Research on Fingerprint Display Technology of Different Trace-bearing Objects under Nano-Enhanced Effect

Jin Wang, Yang Zhang, Haofei Tang, Baohua Tang*
China People's Police University, Langfang, Hebei, China
**Corresponding Author*

Abstract: Fingerprinting is a key component of trace extraction in court science, and its effectiveness is significantly affected by the surface characteristics of the object bearing the traces and environmental factors. Although the traditional fingerprint technology has developed greatly over the years, there are still limitations in non-destructive display, contrast, line breakage and humidity sensitivity. In order to address the problem of poor rendering effect in grease-enriched humid environments, this paper proposes a new method based on the composite synergistic system of nano-SiO_2-CTAB-isopropanol. The study determines the optimal solvent system through parameter optimisation; compares different concentration ratios to find out the optimal composite system composed of nano-SiO_2 (5g), CTAB (1.5g) and 6% isopropanol (50mL); examines the effect of ambient humidity; and compares the powder method with the system's effect of manifestation on different non-permeable smooth objects. The experimental results showed that the nanocomposite enhancement system had excellent rendering effect and clear detail characteristics under the optimal ratio. Compared with the traditional powder method, its significant advantages are high contrast, high sensitivity, good selectivity and wider range of applicable objects. This technology provides a new path for the non-destructive and efficient extraction of fingerprints on different objects, which is of great practical significance for improving the standardisation of physical evidence examination.

Keywords: Fingerprint Manifestation Technology; Nanocomposite Enhancement System; Non-Permeable Smooth Object

1. Introduction

Fingerprint manifestation stands as one of the most prevalent forms of trace evidence and serves as a widely employed means of individual identification [1]. Within the realms of criminal investigation and forensic identification, latent handprints, as crucial biological features for identity confirmation, play a pivotal role in the identification, comparison, and subsequent forensic examination of crime scene evidence. Nevertheless, the efficacy of latent handprint manifestation is significantly influenced by the surface characteristics of the trace-bearing object (such as material, roughness, permeability, and non-permeability) and environmental factors (such as ambient humidity, acidity, and alkalinity) [2-4].

In traditional fingerprint manifestation techniques, the latent print development by powder application has limited ability to enhance the contrast of fingerprints on non-permeable smooth surfaces like glass, tin foil, plastic, and aluminum. This method is also prone to issues such as line breakage and object contamination due to operational errors. While chemical reagent methods are effective for permeable surfaces, they require strict reaction conditions that can potentially cause irreversible damage to the object. Furthermore, in environments where there is an abundance of grease residues (such as fingerprints left behind after contact with engine oil, hand cream, or lipstick) or in humid conditions, the effectiveness of these methods decreases significantly. Of particular concern is the impact of high humidity environments on traditional techniques, which often result in unclear features of small sweat pores, poor continuity of lines, and unstable manifestation outcomes. These challenges make it difficult to meet the practical demands of complex forensic scenarios [5].

In recent years, the advancement of nanomaterial science has provided new opportunities for innovation in latent fingerprint manifestation techniques. Nanoparticles, due to their high specific surface area, surface modifiability, and targeted adsorption properties, have become a promising approach in this field. Among these, nano-SiO_2 particles stand out due to their excellent biocompatibility, chemical stability, and functionalization potential. By modifying their surface functional groups, nano-SiO_2 particles can enhance specific interactions with fingerprint residues, such as polar amino acids and non-polar oils, making them a focal point of current research. However, most existing studies have concentrated on the mechanisms of single nanomaterials on specific object surfaces. There is a lack of comprehensive analysis on the synergistic effects between the “nanomaterial-surfactant-solvent-object surface” system. This gap limits the general applicability of the technology, especially in complex environments with high grease residue, where significant improvements in fingerprint manifestation efficiency are still needed [6-9].

To address the aforementioned bottlenecks, this study focuses on non-permeable smooth objects and establishes a nano-SiO_2-CTAB-isopropanol composite enhancement system. By employing a synergistic optimization strategy involving surface functionalization modification, solvent evaporation kinetics control, and interface equilibrium system design, the research aims to tackle the three core challenges faced by traditional methods in humid environments: (1) insufficient contrast of fingerprint micro-features (such as sweat pore edges and fine ridge details); (2) adhesion and breakage of ridge lines due to nanoparticle accumulation; (3) interference of humidity and surface contaminants on manifestation stability.

Through analyzing the impact of solvent systems, nano-SiO_2 particle concentration, environmental humidity, and pH on manifestation effectiveness, the study seeks to develop a fingerprint manifestation technique suitable for various trace-bearing objects. This endeavor aims to provide theoretical support and technological innovation for the efficient and precise manifestation of latent fingerprints in complex scenarios, thereby advancing the development of forensic evidence extraction towards refinement and standardization in the realm of forensic science.

2. Experiment

2.1 Experimental Preparation

2.1.1 Experimental reagents and materials

Nanometer SiO_2 particles (particle size 20nm, Shanghai Yuzhuoyi New Materials Co., Ltd.), CTAB (Cetyl Trimethyl Ammonium Bromide, AR grade, Tianjin Zhonglian Chemical Reagent Co., Ltd.), isopropanol (1 mol/L, AR grade, Xilong Scientific Co., Ltd.), anhydrous ethanol (1 mol/L, AR grade, Aibo Anti (Shanghai) Trading Co., Ltd.), glacial acetic acid (1 mol/L, AR grade, Abcam (Shanghai) Trading Co., Ltd.), acetone (1 mol/L, AR grad Abcam (Shanghai) Trading Co., Ltd.), hydrochloric acid (0.1 mol/L, AR grade, Abcam (Shanghai) Trading Co., Ltd.), sodium bicarbonate (Batch number: 20240913, AR grade, China National Pharmaceutical Group Chemical Reagent Co., Ltd.), sodium carbonate (Batch number: 20240527, AR grade, China National Pharmaceutical Group Chemical Reagent Co., Ltd.), medical vaseline (Batch number: 20240801, China National Pharmaceutical Group Chemical Reagent Co., Ltd.), cotton swabs, distilled water.

2.1.2 Experimental instruments

Spray bottle, PL203 electronic balance, glass rod, graduated cylinder (200mL), beaker (200mL), glass slides, examination box, multifunctional forensic examination instrument (Model: FGWZ-D2, Beijing Fenge Technology Co., Ltd.), digital camera (Model: A7CII, Sony China Co., Ltd.).

2.1.3 Trace-bearing objects-non-permeable smooth objects

Glass slides (100*100*5 mm, Longwan Mingliang Glass Shop, Wenzhou City), plastic (PET release film), aluminum foil, aluminum sheets from beverage cans.

2.2 Preparation of Latent Handprint Samples

2.2.1 Volunteer pre-treatment

Seventy-two hours prior to the experiment, volunteers refrain from using any hand care products. On the day of the experiment, hands are not washed in the morning to maintain the baseline sebum state.

2.2.2 Object pre-treatment (refer to Table 1)

Table 1. Pre-Treatment of Objects and Corresponding Steps

Pre-treatment Object	Step 1	Step 2
Glass Slide	Soak in dishwashing water or 1% neutral detergent for 1-2 minutes, gently wipe the surface with a soft	Rinse with clean water, wipe or soak with anhydrous ethanol for

	cloth to remove fingerprints and grease	10 seconds, air dry naturally
Aluminum Foil	Wipe the surface with a cotton swab dipped in anhydrous ethanol, focusing on removing fingerprint marks and oil stains	Air dry naturally
Plastic Sheet	Wipe the surface with a cotton swab dipped in anhydrous ethanol to remove oil stains	Air dry naturally

2.2.3 Preparation of latent handprint samples - non-polar component enhancement model construction

An appropriate amount of medical vaseline is taken onto a glass slide and evenly applied to the thumb pulp using a sterile cotton swab (covering an area of 1.80±0.05 cm², encompassing the entire fingerprint ridge area). After the vaseline application, a strict waiting time of 1.0±0.1 minute is maintained to ensure sebum penetration into the stratum corneum. Subsequently, the thumb pulp is gently pressed onto the pre-treated object, completing the preparation of the latent handprint sample.

2.3 Experimental Grouping

2.3.1 Solvent screening for composite enhancement systems

Following the latent handprint sample preparation method outlined in 2.2, with glass slides as the primary representative object, varying amounts of 1.00g, 1.50g, 2.00g CTAB, and 5.00g SiO_2 were used as solutes. Solvent systems including 50mL isopropanol, anhydrous ethanol, glacial acetic acid, and acetone were employed to compare the manifestation effects of different solvent composite systems, aiming to identify the nano SiO_2 particle composite enhancement system with superior manifestation results. This process aimed to explore the optimal solvent system.

2.3.2 Selection of nano SiO_2 particle concentration ratios in composite enhancement systems

Based on the identified nano SiO_2 particle composite enhancement system with superior manifestation effects, 50mL isopropanol was chosen as the solvent. Different volume ratios of 3.00g, 4.00g, 5.00g, 6.00g, 7.00g SiO_2 to 1.50g CTAB were mixed to explore the manifestation of handprints on samples.

2.3.3 Adjustment and comparison of environmental humidity

Distilled water was sprayed using a spray bottle to control environmental humidity, primarily categorized into dry and humid conditions without specific humidity exploration. Experiments were conducted under dry, humid levels in humid environments to evaluate the impact of composite system environmental humidity on fingerprint manifestation.

2.3.4 Comparison of composite systems and traditional methods in manifestation effects on different objects

Utilizing the optimal manifestation conditions derived from the aforementioned experiments (concentration ratio: 10g nano SiO_2, 3g CTAB, 100moL isopropanol; environmental humidity: humid;), the nano SiO_2 particle composite enhancement system was compared with traditional fingerprint manifestation methods (such as metal powder brushing and black magnetic powder brushing). Various non-permeable smooth objects like glass slides, plastic, and aluminum foil were selected to compare the manifestation effects of the composite system and traditional methods on different objects. This aimed to explore the advantages of the nano SiO_2 particle composite system in humid environments on different objects [10].

2.4 Experimental Procedures

2.4.1 Preparation of composite suspension

Weighing: The appropriate amounts of nano SiO_2 particles and CTAB were weighed using an electronic balance and placed in a beaker. 100mL of isopropanol was measured using a graduated cylinder and added to the beaker.

Mixing: The weighed nano SiO_2 particles, CTAB, and isopropanol were combined and stirred with a glass rod until complete dissolution was achieved.

2.4.2 Aerosol spraying technique

Calibration: The spray bottle pressure was calibrated, and the prepared nano suspension was loaded into the spray bottle. The suspension was evenly sprayed onto the surface of the trace-bearing object. It is important to maintain a 10 cm perpendicular distance between the nozzle and the object's surface, and to control the spraying time to within 2 seconds, ensuring complete coverage of the fingerprint sample area.

Resting and Curing: After spraying, the object was left to rest for 30 seconds to allow for preliminary fixation of the nano particles due to the rapid evaporation of isopropanol. For samples in high-humidity environments, the resting time was extended to 45 seconds to prevent interference from water vapor.

Washing and Drying: The object was sprayed with distilled water to thoroughly wash away any residual particles from the fingerprint ridge areas. Subsequently, a blow dryer was used to dry the object.

Environmental Control: The experiment was conducted on a clean operation table with a temperature of 25.0 ± 0.5°C and humidity of 50 ± 2% RH to avoid airflow fluctuations.

Quality Control: Each group of samples was repeated three times under identical conditions, with the best manifested sample selected as the representative result for each group to minimize experimental variability. If background residue was observed after spraying, a cotton swab was used to gently wipe and correct the localized area of the object.

Fixation and Evaluation of Manifestation Effects: The fingerprint manifestation effect was captured using a digital camera, followed by the use of a multifunctional evidence examination device to capture the second- and third-level features of the fingerprint for further evaluation of the manifestation effect.

3. Results and Discussion

3.1 Selection of the Optimal Solvent for the Composite Enhancement System (Using Glass as the Object)

Fingerprint samples with a fixed concentration of nano particles were subjected to manifestation experiments with different solvent composite systems, varying the CTAB ratio, such as isopropanol, anhydrous ethanol, glacial acetic acid, and acetone. The experiment results on a non-permeable glass surface serve as an example, as shown in Figure 1. When isopropanol was chosen as the solvent, the composite system produced the best manifestation effect: the fingerprint's color was uniform, the ridge lines were clear and continuous, and the fine details were prominent. In contrast, when glacial acetic acid, anhydrous ethanol, or acetone were used as solvents, the fingerprint ridge lines were disjointed, and in some cases, they were entirely absent, showing no attachment of nano particles. In other areas, the nano particles excessively adhered, causing the fingerprint ridge lines to become blurred and making detailed features difficult to observe. As seen in Figure 1, the best manifestation effect was achieved with 1.5g CTAB in the isopropanol solvent system. Therefore, the conclusion can be drawn that the optimal solvent composite system for fingerprint manifestation is the nano SiO_2 particles-CTAB-isopropanol composite solvent system, with the best manifestation effect achieved at a 1.5g CTAB ratio.

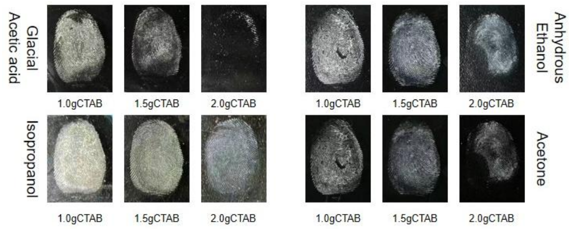

Figure 1. Fingerprint Manifestation Effects with Different Solvent Composite Systems

3.2 Selection of the Optimal Nano SiO_2 Particle Concentration for the Composite Enhancement System (Using Glass as the Object)

Through the grouped experiments in section 2.3.1, it was determined that the isopropanol solvent system yielded the most optimal manifestation effect in the nano SiO_2 composite enhancement system, with the best fingerprint manifestation achieved at a CTAB ratio of 1.5g. Therefore, in the grouped experiments of section 2.3.2, the CTAB dosage was fixed at 1.5g, and by controlling the single variable of the nano SiO_2 dosage, it was found that the best manifestation effect occurred when 5.0g of nano SiO_2 was added (as shown in Figure 2). In this case, the fingerprint ridge lines were complete, continuous, and exhibited a strong contrast against the background, with no aggregation of nano SiO_2 particles, allowing for clear observation of the detailed features. When 3.0g or 4.0g of nano SiO_2 was added, the nano particle concentration was too low, resulting in an incomplete fingerprint manifestation with severe ridge line breaks and poor contrast against the background. On the other hand, when 6.0g or 7.0g of nano SiO_2 was used, the concentration of nano particles was too high, leading to localized aggregation of the nano particles, which caused the fingerprint to appear blurred and obscured, preventing the observation of fine details. Therefore, the best manifestation effect in the aforementioned experiments was achieved with 50mL of isopropanol, 1.5g of CTAB, and 5.0g of nano SiO_2.

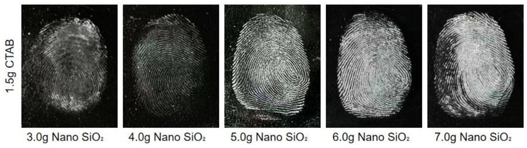

Figure 2. Fingerprint Manifestation Effects with Different Nano Particle Concentration Ratios

3.3 Effect of Environmental Humidity on the Manifestation Effect of the Composite Enhancement System

As shown in Figure 3, in a dry environment, the fingerprints manifested using the latent print development by metallic powder application and the black magnetic powder application appeared relatively complete, but local areas still exhibited excessive powder adhesion, leading to blurred ridge lines and an inability to observe detailed features. In a humid environment, the latent print development by metallic powder application resulted in an excessive attachment of powder, causing severe loss of fingerprint features, while the black magnetic powder application showed poor fingerprint integrity with severe ridge line breaks. In contrast, the nano SiO_2 composite enhancement system demonstrated better manifestation results than traditional methods in both dry and humid environments. The fingerprint was more complete, with clear and continuous ridge lines, strong contrast against the background, and observable detailed features. In conclusion, the nano SiO_2 composite enhancement system is suitable for fingerprint manifestation in humid environments.

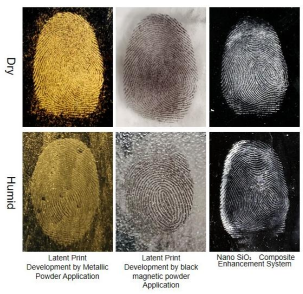

Figure 3. Comparison of Fingerprint Manifestation Effects under Different Environmental Humidity Levels between Traditional Methods and the Composite Enhancement System

3.4 Comparison of Manifestation Effects between the Composite System and Traditional Methods on Different Substrate Objects

To further investigate and validate the manifestation effects of the optimized nano SiO_2 composite enhancement system on different trace-bearing objects, the grouped experiment compared the fingerprint manifestation effects on non-permeable smooth objects such as glass, aluminum foil, and plastic with the latent print development by metallic powder application and metallic powder application as representatives of traditional fingerprint manifestation methods. Observations using a multifunctional forensic examination instrument revealed that the traditional fingerprint manifestation methods (by metallic powder application and metallic powder application) exhibited localized aggregation of fingerprint ridge lines on glass objects, with blurred ridge lines and limited reference value for detailed features. On aluminum foil objects, significant background reflection interference hindered the advantage of the metallic powder's reflective properties, and the fingerprints manifested using the black magnetic powder application showed severe breaks and poor detailed features. On plastic objects, notable background residue was present, sweat pores were indiscernible, and detailed features were unobservable. In contrast, under the nano SiO_2 composite enhancement system, the distribution of nano particles on glass, aluminum foil, and plastic objects was uniform. The manifested fingerprint ridge lines had sharp edges, clear sweat pores, prominently visible detailed features, and a high level of completeness in three-level characteristics (as shown in Figure 4). Overall, the manifestation effect significantly improved compared to traditional fingerprint manifestation methods.

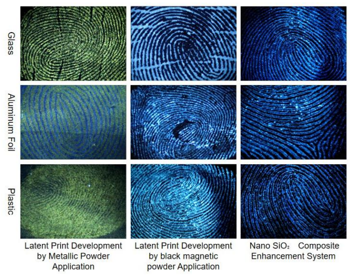

Figure 4. Comparison of Fingerprint Manifestation Effects between Traditional Methods and the Composite Enhancement System on Different Substrate Objects

4. Conclusion

This study primarily explored the latent fingerprint manifestation effects of the nano SiO_2-CTAB-isopropanol composite enhancement system on non-permeable smooth

objects (glass, aluminum foil, plastic). By screening solvent composite systems, optimizing the concentration ratios of nano particles, analyzing the impact of environmental factors, and comparing manifestation effects on different substrates, the study successfully addressed several issues present in traditional techniques, such as blurred detailed features, high ridge line breakage rates, poor environmental adaptability, and instability in fingerprint manifestation. The main conclusions and innovations are as follows:
First, this study fully leveraged the characteristics of nanomaterials, such as easy functionalization, high surface area, controllable surface modification, and multi-scale interactions, to enhance the sharpness of fingerprint ridge line edges and contrast of detailed features.
Second, the nano SiO_2-CTAB-isopropanol enhancement mechanism proposed in this research significantly improved the expression of detailed features in latent fingerprints. CTAB regulated the dispersion of nano particles through electrostatic adsorption, inhibiting aggregation, which in turn improved ridge line sharpness, increased contrast with the background, and greatly enhanced sweat pore recognition compared to traditional fingerprint manifestation methods. As a cationic surfactant, CTAB strengthened the targeted binding of nano particles to fingerprint residues (especially lipid components), improving the stability of fingerprint manifestation and providing favorable conditions for prolonging the preservation time of manifested fingerprints.
Furthermore, this study employed a suspension method for fingerprint manifestation, demonstrating high adaptability to humid environments. The research also showed that the composite enhancement system performed better, rather than worse, in environments with grease accumulation and strong acidity, exhibiting strong resistance to environmental interference.
Finally, this study compared the manifestation effects of traditional methods and the composite enhancement system on different substrates, finding that the nano SiO_2 composite enhancement system provided superior fingerprint manifestation on non-permeable smooth objects such as glass, aluminum foil, and plastic, compared to traditional methods. Given its broad applicability, it could be considered for practical promotion and use.
This research provides a robust solution for latent fingerprint manifestation on non-permeable smooth objects such as glass, aluminum foil, and plastic. The "targeted adsorption-structural stability-environmental interference resistance" triple optimization mechanism can be extended to other complex trace-bearing objects (such as metals and plastics) for trace extraction, contributing to the standardization and intelligent development of forensic examination technology. This holds significant practical value.

5. Innovation

1)Leveraging the characteristics of nanomaterials, such as easy functionalization, high surface area, and low cost, to their full potential.
2) The nano SiO_2 composite enhancement system possesses a triple optimization mechanism of "targeted adsorption-structural stability-environmental interference resistance".
3) The nano SiO_2 composite enhancement system demonstrates superior fingerprint manifestation effects on different substrates compared to traditional methods.

Acknowledgment

Hebei Department of Education Project—Higher Education Institution Scientific Research Project "Optimization of Fingerprint Visualization Techniques on Different Trace-bearing Substrates" (ZC2024011).

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