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A Multiple Technology Approach of Detecting Latent Fingerprints from Paper Currency, Fabrics, and Tiles: A Quasi-Experimental Study Using a Green Laser Device (532 nm)

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Abstract

Rapid detection, visualization, and photographing latent fingerprints in the field remain as a challenge to the forensic science community. A more challenging situation is the types of the surfaces that latent fingerprints were deposited, such as paper currency, fabric cloth, and floor tiles simple because these surfaces are porous, absorptive, and textured and often render latent fingerprints undetectable using conventional methods. This paper addresses such elusive fingerprints using a new brand of laser device with four new technologies: a compact diode pump solid-state laser (532 nm wavelength), a 1 nm color-purity bandwidth, a special biological tagging agent, and special orange/red filter/goggles. With a quasi-experimental design, the four-component approach can detect and visualize latent fingerprints from the paper currency and the fabric cloth almost simultaneously. To date, this new technique may represent a new field-based approach to handle latent fingerprints on the difficult surfaces, a common situation at crime scenes. In sum, this work progresses toward the ultimate goal of rapidly detecting latent fingerprints that would otherwise remain undetected using traditional development methods.

Keywords: Laser Detection (532 nm); Color Purity Bandwidth (1 nm); Biological Tagging Agent; Forensic Science; Criminal Investigation; Latent Fingerprints; Difficult Surfaces

Introduction

Today, fingerprints are still being used as the most common and practical method for human identification in forensic science worldwide since they are unique, systematic, and identifiable. Surfaces of objects that have been touched by human fingers (without wearing gloves) usually contain the transferred fingerprints that have deposited. Three types of fingerprints are often encountered at a scene:

a. Patent fingerprints are visible directly when the finger touches colored materials and then touched the surface, for example, ink, blood or paint.

b. Plastic fingerprints are molded fingerprints when the finger touches soft materials, such as thick paint, thick dust, or wax.

c. Latent fingerprints are the majority of prints on surfaces that are invisible directly to the naked eye, such as on paper, tile, furniture, etcetera.

Although invisible, latent fingerprints left on surfaces still possess sweaty residues, such as amino acid, skin oil, and vitamins that have been transferred from the finger. To be more specifically, approximately 0.1 mg of materials is transferred onto the surface to form fingerprints or latent fingerprints, depending on the type of surface. Of the 0.1 mg materials, 98~99% is the water from the sweat that evaporates in a short period, depending on the temperature. Half of the rest is inorganic material of NaCl, and the other half is the organic complex mixture, such as amino acids, lipids (skin oil), and vitamins [1].

Depending on the type of surfaces, the common developing methods for latent fingerprints include the physical (different powders), the chemical (various spraying, soaking, vaporing agents), and the better non-destructive optical (multi-light sources) applications. While most of the researchers focus on the physical and chemical approaches of detecting, developing, and examining fingerprints (including latent fingerprints), a few have shifted to the laser approach as a modern technique, or a combination of a multiple technology approach to detect latent fingerprints from difficult surfaces in forensic science.

Laser Technology

Laser technology, in general, refers to a special device that can emit light through a process via the simulated emission of electromagnetic radiation, also known as "light amplification by simulated emission of radiation." The laser method is largely dependent on the technology available. The earliest application of developing latent fingerprints was conducted by fluorescence exciting of the oil on the fingerprint via argon ion lasers in the early 1970s [2]. Since then, several attempts have been made to enhance the low emission levels from the fingerprint oil and reduce the interference from the fluorescent signal from the background substrate. One improvement was to use a 0.3 m f/4 mono-chromator and spectrally optimize the choice of fluorescent dye agents and filters for photography of fingerprints [3]. Another method intensified a double-charged device to detect and eliminate interfering lights from highly illuminated substrates such as exterior walls during daylight hours [4].

Further, a new technique was reported to modulate the illumination by laser at several MHz to induce a phase shift between the substrate background and the latent fingerprint signals [5]. No further studies were reported due to the limitation of the laser technology until 1997 when a portable laser device was invented using the continuous laser emission technology. These early studies, however, reported that the process required complex pre-procedures or extra chemical dye agents, and huge equipment. Therefore, these non-field processes and equipment are limited due to their expensive cost, potential harm to the examiners' eyes, and lack of portability for field use. Ideally, a better laser device can produce a highly concentrated laser beam in three special functions that are different from other optical sources. The space coherence of the laser beam can have little or no divergence, thus focusing on a targeted area. The temporal coherence can emit the light in a single color, most commonly referred to as monochromatic light source, such as blue, green, or red. Finally, the device can be battery-based to scan or sweep a large area at any location.

Many types of laser are being used for different purposes. One of the improved laser technological methods is the optically pumped semiconductor function based on a diode pump solid-state laser. This new type of laser can produce a more compact, firm, and powerful beam via a portable size. Most importantly, due to the high intensity of the laser beam, the device may detect biological residues contained in latent fingerprints that has deposited on difficult surfaces. Essentially, the narrow laser spectrum can react with a chemical dye agent that is sprayed on the targeted surface, producing a fluorescence-excited spectrum of the elemental constituent of the surface material. The super spectral brightness of the laser beam is considered to be much superior to those lamp-based systems, such as the multi-light systems.

Fiber Optical Technology

The optically pumped semiconductor technology cannot function without an advance of the fiber-delivery cable that is connected between the device and a laser hand-piece. In other words, to be portable and flexible, the solid-state laser or laser amplifier can render the light to be guided by a single mode optical fiber. In turn, the guided light allows extremely long gain regions, providing good cooling conditions because fibers have high surface area to volume ratio for the efficient cooling. In addition, the fiber wave-guiding properties tend to reduce thermal distortion of the beam. As a result, the extended and flexible cable from the device can be operated from any direction and at any angle. Regarding the construction material, the fiber cable usually has a double-clad fiber layer, consisting of a fiber core, an inner cladding, and an outer cladding. The index of the three concentric layers is chosen so that the fiber core acts as a single-mode fiber for the laser emission while the outer cladding acts as a highly multimode core for the pumped laser. Consequently, the pump can emit a large amount of power into and through the active inner core region with a high numerical aperture (NA) for easy launching conditions.

In reality, a fiber disk laser or a stack of such lasers is used to prevent a photo-darkening effect. As a fundamental limit, the intensity of the fiber laser light leads to optical nonlinearities (photo-darkening effect), which is induced by the local electric field strength; therefore it becomes dominant and often causes the material destruction of the fiber. With the new technology, small sized laser devices from several companies are being applied in modern forensics. In particular, the new optical fiber cable can minimize laser light divergence, thus producing a 1 nm color-purity bandwidth.

Biological Technology

The next technical obstacle is viewing and photographing laser re-mitted images. A special biological tagging agent is required to spray onto target areas, which enables the laser beam to detect latent fingerprints. The biological agent is non-hazardous and reacts with the sweaty residues (amino acids, skin oil, and vitamins) that have been transferred from the skin onto the surface and produce a bio-chemical combination with higher levels of fluorescence. Next, the strong laser beam excites the combination and in turn re-emits a much longer polarized wavelength for a yellow color (570~590 nm) to cause latent fingerprints to be visualized on the surface under an orange/red filter or goggles.

Optical Filter Technology

The final key area is the filter/goggle that is required for viewing and photographing to avoid the damage from the strong laser beam and is designed to block any wavelength below 540 nm out of the total re-emitted laser beam (570~590 nm). Both the goggles and the filter must reach the OD value (>7), or called "optical depth," which is the natural logarithm of the ratio of incident to transmitted radiant power through a material. The optical depth equals the absorbance time's ln (10). In other words, spectral absorbance in frequency and spectral absorbance in

wavelength of a material are denoted Aν and Aλ and are closely related to spectral optical depth by

$$A_\nu = \frac{\tau_\nu}{In\,10}$$

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$$A_{\lambda} = \frac{\tau_{\lambda}}{In\ 10}$$

where τ_{v} is the spectral optical depth in frequency; τ_{λ} is the spectral optical depth in wavelength

In a simple term, the higher the OD value is reached, the better blocking capacity will be achieved because the remaining wavelength (30~50 nm) renders the human eyes to see with a regular digital camera for photographing under the orange/red filter/goggles. The device is used in the current project for three reasons. The laser beam of the required spatial and temporal coherences may detect latent fingerprints on difficult surfaces, in this case, a paper currency, a piece of fabric cloth, and a piece of floor tile. The special optical fiber cable could minimize laser divergence and produce a 1 nm color-purity bandwidth. The special biological tagging agent enhances effectively the fluorescent image. Finally, the higher quality of the goggles and the filter is able to block certain laser beam for viewing and photographing. In sum, the device is designed to generate a better quality laser beam with stable wavelength radiation and continuous ultra-short laser energy for a better and clearer image for viewing and photographing. This paper reports the preliminary findings of detecting, visualizing, and visualizing latent fingerprints on the three difficult surfaces using a new portable laser device with improved technology.

Materials and Methods of the Quasi-Experimental Design

In the current paper, a preliminary examination is reported under a controlled-setting (a quasi-experimental study) using a new brand of laser device. The laser detection enjoys several advantages over physical (magnetic powders), chemical (ninhydrin), and other optical (multi-source light) methods on latent fingerprints from the difficult surfaces. First, the laser detection is non-destructive, non-contact, and non-invasive by nature (including DNA in fingerprints) and should be used as the first attempt in detecting latent fingerprints. Second, the new laser device is portable, and can be used not only in the field, but also in the lab. Third, the new approach is a one-step spray application without any complex pre-treatment. Next, the laser detection is a real-time method with a direct and simultaneous viewing result. Finally, the laser device may detect latent fingerprints with a quality image on many difficult surfaces where most other traditional methods will likely fail.

The laser device produces a wavelength of 532 nm via diode pump solid-state laser, weighing only 3.5 kg with a dimension of 225 mm (Length), 105 mm (Width), and 165 mm (Height) (Figure 1). Either AC or an inserted battery (1.5 kg) can operate the device. The battery can last 4~6 hours for interrupted or continuous operations for an output power of 8- watts and can be rechargeable for 4 hours for another full use. The device has a metal covering fiber optical cable (L=1.2 m.) for minimizing light divergence. The hand-piece controls the volume of the laser beam and can produce a maximum illumination of a circular area (D=50 centimeters) with no speckles on the target area. The fiber delivery cable renders a 1 nm color purity bandwidth (green light) that is a huge advantage over the other commercial diode-pumped solid-state laser devices (The manufactory information of the laser device is provided in the Acknowledge Section).

Figure 1: The portable laser device (532 nm) was employed in the quasi-expermental study.

To simulate a real scenario of a crime scene, three pieces of difficult objects were chosen: a U.S. $20 bill (absorptive), a piece of cloth (porous), and a piece of floor title (textured). A volunteer was asked to deposit any finger onto the three different objects without telling the author of the exact location(s), which in principle is similar to the so-called black box study. The volunteer was warned not to rub his fingers against his forehead, a common practice in many studies, which may deviate from a real crime situation. The main purpose of the study was to simulate acts that a suspect may do during committing a crime. In order to better compare and contrast the three surfaces, a quasi-experimental design was selected. The design is unique and practical, allowing the researcher to control the assignments to the treatment condition and use some criterion for practical purposes. In addition, the researcher can have control or manipulation over assignments to the treatment due to limitations of time and resources [6]. The quasi-experimental design consists of the two steps: to photograph the surface without the laser scanning and the biological application (before the treatment) and to photograph the surface after the laser scanning and the biological application (after the treatment). The before-and-after treatment method is a common procedure employed by many studies [7].

Figure 2: A latent fingerprint was deposited on a $20 backside and photographed by a regular digital camera before the laser application, but no fingerprint was visible to the naked eye at present.

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I. Quasi-Experiment 1: A volunteer was asked to deposit his fingerprint by snapping a $20 bill. The snapping act (Assignment 1) was exercised with a normal force, simulating a scenario where a suspect was trying to rob the money. The bill was then thrown onto the floor for two hours and was photographed by a regular digital camera for a comparison purpose. To the naked eye, no fingerprint was yet visible at this time (Figure 2).

Figure 3: A latent fingerprint was deposited on a piece of fabric cloth and photographed by a regular digital camera before the laser application, but no fingerprint was visible to the naked eye at present.

II. Quasi-Experiment 2: The volunteer was asked to grab a piece of fabric cloth with a much force (Assignment 2). The cloth was thrown onto the floor for two hours and then was photographed by a regular digital camera for a comparison purpose. The scenario was designed for a common crime situation where a suspect held a victim's clothes tightly during a struggle. To the naked eye, no fingerprint was yet visible at the time (Figure 3).

Figure 4: A latent fingerprint was deposited on a piece of tile and photographed by a regular digital camera before the laser application, but no fingerprint was visible to the naked eye at present.

III. Quasi-Experiment 3: The same volunteer was asked to touch his finger onto a piece of floor tile with a natural force (Assignment 3). The tile was thrown onto the floor for two hours and then was photographed by a regular digital camera for a comparison purpose. The scenario was designed for a common situation where a suspect touched tiles or tile-like materials while committing a crime. To the naked eye, no fingerprint was visible at the time (Figure 4). By now, the volunteer has deposited his fingers on three types of surfaces by three different acts without telling the author of the exact location(s), which in principle is similar to the so-called black box study.

Results

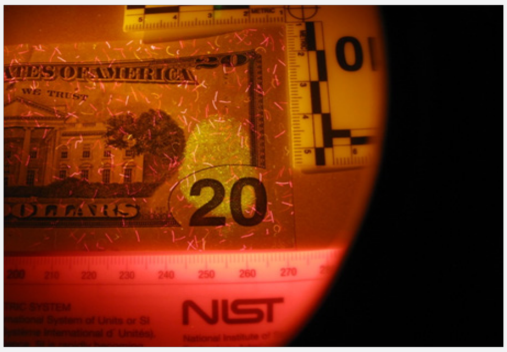

Figure 5: A latent fingerprint (a whorl pattern) with a high-level quality can be clearly observed on the $20 backside after the laser application and photographed under the orange/red filter.

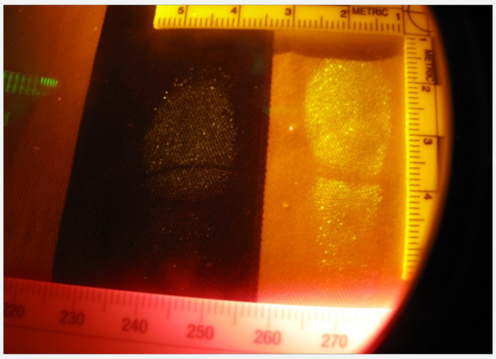

Figure 6: A latent fingerprint (a whorl pattern) with a middle-level quality can be seen on the piece of the fabric cloth after the laser application and photographed under the orange/red filter.

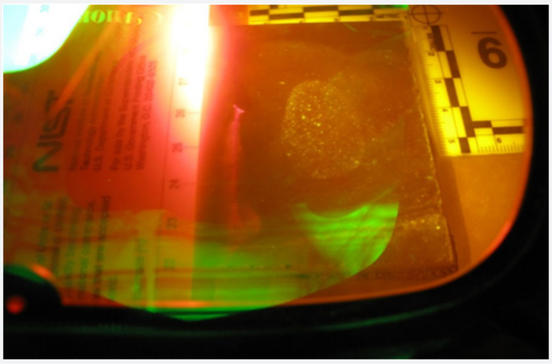

Figure 7: A latent fingerprint with a low-level quality can be noticed on the piece of the title after the laser application and photographed under the orange/red filter.

Wearing the orange/red goggles, the author sprayed a special biological tagging agent on each surface. Minutes after applying the special agent to tag or enhance fluorescent response, a fingerprint with a clear image was visible under the orange/red goggles on the backside $20 bill (Figure 5). In other

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words, a two-dimensional fluorescent image of a whorl pattern fingerprint with excellent minutia details was successfully visualized under the laser beam (532 nm wavelength) and by the biological tagging agent. When the same procedure was applied to the fabric cloth, a noticeable fingerprint could be observed with much-detailed minutia (Figure 6). Finally, only a vague outline of a fingerprint could be observed with a low-level image by the same procedure.

In sum, the laser beam was emitted at the 532 nm wavelength with the color purity level of 1 nm to minimize all light divergence. Subsequently, the presence of fingerprint ridges was detected and visualized by observing the fluorescent lines resulting from the new molecular material from the reaction between the biological tagging agent and the transferred sweaty residues (amino acids, skin oil, and vitamins). However, three levels of image quality of the latent fingerprint were detected, visualized, and photographed by the same application process by three different acts (Assignments) [8] on three difficult surfaces. The diagram below summarizes the comparison results from the quasi-experimental study (Table 1).

Table 1: Latent fingerprints were detected, visualized, and photographed using a green laser (532 nm), a special biological tagging agent, and an orange/red google/filter.

Types of Objects	Types of Materials	Types of Forces	Types of Acts	Types of Surfaces	Goggle/Filter Used	Image Results
Paper Currency	Cotton Paper	Normal	Snapping	Absorptive	Orange-Red	Excellent
Cloth	Fabrics	Heavy	Grabbing	Porous	Orange-Red	Noticeable
Floor Tile	Ceramics	Natural	Touching	Textured	Orange-Red	Vague

Discussion

The fingerprint examination community can observe three lines of inquiries and research in the literature regarding the general challenges on latent fingerprints in the field of forensic science. First, what are some of the quantitative methods available to compare fingerprints (partial against full fingerprints) [6] Second, what are some of the practical methods available to lift latent fingerprints from certain surfaces (human skin, raw wood, or leather) [9]. Finally, what are some of the special techniques available to develop latent fingerprints from difficult surfaces, e.g., paper currency, fabric cloth, and floor tile? The preliminary purpose of this project was to employ a new type of laser device and to detect and visualize latent fingerprints deposited on the three difficult surfaces.

The scenarios in the quasi-experimental design consist of three levels of specific challenges to the fingerprint examination community:

a. Three difficult surfaces,

b. Three different acts (the assignments), and

c. A special laser device using the 532 nm wavelength, the special biological tagging agent, and the special filter/goggle for viewing and photographing (the treatment).

The preliminary result from the quasi-experimental study indicates that a much higher quality of a latent fingerprint was detected and visualized from the $20 bill and the level of clarity can be rated as excellent (Figure 5). A middle-level quality of the fingerprint image is noticeable with limited minutia from the fabric cloth (Figure 6). However, only a vague outline of a fingerprint can be observed on the floor tile (Figure 7).

As to the scientific principle involved, the photochemical rule, in a simple term, regulates a chemical reaction caused by absorption of light spectrum 100~400 nm as ultraviolet, 400~750 nm as visible, and 750~2500 as infrared radiation. Due to its high energy encountered, a photochemical process produces non-destructive reactions much quicker than that via a thermal process. Photoexcitation is part of the photochemical process. According to the Grotthuss-Draper law, certain substances can be elevated or excited to a state of higher energy (excited state or fluorescence). In this study, the green laser beam is almost monochromatic and has a relatively narrow band that can be efficiently used as the light source to get an approximate monochromatic beam and provide the activation energy for the reaction [10].

Therefore, it is possible to excite a molecule selectively and to produce a desired electronic and vibrational state. In turn, the emission from a particular state may be selectively observed. Finally, if the chemical interaction is at a low pressure after filtering, this enables the researchers to observe the energy distribution of the products of a chemical reaction or in this project, the re-emitted latent fingerprint image under the orange/red filter or goggles. However, the textured ceramic tile does reflect much of the laser beam and does not produce a desired electronic and vibrational state. Expressed differently, the substrate also exhibits fluorescence, which can partially or totally obscures the re-emitted fingerprint.

Several advantages of this laser device can be summarized directly from the quasi-experimental project, compared with other similar products. First, the light weight (3.5 kg.) and the compact size (225 mm (L.), 105 mm (W.), and 165 mm (H.) qualifies for a portable equipment for field as well as lab applications. Second, the battery (1.5 kg) is detachable/

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insertable and ready to use immediately without any starting time for approximately 4~6 hours. Third, using a special TE automatic cooling control system, the delivery system (the hand-piece) with a continuous adjustable focus can minimize the interference of the laser beam and produce a spot area (D=50 centimeters) without any speckles in the image, for which similar laser products suffer. Next, instead of DFO and rhodamine 6G that are often used by other similar laser devices for dying, this device uses a biological and non-hazardous material for the tagging. DFO and rhodamine 6G are considered by many examiners as less safe chemicals to use.

Next, the spray of the biological tagging agent is easy to perform without any complex pre-processing. Finally, the photographing is also easy to operate with a regular digital camera and a special orange/red filter. In fact, the goggles provided can be used as a filter as well because both can effectively block the laser light source, isolate the excited fluorescence by the chemical reaction, and in some cases reduce the exhibited fluorescence from the surface. Therefore, the combined technologies contained in this laser approach (the 532 nm wavelength, the improved optical fiber cable, the special biological tagging agent, and the orange/red filter) add significantly to both the extent and clarity of inherently and chemically treated fluorescing fingerprints on the $20 bill and the fabric cloth. All of these observations from the quasi-experimental project should render the portable laser device a practical instrument for crime scene investigation and identification in the field as well as in the lab. In sum, such a device may reduce the time required to process a crime scene by providing quick real-time feedback to forensic investigation.

While the image quality of the latent fingerprint in this study is an ideal situation for fingerprint examiners at the scene or in the lab, many other new issues remain for further development. First, the biological tagging agent plays an important role. However, the tagging agent is not in a universal format yet, requiring special ingredients for certain surfaces. Second, after the project, the volunteers' hands were carefully examined and it was determined that he had "sweaty hands." Thus, the next project should be conducted to test "dry hands" for different amounts of sweaty residues on the three surfaces. Finally, to explore the utility of the technique, latent fingerprint samples on a variety of difficult surfaces, such as stones and bricks, will need to be investigated.

Conclusion

A preliminary investigation by a combined technology approach for detecting, visualizing, and photographing latent fingerprints on three difficult surfaces was conducted with a portable laser device. The different levels of fluorescent images of latent fingerprints on a $20 bill, a piece of fabric cloth, and a piece of floor tile were reported using a single 532 nm wavelength with the 1 nm color-purity bandwidth.

The 2D images of the latent fingerprints depicted in Figures 5 & 6 demonstrate an excellent quality of the fingerprint pattern and the minutia. Each processing time was less than five minutes and thus provided a real-time detection and viewing functions. The quasi-experimental project indicates that the green laser device (532 nm) may be a practical instrument for quickly detecting latent fingerprints at the scene or in the lab settings. Further studies may be expected to apply the device/technique to samples of dry hands (females) and on oily and dusted fingerprints. Next, the laser device should be applied to latent fingerprints on other difficult porous and rough surfaces, such as stones, bricks, unpolished wood or leathers surfaces. In addition, a new direction for latent evidence deserves much attention, such as sweat, semen, urine, paint, and/or explosive residues at crime scenes for real-time and direct detections. If possible, a universal biological tagging agent should be explored to make detection of latent fingerprints on the various surfaces in a real-time, easy, and fast manner. Finally, a better filter/goggle is needed to better block the light source reflection and isolate fluorescence [11].

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