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Technical note

Towards reconstruction of overlapping fingerprints using plasma spectroscopy☆

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ABSTRACT

Chemical analysis is commonly used in the field of forensic science where the precise discrimination of primary evidence is of significant importance. Laser-Induced Breakdown Spectroscopy (LIBS) exceeds other spectroscopic methods in terms of the time required for pre- and post-sample preparation, the insensitivity to sample phase state be it solid, liquid, or gas, and the detection of two-dimensional spectral mapping from real time point measurements. In this research, fingerprint samples on various surface materials are considered in the chemical detection and reconstruction of fingerprints using the two-dimensional LIBS technique. Strong and distinct intensities of specific wavelengths represent visible ink, natural secretion of sweat, and contaminants from the environment, all of which can be present in latent fingerprints. The particular aim of the work presented here is to enhance the precision of the two-dimensional recreation of the fingerprints present on metal, plastic, and artificially prepared soil surface using LIBS with principal component analysis. By applying a distinct wavelength discrimination for two overlapping fingerprint samples, separation into two non-identical chemical fingerprints was successfully performed.

1. Introduction

Laser-induced breakdown spectroscopy (LIBS) is an atomic emission spectroscopy that uses laser-induced plasma for analysis of any matter regardless of its physical state, be it solid, liquid or gas. As elements emit light of characteristic frequencies when excited via plasma, LIBS makes use of the optical emission spectrometry. Several known advantages of LIBS include the lack of a requirement for sample preparation, real-time detection, and a limited damage done during the microscale ablation [1,2].

LIBS has attracted considerable attention in forensic applications due to its accuracy of fast forensic discrimination of evidence samples. Bridge et al. [3] and El-Deftar et al. [4] employed both LIBS and LA-ICP-MS, respectively, to classify types of glass and proposed analysis methodologies for crime scene investigation. In Hoehse et al., LIBS is also used to discriminate paint sources [5], and a combined LIBS-Raman is adopted to increase the classification ability of ink at the forensic site in McIntee et al. [6]. Jantzi et al. [7] claimed that LIBS is suitable in bulk soil analysis, as there is fewer misclassification. Also, bone analysis at crime scenes has been reported [8], suggesting the use of LIBS in fire and arson investigations. Additional applications of LIBS in the field of forensic science are also found in [9].

Recent efforts to apply LIBS in detecting fingerprints have focused on obtaining the chemical distribution from the inherent point measurement of LIBS. Abdelhamid et al. [10] drew an explosive trace distribution on a fingerprint sample by applying LIBS combined with optical catapulting. Laserna et al. [11] detected explosive-contaminated fingerprints using stand-off LIBS. Also, studies have been carried out to draw the ridges of fingerprints using the femtosecond LIBS [12], where the femtosecond laser can provide lines of a nanometer height, but the resulting print is far too localized to be recognizable via visual inspection.

The separation of the overlapping fingerprints has been reported in the literature, where the captured images are improved via computer algorithms, and the direction of the fingerprint ridges is reconstructed by the computer image processors. In works by Feng et al. [13], efficient algorithms were applied that can estimate the component orientation fields of latent fingerprints. Stojanovic et al. [14] demonstrated the use of neural networks in separating latent fingerprints. Bradshaw et al. [15] demonstrated the ability to distinguish between overlapping images using Matrix Assisted Laser Desorption Ionization Mass Spectrometry Imaging (MALDI MSI) with multivariate statistical analysis. By analyzing the endogenous and exogenous species, it was claimed that fingerprints could be separated. However, the success of image separation depends on the initial estimation of the orientation field, which strongly affects the performance of separating the overlapping

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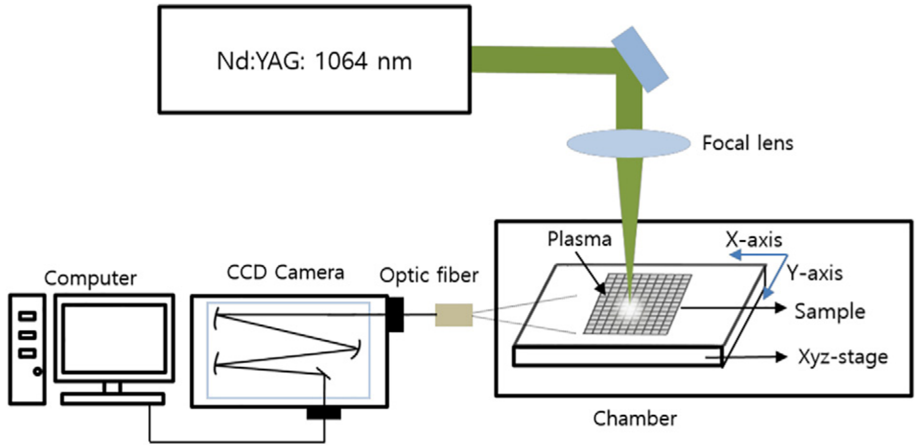

Fig. 1. Arrangement of detection apparatus showing automated stage for 2D LIBS procedure.

fingerprints. Also, the chemical pre-sequencing needed prior to analysis is a strong drawback of currently available approaches.

The aforementioned studies have shown that forensic analysis can benefit from point measurement technique such as LIBS that may enhance the possibility of capturing suspects by maximizing the amount of information that can be obtained from limited evidence. In the case of overlapping fingerprints, although image processing is generally used, the image takes some time to process and can present different results depending on the initial conditions. However, to obtain fingerprint images and evidence, chemical pre-treatment using tape-lift and powder must be performed. This chemical treatment can lead to the degeneration of evidence, particularly in micro-samples of very limited fingerprint samples.

The aim of this work is to construct two-dimensional images from the point measurements of LIBS signals of chemical elements from the fingerprint. This is because chemical compositions of the latent fingerprint vary with time, intake, and age [16–18]. Two distinct overlapping fingerprints collected at a crime scene contain distinct chemical elements from which two separate fingerprints can be effectively constructed with LIBS. Depending on the surface material, the residue fingerprints can be difficult to detect using the conventional methods utilizing visual inspection. When the LIBS based chemical mapping is applied to a metal plate, a non-transparent plastic (hydroxyl-terminated polybutadiene) plate, and a soil pellet as substrates, the identified signals can be selected to restore the fingerprints that might not have been obtained by other means. A considerable advantage of the proposed approach is that both visual images and elemental signals from the fingerprint are used to favorably enhance the quality of the separated images of independent fingerprints. This research is the first attempt to separate the overlapping latent fingerprints using the LIBS method.

2. Materials and methods

A Q-switched Nd:YAG laser is used in a LIBS system (RT-250Ec, Applied Spectra Inc.) that operates at 1064 nm, 2–5 ns pulse duration. The pulse energy of the laser varied from 4.64 mJ to 39.57 mJ according to the diminishing size of the ablation crater. A spectrometer which has 6 channels to enhance ability of resolution can cover from 190 nm to 1040 nm as the detected spectrum range. The resolution of the spectrometer is 0.1 nm or less from ultraviolet to visible, and 0.12 nm from visible to near infrared. The gate delay and gate width were set as 0.5 μs and 1.05 ms, respectively. The pressure in the chamber was maintained at 760 Torr. The laser beam was exposed to both ink sample and latent fingerprints. Fig. 1 shows a schematic of the experimental setup. The experiment was conducted as a grating sequence to decrease the analysis time, and the sample stage was allowed to move in x-y directions. Additionally, during the laser ablation, both the distance from the laser to the sample and the chamber pressure were maintained.

In this research, the fingerprint samples were placed on aluminum, plastic, and artificially prepared soil substrates with no chemical pretreatment. Four latent fingerprints were collected from four distinct individuals. An ethanol-wiped finger was rubbed against the individual's forehead for extracting the body oil, and then pressed onto the aluminum plate for about 10 s. The laser beam was focused on the sample and was fired ten times to assure signal readability. To draw two-dimensional mapping of the emission spectra, the stage below the sample plate was moved along the x-axis and y-axis by 125 μm increment in a grid formation. For the Principal Component Analysis (PCA), statistical program (The Unscrambler X, CAMO Software Inc.) was utilized.

For preparation of the soil substrate containing calcite and aragonite, an X-Press machine up to 15 tons was used [19,20]. As the latent fingerprint is hardly visible via inspection, the known composition of the soil helps to focus on the fingerprint elements from the LIBS analysis.

3. Results and discussion

The LIBS is first used as a point-measurement procedure before applying it to construct the two-dimensional chemical fingerprint images. 10 pulses are used to obtain the relevant spectra. Then 2 pulses are used at each node of the 2D mapped image. The atomic signals of potassium (766.587, 770.047 nm), sodium (521.009 nm), calcium (616.129 nm), and iron (526.998 nm) are particularly of interest when constructing

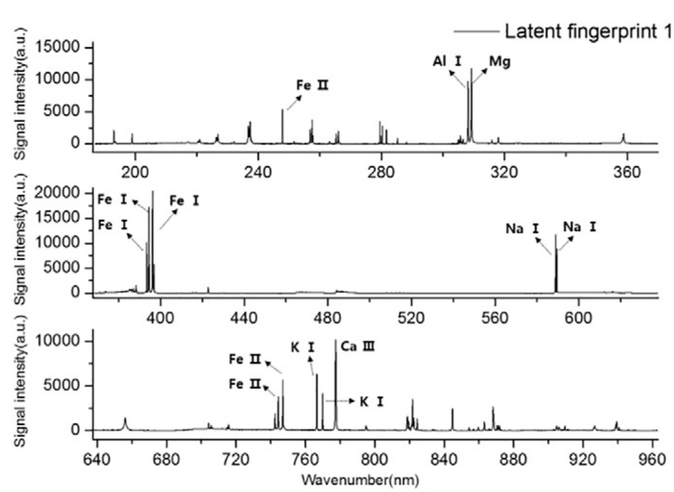

Fig. 2. Emission spectra of a latent fingerprint on the aluminum substrate.