhancement methods A and B, adapted from the IFRG guidelines (Almog et al., 2014).

+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

Usually, to utilise the UC comparative scale, split fingermarks are utilised. Since this project mainly examined optical techniques, splitting of fingermarks was not required. Due to this UC comparisons were completed using whole impressions imaged using two optical techniques and with the two images placed side by side in a single image (Figure 2.2).

Optical Technique A **Optical Technique B**

Figure 2.2; A comparison image created using two images of the same fingermark but enhanced using two different optical techniques.

Once comparison images were created, they were graded by three individuals of varying experience with the UC comparison scale, but all had experience with fingerprint research or practical industry experience. Grading was a blind comparison, the techniques used in each image was not known to the graders and both image halves were adjusted to be black and white. The median UC grade was calculated for each individual fingermark using the grades provided from each grader. If a comparison was unable to be graded by most graders due to either poor overall quality, such as no usable ridge detail in both images of the impression, or no visible fingermark, then *'Non-Comparable'* (NC) was recorded.

2.1.3 Comparison of pECI v1 to the Current In-field Enhancement Sequence

The first experiment involved the comparison of images obtained using the pECI device to images obtained using current standard in-field optical enhancement technique common to fingermarks on non-porous, flat, and reflective substrate, in this case, diffused reflection. The main purpose of this experiment was to evaluate the pECI v1 capability as an onsite examination method to supplement existing techniques. This was completed with images captured using handheld photography as this is what the device was designed for.

The three donors each deposited two natural fingermarks on each substrate. Substrates for this experiment were fixed, non-porous substrates that are commonly encountered at crime scenes: (1) a glass window in a door; (2) a conventional glass mirror; (3) tinted glass desk; and (4) a stainless steel oven door (Table 2.2).

Table 2.2: Substrates utilised comparing pECI v1 to the standard approach to in-field fingermark enhancement and their reference images.

Substrate	Glass Window in Door	Conventional Glass Mirror	Tinted Glass Desk	Stainless Steel Oven Door
Reference Image				

The following fingermark detection and enhancement sequence was tested. After detecting a fingermark, photographs of the fingermark were taken using diffused reflection followed by pECI photography. Once photography of the latent fingermark was completed using both optical techniques, white powder was applied. *Opti-Hadonite white fingerprint powder* supplied by Optimum Technology (Australia) was used and applied using a No. 6 squirrel-hair brush, along with a clean-out brush also supplied by Optimum Technology. Post powder enhancement then included diffused reflection photography and pECI photography again (Figure 2.3).

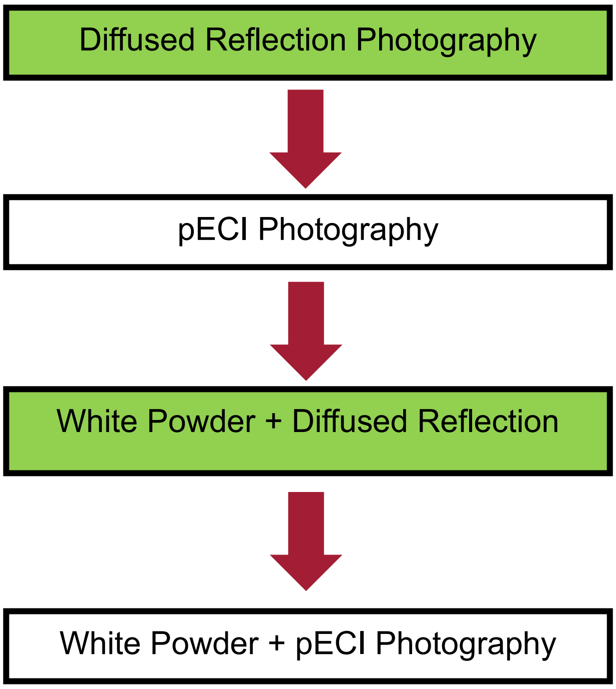


Figure 2.3; Flow chart of the detection and enhancement sequence utilised during the comparison of pECI v1 to the current in-field enhancement sequence. Techniques highlighted in green indicate the current standard approach used operationally for non-porous flat and reflective substrates at crime scenes.

Of the two fingermarks deposited by each donor on each substrate, one was examined after one hour, and the other after 24 hours. A total of 24 fingermarks were examined in this experiment, with each mark processed using the entire sequence indicated above.

The same camera was used to record all the fingermarks: a Canon EOS 90D DSLR camera. When enhancing fingermarks using the pECI device, a Canon Macro Lens EF 100 mm 1:2.8 USM was utilised; however, when recording images using diffused reflection, prior to and after powdering, a Canon EF 50 mm f/2.5 compact macro lens was used. The reason for using a larger lens for the pECI device is to increase the working distance between the subject and device. While standard practice for current CSIs is to use a 50 mm or 60 mm macro lens (hence the 50 mm for diffused reflection photography), pECI v1 was initially designed to function best with a 100 mm lens which was a design limitation that was addressed later in the project.

When recording images using the pECI device or diffused reflection, the following exposure settings were utilised (Table 2.3). Adjustment of the flash exposure compensation was performed depending on the substrate/fingermark detail visible in previous images.

Table 2.3: Typical exposure settings utilised when recording images with the pECI and when performing diffused reflection photography.

Mode	Aperture	ISO	Shutter Speed	Metering Mode
Manual (M)	f/22	100	1/125 sec	Spot

2.1.4 Comparison of pECI v1 to Laboratory ECI Device

The second experiment involved the comparison of fingermark images obtained by the pECI prototype and fingermark images obtained using a commercial ECI device, the *Coaxial Light Guide and Illuminator* manufactured by Arrowhead Forensics. The purpose of this experiment was to assess the quality of fingermarks obtained by the pECI device in a controlled environment, using the Arrowhead device as a benchmark.

To compare the two devices, the three fingermark donors each donated one natural fingermark on three substrates: (1) glass pane; (2) polished metal; and (3) plastic CD case.

As such, a total of nine fingermarks were donated; these were enhanced one hour after deposition and then enhanced again 24 hours after deposition, creating 18 images from the nine latent fingermarks per optical technique.

When using both ECI devices, the same DSLR camera and lens was employed, a Canon EOS 90D camera with a Canon Macro Lens EF 100 mm 1:2.8 USM. All images recorded were subjected to the same contrast enhancements as described for the previous experiment.

To record images using the pECI device, it was attached to the end of a DSLR camera lens; the camera was then attached to a copy stand (Figure 2.4;). A spirit level was used to confirm that the camera was perpendicular to the substrate placed directly below. For consistent results, the flash unit was positioned on top of two height-adjustable lab jacks instead of holding the flash by hand. Images obtained using the pECI device utilised exposure settings consistent with handheld photography to mimic in-field use, with the inclusion of manual mode operation and shutter speeds consistent with handheld photography (Table 2.4).

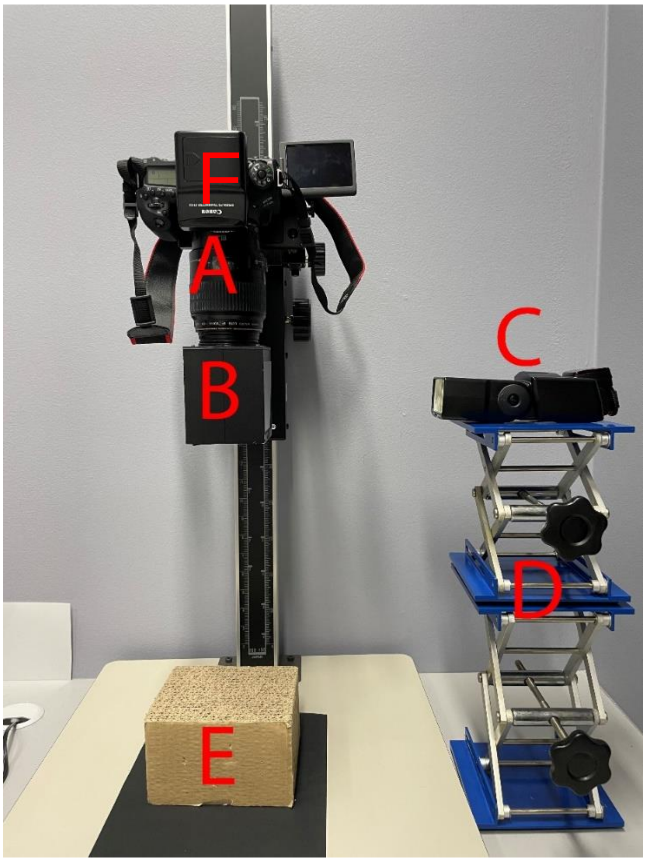


Figure 2.4; Experimental setup for pECI examinations: A) Canon DSLR camera with 100 mm macro lens; B) pECI device attached to the camera's macro lens; C) Canon 550EX wireless flash unit; D) height adjustable lab jacks; E) cardboard cube for raising substrates; and F) Canon Speedlight Transmitter ST-E2.

Table 2.4. Typical exposure settings used for recording fingermarks using the pECI system.

Mode	Aperture	ISO	Shutter Speed	Metering Mode
Manual (M)	f/22	100	1/60 sec	Spot

When recording images using the Arrowhead ECI device, it was placed on top of two lab jacks to allow it to be height-adjusted. A cardboard support was placed under the substrate to raise it and ensure that the subject was in focus. The camera was mounted directly above the Arrowhead device. A spirit level was used to confirm that the camera was perpendicular to the substrate, looking directly through the Arrowhead ECI device (Figure 2.5). Note that a mains-powered light source is incorporated in the body of the device so no separate light source is required.

Exposure settings utilised with the Arrowhead device are summarised in Table 2.5, with adjustments of the exposure compensation performed depending on the substrate/fingermark detail visible in previous images.

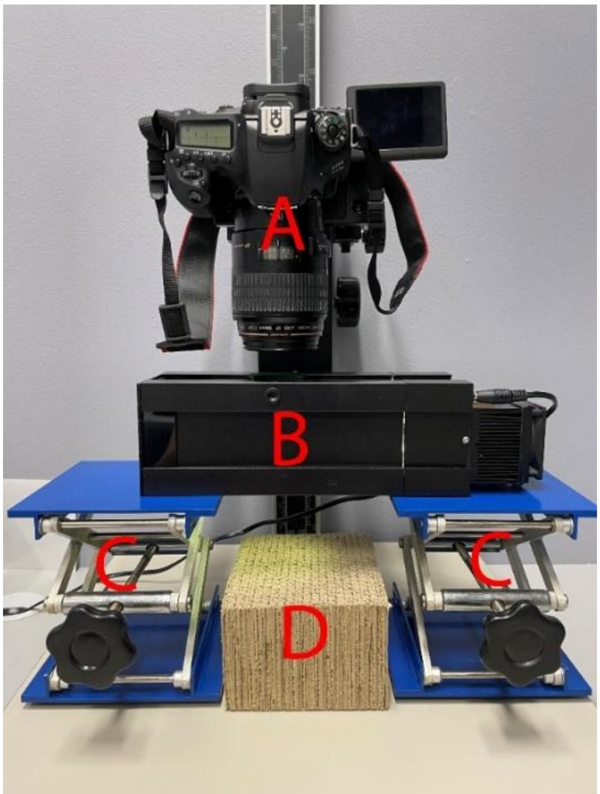


Figure 2.5; Experimental setup for Arrowhead ECI examinations: A) Canon camera with 100mm macro lens. B) Arrowhead coaxial light guide and illuminator. C) Height adjustable lab jacks. D) cardboard cube for raising substrates.

Table 2.5: Typical exposure settings used for recording fingermarks using the Arrowhead ECI device.

Mode	Aperture	ISO	Exposure Compensation	Metering Mode
Aperture priority (Av)	f/8	100	Minimum +1	Spot

2.1.5 Copystand vs Handheld pECI Photography

The final proof of concept experiment compared images from the mounted pECI device (using a copystand) to images from handheld operation of the pECI v1. This was completed to assess whether there was a decrease in image quality due to handheld use.

For this experiment, the three fingermark donors each donated one natural fingermark on each of these three substrates: (1) glass pane; (2) polished metal; and (3) plastic CD case.

A total of nine fingermarks were examined after being aged 24 hours and recorded using the pECI device set up on a copystand in the same manner as the laboratory comparison experiment. The exact same fingermarks on the same substrates were then recorded using the pECI device again but now utilised handheld. Fingermark age was not examined in this experiment as the aim of this experiment was to evaluate the performance of the pECI device when handheld as compared to being mounted on a copystand setup under controlled conditions.

2.2 Optimisation of the pECI Case

The first step in the optimisation of the pECI device was to create a new case to house the ECI componentry. The case design of pECI v1 had its flaws, mainly the inability to function with smaller macro lenses. CSIs are not commonly using 100 mm macro lens for standard fingermark photography at scenes, hence the new pECI case had to be compatible with smaller lenses such as 50 or 60 mm macro lens, but it also had to be cost-effective, robust, light, and small. To create the new pECI case, a few stages had to be completed: the area of view (AOV) of several lenses had to be determined for the new case to be used with smaller macro lenses more aligned with current standard CSI lenses. Using the AOV of the lenses, the dimensions of the new pECI could be determined, allowing for a 3D model to be created. Finally, the case was 3D printed.

2.2.1 Calculating AOV

Three lenses were examined to determine their AOV at specific macro ratios to ascertain a practical pECI case size. These lenses included a 50 mm, 60 mm, and 100 mm macro lens. To determine an accurate AOV of these three lenses, a Canon 90D DSLR was used with each lens for consistency. It should be noted that this camera model has a cropped sensor, specifically the APS-C CMOS, which is 22.3 x 14.9 mm (width x height) (Canon, N.D).

The AOV of each lens was determined using an empirical method. Each lens was attached to the same camera which was mounted to a copy stand and a right-angle linear scale was used as the photographic subject. Images of the linear scale were taken at different macro ratios and corresponding focal distances. These images were then placed into the latest version of Photoshop (2022, Version 23.0 - 23.5) and using the measurement tool, the height, width, and diagonal measurements were recorded, allowing an approximate AOV to be determined for each image (Figure 2.6).

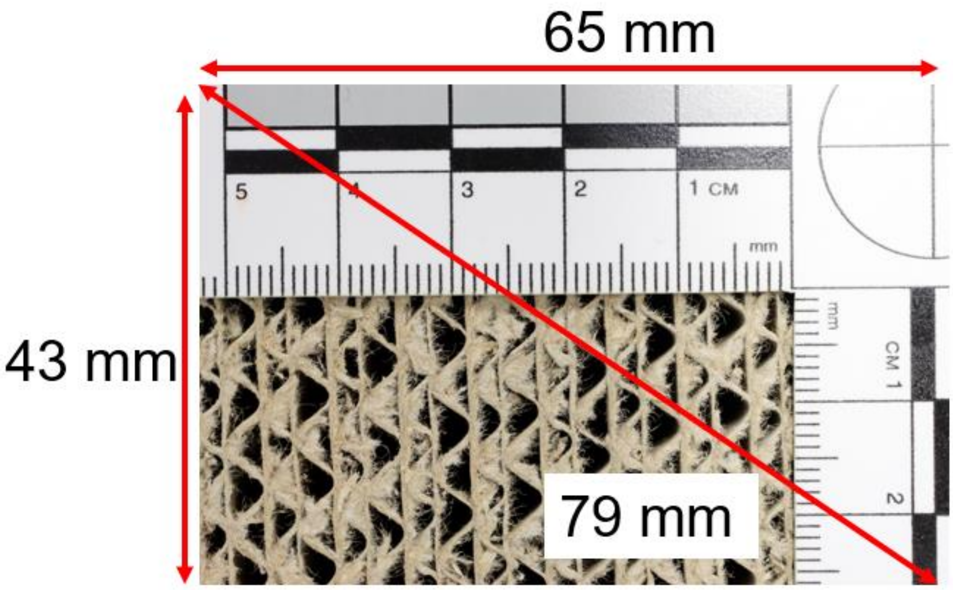


Figure 2.6; Example image of right-angle linear scale acquired using a 50 mm macro lens at a 1:3 macro ratio at a working distance of 207 mm.

2.2.2 New pECI Design

When determining the design of the new case, several factors were considered. The interior had to be larger than 66 x 44 mm (length x width) as this is the AOV of the 50 mm macro lens at a 1:3 macro ratio and will prevent the pECI from being visible in the final images when using a 50 mm macro lens. It also had to be shorter than 90 mm as this was the length of the last pECI case (pECI v1) and that length was the reason it was visible originally. There also had to be a slot/ledge built into the design for the semi-transparent mirror to be held in place at exactly 45° preventing it from moving while using the device. There had to be a slot for the diffuser to sit that was equal size to the interior to allow for an even illumination of the entire semi-transparent mirror while also not allowing it to be easily removed or mis-aligned while in use. Finally, there had to be a method to remove and replace components with ease for maintenance.

The final case design consisted of two sections, the base of the case (Section 1) which holds the optical components within the case and a lid (Section 2) with a view port that would slide on and off the top of section 1, locking the components inside while also allowing the swapping of components for testing (Figure 2.7).

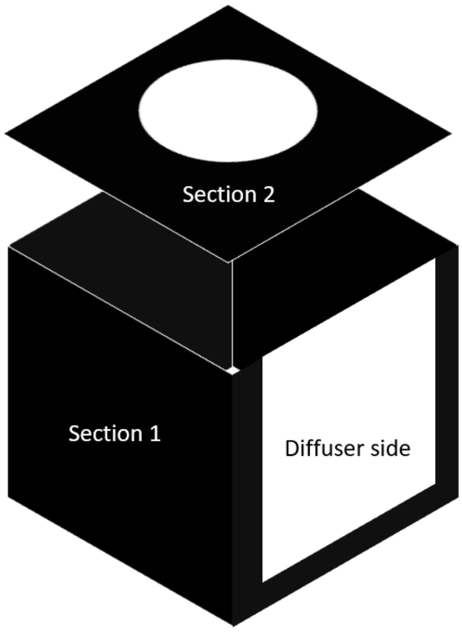


Figure 2.7; The final case design illustrating the two main sections. Section 1 to hold all optical components and Section 2 being the lid for the case capable of sliding on and off locking components in while allowing for the interchanging of components with ease.

With a base now designed and a slot required to hold the semi-transparent mirror in place at exactly 45°, the length of that slot had to be calculated which was simply done using Pythagoras theorem.

2.2.3 3D Modelling and Printing

Once the new pECI case was designed it had to be modelled for 3D printing. All models were made using Blender software (version 3). To 3D print the model, a *FlashForge Adventurer 3* manufactured by FlashForge (China), was utilised (Figure 2.8). The Adventurer 3 printer has the capability to print objects with a maximum size of 150 x 150 x 150 mm (length x width x height). It utilises a 0.4 mm diameter nozzle that can heat plastic filament or resin up to 240^{O}C and can print layers between 0.1 and 0.4 mm wide with a print precision of +/- 0.2 mm (FlashForge, N.D). The filament used in these prints was 1.75 mm black polylactic acid filament and the filament was heated to ~200^{O}C. The total print time for both case sections was ~8 hours: ~6.5 hours for section 1 (base) and ~1.5 for section 2 (lid).

Figure 2.8; Image showing FlashForge adventurer 3D printing new pECI casing.

2.3 Optimisation of the pECI Optical Components

The experimentation for the optimisation of optical components attempted to follow recommendations in the Phase 2 (optimisation and comparison) section of the IFRG Guidelines for the Assessment of Fingermark Detection Techniques (Almog et al., 2014).

The following set of experiments were completed to determine which optical components to incorporate into the optimised pECI design. The optical components that were evaluated included the semi-transparent mirror and diffuser – the specific materials tested for each component are outlined in detail below. When choosing materials to test, variables such as weight, cost, reflection/transmission ratio (for the mirror only), and product availability were considered. Fingermark quality from the pECI images were then evaluated for the various materials. A series of experiments were conducted to determine: (1) the quality of fingermark enhancement from each component combination when mounted (copystand); (2) the quality of fingermark enhancement from each component combination when alignment variables were uncontrolled (handheld); and (3) if there was a notable decrease in quality when using any component combination handheld.

2.3.1 Photography Equipment

Following the creation of the new pECI case, the following camera equipment was utilised. A Canon 90D DSLR with a Canon EF-S 60mm F/2.8 Macro USM Lens, and a Canon Speedlight 550EX flash unit connected wirelessly using a Canon Speedlight Transmitter ST-E2.

This camera equipment was chosen as it best compares to the current camera equipment utilised by local law enforcement for crime scene fingermark photography (Riley, B, personal communication, March 4, 2022). This camera equipment was utilised for all subsequent experimentation in this project.

2.3.2 Semi-transparent Mirrors

Three different semi-transparent mirrors were chosen for testing: the original polystyrene CD case (utilised in pECI v1); a glass beamsplitter; and an acrylic two-way mirror. These three semi-transparent mirrors were chosen as they all differ with regards to reflection/transmission ratios, price, and weight, which will be the major variables being compared between the mirrors. All mirrors were sourced in Australia (Table 2.6).

Table 2.6: Semi-transparent mirrors tested for optimised pECI device, their details, reflection to transmission ratio (R/T), price and supplier.

Reference Name	Details	Reflection to Transmission Ratio (R/T)	Price (AUD)	Supplier
CD Case	Polystyrene 70 x 100 mm, 1 mm thick.	Unknown	10 pack (10.00)	Officeworks (Australia)
Beamsplitter	75 x 75mm 50R/50T, VIS Plate Beamsplitter #48-904	50/50	400.00	Edmund Optics (Australia)
Acrylic Mirror	Two-way mirrored acrylic sheet (3 mm thick, 148 x 210 mm, saw cut edge finish)	75/25	20.00	Acrylics Online (Australia)

2.3.3 Diffusers

There were two possible avenues for diffusing light prior to entering the pECI system: (1) the use of conventional diffusive material such as acrylic plastic; or (2) using light collimated by a Fresnel lens. Both avenues were tested to determine the best avenue to pursue for the optimised pECI device.

Two diffusive materials were examined, acrylic sheeting (utilised in pECI v1) and Matelux glass, both sourced from local hardware stores (Table 2.7).

Table 2.7: Diffuser materials tested for the optimised pECI device, their details, price, and supplier

Reference Name	Details	Price (AUD)	Supplier
Acrylic Diffuser	900 x 600 (L x W) 3 mm thick white acrylic sheeting	~ $8	Bunnings Warehouse (Australia)
Glass Diffuser	77 x 77 (L x W) 4 mm thick Matelux, glazed glass plane	$10	Windsor Glass and Glazing (Australia)

Four Fresnel lenses were also included in preliminary tests, but it was quickly determined that Fresnel lenses were too impractical for replacing the use of conventional diffusers. Due to this, Fresnel lenses were removed from any further experiments. Refer to Appendix I - for more information.

2.3.4 pECI Test Component Combinations

Using the new pECI case, the various semi-transparent mirrors and conventional diffusers were interchanged and tested in a pairwise manner. Each mirror/diffuser combination was labelled as a unique pECI combination (pECI C#) in the development of pECI v2 as listed below (Table 2.8).

Table 2.8: pECI test combinations (pECI C#), their reference name, and specific components

pECI Combination (C#)	Diffusive Material	Semi-transparent Mirror	Combination Cost
pECI C1	Acrylic	CD Case	$18
pECI C2	Acrylic	Acrylic Two-way	$28
pECI C3	Acrylic	Beamsplitter	$408
pECI C4	Glass	CD Case	$20
pECI C5	Glass	Acrylic Two-way	$30
pECI C6	Glass	Beamsplitter	$410

Each combination went through a series of preliminary tests to determine if they were functional and worthwhile testing. During these tests, image exposure, image artefacts and repeatability were examined.

These preliminary tests conducted focussed on determining optimal exposure and flash distance. The combinations were tested with the pECI device attached to a copy stand. First the optimum flash distance was determined by moving the flash in 5 cm increments away from each device, commencing at 5 cm from the device and halting at 30 cm. The next was a series of bracketed images taken with the pECI device, where the flash exposure compensation was changed in one-third stop increments with images taken with both positive and negative exposure compensations examined.

Following these preliminary tests, it was determined that when testing any pECI combination that had an acrylic diffuser, the best results were obtainable with a flash distance of 15–25 cm from the diffuser, while using any pECI combination with a glass diffuser the flash should be 20–30 cm away from the diffuser. As for the flash compensation it was determined that lowering the flash compensation to about -1 provided improved contrast when using any pECI combination.

2.3.5 Donor Categorisation

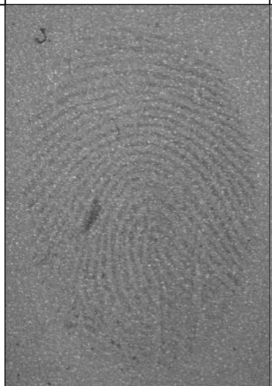
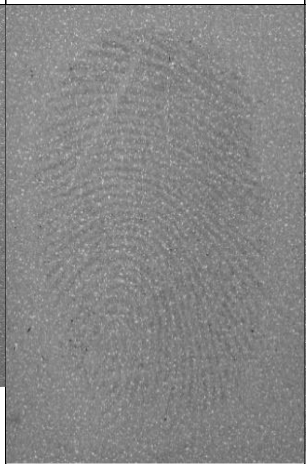
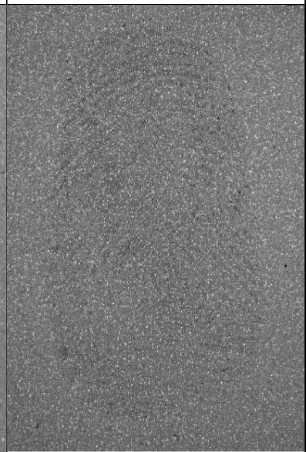
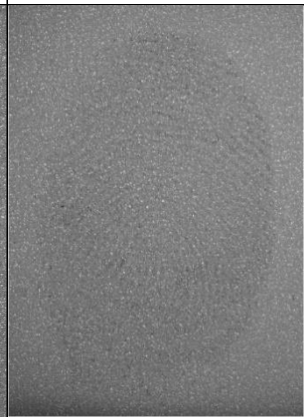
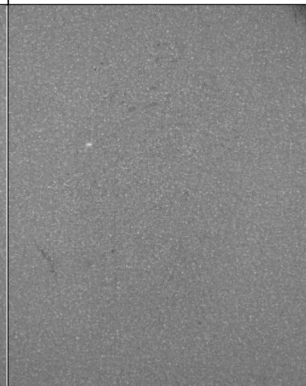
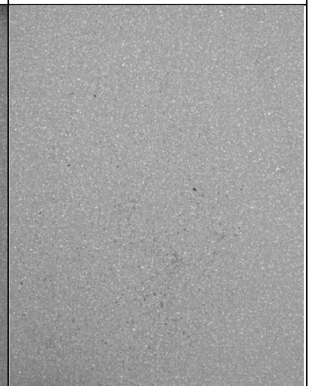
For this experiment, six donors were utilised. The donor pool varied in gender, age and occupation and a summary of the donor details can be seen below (Table 2.9).

Table 2.9: The variance of the donor pool in regard to age, gender, occupation, and secretion categorisation.

Donor Strength	Donor ID	Age	Gender	Occupation
Strong	A	33	M	Academic
Strong	E	27	F	Student
Medium	C	31	M	Academic
Medium	F	36	M	Professional
Weak	B	46	M	Academic
Weak	D	28	F	Student

Each donor had 12 fingermarks enhanced using the Arrowhead ECI device, and they were categorised based on the amount of clear ridge detail present in all donated fingermarks. Using the results each donor was categorised as either a strong, medium, or weak donor. Fingermarks that may have been affected by the donation of the impression such as areas of high pressure or smudging were not examined in detail. The final categorisation of each donor can be seen below with an example fingermark donated (Table 2.10).

Table 2.10: Table detailing the six donor's donor categorisation, determined to be either strong, medium, or weak, based on donated impressions enhanced with the Arrowhead ECI device. Example impressions provided.

Donor Letter	A	E	C	F	B	D
Categorisation	Strong	Strong	Medium	Medium	Weak	Weak
Example impression						

2.3.6 Fingermark Donation Procedure

For the comparison experiments, each donor donated one fingermark on three different substrates. The three substrates included: (1) glass (glass smart phone screen protector); (2) polished metal (metal jar lid); (3) and plastic (CD cover). This resulted in six fingermarks per substrate and 18 fingermarks deposited in total. The substrates were chosen as they replicated common types of non-porous substrates encountered at crime scenes. Fingermarks were only aged 24 hours before being enhanced. Fingermark age was not examined in these experiments due to the limited time available for the study and the considerable number of enhanced images that required examination.

2.3.7 Photographic Parameters

Each fingermark was photographed using each pECI component combination using two separate methods: (1) copystand photography; and (2) handheld photography.

For experiments involving copystand photography, the pECI case containing each combination of optical components was attached to the camera and lens and subsequently attached to a copy stand. Confirmation that the pECI was perpendicular to the substrate was achieved using a spirit level and the flash unit was placed and measured to be at the optimal distance and angle towards the pECI device. The 18 deposited fingermarks were photographed using each of the six different pECI combinations. In total a 108 fingermark images (18 images per pECI combination) were obtained for comparison.

For the handheld photography, each pECI combination was attached to the camera and lens, using the same fingermarks and substrates, were then photographed handheld with the substrate and flash manually aligned as the device was designed for. This resulted in an additional 108 fingermark images (18 images per pECI combination) that were obtained for comparison.

While 18 fingermarks at first glance is a small sample size, due to the considerable number of component combinations and limited time available in the research project, these 18 fingermarks were used as efficiently as possible. Using only the 18 fingermarks over all three experiments, there were a total of 648 fingermark comparison images created. The advantage of this project is that it is the optimisation of a non-destructive optical enhancement technique, which allowed for the repeat usage of the same 18 fingermarks for all comparisons. If this project was examining six different versions of a chemical or physical enhancement method, then a much larger number of fingermarks would be required due to the destructive nature of these techniques.

2.3.8 Fingermark Grading and Data Analysis

To compare the pECI combinations, the UC comparative scale was utilised across three comparisons. While all six combinations are technically performing the same technique (ECI), the variation in optical components needed to be compared pairwise between the six different combinations, hence the UC grading scale was most suitable.

The three comparisons were each completed: (1) copystand photography; (2) handheld photography; and (3) copystand verse handheld photography. The same three graders utilised in previous experiments graded for these experiments as well, with the median grade of each comparison utilised.

For the copystand photography comparison, each enhanced fingermark was photographed using each of the six different pECI combinations. This resulted in 18 fingermark images per pECI combination, 108 images total. Using these 18 images from each pECI combination were then compared pairwise (Table 2.11).

Consequently, 270 UC comparisons were made. This comparison evaluated the true enhancement quality of each pECI combination as external factors such as misalignment of the pECI, substrate or flash unit were controlled and could not affect the image quality.

Table 2.11: Table showing how each pECI combination was compared.

	Number of Comparisons					**Total**
pECI Combination	C2	C3	C4	C5	C6	
C1	18	18	18	18	18	90
C2		18	18	18	18	72
C3			18	18	18	54
C4				18	18	36
C5					18	18
						270

The handheld photography comparisons were designed similarly to the copystand comparison experiment. Images were acquired of each fingermark using each pECI combination handheld resulting in 108 images, 18 images per pECI combination. Similarly, a total of 270 UC grade comparisons were generated from this experiment and were compared the same way as the copystand images. This comparison evaluated which components functioned best while being used in the situation the device is designed for, handheld.

The final comparison for this set of experiments was between the copystand, and handheld images acquired using each pECI combination. For example, images generated from pECI C1 while using a copystand were compared to images from using the pECI C1 handheld. Repeating the comparisons between each pECI combination resulted in another 108 comparisons for UC grading. This comparison evaluated the true affect that handheld photography has on each pECI combination. Furthermore, this indicated if alignment features were required or not when photographing handheld with the pECI.

Over all three experiments there were a total of 648 UC comparison images created from the 18 original fingermarks. Between the three graders this was a substantial request. If any variable was increased in the donation process, for instance, a repeat donation of 18 fingermarks, this would double the fingermarks being enhanced by each pECI combination to 36 and would subsequently double the amount of grading required for this experiment to 1296 comparison images. Given this experiment is only a single step in the optimisation and development of the device, if the initial 648 comparisons provided reasonable results to identify an efficient pECI component combination then the project did not need to spend a substantial amount of time performing 1000 comparisons during this one section.

This part of the research resulted in the development of version 2 of the device, pECI v2.

2.4 In-field Testing of the pECI v2 Device

A comparison was performed between the optimised pECI v2 device and the current standard approach for in-field optical fingermark enhancement on non-porous substrates at crime scenes.

This final set of comparison experiments was completed using the pECI v2, attempted to follow recommendations in the Phase 2 (optimisation and comparison) section of the IFRG Guidelines for the Assessment of Fingermark Detection Techniques (Almog et al., 2014).

2.4.1 Fingermark Donation Procedure

Fingermarks were donated from three donors, three males who were 31, 33 and 36 years of age. Unfortunately, the donor pool variability in this experiment was minimised due to unforeseen circumstances. The availability of donors from the donor pool was limited during the timeframe of this experiment.

All three donors deposited three natural fingermarks on each of the six different substrates. This totalled nine fingermarks per substrate and 54 total fingermarks donated over the experiment. Substrates for this experiment were located in the Western Sydney University Crime Scene Investigation Training and Research Facility. These substrates were chosen to represent typical substrates that would be found at real crime scenes. Each substrate, given their large size, were marked with areas to indicate to donors where to donate their fingermarks. The six substrates are outlined below (Table 2.12).

Table 2.12: Substrates utilised for comparing the optimised pECI device to the standard approach for in-field fingermark enhancement and their reference images.

Substrate	Glass Window	Conventional Mirror	Plastic Information Sheet Holder
Reference Image			

Table 2:12 continued: Substrates utilised for comparing the optimised pECI device to the standard approach for in-field fingermark enhancement and their reference images.

Substrate	Whiteboard	White Fridge	Filing Cabinet
Reference Image			

2.4.2 Detection and Enhancement Sequence

Each fingermark went through the same detection and enhancement sequence. Firstly, an attempt was made to detect the fingermark through diffused reflection. This was completed using a 1000 lumen white light torch, the *LedLenser P7R* Manufactured by LedLenser (Australia), which was held obliquely to the fingermark/substrate. A subsequent detection attempt was made using the pECI device with the *LedLenser P7R* torch as a light source. It was not the aim of this step to test the searching capabilities of the user, but instead to test the capabilities of the pECI device as a detection technique. Knowing the location of the fingermarks (through marked donation areas) allowed the testing of the detection capabilities of the pECI compared to diffused reflection. Note that these visible detections were completed by eyesight and not through a camera. If a fingermark was detected using either diffused reflection or the pECI, the optical sequence would continue. If no fingermark was detected, the application of the recommended powder for that substrate type and colour was applied, an image was taken, and details recorded but the fingermark would not be assessed through grading. The reason for this was to confirm there was fingermark residue deposited on the substrate that was missed during optical detection.

If a fingermark was detected with diffused reflection, pECI or both, photographs of the fingermark would be taken using diffused reflection followed by pECI photography. Once photography was completed using both optical techniques, application of white powder would commence. *Opti-Hadonite white fingerprint powder* supplied by Optimum Technology (Australia) was used and applied using a No. 6 squirrel-hair brush (also supplied by Optimum Technology), along with a clean out brush. Post powder enhancement then included diffused reflection photography and pECI photography again (Figure 2.9).

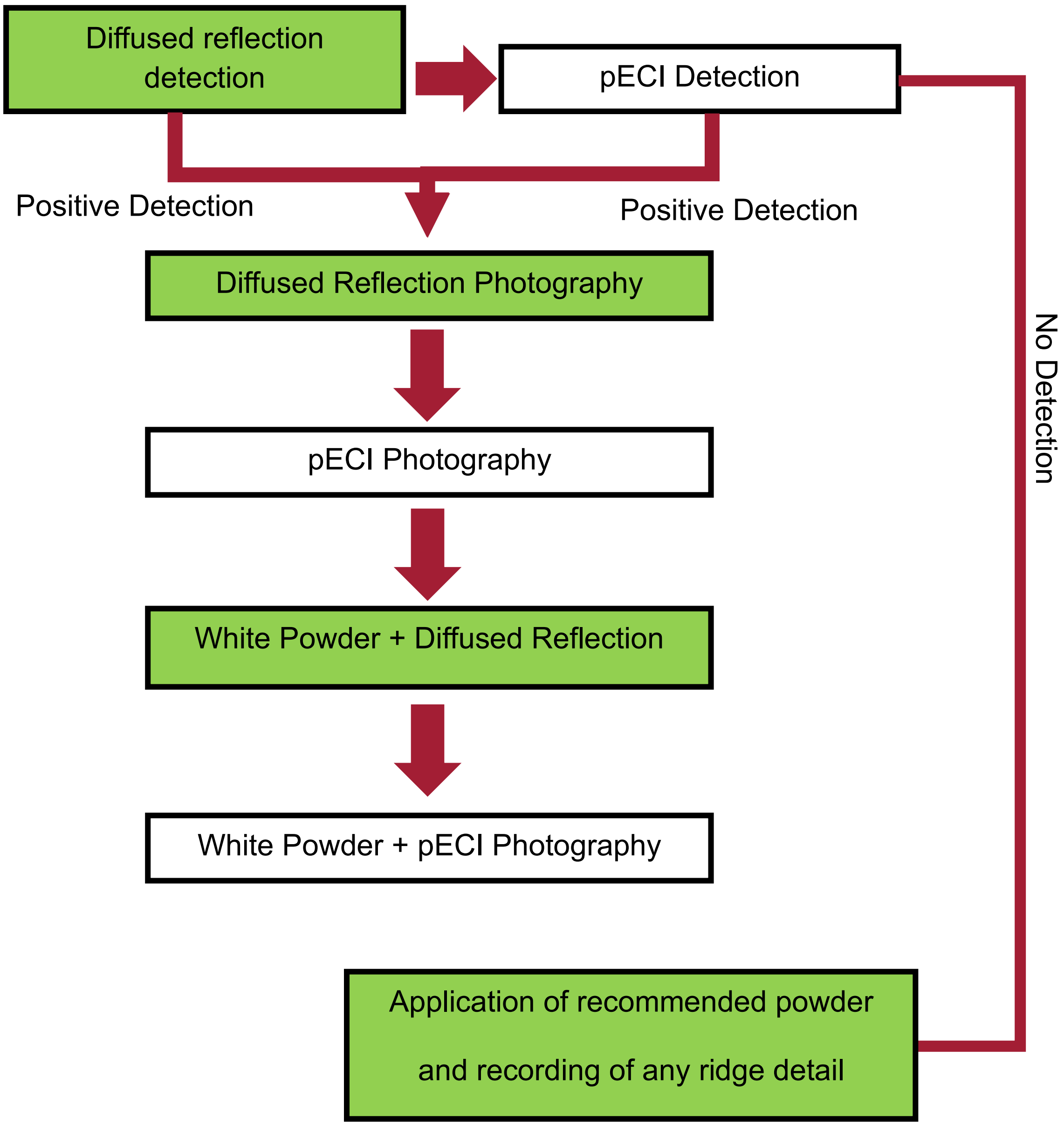


Figure 2.9; Flow chart of the detection and enhancement sequence utilised during in-field testing of optimised pECI device. Techniques highlighted in green indicate the current standard approach used operationally for non-porous flat and highly reflective substrates at crime scenes.

It is important to note that only white powder was used for this stage of the experimental design, despite the colour of the test substrates. In casework, it is standard practice to apply a powder that provides the best contrast between the fingermark and the substrate. On the white substrates, black powder would be preferred as the fingerprint powder adheres to the fingerprint ridges resulting in black ridges on a white background. This experiment was designed to primarily compare the performance of the two optical techniques, diffused reflection and pECI, hence white powder was applied to all detected latent fingermarks as these optical methods work best with white powdered fingermarks.

When recording images using the pECI device or diffused reflection, the following exposure settings were utilised (Table 2.13). Adjustment of the flash exposure compensation was performed depending on the substrate/fingermark detail visible in previous images.

Table 2.13: Typical exposure settings utilised when recording images with the pECI v2 and when performing diffused reflection photography.

Mode	Aperture	ISO	Shutter Speed	Metering Mode
Manual (M)	f/22	100	1/125 sec	Spot

To better visualise the pECI v2 in use compared to standard diffused reflection photography see below in Figure 2.10. Take note the same camera equipment was utilised for both techniques, with only the pECI v2 screwed to the end of the lens in a matter of seconds.

Diffused Reflection Photography

pECI v2

Figure 2.10; Example of positioning of camera and flash unit while performing diffused reflection photography (top), compared to positioning of camera and flash unit while performing pECI photography (bottom).

2.4.3 Fingermark Grading and Data Analysis

Two direct comparisons of fingermarks were completed in this experiment: (1) the comparison of latent fingermarks photographed using diffused reflection and the pECI v2; and (2) the comparison of post-powdered fingermarks when photographed using diffused reflection and the pECI v2. For these comparisons, the UC comparative scale was utilised the same three graders used previously. Across the 54 fingermarks that were originally donated, 47 were detected, resulting in 94 subsequent UC comparisons.

To determine overall if the pECI v2 provided any additional fingermark detail to the current standard in-field approach, the Centre for Applied Science and Technology (CAST) grading scheme was utilised (Table 2.14). The CAST grading scheme is an absolute scale ranging from 0 to 4 that determines the quality of a fingermark enhanced by a single enhancement technique (Almog et al., 2014).

Table 2.14: Centre of Applied Science and Technology (CAST) grading scheme, adapted from the IFRG Guidelines (Almog et al., 2014)

CAST Grade	Grade Definition
0	No evidence of a fingermark
1	Some evidence of a fingermark
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

If a fingermark was detected and the enhancement sequence was completed, there were four images acquired: (1) diffused reflection of latent fingermark; (2) pECI image latent fingermark; (3) diffused reflection of powdered fingermark; and (4) pECI image of powdered fingermark.

Each image was graded using the CAST scheme by three graders and the median CAST grade for that image was calculated. CAST grades were used to determine how much ridge detail was collected from each technique throughout the sequence and to ascertain what techniques were providing the most valuable information with regards to ridge detail. Of the 54 fingermarks donated, 47 were detected, resulting in 188 CAST graded images.

Chapter 3. Results and Discussion

3.1 Proof of concept: Evaluating the Capabilities of the pECI v1 Device

This section of experiments set out to answer research question 1:

How does the initial pECI device (pECI v1) currently perform?

3.1.1 Comparison of pECI v1 to the Current In-field Enhancement Sequence

To determine the capabilities of the pECI v1 device, a comparison was conducted between pECI v1 and the current standard for in-field optical enhancement of fingermarks on flat, highly reflective, and non-porous substrates. Diffused reflection is currently the only non-destructive technique that CSIs have at their disposal for non-porous substrate when at a crime scene. When comparing the two techniques, the data was split in two: (1) enhancements completed on latent, non-powdered fingermarks; and (2) enhancements completed on powdered fingermarks.

The comparison between pECI v1 and diffused reflection on only latent fingermarks involved the assessment of 24 fingermarks enhanced in a simulated crime scene environment, with fingermarks deposited on four substrates: (1) a glass window in a door; (2) a conventional glass mirror; (3) tinted glass desk; and (4) a stainless-steel oven door. All the data presented below was not separated and discussed by substrate and is presented considering all fingermarks across the four substrates. The reason for this is due to the preliminary design of this experiment which used a small number of fingermarks donated per substrate and thus did not allow for a reasonable discussion on substrate variability.

For this experiment the UC scale was as follows. A positive UC grade indicated that diffused reflection showed a significant (+2) or slight (+1) improvement in fingermark enhancement – ridge detail and/or contrast – compared to the pECI v1. A

0 grade indicated there was no significant difference in fingermark enhancement between the two techniques. A negative grade indicated that pECI v1 showed slight (-1) to significant (-2) improvement in fingermark enhancement compared to diffused refection (Figure 3.1).

+1 UC Grade	0 UC Grade	-1 UC Grade

Figure 3.1; Example images comparing diffused reflection (left) and pECI v1 (right inverted black and white), demonstrating the UC grade scales: +1 indicates slight improvement in fingermark enhancement from diffused reflection; 0 indicates little to no difference in fingermark enhancement between the two enhancement techniques; and -1 grade indicates slight improvement in fingermark enhancement from the pECI v1.

Of the 24 latent fingermarks examined, 50% were graded +1, indicating slight improvement using diffused reflection compared to the pECI v1. 16.7% fingermarks were graded +2, indicating significant improvement in fingermark enhancement from diffused reflection compared to the pECI v1. 8.3% fingermarks were graded as 0 indicating little to no difference in quality between the two techniques. 16.7% fingermarks were graded as -1, indicating slightly improved fingermark enhancement from the pECI v1 compared to diffused reflection. Only 8.3% fingermarks were concluded to be non-comparable and could not be graded. No fingermarks were graded -2 which would have indicated significant improvement from pECI v1 device compared to diffused reflection (Figure 3.2).

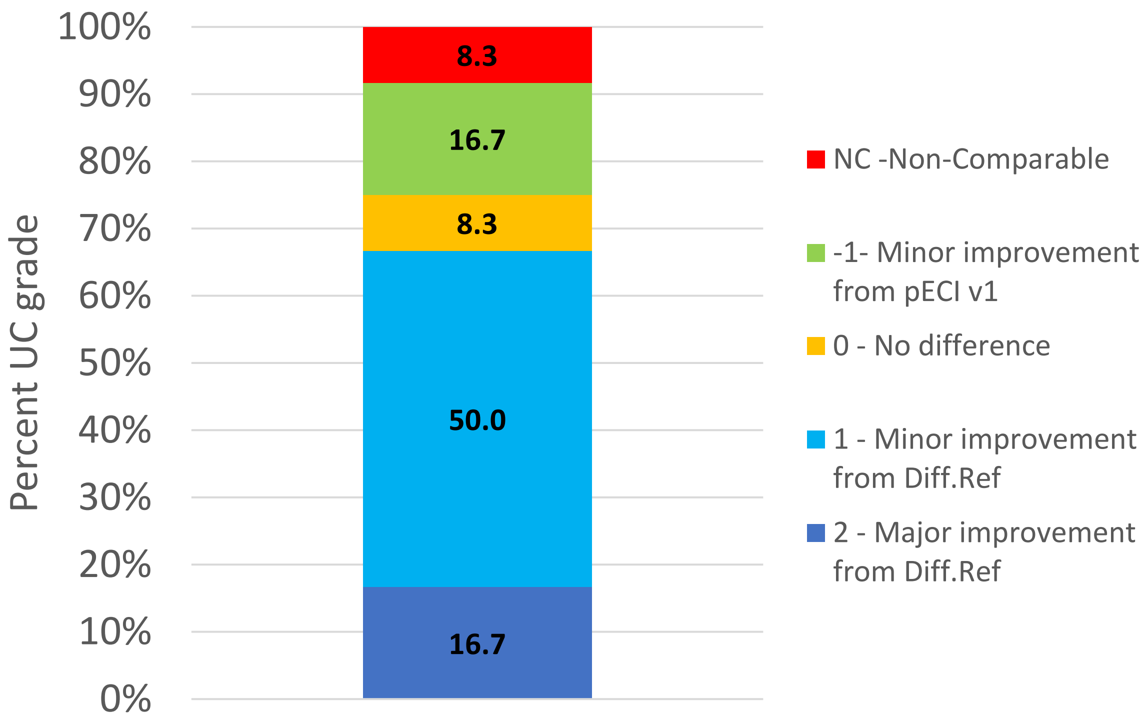


Figure 3.2: Column graph showing percentage UC grades comparing fingermarks enhanced using diffused reflection (Diff. Ref) (blue) and the pECI v1 (green) in a simulated crime scene.

Overall, diffused reflection performed better than the pECI v1, enhancing 67% of fingermarks to an improved quality. A majority of these grades were +1 grades indicating only slight improvement in enhancement created by diffused reflection compared to the pECI v1. In the fingermarks graded +1, as noted by grader comments, the improvement was mainly decided based on slight contrast improvement created by diffused reflection. Indicating that the pECI still recorded the same level of detail as diffused reflection but did not produce the competing contrast for the majority of fingermarks compared. The other issue that adversely impacted the grades for pECI enhancement was the presence of uneven illumination in the images, particularly around the edges. This uneven illumination was emphasised once image enhancements were made and were likely due to poor alignment of the flash unit or poor diffusion of light using the acrylic diffuser (Figure 3.3).

Diffused Reflection **pECI**

Figure 3.3; Fingermark impression on glass window enhanced with diffused reflection (left) and pECI v1 (right). pECI Image has black and white inverted to better compare the two image halves. Clear uneven lighting due to uneven flash illumination can be seen in the bottom of the pECI image.

After initial optical enhancement, the fingermarks were then powdered. Of the 24 powdered fingermarks examined, 29.2% were graded +1, indicating slight improvement using diffused reflection compared to the pECI v1. 29.2% fingermarks were graded as 0 indicating little to no difference in quality between the two techniques. 25% fingermarks were graded as -1, indicating slightly improved fingermark enhancement from the pECI v1 compared to diffused reflection. Only 16.7% fingermarks were concluded to be non-comparable and could not be graded. No fingermarks were graded as +2 or -2 (Figure 3.4).

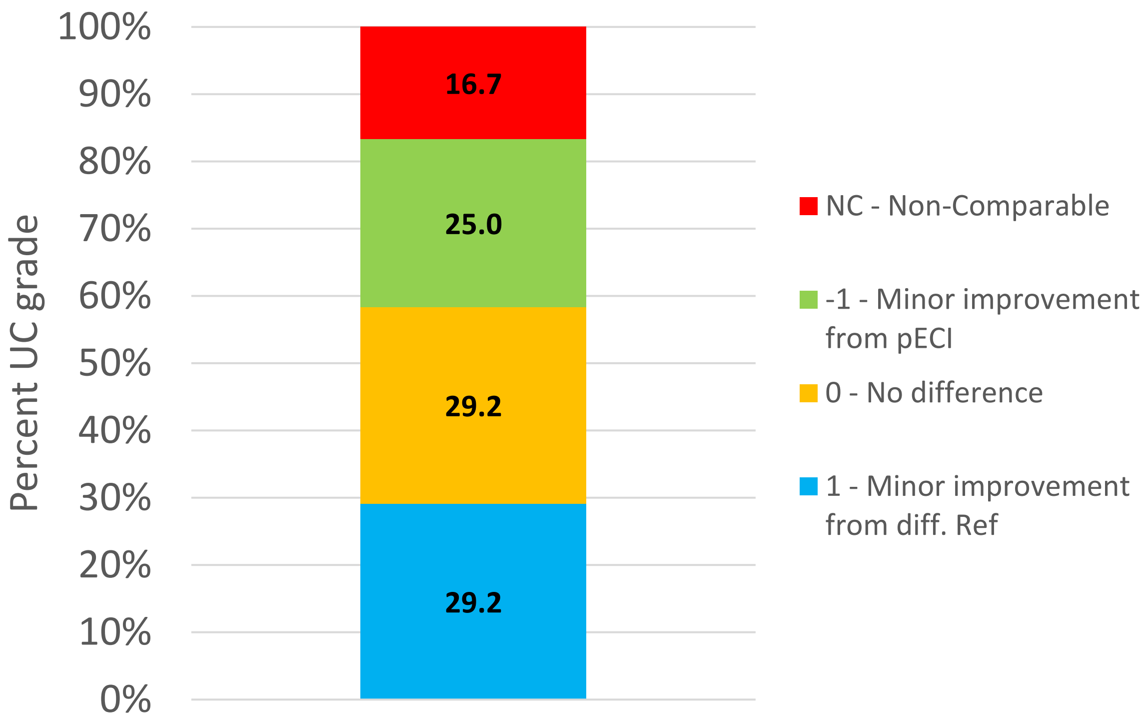


Figure 3.4: Column graph showing percentage UC grades comparing powdered fingermarks enhanced using diffused reflection (blue) and the pECI v1 (green).

Overall, there was an almost even split between the performance of the pECI v1 and diffused reflection in the ability to enhance powdered fingermarks.

After examining how pECI v1 performed against diffused reflection in an in-field environment, the practicality of pECI v1 was reconsidered for further optimisation. Positively, undertaking imaging of latent fingermarks using pECI v1 was not more time consuming compared to diffused reflection. The largest time-consuming factor was switching between the 50 mm macro lens for diffused reflection and the 100 mm macro lens as the pECI v1 still required the 100 mm lens. A re-design of the pECI case would allow the device to be used with a smaller lens, meaning little time will be lost in future as the user would simply need to attach or detach the pECI to the same macro lens and perform either technique at the crime scene in seconds. The main difficulty while using the pECI device was the alignment of the device to be perpendicular to the substrate, as well as aligning the flash correctly towards the diffuser was challenging.

After continuous use and training, alignment was not difficult to achieve but a decrease in image quality was noticeable when either the flash or substrate was not aligned. A noted design flaw was the lack of consistent stability of the semi-transparent mirror as it was especially prone to becoming mis-aligned, particularly when the device was moved. Consequently, the mirror was not always correctly aligned at 45° which would have likely decrease enhancement quality drastically if not checked. Overall, this would improve the ability to implement pECI into the current standard workflow for fingermark detection and enhancement on flat, highly reflective non-porous substrates at crime scenes.

When examining the results of all fingermarks enhanced, both latent and powdered, the pECI v1 underperformed compared to diffused reflection. This was expected as the device was a proof of concept design at this stage. Positively, the pECI v1 still enhanced fingermarks, showing the same amount of detail as diffused reflection, but the contrast was not as prominent. To determine what the decrease in contrast was related to, the pECI v1 was compared to a laboratory ECI device to see if the pECI produces poor contrast due to its componentry. Following the second comparison, the pECI v1 was then tested to see if using the device handheld was decreasing fingermark quality.

3.1.2 Comparison of pECI v1 to Laboratory ECI Device

The comparison between the Arrowhead device and the pECI v1 involved an assessment across 18 fingermarks enhanced in a laboratory environment on three different substrates: (1) a glass plane, (2) polished metal lid, and (3) a plastic CD cover. For this comparison, a positive UC grade indicated that the Arrowhead device showed a significant (+2) or slight improvement (+1) in fingermark enhancement. A negative grade indicated that the pECI device showed slight (-1) to significant (-2) improvement in fingermark enhancement.

Of the 18 fingermarks examined, 38.9% were graded +1, indicating slight improvement with the Arrowhead device compared to the pECI v1. 27.8% fingermarks were graded 0, indicating little to no difference in quality between the two devices. 11.1% fingermarks were graded as +2 indicating significant improvement in fingermark enhancement from the Arrowhead device compared to the pECI v1. There were 22.2% fingermarks that were concluded to be NC and could not be graded. No fingermarks were graded as -1 or -2 (Figure 3.5).

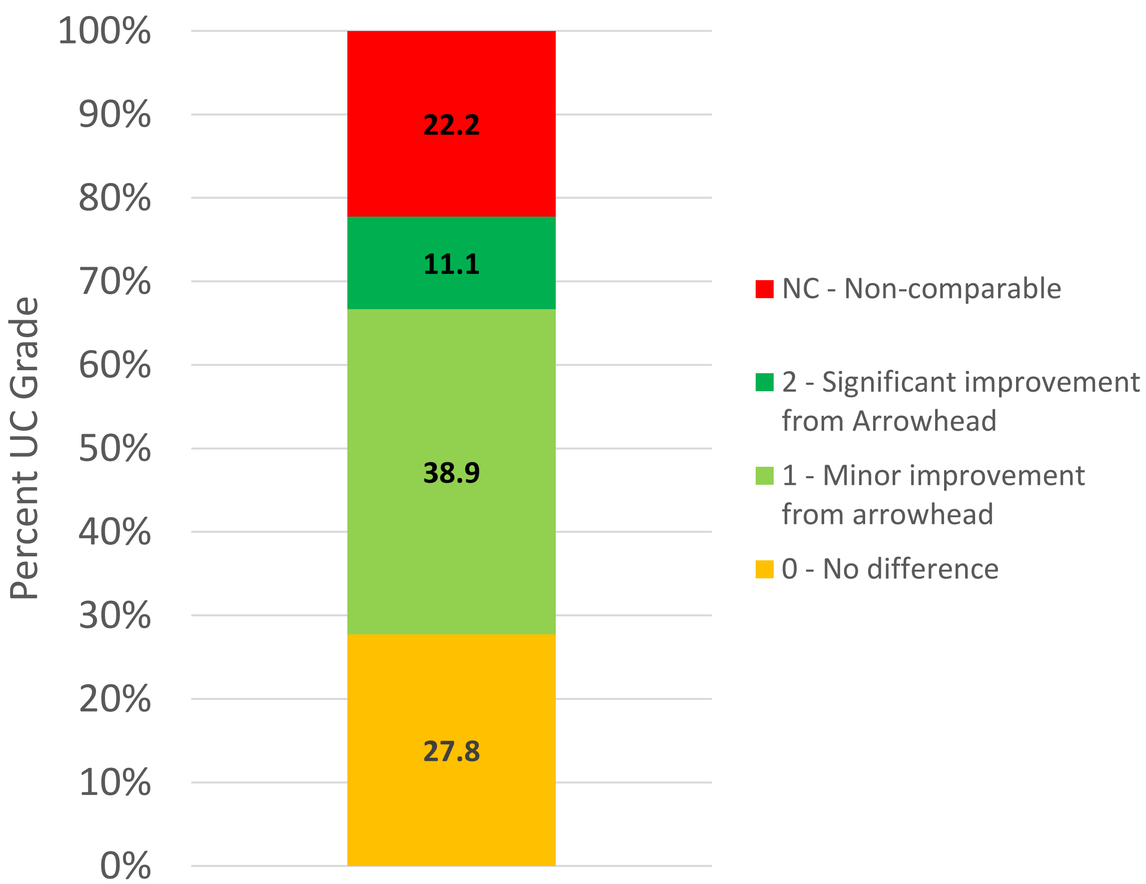


Figure 3.5; Column graph the overall percent UC grades for all 18 fingermarks enhanced using the Arrowhead device (green) and pECI v1 device (blue).

When excluding the fingermark images determined as NC from the data, the pECI device enhanced fingermarks to the same quality (UC grade 0) in 42.9% of all fingermarks in comparison to the images recorded using the Arrowhead device. It should be noted that where the Arrowhead device was determined to provide improved fingermark detail or contrast, the majority of instances showed only slight improvement over the pECI device.

The higher quality components used in the manufacture of the Arrowhead device – in particular, the semi-transparent mirror – would explain the improved enhancement quality observed with many of the fingermarks examined. The Arrowhead device is significantly more expensive than the prototype pECI device and is primarily designed for laboratory use. As noted by grader comments for fingermarks graded +1, the Arrowhead device only produced marginally sharper ridge detail as compared to pECI v1. A difference in image sharpness between the two ECI devices may be due, in part, to a difference in working distance and again the choice of semi-transparent mirror in the pECI (CD cover). The CD cover was of considerably poorer quality than the beamsplitter used in the arrowhead device and likely had imperfections that would have decreased image quality. Another disadvantage using the pECI device, is that images were recorded further away from the fingermarks and significant cropping of the pECI images was required. This cropping reduced the sharpness of the final pECI image being compared, subsequently reducing the sharpness of ridge detail, and decreasing overall image quality (Figure 3.6).

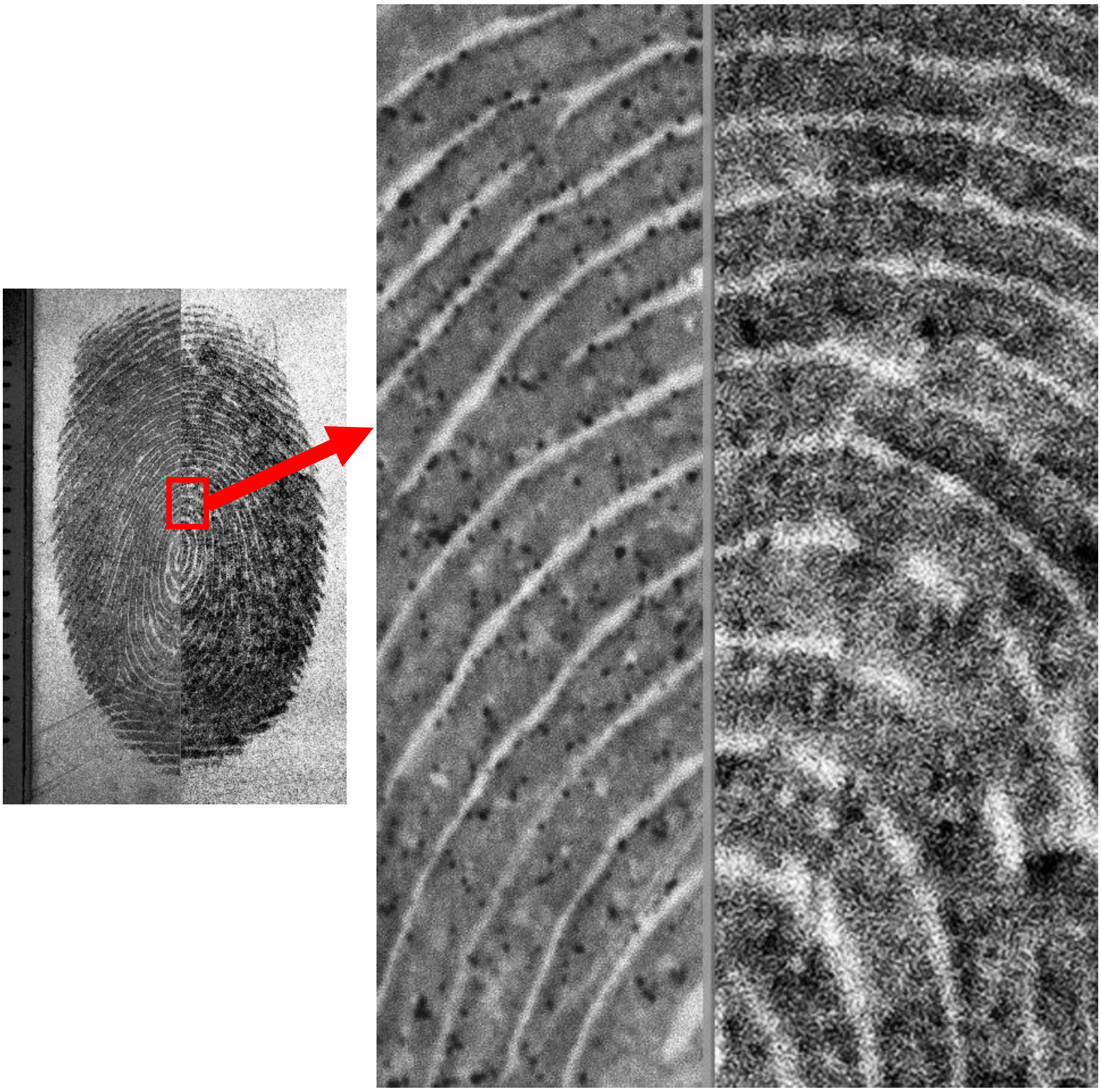


Figure 3.6; Zoomed split image of fingermark enhanced by the Arrowhead device (left) and the pECI v1 (right) demonstrating a difference in sharpness of ridge detail.

The Arrowhead device was also better at capturing Level 3 fingermark detail (such as pores), though pECI v1 was still effective at capturing Level 2 ridge characteristics. While finer level 3 details were recorded by the Arrowhead ECI, the level 2 details recorded by both devices are more commonly utilised by fingerprint analysts and automated fingerprint identification systems for fingermark identification. Due to both ECI devices recording equal amounts of level 2 details it can be argued that the performance of pECI v1 was still operationally fit-for-purpose (Figure 3.7)

Arrowhead Device **pECI v1**

Figure 3.7; A fingermark deposited on a glass substrate enhanced using the Arrowhead device (left) showing more consistent level 3 detail compared to the pECI device (right) with little apparent level 3 features. Both devices were effective in recording level 2 features.

The Arrowhead device outperforming the pECI device was again expected due to the difference in component quality and the intended application of the Arrowhead (controlled laboratory imaging) compared to the pECI (portable). While the pECI device under-performed, for a cost-effective design, it still produced a high percentage of quality images and recorded the same level 2 features required for identification purposes as the Arrowhead device.

3.1.3 Copystand vs Handheld pECI Photography

The final comparison was between the pECI v1 on a copystand and the pECI v1 used handheld. This comparison was conducted to determine if manual alignment between the substrate and device and alignment of the flash to the device was causing negative effects. For this comparison nine fingermarks were enhanced in a laboratory environment with three fingermarks (one from each donor) donated onto three different substrates, (1) a glass plane, (2) polished metal lid, and (3) a plastic CD cover. For this comparison, a positive UC grade indicated that the mounted pECI showed a significant (+2) or slight improvement (+1) in fingermark enhancement. A negative grade indicated that handheld use of the pECI showed slight (-1) to significant (-2) improvement in fingermark enhancement compared to using the pECI on a copystand.

Of the nine fingermarks examined, 33.3% of fingermarks received a grade of +1 indicating the pECI showed minor improvement in enhancement while being used on a copystand rather than handheld. 22.2% of fingermarks received a UC grade of 0, indicating no difference in enhancement quality between using the pECI device on a copystand vs handheld. 33.3% of fingermarks were graded as NC as they could not be compared due to a lack of ridge detail in both halves of the compared Images. 11.1% of fingermarks were graded as -1 indicating improved enhancement while using the pECI device handheld rather than on a copystand (Figure 3.8).

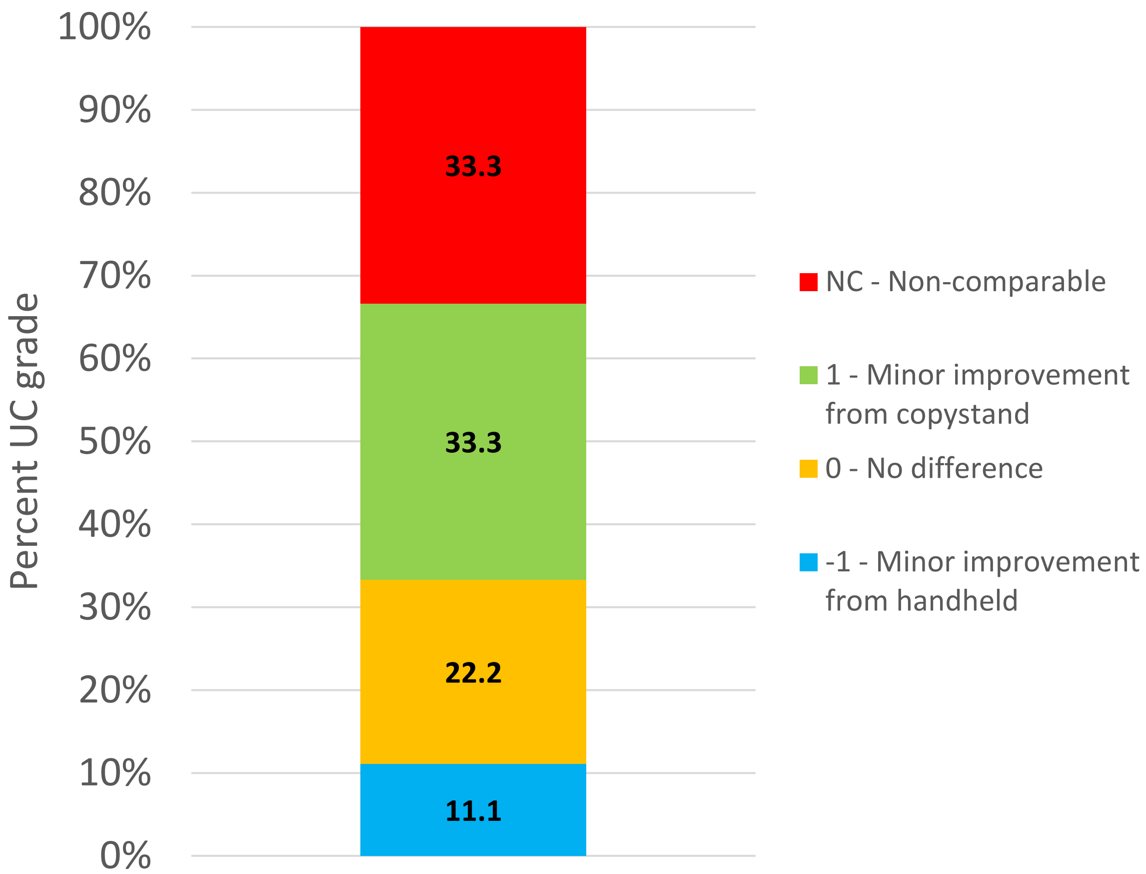


Figure 3.8; Column graph describing the percent UC grades comparing nine fingermarks photographed using the pECI v1 device handheld (blue) against using the device on a copystand (green).

It was observed that using the pECI device mounted better enhanced fingermarks in more than half of the comparable fingermarks recorded, but this was only a minor improvement with most cases being a minor increase in contrast. An increase in enhancement quality was expected as all critical components are aligned when the pECI is mounted. This indicated that perhaps the device currently underperforms in-field due to difficulty aligning the device to the target substrate. This was investigated further into the research when examining improved optical components.

3.2 Optimisation of the pECI Case

This section of experiments aims to answer research question 2:

> *How can the pECI v1 design be optimised so that it is more practical, cost effective and reproducible?*

3.2.1 Limitations of the Original pECI Device Design

The pECI v1 casing had several limitations. Firstly, the device had restricted lens compatibility, only functioning with lenses of larger focal lengths (100 mm macro lens or larger). This was due to the narrow design of the device creating the need for a narrow field of view (FOV) only obtainable with longer focal length macro lenses. When attaching the pECI v1 to a shorter focal length macro lens, such as a 50 mm macro lens with a larger field of view (FOV), the edges of the device were visible, which was not ideal. This could obstruct key details in images, especially when recording fingermarks at a 1:1 macro ratio common for fingermark photography. The other concern with this limitation is that CSIs are not commonly utilising 100 mm macro lenses for fingermark photography in-field, immediately limiting the use of the pECI v1 device in-field. Allowing the pECI to function with smaller 50 mm and 60 mm lenses would allow investigators to seamlessly switch between diffused reflection and pECI without having to switch lenses.

The second limitation was the ability of the pECI case to hold optical components appropriately. The pECI v1 held components similar to a jigsaw in which components were cut to size and carefully placed within the device staying in place with no supports. This allowed components used in the pECI v1 to be easily knocked out of the device by accident during use, such as the semi-transparent mirror constant misalignment as mentioned previously. This subsequently increased the possibility of components becoming dirty or damaged.

The final limitation of the device was the weight and structural integrity. The aluminium frame weighed less than 240 g (including felt and ring adapter), which is light and can be supported by a 100 mm macro lens. Though it was noted that the extra weight attached to the DSLR from the pECI device and the large 100 mm lens, strained the user when using pECI for prolonged periods of time. There were also concerns that aluminium would be too heavy for small lenses such as a 50–60 mm macro, risking possible damage to the lens. The device was also fragile and, when dropped, the device would shatter. A device intended for in-field use must be robust.

To improve the pECI v1 case, requirements were identified to create a new pECI case that was work-flow friendly and accessible to CSIs. These requirements were to:

1. Maintain the current overarching design as a DSLR attachment utilising a flash unit as the light source.
2. Allow the device to function with smaller macro lenses (e.g., 50–60 mm macro) of any brand (Canon, Nikon, etc).
3. Design a case that accurately aligns the optical components within the device.
4. Reduce weight and increase structural integrity.
5. Allow easy access to components for maintenance (replacements/cleaning) when necessary.
6. Create a device that is more robust, both for component alignment and sturdiness of the device.

It was concluded that 3D printing was the ideal method to achieve these requirements. 3D printing is the creation of solid objects from digital models via layer fabrication, in which a material (commonly plastic) is heated to a liquid form and subsequently “drawn” on to a platform in thin layers on top of each other, cooling down and solidifying to create any object the user can model (Shahrubudin et al., 2019). The final object can be durable and lightweight, and models can also be quickly edited on a computer and re-printed if an adjustment is required, allowing for multiple pECI prototypes to be printed quickly. The model can also be precise, allowing for subtle design modifications that would help hold and maintain the alignment of optical components within a pECI case. Though it should be noted that some printers may not be as precise compared to other printers.

3.2.2 Empirical Method for Calculating AOV

The AOV measurements that were recorded at different macro ratios with a 50 mm, 60 mm and 100 mm macro lens using the empirical method are shown below (Table 3.1,Table 3.2, & Table 3.3).

Table 3.1: AOV measurements of a 50 mm macro lens using the empirical method.

50 mm Macro Lens / Macro Ratio	Focal Distance (mm)	Working Distance (Focal distance – Lens length) (mm)	Horizontal (mm)	Vertical (mm)	Diagonal (mm)
1:1	Unable to achieve 1:1 without lens compensator				
1:2	220	157	44.2	29.2	52.9
1:3	270	207	66.0	44.0	79.3
1:5	360	297	115.9	77.1	139.3

Table 3.2: AOV measurements of a 60 mm macro lens using the empirical method.

60 mm Macro Lens / Macro Ratio	Focal Distance (mm)	Working Distance (Focal distance – Lens length) (mm)	Horizontal (mm)	Vertical (mm)	Diagonal (mm)
1:1	200	130.2	22.5	15.0	27.0
1:2	260	190.2	44.7	29.9	53.9
1:3	320	250.2	67.8	45.3	81.8
1:5	440	370.2	105.4	70.5	126.9

Table 3.3: AOV measurements of a 100 mm macro lens using the empirical method.

100 mm Macro Lens / Macro Ratio	Focal Distance (mm)	Working Distance (Focal distance – Lens length) (mm)	Horizontal (mm)	Vertical (mm)	Diagonal (mm)
1:1	310	191	21.8	15.5	26.2
1:2	390	271	49.1	32.7	59.1
1:3	490	371	77.0	51.3	92.6
1:5	690	571	126.1	83.8	151.5

3.2.3 New pECI Case Dimensions

Following the AOV measurements, the interior of the new pECI case was determined. It was decided that the new case should be capable of achieving a 1:3 macro ratio image with a 50 mm macro lens. A 50 mm macro lens was chosen as this is the smallest lens tested. If the pECI functions with a 50 mm macro lens, then it would function with 60 mm and 100 mm macro lenses as well, though different size ring adaptors would be required. A 1:3 macro ratio was chosen to reduce the size of the pECI casing, as attempting to create a device to illuminate the area at a 1:5 macro ratio would immediately become too large and impractical to transport and utilise. Unfortunately, this will only allow the pECI device to illuminate one or two fingermarks at a time and will not be usable for palm impressions. While designing the device for a 1:1 macro ratio may be too restrictive as the pECI would now need to be quite close to the subject risking contact. Following these decisions and the associated AOV measurements, the new pECI case had to have an interior larger than 66 x 44 mm in length and width (AOV measurement of a 50 mm macro lens at a 1:3 macro ratio), and in order to have the mirror at exactly 45° the height had to be equal to the interior's length. To make it simple to design and amend further into the project it was decided that the interior would be a perfect cube, with the length, width, and height all equal.

The interior dimensions of section 1 (the base) of the new pECI design were 75 x 75 x 75 mm (length x width x height), which provided an adequate size to test all components. Within the interior walls, a slot was designed diagonally across the two side walls for the semi-transparent mirror to slide in and out from the top. This prevented the mirror from moving and becoming mis-aligned while in used. The slot length for the mirror was calculated using Pythagoras theorem to ensure that the mirror was held at exactly at 45° within the case. The mirror slot was 106.1 mm in length, 2 mm deep and 4 mm wide (Figure 3.9).

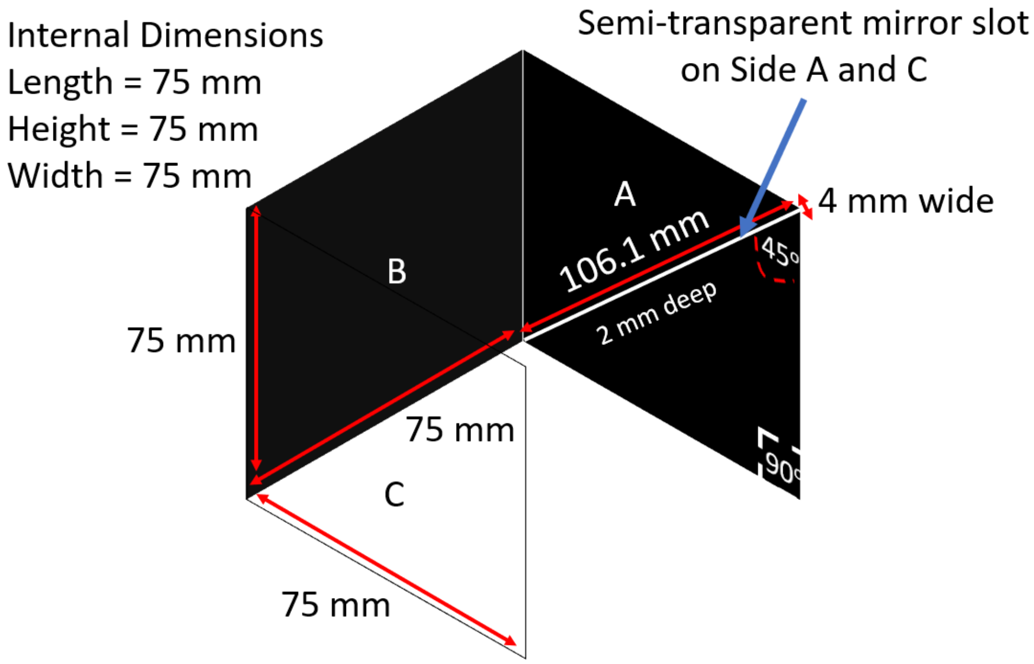


Figure 3.9; Diagram of interior dimensions of the pECI base (section 1), including the dimensions of mirror slot on interior wall A and C.

The diffuser wall of section 1 was designed for any diffusive material to slide in and out from the top and subsequently lock into place once the lid is slid over the top. The diffuser slot is a 5 mm wide slot capable of holding any material 77 x 77 mm (length x width), allowing the material to evenly illuminate the whole semi-transparent mirror. There is a 1 mm lip around the diffuser that prevents it from being removed from any direction except from the top (Figure 3.10).

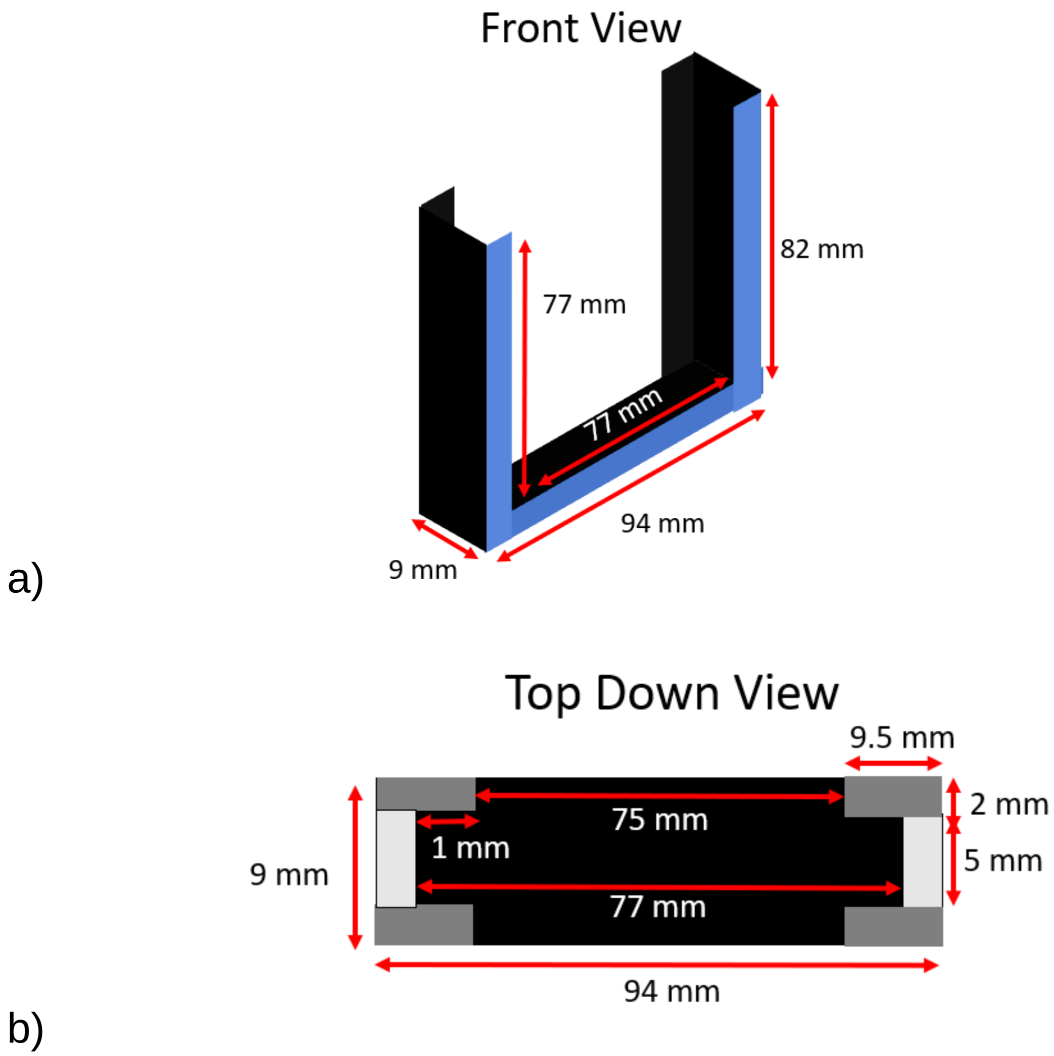


Figure 3.10; Diagram of the diffuser slot built into section 1 (pECI base). a) depicting diffuser slot from front view and dimensions. b) depicting diffuser slot from top-down view when the diffuser will enter showing dimensions.

Knowing the dimensions of the component holders, the external dimensions of section 1 (the base) was then designed. The back wall of the base was 6 mm thick, the side walls 9.5 mm thick, and the diffuser side (as described above) was 9 mm thick. The exterior was 90 x 94 x 82 mm (length x width x height); a height of 90 mm was avoided to ensure that the casing would not be visible in images recorded with the pECI (Figure 3.11).

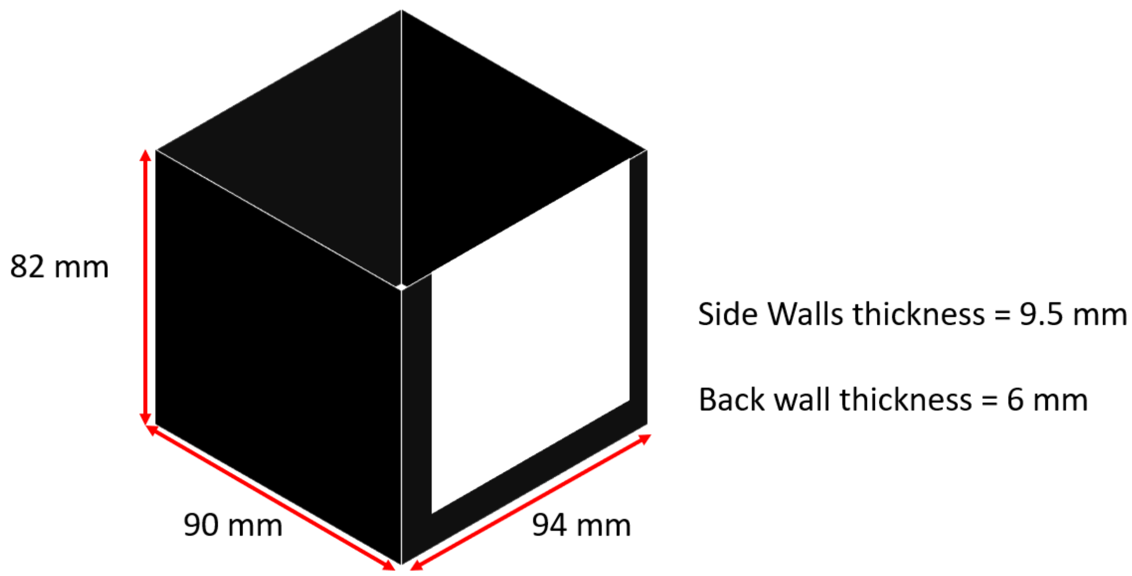


Figure 3.11; Diagram of the exterior dimension of the pECI base (section 1).

Section 2 (the lid) was a flat piece that was 4 mm thick and 85 x 88 mm (length x width) with a viewport 55 mm in diameter. The viewport was set off-centre, taking into consideration that the diffuser wall was 3 mm thicker than the back wall of the base as to ensure the viewport is centred towards the 75 x 75 mm interior square. The viewport also had a 3 mm tall, and 2 mm thick ring designed to help guide and attach the ring adapter once the case was printed (Figure 3.12).

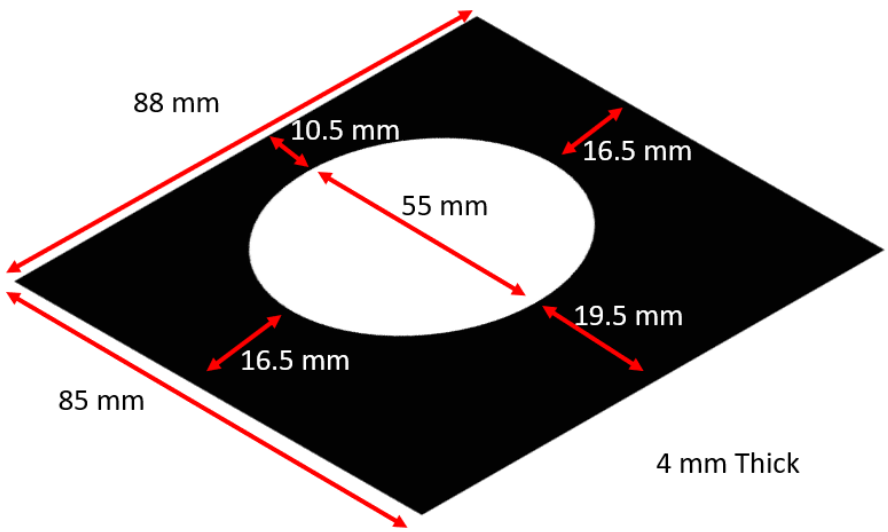


Figure 3.12; Diagram depicting the dimensions of the lid (section 2) for new pECI case.

For the two sections to slide together, various sliding mechanisms were designed and tested. After preliminary tests, the final mechanism used friction created from wedges holding the pieces together that allow the lid to slide in and out only when sufficient force is provided via the user. The male connector consisted of a wedge that is 48 mm in length, commencing from a width of 5 mm reducing to a 2 mm edge. The female connector consisted of a 58 mm long hole commencing at a 5 mm wide opening that reduces further into the connector (Figure 3.13). For the new pECI case, the male connector was added to the top of section 1, while the female connector was added to the underside of section 2.

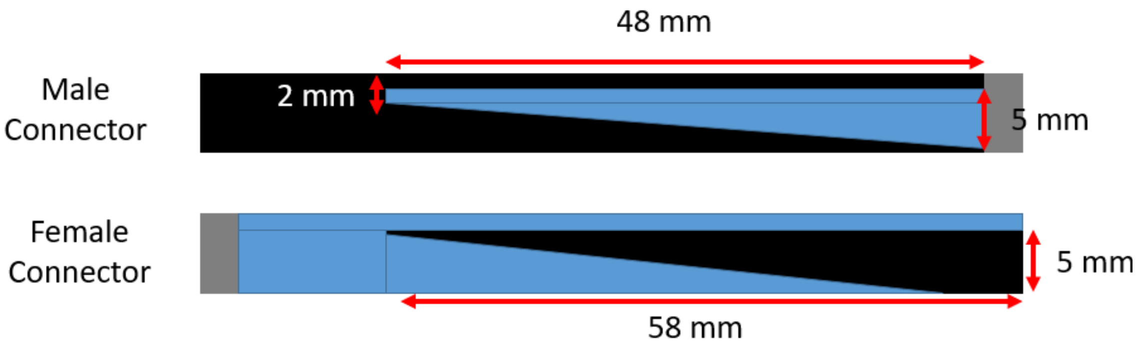


Figure 3.13; Diagram depicting the sliding mechanism and dimensions designed for to connect the lid and base of new pECI case.

3.2.4 3D Models

Once the new pECI case was designed it had to be modelled for 3D printing. All models were made using Blender version 3. The models can be seen below (Figure 3.14 & Figure 3.15)

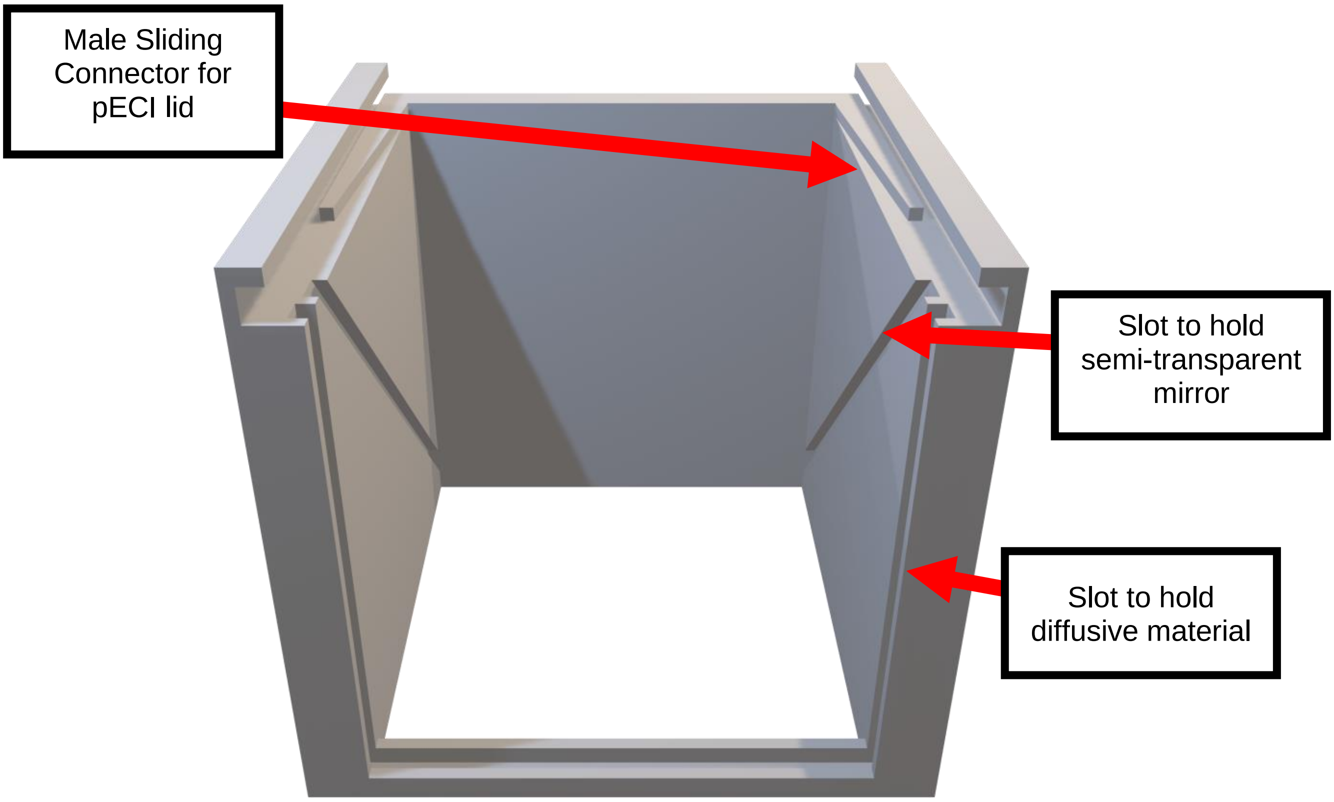


Figure 3.14; 3D Model of new pECI base, detailing location of male sliding connector, and slots for holding semi-transparent mirror and diffusive material.

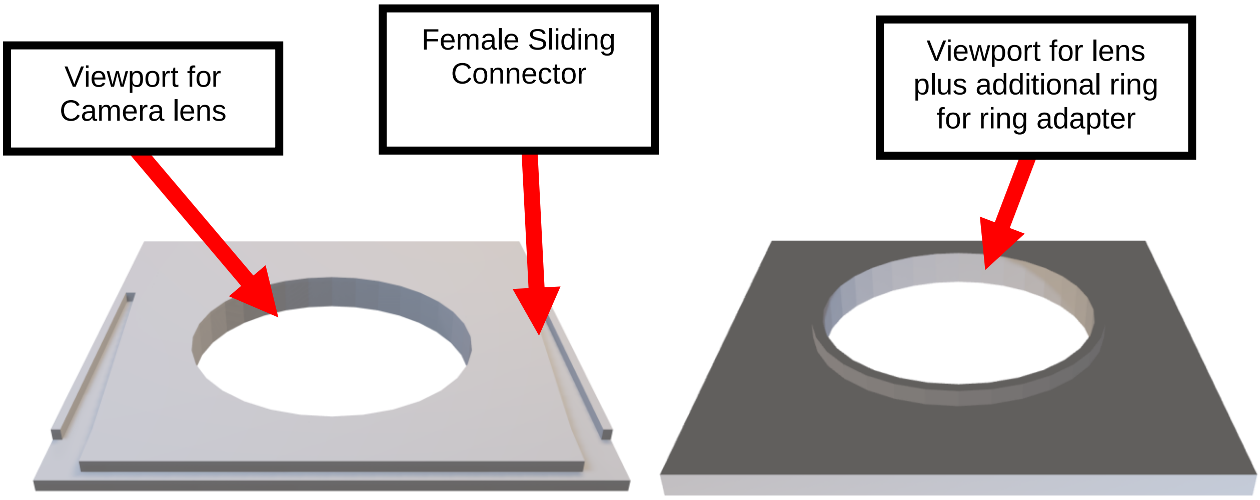


Figure 3.15; 3D model of underside (left) and topside (right) of new pECI lid demonstrating view port and female slide connector.

3.2.5 Final Printed pECI

The final printed pECI v2 case can be seen below (Figure 3.16).

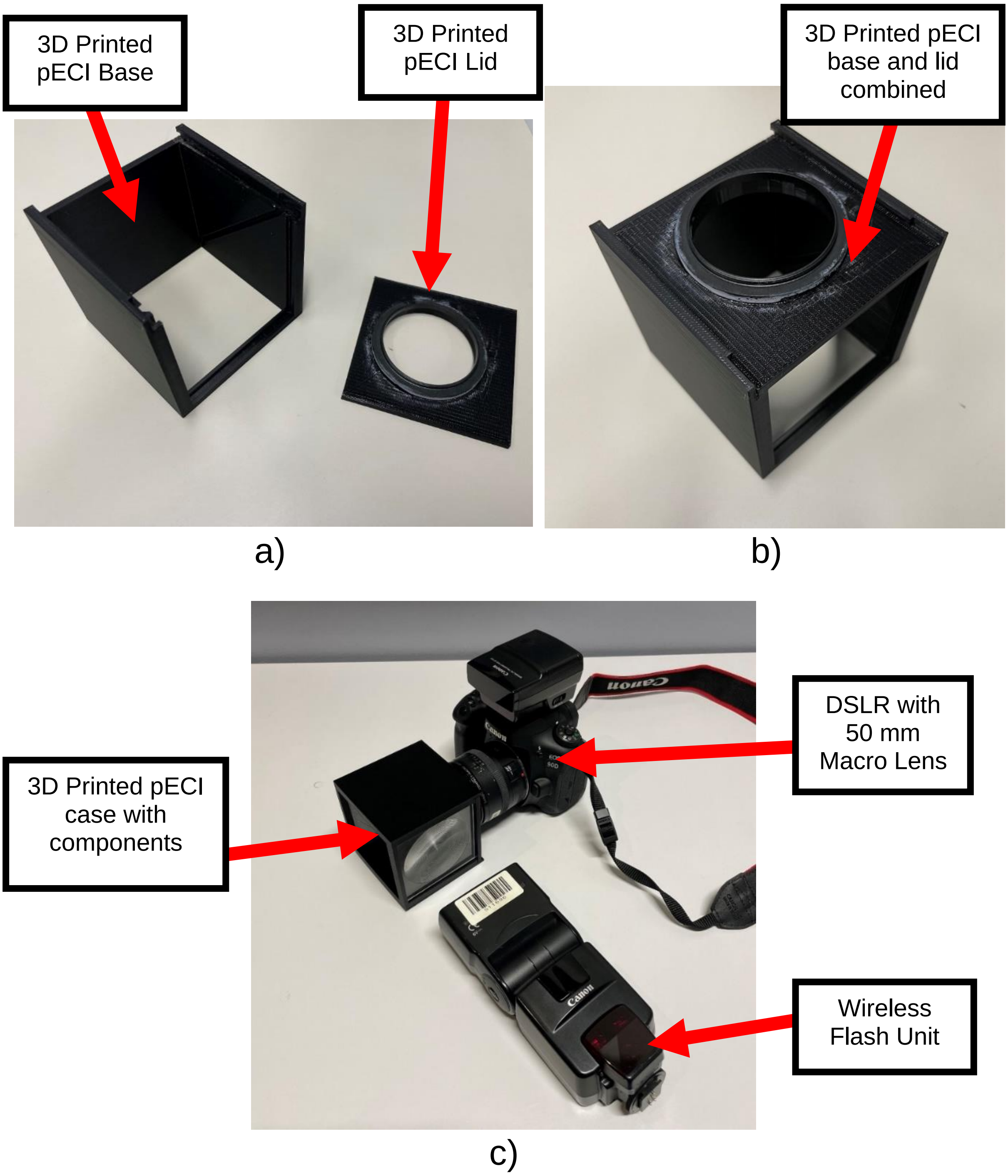


Figure 3.16; Images demonstrating the new 3D printed pECI device. a) Image showing the two separate printed components, the base, and the lid. b) image demonstrating two components connected. c) Image demonstrating new pECI case attached to a 50 mm macro lens. Ring adapter visible in a) and b) is bought separately and glued to top of pECI lid.

An image was acquired with the pECI v2 case (with no optical components inside) attached to a 50 mm macro lens above a subject to demonstrate that the pECI v2 case was not visible in the final image. This was conducted using a 50 mm macro lens and was also compared back to the pECI v1 case where the case itself was visible in the image (Figure 3.17).

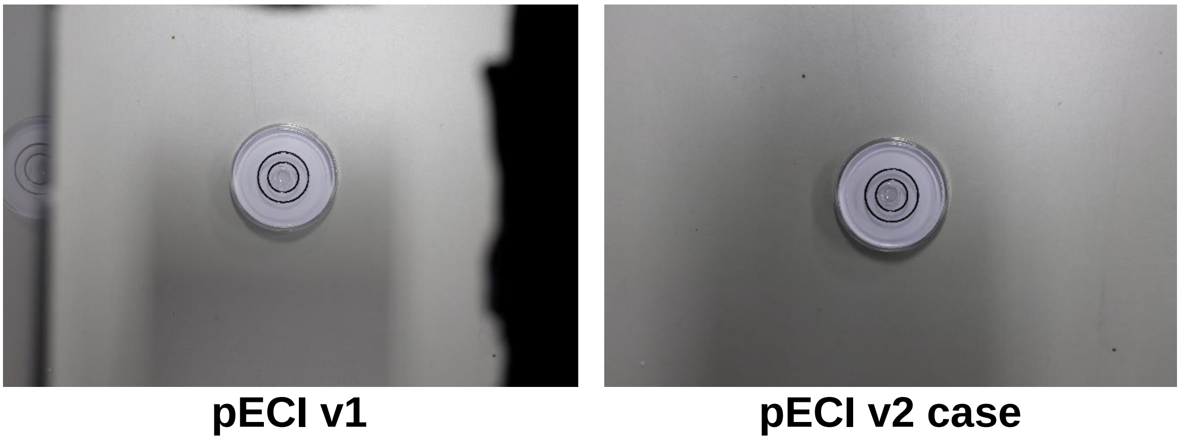
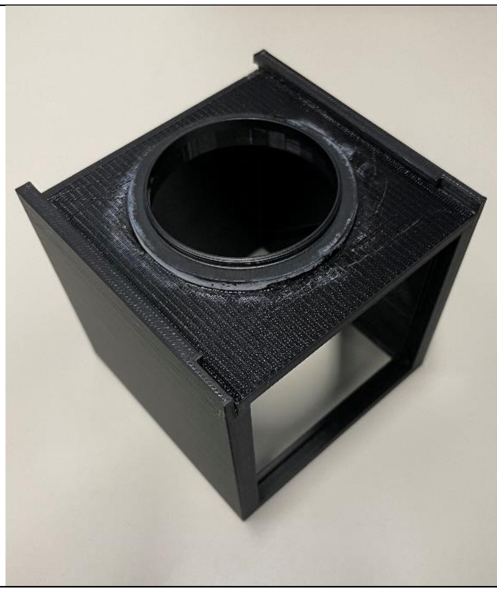


Figure 3.17; Images acquired using the pECI v1 case (left) and pECI v2 case (right) attached to a 50 mm macro lens. pECI v1 case and semi-transparent mirror visible in left image.

The pECI v2 case already showed improvements when compared to the pECI v1 case. The greatest improvement was the ability to now utilise pECI with smaller lenses, which will allow investigators to continue using their smaller 50–60 mm macro lens for this technique. Other improvements include the security of the internal optical components when using the device and more than halving the total weight of the pECI device while making it sturdier – now no longer shattering when dropped (Table 3.4). It should be noted that this case was designed solely for a camera with a cropped sensor size and may need adjustment if utilising a full-frame camera.

Table 3.4: Comparison of weight, cost, smallest compatible lens between the commencing pECI case and pECI V2. *Cost does not include the cost of the felt or ring adapters.

	pECI v1 Case	pECI v2
		
Weight	240 grams	104 grams
Cost	~ $5 AUD*	~$4 AUD*
Smallest compatible Lens	100 mm macro	50 mm macro

The new 3D printed pECI v2 case achieved the design requirements outlined at the commencement of the re-design and was used for the next stage of the project.

3.3 Optimisation of the pECI Optical Components

This section of experiments aims to answer research question 3:

What would be the most effective optical components to be used in the optimised pECI device (pECI v2)?

Prior to commencing large scale experiments to determine the best combination of optical components, some preliminary photographs were taken with each combination using fingermarks deposited on three substrates: glass (glass smart phone screen protector), polished metal (metal jar lid), and plastic (CD cover). The substrates were the same as those used in the optimisation experiments discussed below. These preliminary photos were taken to determine if any pECI combinations or specific components were not worth further investigation due to impracticality or poor image quality. It was quickly determined that Fresnel lenses were too impractical for use and negatively impacted image quality. Refer to Appendix I - for further information.

With the remaining combinations confirmed to work to a reasonable extent, some additional preliminary tests were conducted to determine an optimum flash distance from the diffusers. The optimum flash distance for the acrylic diffuser was determined to be in the range 15–25 cm, while the optimum flash distance for the glass diffuser was determined to be in the range 20–30 cm. This 10 cm difference between the two diffusers was due to the acrylic diffuser spreading more light compared to the glass diffuser. The user will notice if the flash is too close to the diffuser as the area of illumination will appear as a rectangular hotspot in the final image. If the flash is too far away, then stray light from the flash will cause interference and decrease contrast in the impression. This will be noticeable as the boundary area of pECI illumination will blend with the areas around the substrate that should be darker (Figure 3.18).

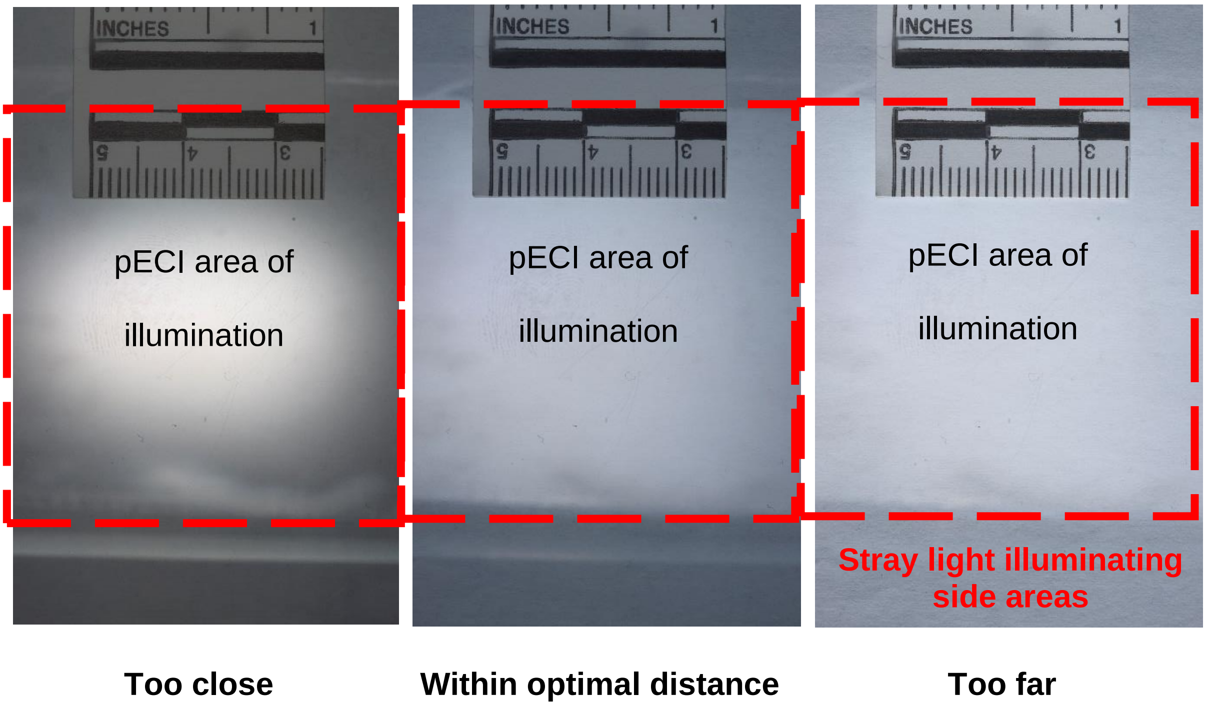


Figure 3.18; Example Images of when the flash is too close (left), at a correct distance (middle) and too far away (right) from the pECI device.

Once an optimum flash distance was determined, test images were taken using the same three substrates with each pECI device combination to determine how much flash exposure was expected to be adjusted. It was noted with all the combinations that the most detail was visible when the flash exposure was lowered to -1.3 exposure compensation being the most it was adjusted before images became underexposed, reducing contrast in the impression. For most combinations, adjusting the exposure compensation to -1 was producing the best contrast. Though it should be noted that a change in exposure compensation may be minor or drastic depending on the strength of the impression and the reflectivity of the substrate. To grasp the true capabilities of each combination, further experiments described below were required.

3.3.1 Mounted Comparisons Between pECI Combinations

The first set of images that were compared were taken while the camera, flash and substrate were all aligned perfectly using a copystand and lab jacks. This comparison indicated the true enhancement quality of the optical components within each pECI combination. The comparison was completed using six donors, each donating one natural fingermark to each of the three different substrates: (1) glass (glass smart phone screen protector); (2) polished metal (metal jar lid); and (3) plastic (CD cover). This totalled 18 fingermarks enhanced using each pECI combination.

When comparing pECI combinations the UC grading scheme was as follows. A positive UC grade indicated minor (+1) or significant (+2) improvement in enhancement quality from the pECI combination being discussed. While a negative UC grade indicated minor (-1) or significant (-2) improvement from the opposing pECI combinations.

Commencing with pECI C1, this combination underperformed greatly compared to all other combinations. All other pECI combinations showed minor to significant improvement in enhancement quality in 50% or more of the comparable fingermarks when compared to pECI C1. These results were interesting as pECI C1 was the original combination of components used in the commencing pECI v1, those components consisting of the original semi-transparent mirror (CD cover) and acrylic diffuser. These results indicated any component change from the original two components produced better results, which supported the theory the original optical components may have been diminishing image quality in the pECI v1. Specifically comparing pECI C1 to C4 supports this theory further as C4 utilises the same semi-transparent mirror but uses a glass diffuser rather than the acrylic found in C1. This suggested that the glass diffuser may mitigate some of the negative effects of the CD cover when used as a semi-transparent mirror. Due to the underperformance of pECI C1, was not examined further in this project (Figure 3.19).

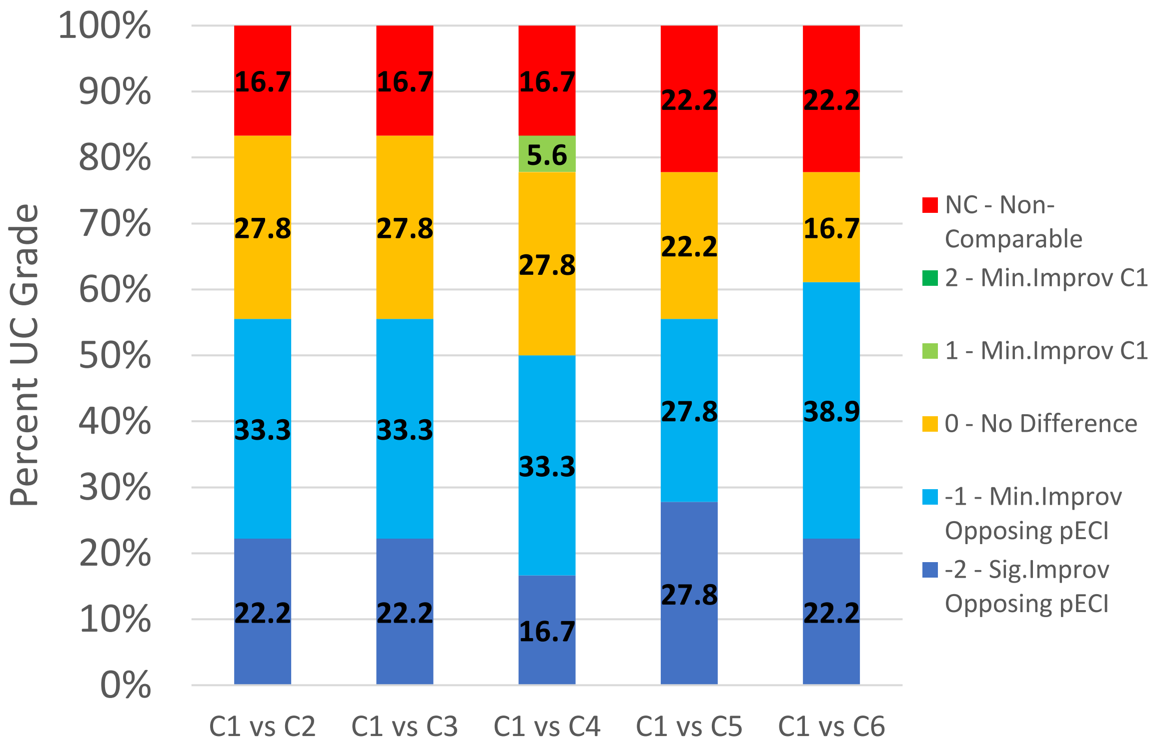


Figure 3.19; Column graph describing the percentage UC grades when comparing pECI C1 (green) to the remaining pECI combinations (blue) while the camera, flash and substrate were all aligned.

Moving onto pECI C2, this combination performed to equal quality as pECI C3. Both pECI C2 and C3 have the acrylic diffusers but differ in semi-transparent mirror, with C3 utilising the more expensive beamsplitter. These results indicated that perhaps the large price difference in semi-transparent mirrors did not make that much of an improvement in fingermark enhancement. C2 also performed to the same quality as pECI C4 despite C4 utilising the CD cover as the semi-transparent mirror, indicating again that the glass diffuser might mitigate some of the negative effects of the CD cover. When comparing pECI C2 to the remaining combinations C5 and C6, C2 underperformed. Examining C2 against C5, with both combinations using the acrylic two-way as the semi-transparent mirror, the glass diffuser in C5 produced improved enhancement in 22.2% of fingermarks compared to C2 which utilises the acrylic diffuser. This indicated the glass diffuser may improve enhancement quality compared to the acrylic diffuser no matter what semi-transparent mirror was being used. Given C2 underperformed compared to C5 and C6, C2 was not examined further in the project (Figure 3.20).

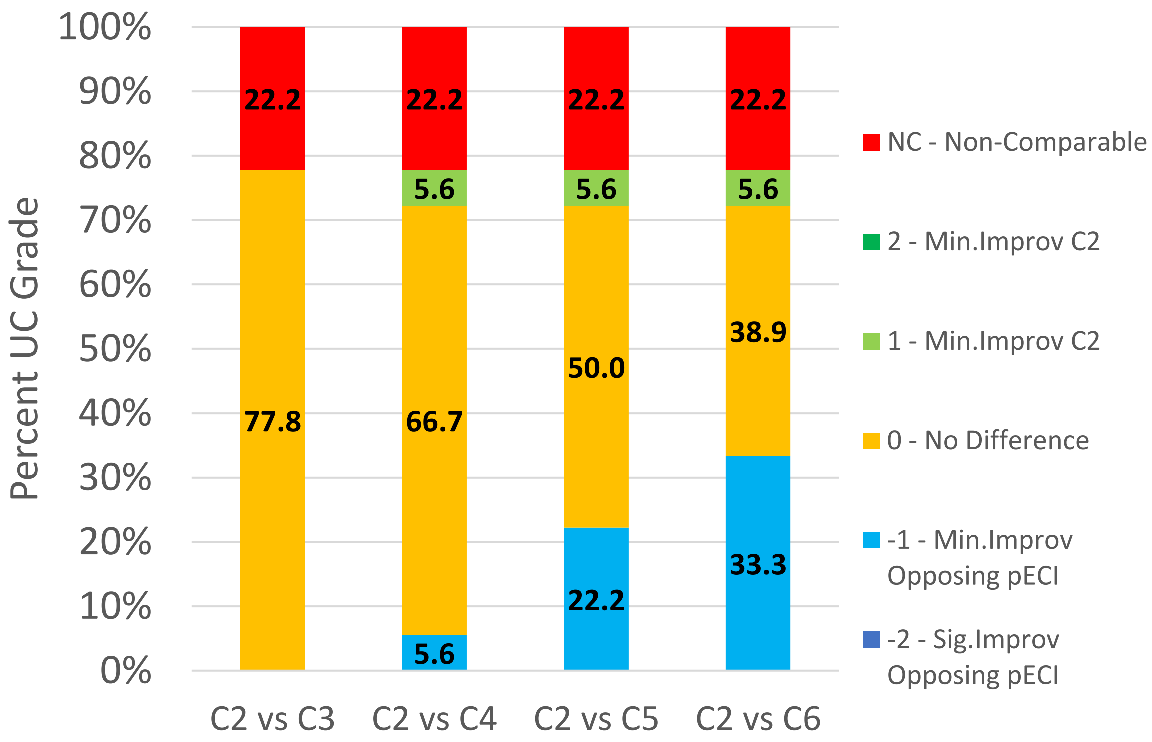


Figure 3.20; Column graph describing the percentage UC grades when comparing pECI C2 (green) to the remaining pECI combinations (blue) while the camera, flash and substrate were all aligned.

Comparing pECI C3 to the remaining pECI combinations, C3 performed to the same quality as pECI C4 but underperformed when compared to C5 and C6. Comparing pECI C3 to C6, both combinations utilised the beamsplitter as the semi-transparent mirror, but differed in diffuser. C6 was utilising the glass diffuser and outperformed C3, indicating that the glass diffuser was increasing enhancement quality when used with any semi-transparent mirror as similar improvements in enhancement quality were noted when examining pECI combinations C1 and C2.

Following the underperformance of pECI C3, the combination was not examined further in the project (Figure 3.21).

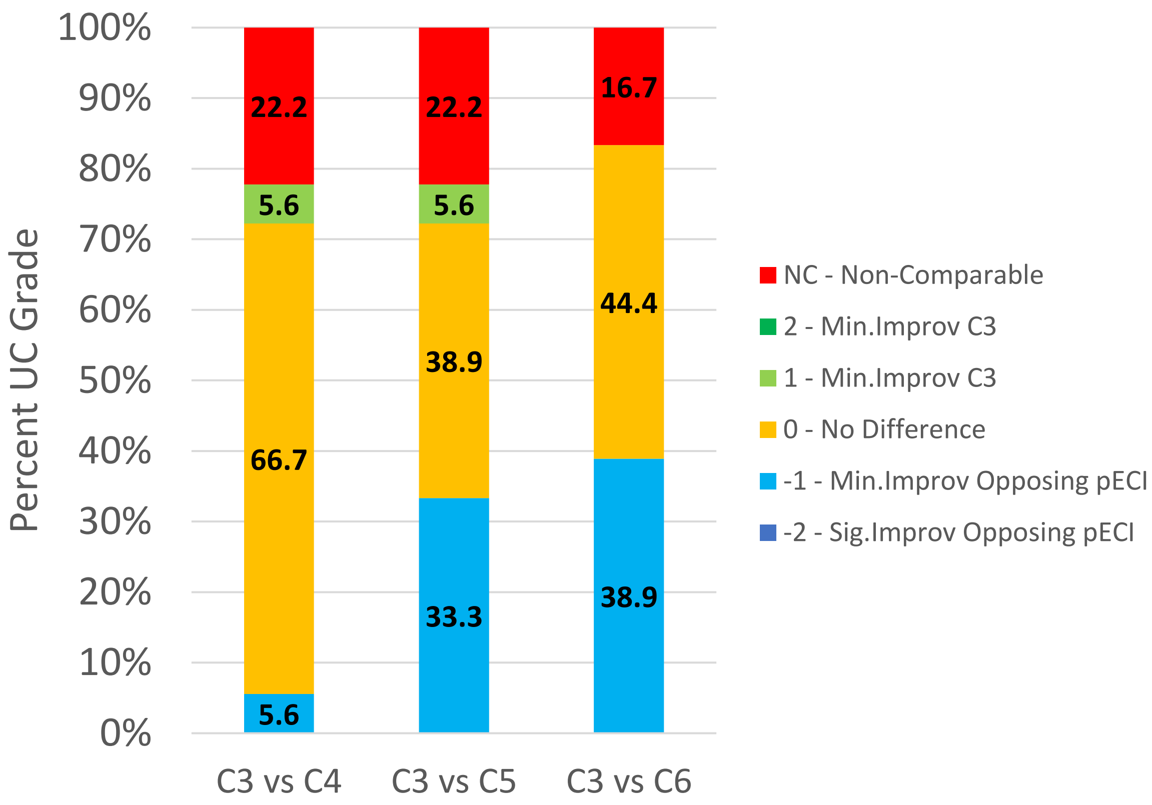


Figure 3.21; Column graph describing the percentage UC grades when comparing pECI C3 (green) to the remaining pECI combinations (blue) while the camera, flash and substrate were all aligned.

When comparing pECI C4 to C5 and C6, C4 underperformed with both C5 and C6 better enhancing more than 25% of fingermarks to higher quality. All three combinations utilised the glass diffuser and only differed in semi-transparent mirror. This indicated that the acrylic two-way mirror and beamsplitter found in C5 and C6 respectively, increased enhancement quality greatly compared to the original CD cover material which is found in C4. Following the underperformance of pECI C4, the combination was not examined further in the project (Figure 3.22).

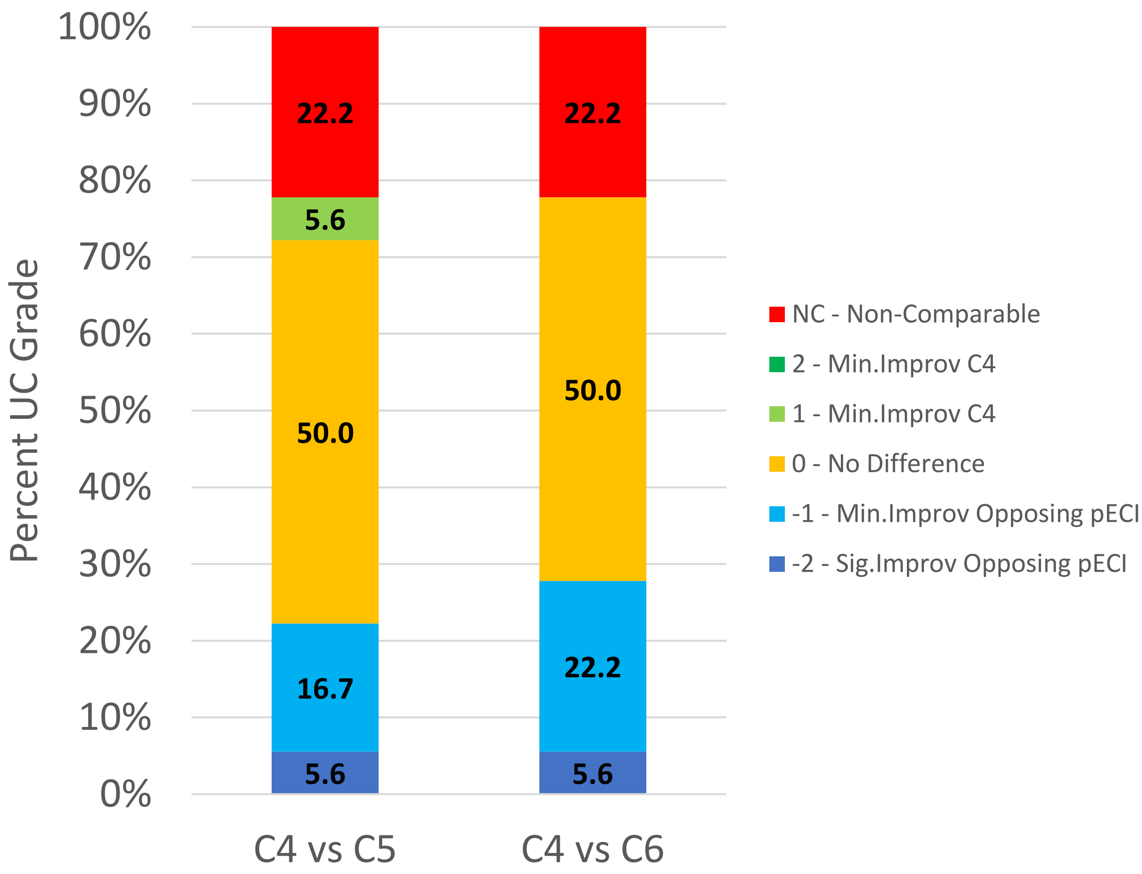


Figure 3.22; Column graph describing the percentage UC grades when comparing pECI C4 (green) to the remaining pECI combinations (blue) while the camera, flash and substrate were all aligned.

The final comparison was between pECI C5 and C6, where pECI C6 outperformed by only 11.1% (Figure 3.23).

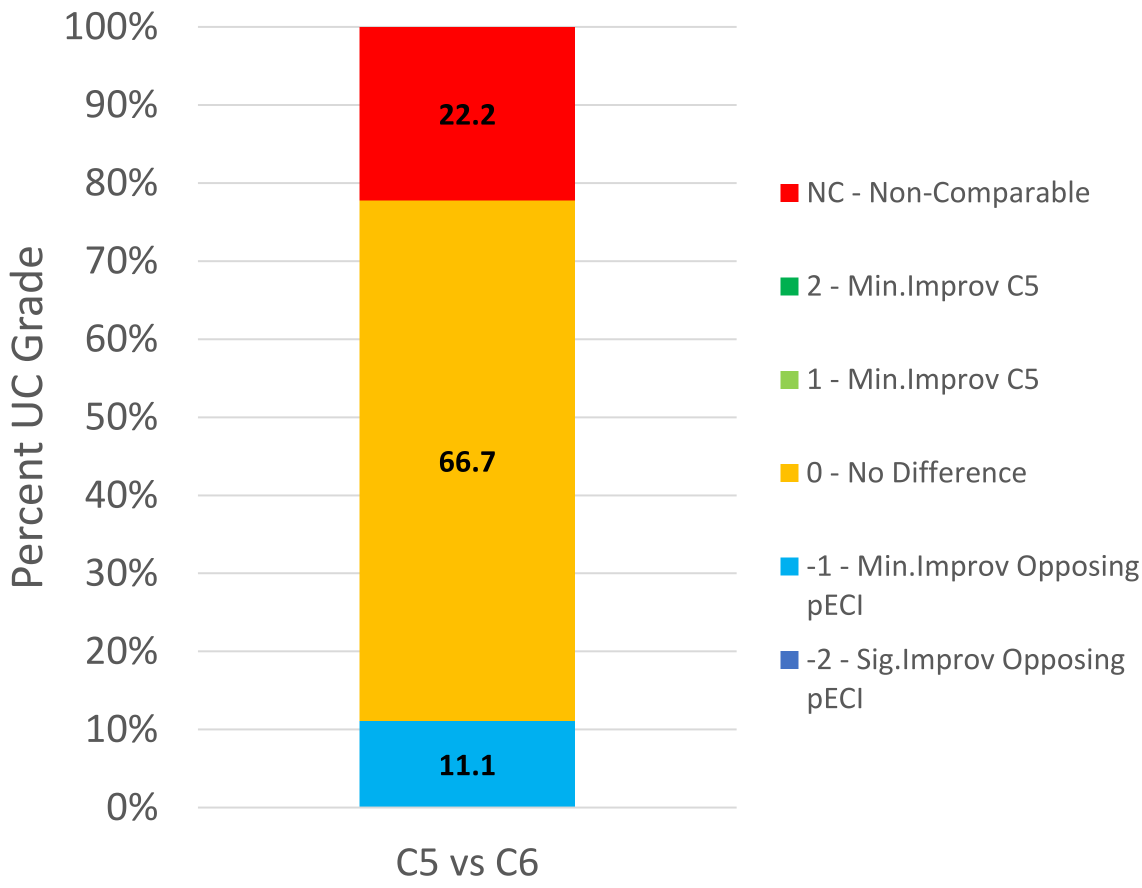


Figure 3.23; Column graph describing the percentage UC grades when comparing pECI C5 (green) to pECI C6 (blue) while the camera, flash and substrate were all aligned.

Examining the composition of pECI C5 and C6, the only difference between the two combinations is the semi-transparent mirror. C5 had the $20 acrylic two-way mirror and C6 had the $400 beamsplitter equipped. When examining comparison images that were graded as +1 (minor improvement from C6), the contrast produced by C6 was evidently improved, but the same amount of ridge detail was recorded using both combinations, thus images obtained using either of these combinations could be used for identification purposes despite the $380 price difference in componentry (Figure 3.24).

pECI C5 **pECI C6**

pECI C5 **pECI C6**

Figure 3.24; exemplar images of fingermarks graded +1 indicating minor enhancement improvement from pECI C6 when compared to pECI C5.

In conclusion pECI C6 provided the most amount of contrast but pECI C5 and C6 provided the same amount of ridge detail despite the significant difference in price. Due to the performance of C5 and C6, both were examined further while pECI combinations C1 through C4 were not further examined.

3.3.2 Handheld Comparisons Between pECI C5 and C6

This comparison only focussed on the two best performing pECI combinations (C5 and C6), and compared images taken while using the two pECI combinations handheld. When handheld, the flash unit and substrate had to be manually aligned to emulate in-field use. The comparison was completed using the same 18 fingermarks utilised in the previous experiment (Section 3.3.1).

61.1% of fingermarks were graded as 0 indicating no difference in enhancement quality between C5 and C6. 11.1% of fingermarks were graded as -1 indicating minor improvement in enhancement quality with C6 compared to C5. 5.6% of fingermarks were graded as +1 indicating minor improvement in enhancement quality with C5 compared to C6. The remaining 22.2% of fingermarks were graded as NC (Figure 3.25).

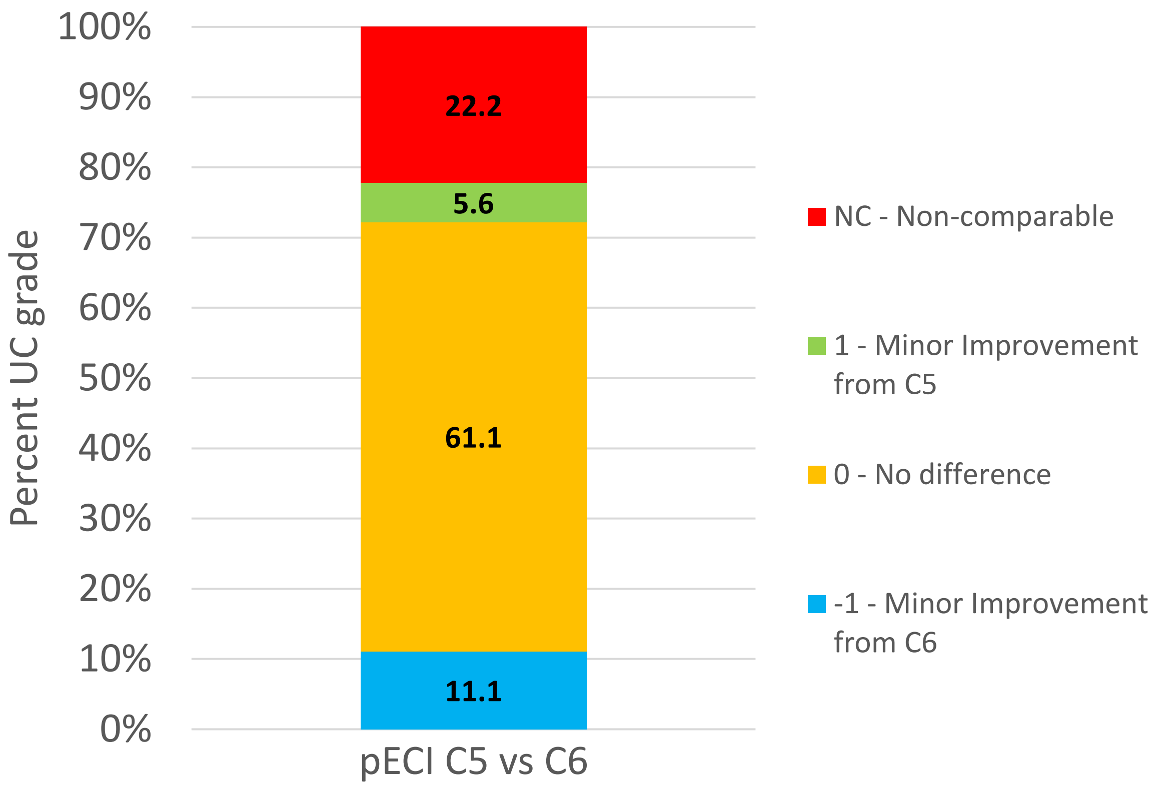


Figure 3.25; Column graph describing the percentage UC grades when comparing pECI C5 (green) to pECI C6 (blue) while the camera, flash and substrate were all manually aligned through handheld photography.

Similar enhancement quality was obtained when using both pECI C5 and C6 handheld. When examining any comparison images that were graded +1 or -1, the same observations that were noted in the previous comparison were noted here; while there were instances where one pECI combination would produce slightly improved contrast, both combinations still recorded the same amount of ridge detail useful for identification purposes, despite the large price difference between the two combinations. Hence both combinations were examined in the final comparison.

3.3.3 Controlled vs Handheld Photography

The final comparison was conducted to determine if either pECI C5 or C6 had a notable decrease in enhancement quality when used handheld. If there was a noticeable decrease in quality, the incorporation of alignment features into the pECI v2 design would be required. To determine if there was a decrease or not in fingermark quality, the same 18 fingermarks utilised in the two previous experiments were utilised. The 18 fingermarks were recorded using C5 and C6 attached to a copystand with the substrate, flash and camera aligned perfectly. The same set of fingermarks were then recorded again with C5 and C6, but now using each pECI combination handheld where the substrate, flash and camera had to be manually aligned.

Firstly, examining only pECI C5, 61.1% of fingermarks were graded as 0 indicating no difference in enhancement quality when using C5 on a copystand or handheld. 11.1% of fingermarks were graded as +1 indicating minor improvement in enhancement quality when using C5 on a copystand compared to using it handheld. 5.6% of fingermarks were graded as -1 indicating minor improvement in enhancement quality when using C5 handheld compared to on a copystand. The remaining 22.2% of fingermarks were graded as NC.

When examining only pECI C6, 66.7% of fingermarks were graded as 0 indicating no difference in enhancement quality when using C6 on a copystand or handheld. 11.1% of fingermarks were graded as +1 indicating minor improvement in enhancement quality when using C6 on a copystand compared to using it handheld. The remaining 22.2% of fingermarks were graded as NC (Figure 3.26).

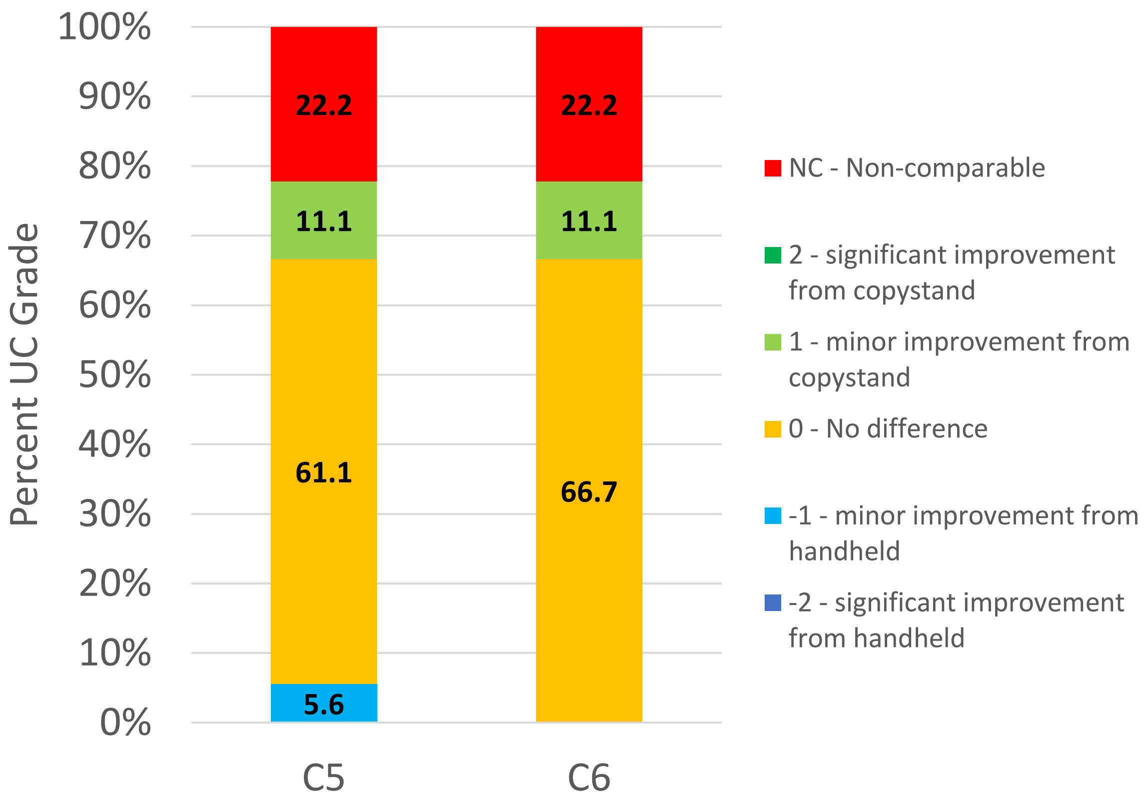


Figure 3.26; Column graph describing the percentage UC grades when comparing controlled photography against handheld photography using pECI combination 5 and 6.

The results from this comparison indicated that the investment of time and resources into alignment features for the optimised pECI device would not be necessary if using either pECI combination C5 or C6. Though there is some improvement from using either combination with components aligned via copystand photography, this is expected as human error cannot be avoided in every situation.

3.3.4 Donor and Substrate Variability

Given there were 648 comparisons, there were still only 18 fingermarks donated in total, meaning little can be stated about donor and substrate variability. To briefly comment, the only donor trend observed in all three comparisons was related to the categorised weak donors. When comparing pECI combinations, when an NC grade was determined, it was commonly due to a comparison of fingermarks donated from a weak donor. It was anticipated that weak donors will transfer less secretions from the finger to the substrate, hence increasing the likelihood of no detection and an NC grade. With regards to substrate variation, there was no notable substrate that was difficult for any pECI combination.

To truly test donor or substrate variability, more time would be needed to allow for more repeats of fingermark donations on a variety of substrates.

3.3.5 Optimal Optical Components for pECI v2

Considering the results from all three comparisons, it was determined that the most optimum combination of optical components was pECI C5, which contained the acrylic two-way mirror and a glass diffuser. While the argument can be made that pECI C6 is the ideal combination due to the slightly improved contrast, when considering the price difference and accessibility of the two combinations, C6 cannot be recommended. The acrylic two-way mirror performed almost to the same standard as the beamsplitter despite the price difference of $380. Another negative factor that should be discussed related to using the beamsplitter is the extra weight it provides and the fragility of the material. The acrylic two-way mirror is lighter, weighing 27 g compared to the beamsplitter weighing 43 g. The acrylic mirror is also stronger hence less likely to crack, or shatter compared to the beamsplitter if dropped accidently. As emphasised previously, a durable design is important for in-field use hence the acrylic mirror is more suitable. Furthermore, if the acrylic mirror does break, it is readily replaceable at a lower cost.

In regard to the addition of alignment features in the pECI design, this is not justified as there was a minor difference in enhancement quality when having the flash and substrate aligned with assistance as compared to manually aligned/handheld.

With minimal training and practice, the pECI can easily be used in a portable handheld manner.

3.4 In-field Testing of the pECI v2 Device

This section of experiments set out to answer research question 4:

> *How does the optimised pECI device (pECI v2) compare to the current standard for optical detection and enhancement in-field at crime scenes?*

For this experiment, fingermarks were enhanced in a simulated crime scene scenario using substrates representative of what would be found in-field. Three fingermark donors deposited three natural fingermarks on each of the six different substrates, totalling nine fingermarks per substrate and 54 fingermarks overall. The fingermarks were left to age 24 hours prior to enhancement. The six substrates included: (1) a glass window; (2) a glass mirror; (3) a plastic information sheet holder; (4) a whiteboard; (5) a fridge; and (6) a filing cabinet. The results of this experiment are discussed based on substrate variation. While each substrate is categorised as non-porous, flat, and reflective, these substrates differ in material and colour, and the results were observed to vary across these difference substrates.

When discussing UC grades on any substrate, the following applied. A positive UC grade indicated that diffused reflection showed a significant (+2) or minor (+1) improvement in fingermark enhancement – ridge detail and/or contrast – compared to the pECI v1. A negative grade indicated that pECI v2 showed minor (-1) to significant (-2) improvement in fingermark enhancement compared to diffused refection.

3.4.1 Glass Window

A total of nine fingermarks were deposited on the glass window; all nine were detected by both diffused reflection and the pECI v2 device. There were 18 UC comparisons made: nine comparing diffused reflection against the pECI on latent fingermarks; and nine comparing diffused reflection against the pECI on post-powdered fingermarks.

Examining the latent fingermarks, 44.4% of comparisons acquired a UC grade of -1 indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 33.3% were received a UC grade of 0, indicating no difference in enhancement quality between diffused reflection and the pECI device. 22.2% received a UC grade of -2 indicating the pECI device produced major improvement in enhancement quality compared to diffused reflection.

Examining the powdered fingermarks, 66.7% of the fingermarks received a UC grade of 0, indicating no difference in enhancement quality between diffused reflection and the pECI device. 22.2% received a UC grade of -1 indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 11.1% received a grade of +1 indicating diffused reflection produced minor improvement in enhancement quality compared to the pECI device (Figure 3.27).

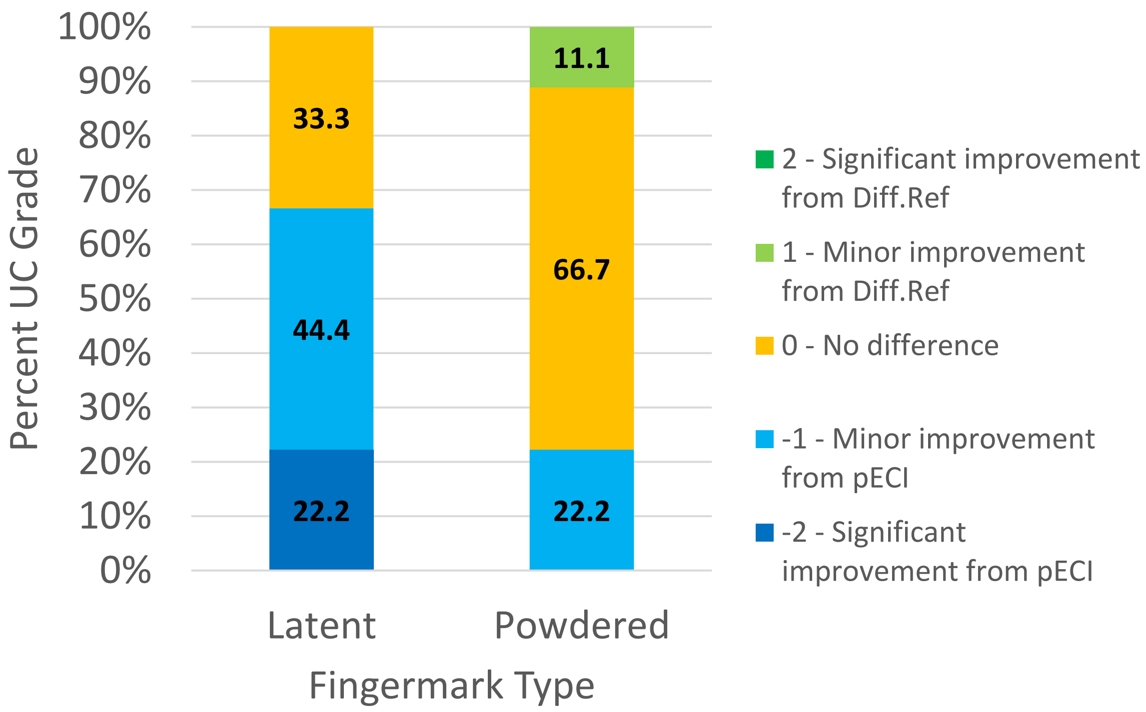


Figure 3.27; Column graph describing the percentage UC grades comparing diffused reflection (green) and the optimised pECI device (blue) enhancing nine latent and nine powdered fingermarks on a glass window.

There was a total of nine latent fingermarks CAST graded per optical technique and another nine powdered fingermarks CAST graded per optical technique. For the latent fingermarks, diffused reflection had an average CAST grade of 2.3 while the pECI had an average CAST grade of 3.4. For the post-powdered fingermarks, diffused reflection had an average CAST grade of 2.8 and the pECI had an average CAST gde of 3.3 (Figure 3.28).

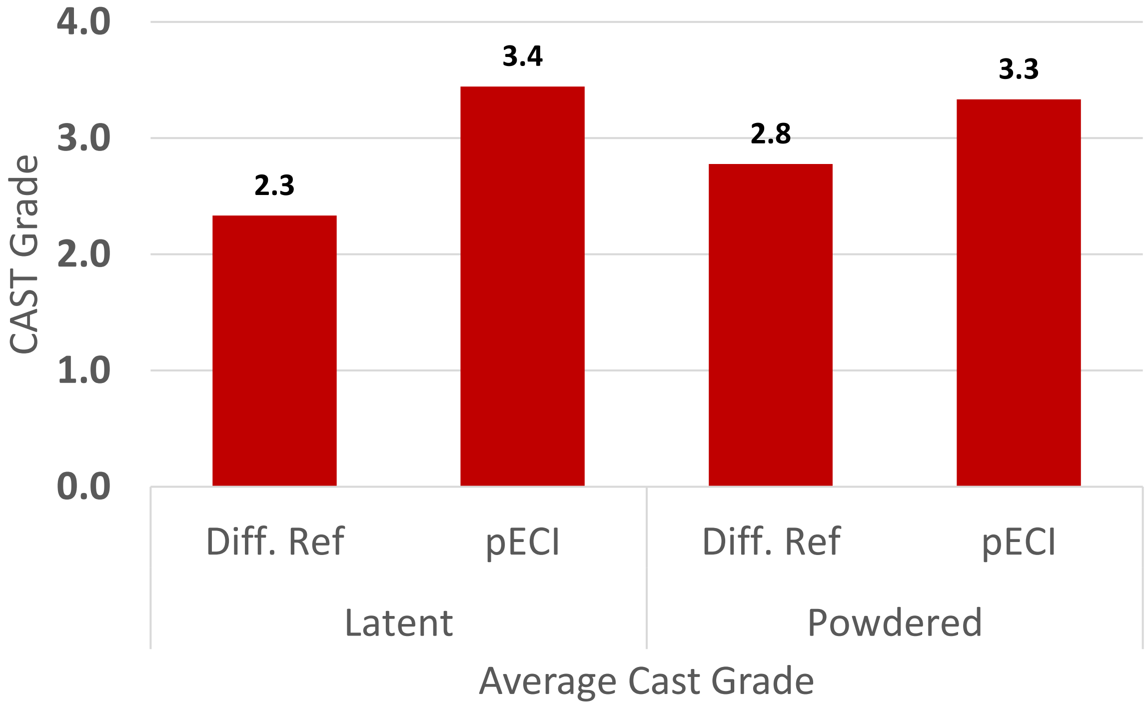


Figure 3.28; Column graph describing the average CAST grade of diffused reflection and the pECI when enhancing nine latent and post-powdered fingermarks on a glass window.

Overall, when enhancing latent fingermarks on a glass window, the pECI device provided more ridge detail in a majority of latent fingermarks as compared to diffused reflection. After the application of powder, most fingermarks were enhanced to the same quality by diffused reflection and the pECI device, but when examining the amount of clear ridge detail enhanced, the pECI had a marginally larger average CAST grade difference of 0.5 compared to diffused reflection (Figure 3.29).

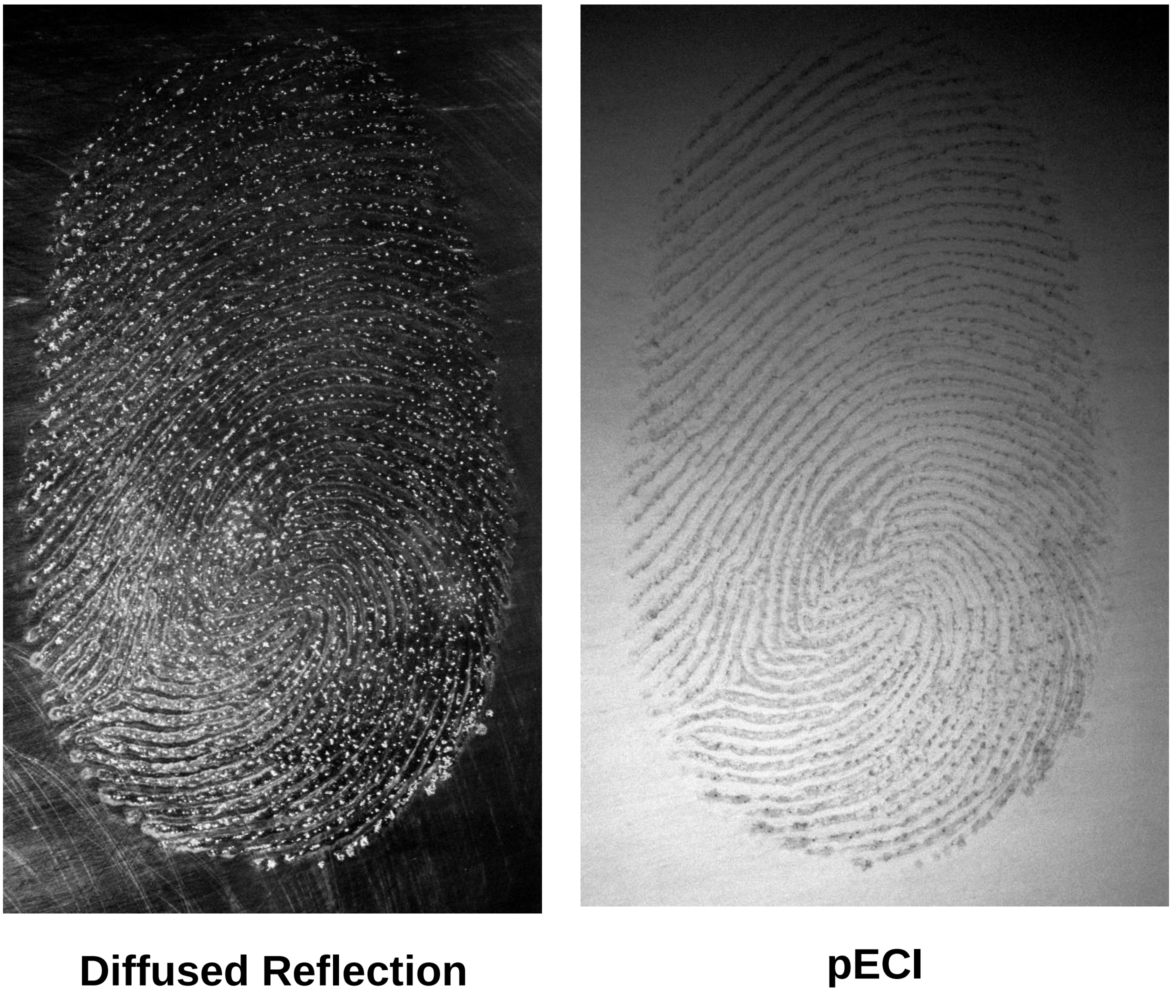


Figure 3.29; Images of a latent fingermark deposited on a glass window and enhanced using diffused reflection (left) and the optimised pECI device (right).

3.4.2 Mirror

A total of nine fingermarks were deposited on the mirror, all nine were detected by oblique lighting and the pECI device. There were 18 UC comparisons made: nine comparing diffused reflection against the pECI on latent fingermarks; and nine comparing diffused reflection against the pECI on post-powdered fingermarks.

Examining the latent fingermarks, 44.4% of comparisons acquired a UC grade of +1 indicating that diffused reflection produced minor improvement in enhancement quality compared to the pECI device. 33.3% received a UC grade of 0, indicating no difference in enhancement quality between diffused reflection and the pECI device.

22.2% received a UC grade of -1 indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection.

Examining the powdered fingermarks, 55.6% of the fingermarks received a UC grade of 0, indicating no difference in enhancement quality between diffused reflection and the pECI device. 44.4% received a UC grade of -1 indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection (Figure 3.30).

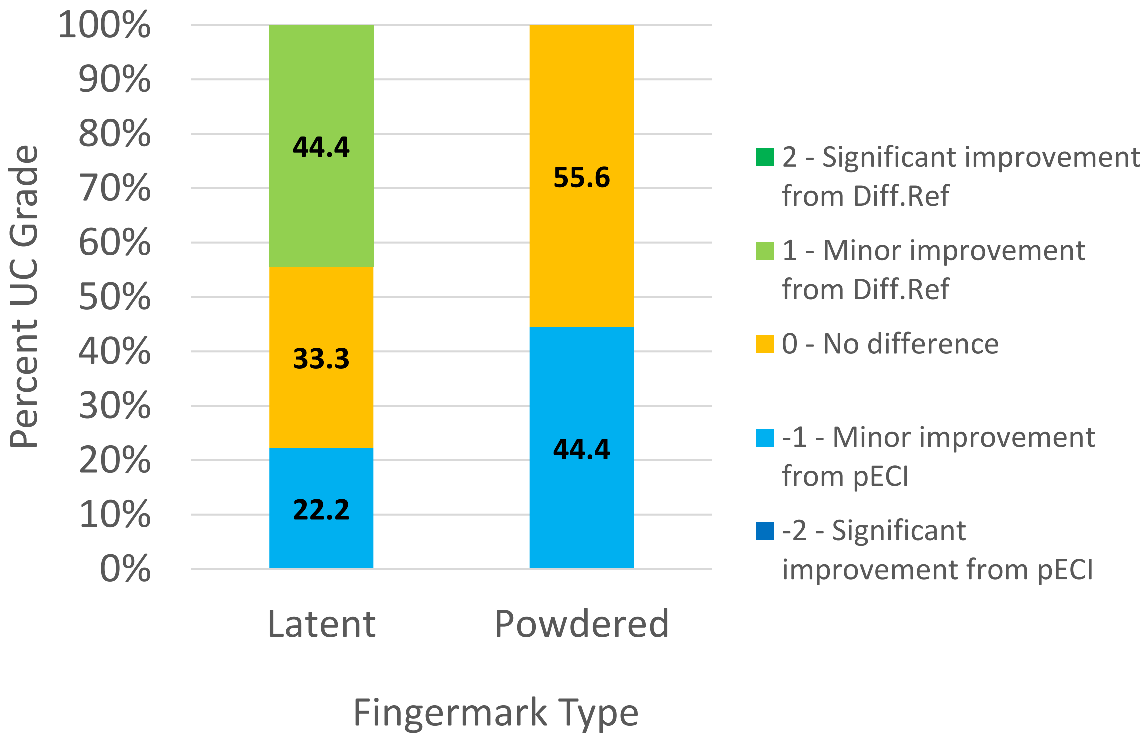


Figure 3.30; Column graph describing the percentage UC grades comparing diffused reflection (green) and the optimised pECI device (blue) enhancing nine latent and nine powdered fingermarks on a mirror.

There was a total of nine latent fingermarks CAST graded per optical technique and another nine powdered fingermarks CAST graded per optical technique. For the latent fingermarks, diffused reflection had an average CAST grade of 2.3, while the pECI had an average CAST grade of 1.8. For the post-powdered fingermarks, diffused reflection had an average CAST grade of 3.0, and the pECI had an average CAST grade of 3.0 (Figure 3.31).

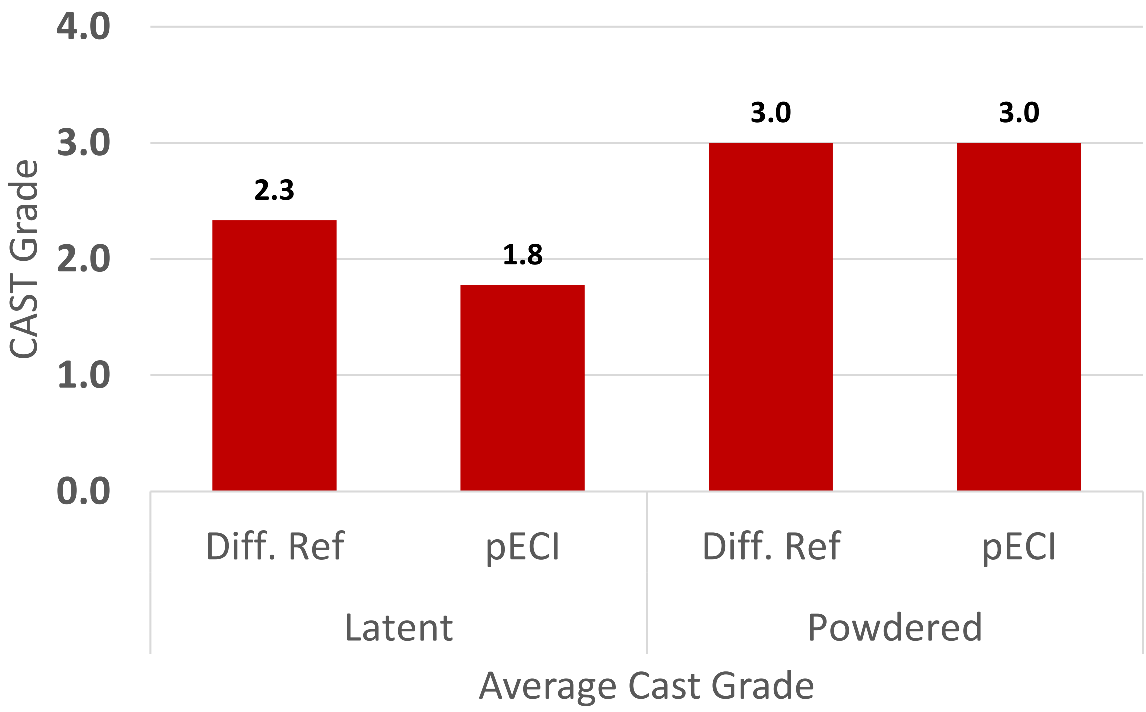
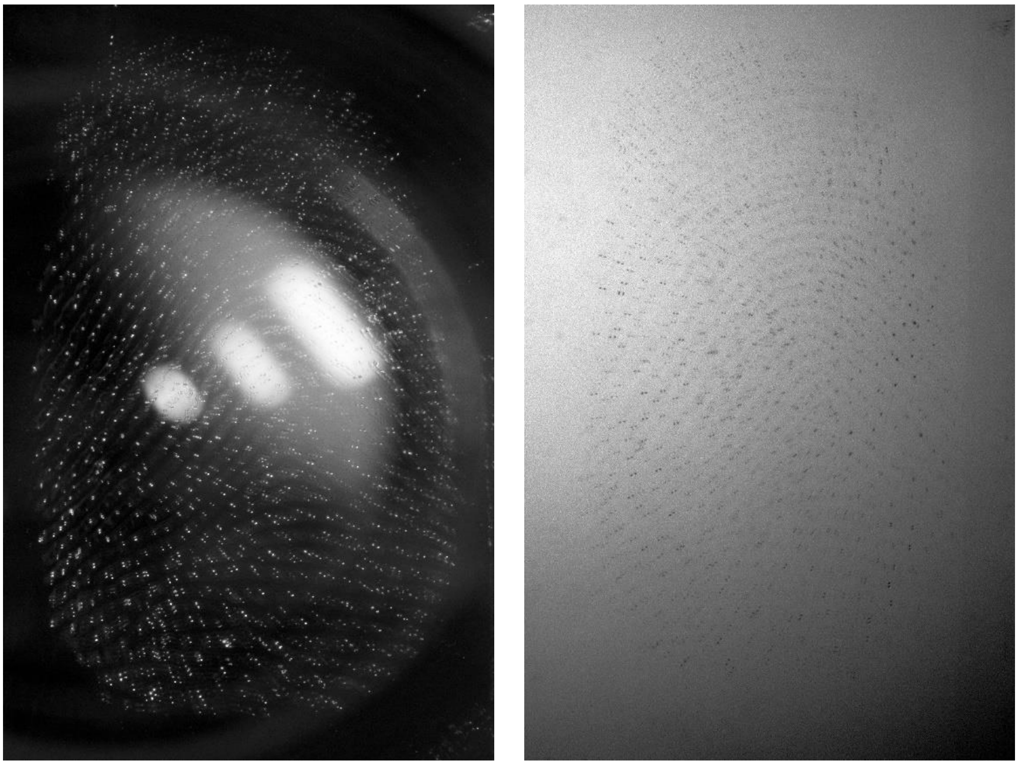


Figure 3.31; Column graph describing the average CAST grade of diffused reflection and the pECI when enhancing nine latent and post-powdered fingermarks on a mirror.

When enhancing latent fingermarks on a mirror, diffused reflection provided the best enhancement quality in a majority of the fingermarks examined. The pECI device struggled to enhance ridge detail on the mirror due to the substrate's ability to reflect a significant percentage of the directed light from the pECI back into the device. While this is the purpose of the technique, this caused the image to be over-exposed in nearly all instances and allowed light to 'engulf' ridge detail. Even with the decrease in flash power, fingermarks with poor ridge detail were difficult to record. When ridge detail was recorded using the pECI, an observed benefit over diffused reflection was the removal of hot spots and the reflection of the camera lens itself, which are common in the diffused reflection images (Figure 3.32).



Diffused Reflection **pECI**

Figure 3.32; Images of a latent fingermark deposited on a mirror and enhanced using diffused reflection (left) and the optimised pECI device (right). Demonstrating the pECI's removal of hot spots and lens reflection visible in the diffused reflection image.

When enhancing fingermarks post powder application on a mirror, the pECI device provided improved enhancement quality compared to diffused reflection in almost half the fingermarks examined and performed just as well as diffused reflection in the remainder. While the pECI device provided improved enhancement quality, this was usually just an increase in contrast as the average CAST grades from both techniques on powdered fingermarks were 3.0. A notable benefit with the pECI was the lack of split ridge detail in some images compared to diffused reflection. Due to the angle of illumination to perform diffused reflection, it is common and difficult to remove this splitting of ridge detail, but when using the pECI device, this splitting effect does not occur and allows for clearer ridge detail to be present (Figure 3.33).

Figure 3.33; Images of a powdered fingermark on a mirror and enhanced using diffused reflection (Left) and the optimised pECI device (Right). Demonstrating the pECI's clearer ridge detail due to the lack of splitting effect caused by diffused reflection.

3.4.3 Plastic

A total of nine fingermarks were deposited on the plastic, all nine were detected by both oblique lighting and the pECI device. There were 18 UC comparisons made: nine comparing diffused reflection against the pECI on latent fingermarks; and nine comparing diffused reflection against the pECI on post-powdered fingermarks.

77.8% of latent fingermark comparisons acquired a UC grade of -1, indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 11.1% received a UC grade of 0, indicating no difference in enhancement quality between diffused reflection and the pECI device. 11.1% received a UC grade of -2 indicating the pECI device produced major improvement in enhancement quality compared to diffused reflection.

Of the powdered fingermarks, 66.7% of comparisons acquired a UC grade of -1 indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 33.3% received a UC grade of -2 indicating the pECI device produced major improvement in enhancement quality compared to diffused reflection (Figure 3.34).

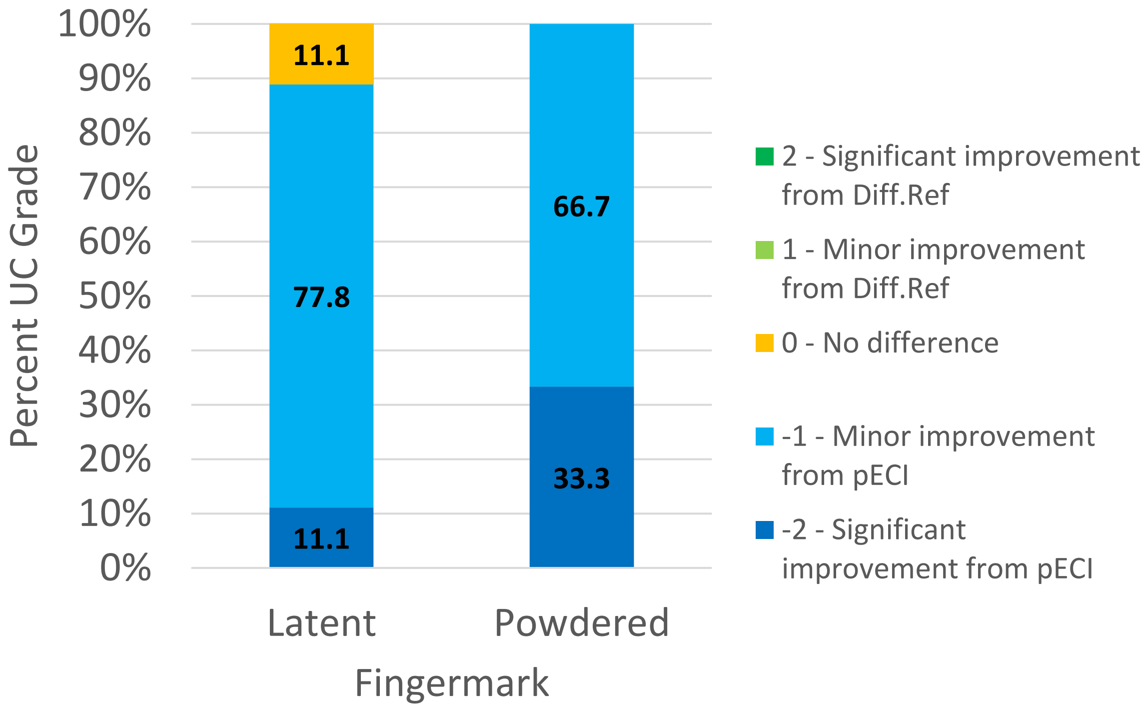


Figure 3.34; Column graph describing the percentage UC grades comparing diffused reflection (green) and the optimised pECI device (blue) enhancing nine latent and nine powdered fingermarks on a plastic substrate.

There was a total of nine latent fingermarks CAST graded per optical technique and another nine powdered fingermarks CAST graded per optical technique. For the latent fingermarks diffused reflection had an average CAST grade of 0.4 while the pECI had an average CAST grade of 2.0. For the post-powdered fingermarks, diffused reflection had an average CAST grade of 1.1, and the pECI had an average CAST grade of 2.7 (Figure 3.35).

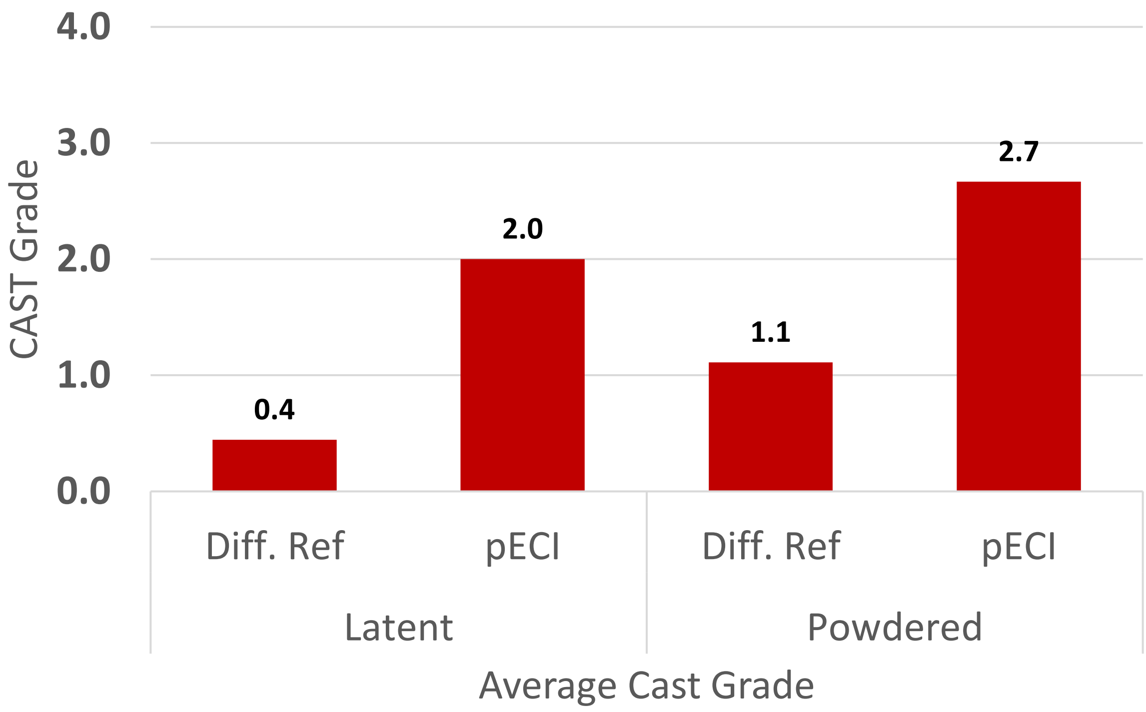
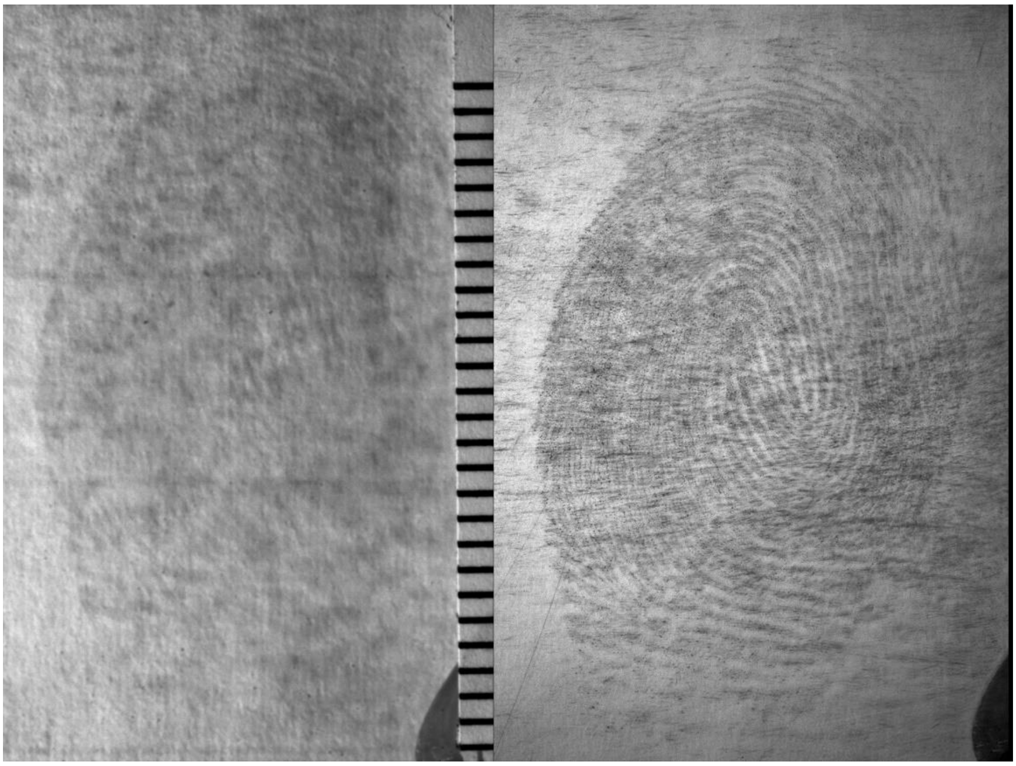


Figure 3.35; Column graph describing the average CAST grade of diffused reflection and the pECI when enhancing nine latent and post-powdered fingermarks on a plastic substrate.

The plastic is an example of a substrate where investigators may currently resort to powder application when diffused reflection fails, however these results show that the pECI device is able to recover some ridge detail prior to powdering. Once powder was applied, diffused reflection was able to recover some ridge detail but the pECI still outperformed diffused reflection both pre- and post-powdering.

The reason diffused reflection underperformed was due to the substrate itself. While it is non-porous, flat, and highly reflective, and even transparent, similar in appearance to glass, there is a backing (paper) behind the substrate which casts a shadow of the ridges. The angle of incidence caused the technique to enhance the shadow of the ridge detail on the backing rather than the ridge detail on the immediate substrate where the incident light was interacting. This caused the splitting affect to be more prominent distorting ridge detail. If just the shadow was visible, the final image using diffused reflection appeared to have dark ridges against a light background which is not the desired effect. The pECI avoided this issue due to the incident light now being directly perpendicular to the substrate and fingermark (Figure 3.36).



Diffused Reflection **pECI**

Figure 3.36; Images of a powdered fingermark on a plastic substrate and enhanced using diffused reflection (Left) and the optimised pECI device (Right). Demonstrating the pECI's clearer ridge detail due to the lack of splitting effect caused by diffused reflection.

3.4.4 Whiteboard

A total of nine fingermarks were deposited on the whiteboard, only eight were detected using oblique lighting and all nine were detected by the pECI device. There were 18 UC comparisons made: nine comparing diffused reflection against the pECI on latent fingermarks; and nine comparing diffused reflection against the pECI on post-powdered fingermarks.

Of the latent fingermarks, 77.8% of comparisons acquired a UC grade of -2, indicating that the pECI device produced major improvement in enhancement quality compared to diffused reflection. 22.2% received a UC grade of -1, indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection.

Of the powdered fingermarks, 44.4% of comparisons acquired a UC grade of -2 indicating that the pECI device produced major improvement in enhancement quality compared to diffused reflection. 44.4% received a UC grade of -1, indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 11.1% received a UC grade of 0, indicating no difference in enhancement quality between diffused reflection and the pECI device (Figure 3.37).

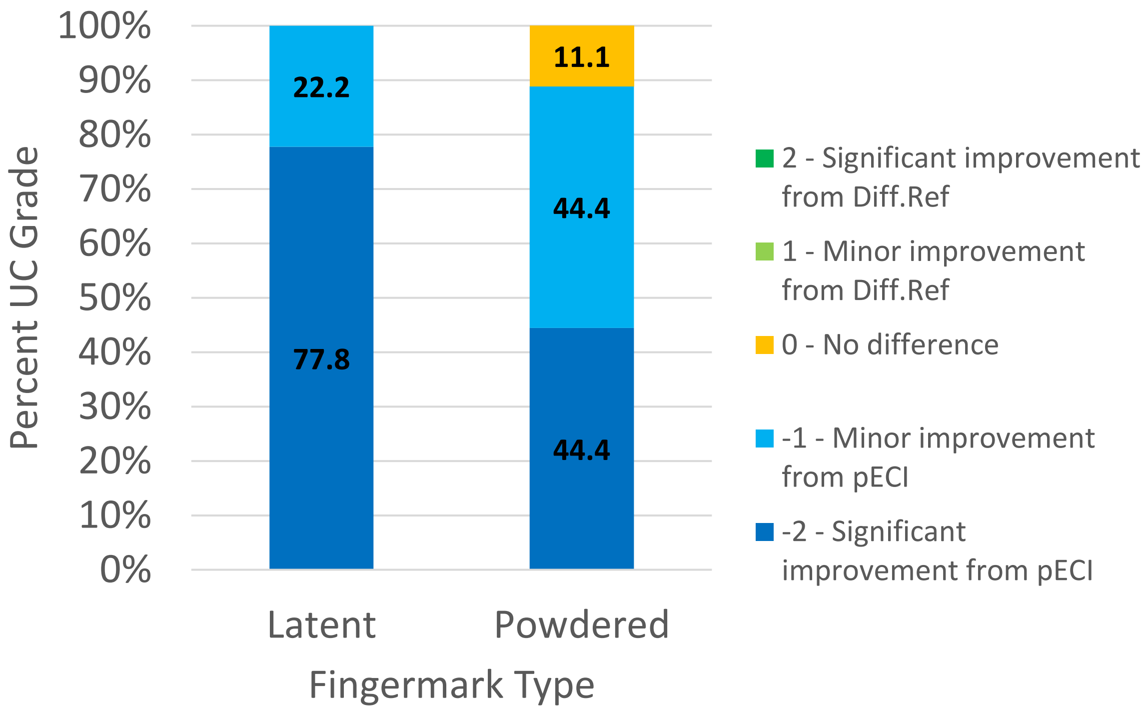


Figure 3.37; Column graph describing the percentage UC grades comparing diffused reflection (green) and the optimised pECI device (blue) enhancing nine latent and nine powdered fingermarks on a whiteboard.

There was a total of nine latent fingermarks CAST graded per optical technique and another nine powdered fingermarks CAST graded per optical technique. For the latent fingermarks, diffused reflection had an average CAST grade of 1.1 while the pECI had an average CAST grade of 3.0. For the post-powdered fingermarks, diffused reflection had an average CAST grade of 1.3 and the pECI had an average CAST grade of 3.0 (Figure 3.38).

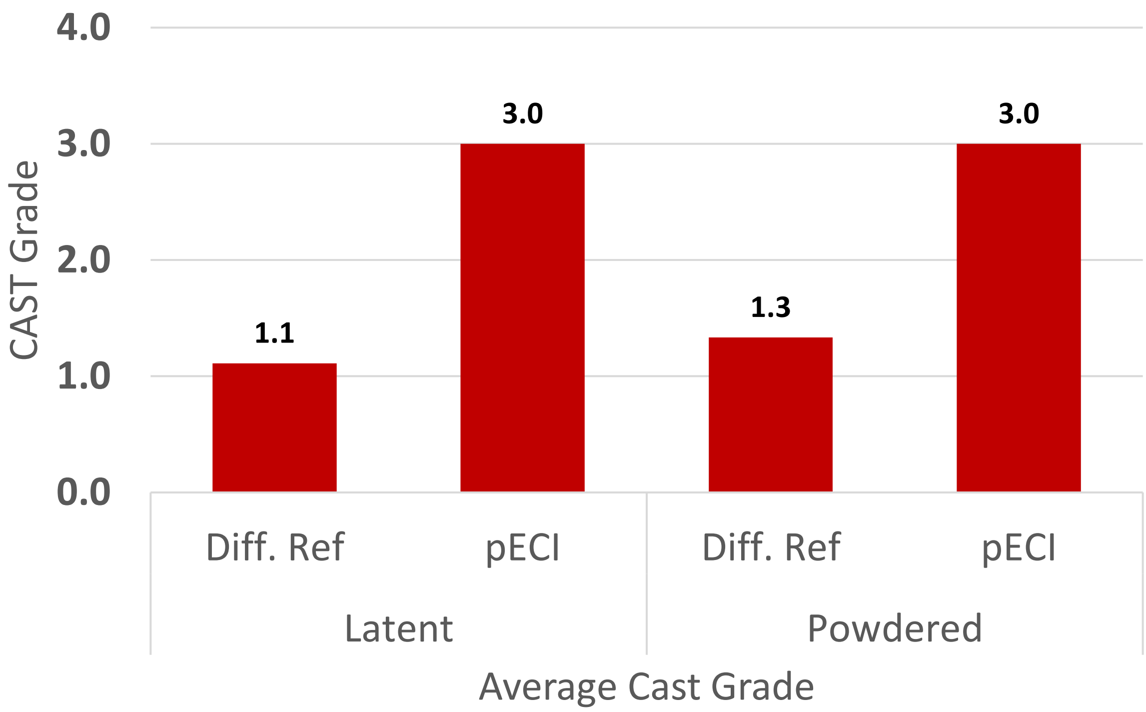


Figure 3.38; Column graph describing the average CAST grade of diffused reflection and the pECI when enhancing nine latent and post-powdered fingermarks on a whiteboard.

Of interest was the extra fingermark detected by the pECI device that diffused reflection was unable to detect. Currently in standard operations, this fingermark would have been missed or powder would have been applied as a searching tool on this substrate, risking a loss of ridge detail due to physical contact between the brush and the fingermark. On the whiteboard, the pECI out-performed diffused reflection when enhancing every latent fingermark with even a major improvement in enhancement quality in 77.8% of instances. Even after powder application, diffused reflection underperformed considerably. The reason for the poor performance for diffused reflection was again the substrate. With the whiteboard being white, it is difficult to produce clear contrast between white ridges and forcing the substrate to darken with or without powdering the fingermark. While the pECI acquired clear ridge detail consistently without struggle due to its darkening of ridge detail on a light background. It should be noted that this is a substrate where it would be standard practice to utilise black powder. The use of white powder and pECI on a white substrate such as this would perhaps benefit the investigator if they were trying to avoid damaging the substrate. Black powder is known for being difficult to clean and avoiding use may be necessary if the substrate being examined it expensive, such as a vehicle. In this circumstance, white powder plus pECI imaging could be an alternative, but a further comparison between black powder against white powder and pECI imaging would need to be completed.

3.4.5 Fridge

A total of nine fingermarks were deposited on the fridge, only eight were detected using diffused reflection and by the pECI device. There were 16 UC comparisons made: eight comparing diffused reflection against the pECI on latent fingermarks; and eight comparing diffused reflection against the pECI on post-powdered fingermarks.

Of the latent fingermarks, 50.0% of comparisons acquired a UC grade of -2 indicating the pECI device produced major improvement in enhancement quality compared to diffused reflection. 25.0% received a UC grade of -1 indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 25.0% of comparisons were grade as NC indicating the fingermarks would not be compared.

Of the powdered fingermarks, 37.5% of comparisons acquired a UC grade of -2 indicating the pECI device produced major improvement in enhancement quality compared to diffused reflection. 37.5% received a UC grade of -1 indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 25.0% received a UC grade of 0, indicating no difference in enhancement quality between diffused reflection and the pECI device (Figure 3.39).

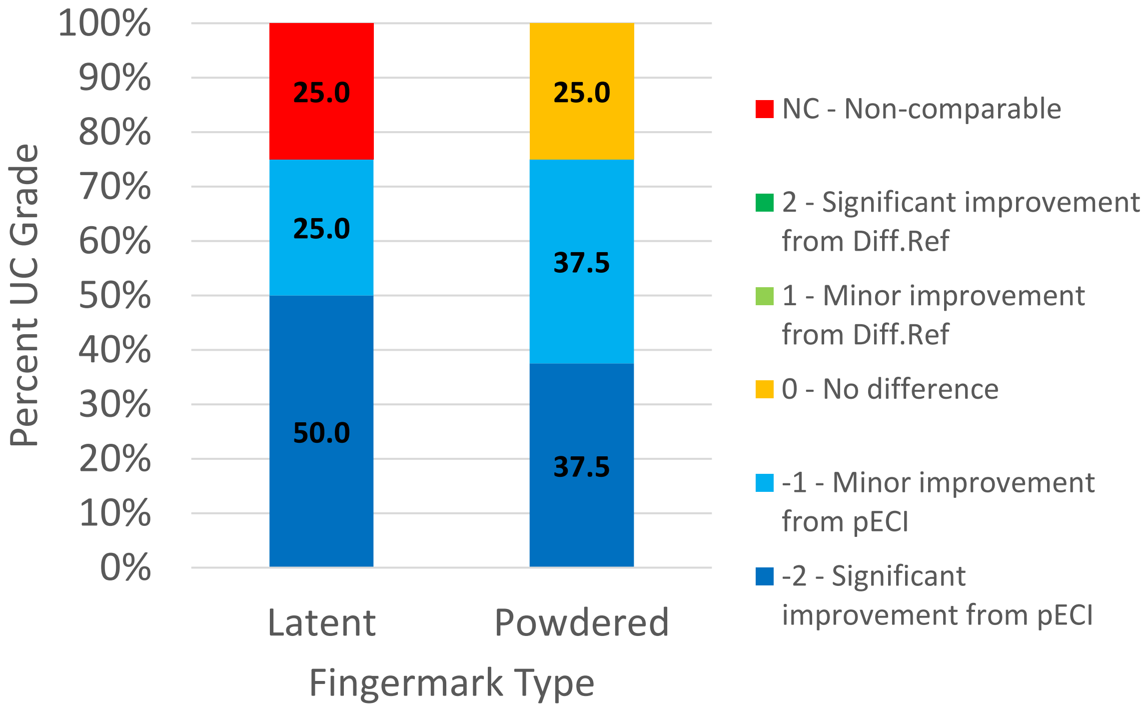


Figure 3.39; Column graph describing the percentage UC grades comparing diffused reflection (green) and the optimised pECI device (blue) enhancing eight latent and eight powdered fingermarks on a fridge.

There was a total of eight latent fingermarks CAST graded per optical technique and another eight powdered fingermarks CAST graded per optical technique. For the latent fingermarks, diffused reflection had an average CAST grade of 0.4 whilst the pECI had an average CAST grade of 1.9. For the post-powdered fingermarks, diffused reflection had an average CAST grade of 1.9 and the pECI had an average CAST grade of 2.9 (Figure 3.40).

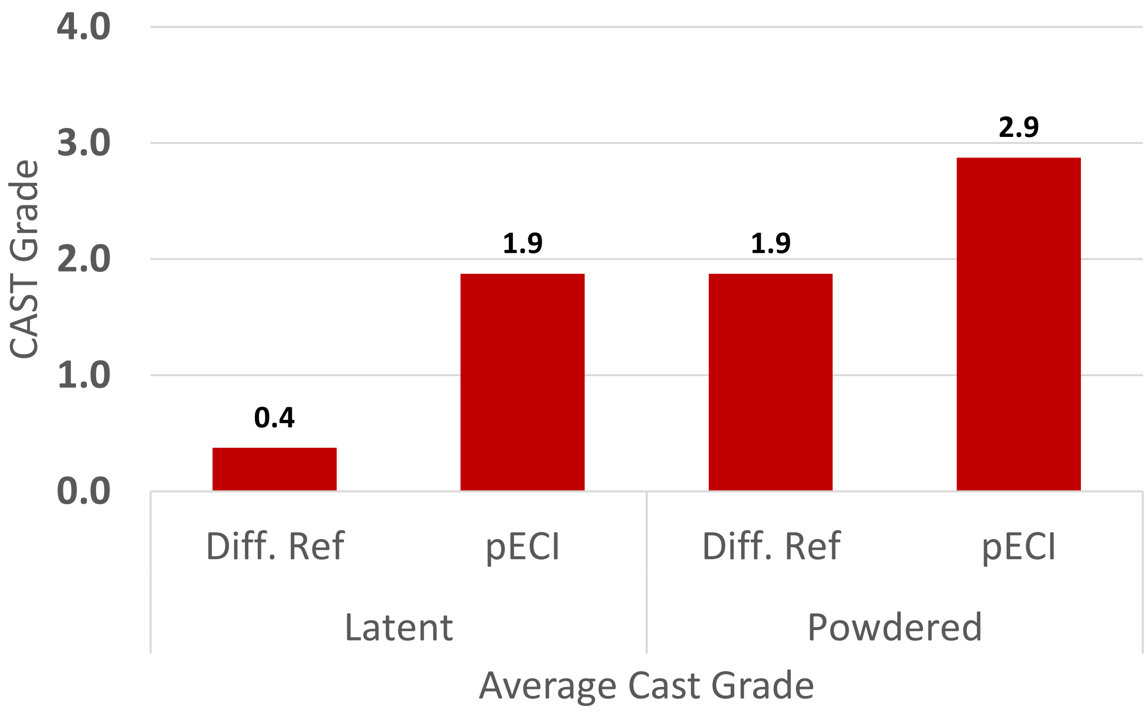


Figure 3.40; Column graph describing the percentage UC grades comparing diffused reflection and the optimised pECI device enhancing eight latent and eight powdered fingermarks on a fridge.

It was difficult to enhance latent fingermarks on the fridge using diffused reflection as the fridge is painted white. Similar issues appeared that were faced when attempting diffused reflection on the whiteboard and the pECI proved to better enhance latent fingermarks (Figure 3.41). Once powder was applied onto the substrate, both diffused reflection and pECI saw an increase in clear ridge detail collected, but overall, the pECI still out-performed diffused reflection in terms of contrast and over all ridge clarity.

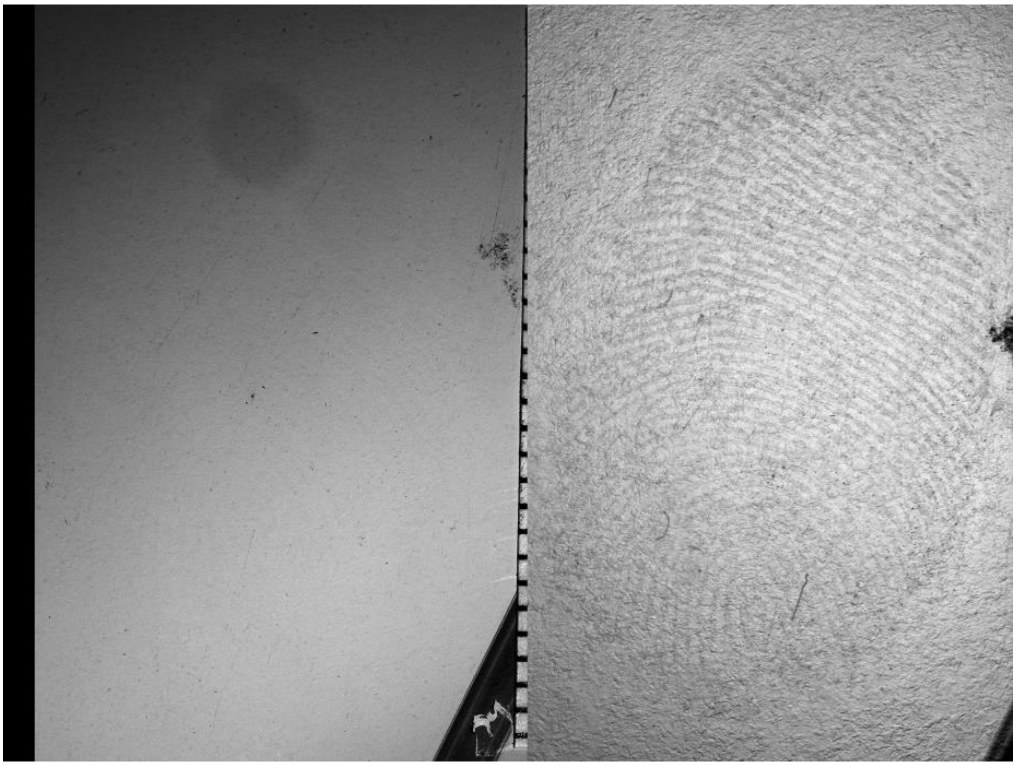


Figure 3.41; Images of a latent fingermark deposited on a white fridge and enhanced using diffused reflection (left) and the optimised pECI device (right).

3.4.6 Filing Cabinet

A total of nine fingermarks were deposited to the filing cabinet, only one was detected using diffused reflection and three were detected by the pECI device. There were 6 UC comparisons made: three comparing diffused reflection against the pECI on latent fingermarks; and three comparing diffused reflection against the pECI on post-powdered fingermarks.

Of the latent fingermarks, 66.7% of comparisons acquired a UC grade of -1, indicating the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 33.3% received a UC grade of -2, indicating the pECI device produced major improvement in enhancement quality compared to diffused reflection.

Of the powdered fingermarks, 66.7% of comparisons acquired a UC grade of -1 indicating that the pECI device produced minor improvement in enhancement quality compared to diffused reflection. 33.3% received a UC grade of -2, indicating that the pECI device produced major improvement in enhancement quality compared to diffused reflection (Figure 3.42).

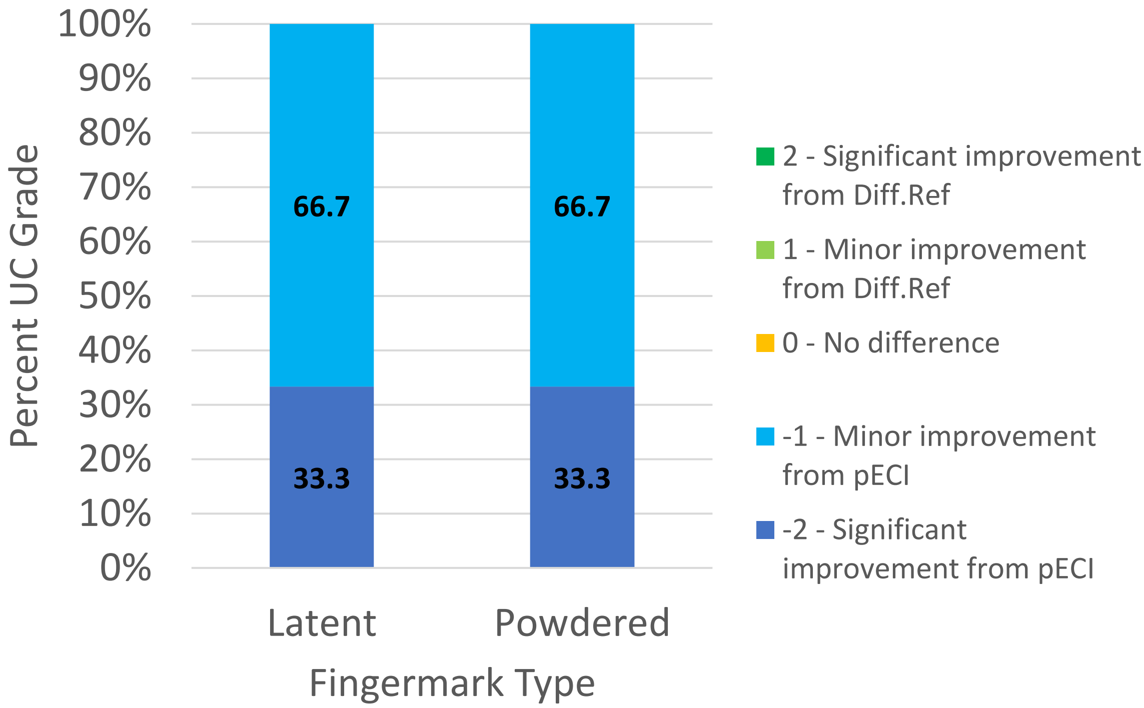


Figure 3.42; Column graph describing the percentage UC grades comparing diffused reflection (green) and the optimised pECI device (blue) enhancing three latent and three powdered fingermarks on a filing cabinet.

There was a total of three latent fingermarks CAST graded per optical technique and another three powdered fingermarks CAST graded per optical technique. For the latent fingermarks, diffused reflection had an average CAST grade of 0.0 while the pECI had an average CAST grade of 2.3. For the post-powdered fingermarks, diffused reflection had an average CAST grade of 0.7 and the pECI had an average CAST grade of 2.7 (Figure 3.43).

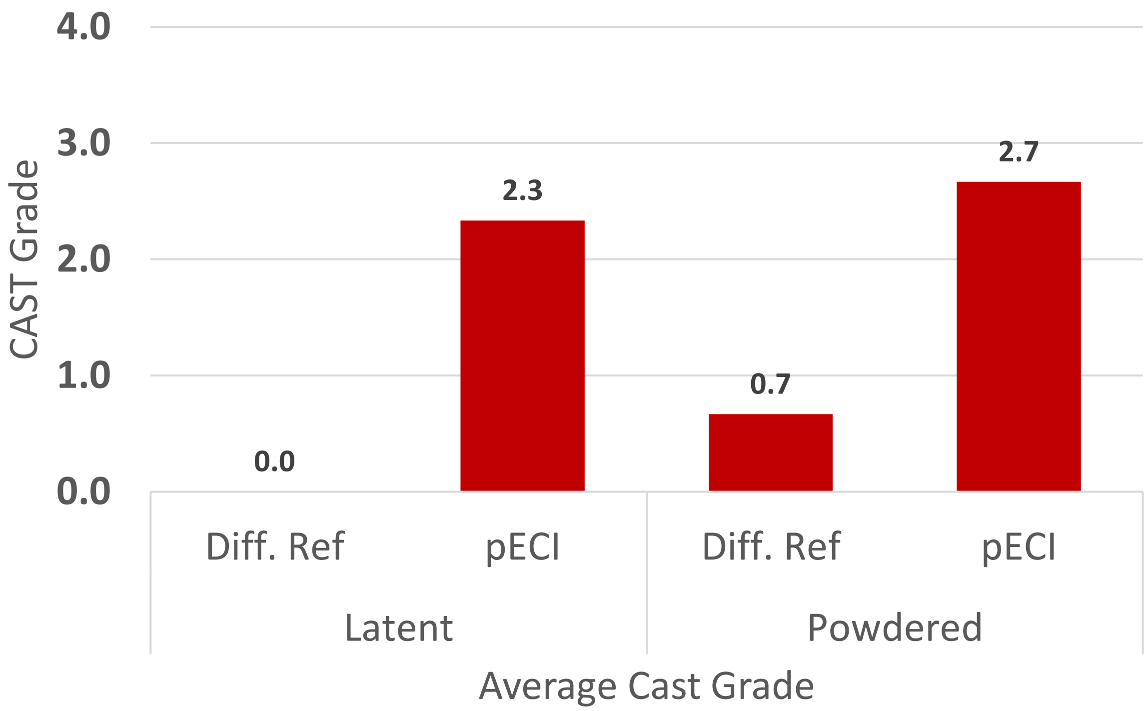


Figure 3.43; Column graph describing the percentage UC grades comparing diffused reflection and the optimised pECI device enhancing three latent and three powdered fingermarks on a filing cabinet.

Considering only three fingermarks were detected and enhanced, the data shown above is not a complete representation and should be interpreted with caution. Of the three detected fingermarks, all were from the same donor, indicating that this donor is clearly a stronger donor compared to the other two. Diffused reflection proved to be ineffective at recovering any ridge detail from the filing cabinet while the pECI was able to enhance all three fingermarks detected with ease. Post powdering, diffused reflection continued to struggle while the pECI was still performing almost to the same quality as the latent fingermarks, with a slight increase in overall ridge clarity. There is little more to comment on the results from this substrate as minimal fingermarks were recovered, but it should be noted that using the current standard approach for this substrate would have resulted in one fingermark detected and no ridge detail recorded using diffused reflection prior to powdering.

Chapter 4. Conclusions

4.1 Conclusions

This research set out to address four research questions, and the conclusions of these questions are outlined below.

1. *How does the initial pECI device (pECI v1) currently perform?*

Commencing the project by examining pECI v1, when compared to the current in-field standard approach to fingermark enhancement and when compared to a laboratory ECI device, pECI v1 underperformed. While this under-performance was expected due to its proof of concept design, the pECI v1 was still able to enhance fingermarks with enough level 2 detail to be used for identification purposes both in-field and in a laboratory environment. It was determined that the performance of the pECI v1 was likely due to the poor componentry utilised in this initial device, particularly the semi-transparent mirror which resulted in poor contrast, hot spots, and areas of distortion. As for the overarching pECI v1 design, it demonstrated the possibility to achieve pECI as a DSLR attachment was possible, though the device needed to be further developed.

2. *How can the pECI v1 design be optimised so that it is more practical, cost effective and reproducible?*

After determining areas of improvement, the optimisation of the pECI case to produce the v2 case helped resolve the issues identified with the v1 case. Calculation of the AOV of various lenses and 3D printing allowed for the creation of a more precise design which was capable of being utilised with a 50 mm macro lens or longer, meaning investigators could now utilise pECI with their current photography equipment. 3D printing also allowed for the new pECI design to hold components in place to prevent misalignment whilst using the device. The weight of the case was also reduced by half, while also increasing the strength of the device compared to the pECI v1.

3. *What would be the most effective optical components to be used in the optimised pECI device (pECI v2)?*

When optimising the optical components to be used in the pECI v2, it was found that a matte glass diffuser and a flat acrylic two-way mirror provided optimal results. The two components demonstrated a considerable increase in fingermark enhancement when compared to the original optical components used in pECI v1 and when compared against other component combinations tested. The acrylic two-way mirror specifically performed to an almost equal standard compared to a 50/50 reflection and transmission ratio beamsplitter, despite a price difference of $380. These optimised components are also practical as they are easily obtainable and replaceable.

4. *How does the optimised pECI device (pECI v2) compare to the current standard for optical detection and enhancement in-field at crime scenes?*

The final experiments conducted in this project compared the pECI v2 device back to the current in-field approach for fingermark enhancement. In this experiment, the pECI was able to detect three additional fingermarks that were missed by diffused reflection. In current practice, these fingermarks would have likely been searched for using fingerprint powder, however this increased the risk of damage to ridge detail due to physical contact of the brushes with fingermarks. When enhancing latent and powdered fingermarks, pECI v2 outperformed diffused reflection demonstrating improved fingermark enhancement with regards to overall contrast, and also increased the amount of clear ridge detail recorded on five of the six substrates examined.

Particularly when examining substrates that would usually be enhanced using black powder (the whiteboard or white fridge), diffused reflection recorded minimal ridge detail when enhancing latent fingermarks, whilst the pECI v2 recorded clear ridge detail consistently. This observation identifies a clear advantage to using pECI in scene as it can be used on white substrates with much greater success compared to diffused reflection. Allowing investigators to detect and enhance fingermarks without having to rely solely on black powder which currently is the case.

In conclusion, this research optimised and developed a functional portable ECI device capable of being used with current CSI photography equipment while remaining accessible and cost effective. This research also demonstrated that pECI has the potential to improve the current approach to fingermark enhancement in-field if it became an additional tool for CSIs. It should be noted that this project was still an optimisation and development project. Following the IFRG guidelines, validation still needs to be conducted to answer questions that could not be answered in this project due to the project limitations, such as small donor pools and lack of fingermark age variability.

4.2 Future Work

Following this research, the pECI device will need further validation studies. The optimised pECI v2 will need to go through various experiments to examine a range of variables with a much larger quantity of fingermarks that could not be completed in the time frame of this project.

Following the IFRG guidelines (Almog et al., 2014), these validation studies would require a much larger donor pool and broader substrate variation. An examination into the effect of aged fingermarks would also need to be completed. Future work should also examine the niche situations where pECI could be of benefit, such a comparison of white powder and pECI against black powder on white substrates, to evaluate it further as an alternative detection and enhancement method over black powder.

The performance of the pECI v2 in conjunction with other techniques within a sequence also needs to be explored. Sequences can include the ones used in this research initially (diffused reflection and powder) but would need to broaden. The addition of pECI v2 in sequence with CA fuming should be explored. CA fuming has been shown to detect and enhance latent fingermarks to a high standard. It is used early on in a non-porous detection sequence and has been shown to work well in conjunction with ECI (Lennard, 2009; Bumbrah, 2017). This is due to the polymerised cyanoacrylate that sticks to the ridges and causes more diffused reflection compared to the latent fingermark prior to treatment, with the substrate still causing specular reflection. This is theoretically an ideal situation for pECI to be used both prior to and after cyanoacrylate enhancement. In casework, CA fuming is routinely used as a laboratory-based technique; however, some studies have demonstrated the use of portable cyanoacrylate fuming systems at crime scenes (Jones et al., 2019;

Fieldhouse, 2011). The addition of both portable CA fuming and the pECI v2 could promote the completion of enhancement sequences on evidence items in-field, rather than sending them to the laboratory which would remove risk of damaging fingermarks in evidence bags.

Another avenue for research would be the assessment of pECI as an additional enhancement method for fingermarks on blood or small blood impressions in-field. The detection and enhancement of fingermarks in blood at crime scenes, also follows a similar sequence which begins with optical techniques. ECI is suggested to work on untreated faint blood marks on non-porous substrates, but not a large quantity of research has been conducted using ECI on blood marks (Bossers et al., 2011; Champod et al., 2016). This is possibly due to more accessible detection methods currently available at crime scenes, such as using a 415 nm light source and absorption mode photography, or diffused reflection. Rofin Australia had created a coaxial illumination accessory that could be used specifically with the PL500 (Bossers et al., 2011); however, this accessory has been discontinued. The pECI, if available, could benefit CSIs as an alternative method to enhance blood marks at crime scenes, but further research is required.

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Appendices

Appendix I - Removal of Fresnel lens from optimisation of optical components experiments.

Four Fresnel lenses were examined, all differing in effective focal lengths, except for one aspheric Fresnel lens which also differed in size and price (Table A-1)

Table A-1: Different Fresnel lenses tested, and their respective dimensions, effective focal lengths, and price supplied by Edmund Optics (Australia)

	Dimensions (mm)	**Effective focal lengths (MM)**	**Price (AUD)**
Fresnel Lens 1	76.2 x 76.2	66.04	60.80
Fresnel Lens 2	76.2 x 76.2	99.06	60.80
Fresnel Lens 3	76.2 x 76.2	200.66	60.80
Aspheric Fresnel lens	63.5 x 63.5	50.8	51.20

It was quickly determined that the Fresnel lens components were impractical for pECI use for two main reasons. The first reason was the creation of rings in the images due to the design of the Fresnel lens itself. Rings were apparent in all images acquired and were difficult to remove without strenuous photoshop adjustments (Figure A-1).

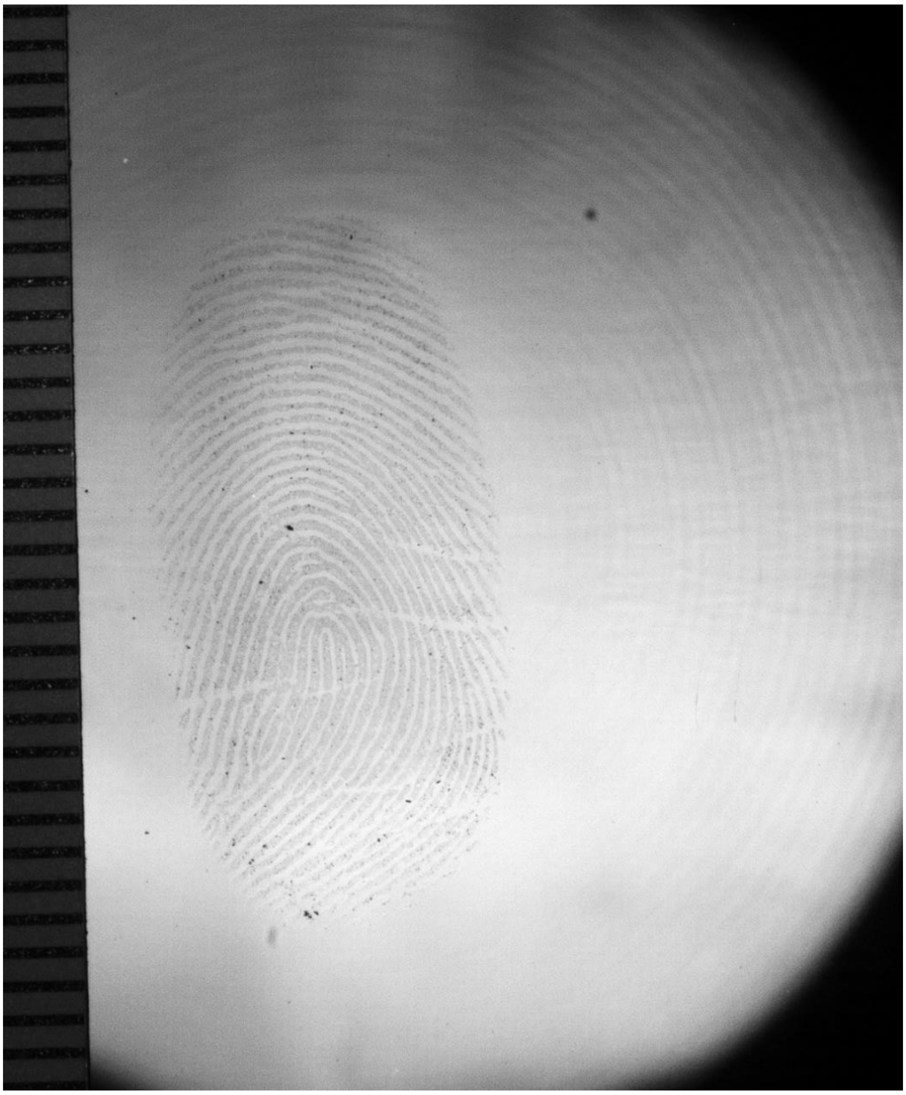

Figure A-1; Example image taken using Fresnel lens as diffuser within pECI V2, showing faint rings within area of illumination.

The rings themselves can be obvious or faint depending upon the donor quality of the fingermark and the amount of software contrast enhancement required. A weak donor's impression may require more software-based contrast enhancement which would also increase the prominence of the rings and compromise image quality which is not ideal. The rings also create distortion disrupting the appearance of the friction ridge detail which would make it difficult for identification.

The second reason was the impracticality of the Fresnel lens when attempting to perform handheld photography. For a Fresnel lens to work, the light source (flash unit) needs to be at an exact distance from the lens, with little margin of error. To have the flash unit at the correct focal length handheld requires a large amount of hand-eye coordination and guessing on the most part, costing the user time and an ample collection of faulty images that are not correctly illuminated.