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Exploitation of very small particles to enhance the probative value of carpet fibers

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ABSTRACT

Environmentally acquired very small particles (VSP), present on the surfaces of carpet fibers, have shown potential for the association of fibers with their carpet source. To unlock this potential, research is required addressing a number of areas, including the application of methods under realistic casework conditions and the utilization of computational methods for the refinement and testing of the approach.

In this work field collections of carpet fibers were conducted by crime scene practitioners under realistic casework conditions. VSP were isolated using previously developed methods, and analyses were conducted using SEM/EDS analytical protocols in an operational crime laboratory setting. Computational methods were designed, allowing sets of hundreds to thousands of VSP to be characterized. Classifiers were designed to associate and discriminate among specimens. These classifiers were applied to the VSP data for specimens collected by crime scene practitioners, as well as to a previously collected research dataset. Quantitative measures of correspondence and probative value were designed based on the classification measures and successfully applied to both sets of VSP data.

Particle sets larger than 500 showed strong promise for quantitative associations with their sources. The use of larger numbers of target particle types (TPTs) showed strong promise to improve the performance of classification and association.

Overall, the usefulness of VSP to provide objective, quantitative associations has been established. Because VSP are acquired post-manufacture, these methods can address fundamental limitations to probative value that arise when class characteristics, determined by manufacture, are shared among mass produced commodities.

These findings are of broad significance for the future of trace evidence analysis. The results of this research are likely extendable, with minor modifications, to other trace evidence types (such as glass, tape and human hair), and are expected to contribute significantly for those types of trace evidence that have long been considered of low evidential value (such as undyed cotton and animal hairs). Furthermore, entirely new approaches to trace evidence are enabled by exploiting VSP profiles, such as comparing different types of trace evidence with one another and comparing VSP defined by crime scene or suspect environments to those on virtually any item of physical evidence.

1. Introduction

Prior research has shown that very small particles (VSP), ubiquitous on the surfaces of carpet fibers, can be used to associate fibers with their carpet source [1]. Hundreds to thousands of VSP occur on the surfaces of individual carpet fibers. The particles can be efficiently removed [2] and analyzed by computer-assisted SEM/EDS, resulting in highly characteristic profiles of target particle types (TPTs). When sufficient VSP are recovered from individual fibers, there is a close correspondence between these TPT profiles and those from the originating carpet area.

This prior research was conducted using fibers cut by researchers from a total of 21 carpets in one community. Nine of these carpets were sampled from three different areas (spaced

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30–90 cm apart). Particles were harvested from the fibers by washing and filtration [2] followed by SEM/EDS analysis. Using a set of well-defined, frequently occurring elemental combinations as TPTs, particles from each specimen were binned, creating a particle profile. These profiles were compared visually and a close correspondence was regularly observed when quantities of VSP exceeded 1000.

This foundational research has extraordinary implications for both carpet fiber evidence and for trace evidence analysis in general. Proof of principle was established that the analysis of VSP on the surface of carpet fibers has the potential to augment class associations with independent, quantitative testing of common origin using populations of VSP.

The goals of the present research were to refine the process for exploiting VSP, apply this process under realistic casework conditions, and develop working prototypes for interpretational methods.

To this end, (1) computational methods have been used to define target particle types (TPTs), replacing those defined based on abundance and heuristics, (2) the method of SEM/EDS analysis has been modified, recognizing and embracing the use for particle characterization, rather than particle identification, (3) specimens have been collected in the field by crime scene professionals and (4) computational methods have been developed and applied resulting in measurements of VSP correspondence and association.

2. Materials and methods

2.1. Collection of carpet fiber specimens

Carpet fiber specimens from residential wall-to-wall carpeting were collected by crime scene practitioners working within nine separate jurisdictions in the United States, as listed in Table 1. At every scene, two carpet fiber specimens were collected:

Carpet fibers transferred by frictional contact to a lint-free inspection glove (representing transferred fiber traces from the source)

Carpet fibers collected with a hook-type lint brush (representing a reference sample from the carpet source)

2.2. Fiber recovery and isolation of particles from fibers

Under a stereomicroscope on a clean bench, forceps were used to recover 3–12 fibers from each of the two carpet fiber specimens in the sampling kit. Kits with less than three carpet fibers in one of the two specimens were rejected and not processed further. Specimen numbers for trace and reference fibers from the same kit were coded to obscure the identity of mated pairs until after analysis.

VSP were removed and recovered from the fibers by ethanol extraction and filtration using polycarbonate filters with 0.4 μm pore size. The published method [2] was followed, except that (1) 13 mm polycarbonate filters were used in place of excised portions of 47 mm filters, (2) these filters were cut in half prior to mounting for SEM, and (3) the filters were not carbon coated following extraction. This procedure resulted in duplicate SEM stubs for each specimen. One SEM stub was selected for analysis and the other was reserved for possible future study.

Table 1
Agencies contributing carpet fiber collection kits for this project.

Contra Costa County Sheriff's Office Criminalistics Laboratory, Martinez, CA
Forensic Laboratory Services Division, Seminole County Sheriff's Office, Sanford, FL
Idaho State Police Forensic Services, Meridian, ID
Iowa Division of Criminal Investigation, Criminalistics Laboratory, Ankeny, IA
Oakland Police Department Criminal Investigation Division, Oakland, CA
Patton Township Police Department, State College, PA
San Diego County Sheriff's Regional Crime Laboratory, San Diego, CA
San Diego Police Department Forensic Science Section, San Diego, CA
Scientific Services Bureau, Los Angeles County Sheriff's Department, Los Angeles, CA

2.3. Computer assisted SEM/EDS analysis of particles

The computer assisted SEM/EDS analysis was performed on an Aspex Corporation 3025 SEM-EDS system using the Automated Feature Analysis (AFA) program within the Aspex Corporation Perception software. Analysis was performed under low vacuum conditions (0.1 Torr) utilizing a 20.0 kV accelerating voltage, backscatter electron detector (BSED), working distance of approximately 14.6 mm, spot size of approximately 33% and dead time of approximately 11%. The magnification for the analysis was 1200× with the number of electronic fields set at a maximum of 5 × 5. A grid dimension of 512 × 512 was used with a dwell time per pixel of 2 μs for searching and 16 μs for measuring. The size criteria for analysis were a minimum size of 0.3 μm and a maximum size of 80.0 μm. EDS parameters had a nominal duration of 3 s, a maximum of 6 s, a minimum count of 1500 and a target count of 2500. An EDS Copper calibration check was performed before each analytical run (~20–30 specimens) and during the run at the beginning of each specimen.

Software settings were selected to restrict particle characterization based on standard X-ray K-shell emission lines of the 18 elements listed in Table 2. These elements were chosen (1) following a review of the manufacturer's recommendations indicating that the AFA software performed best for a number of elements below 20, (2) to avoid overlapping X-ray energies, and (3) to provide broad coverage of X-ray energies appearing in the range of 1–10 KeV.

Raw datasets for each computer-assisted SEM/EDS run consisted of a set of run parameters and results along with individual particle analysis data. Individual particle data were a particle index number, a set of particle size and shape parameters, the four elements in the particle's EDS spectrum having the highest X-ray counts, the corresponding four X-ray counts, live analysis time, total X-ray counts for the particle and the calculated percentages of each of the 18 specified elements.

2.4. Particle dataset from [1]

Particle data collected and previously described [1] (hereafter Dataset 1) were re-analyzed using the computational methods described below in Section 2.5. The dataset consists of SEM/EDS particle analysis results from 39 carpet area sources (taken to represent source references) and 81 individual fibers originating from some of these sources (taken to represent transferred traces). Of the 39 sources, 12 are individual sources (from one area of a carpet) and the remaining 27 come from 9 carpets, with 3 areas taken from each of the 9 carpets. The 81 individual fibers consist of 3 fibers from each of the 27 carpet areas. SEM/EDS data for this set included calculated percentages for 28 elements based on fitting of

Table 2
The 18 elements detected by the automated EDS procedure.

Sodium (Kα, Kβ)	Magnesium (Kα, Kβ)	Aluminum (Kα, Kβ)
Silicon (Kα, Kβ)	Phosphorous (Kα, Kβ)	Sulfur (Kα, Kβ)
Chlorine (Kα, Kβ)	Potassium (Kα, Kβ)	Calcium (Kα, Kβ)
Titanium (Kα, Kβ)	Vanadium (Kα, Kβ)	Chromium (Kα, Kβ)
Manganese (Kα, Kβ)	Iron (Kα, Kβ)	Cobalt (Kα, Kβ)
Nickel (Kα, Kβ)	Copper (Kα, Kβ)	Zinc (Kα, Kβ)