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APPLICATION NOTE

UNCOVERING EVIDENCE: THE IMPACT OF SPECTROSCOPY IN FORENSICS

INTRO

UNCOVERING EVIDENCE: THE IMPACT OF SPECTROSCOPY IN FORENSIC RESEARCH

Forensic science plays a crucial role in uncovering the truth behind criminal events, relying on advanced analytical tools and techniques to examine and interpret evidence. From microscopic trace materials to complex biological samples, forensic investigators need precise and reliable technologies to analyze evidence without altering or destroying it. Spectroscopy has emerged as one of the most valuable tools in this field, offering unparalleled insights by analyzing the molecular and atomic properties of materials.

By leveraging spectroscopy, forensic scientists can uncover hidden details within evidence, helping to establish timelines, identify substances, and even differentiate between seemingly identical materials. Spectroscopy's non-destructive nature makes it particularly valuable in scenarios where the preservation of evidence is critical, enabling repeated analysis or further examination by other techniques. In particular, spectroscopy in the UV/VIS and NIR spectrum allows investigators to characterize chemical compositions with high precision and monitor subtle changes that occur over time. These capabilities have made spectroscopy an essential tool in modern forensic investigations.

Avantes, with its advanced spectroscopic solutions in the UV/VIS and NIR range, has enabled forensic researchers to make critical breakthroughs in applications like estimating the age of biological stains and assessing complex material compositions. This application note highlights two recent studies using Avantes solutions, demonstrating how these spectrometers have enriched forensic research and practice.

CASE STUDY: ESTIMATING THE AGE OF BIOLOGICAL STAINS USING FLUORESCENCE SPECTROSCOPY

RESEARCH OVERVIEW AND IMPORTANCE

One of the core challenges in forensic science is estimating the age of biological stains at a crime scene, such as semen stains, which can provide valuable information on the timeline of events. Traditional methods of age estimation are often limited by their invasive nature, lack of accuracy, or inability to provide immediate on-site results. In the study titled "Towards Onsite Age Estimation of Semen Stains Using Fluorescence Spectroscopy," researchers explored a novel, non-destructive approach using fluorescence spectroscopy to determine the age of semen stains. By capturing fluorescence spectral changes that occur as semen stains age, this study provided forensic investigators with a practical solution to estimate the time of deposition accurately[1].

This research is important because it addresses a significant gap in forensic investigations, where determining the timing of biological deposits could strengthen evidence linking suspects to specific events. Moreover, this approach can be applied in real-time, allowing investigators to make timely decisions without having to wait for laboratory processing.

HOW SPECTROSCOPY ENHANCED THIS RESEARCH

Fluorescence spectroscopy is highly sensitive to biochemical changes, making it ideal for observing the natural degradation of biological materials over time. As semen stains age, specific compounds within them undergo chemical transformations, which affect their fluorescence properties. By capturing these unique spectral changes, forensic experts can create a “timeline” of the stain’s age, enabling a more precise reconstruction of events.

In this study, researchers employed a portable fluorimeter, which measured fluorescence spectra across a range of time intervals. By analyzing the intensity and shape of these spectra, they built a predictive model that could estimate the age of stains with a mean absolute error of less than two days for samples up to 16 days old.

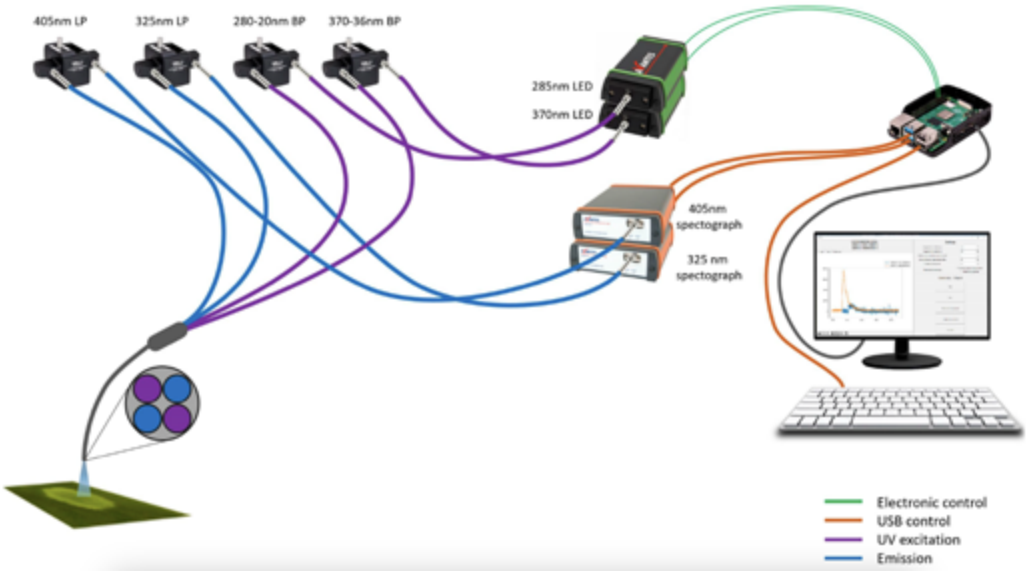

FIGURE 1: Graphical illustration of the developed portable fluorimeter with Avantes solutions.

THE ROLE OF AVANTES SOLUTIONS

In this study, Avantes equipment played a central role in capturing the fluorescence emissions essential for estimating the age of semen stains. The custom-built portable fluorimeter used by researchers was equipped with multiple Avantes products, demonstrating the reliability and versatility of Avantes technology in forensic applications. Specifically, the system included:

- **AvaLight-HPLED:** LEDs for excitation at 285 and 370 nm, ensuring precise fluorescence stimulation necessary for detecting protein and FOX emissions in the biological stains.
- **AvaSpec-ULS2048CL-EVO** and **AvaSpec-ULS2048-USB2-VA-50:** fiber spectrometers, which recorded fluorescence emissions within the 325–1100 nm and 405–1100 nm ranges.

The high sensitivity and broad wavelength range of these spectrometers enabled the accurate detection of subtle spectral shifts, which are crucial for developing a reliable age estimation model.

The setup was controlled by custom software via a Raspberry Pi, demonstrating the compatibility and adaptability of Avantes equipment for both in-house and customized forensic applications. The Avantes components in this setup provided the precision and stability required to create a robust fluorescence model, offering forensic investigators a portable, effective solution for on-site age estimation of biological stains.

CASE STUDY: ON-SITE ANALYSIS OF FORENSIC EVIDENCE WITH LIBS TECHNOLOGY

RESEARCH OVERVIEW AND IMPORTANCE

Another breakthrough in forensic technology is the development of tools that allow for rapid, on-site analysis of evidence, removing the need for lengthy laboratory processing. In the study titled "A Novel LIBS Sensor for Sample Examinations on a Crime Scene," researchers focused on the use of Laser-Induced Breakdown Spectroscopy (LIBS) as a powerful, non-destructive method for analyzing forensic samples directly at crime scenes[2]. LIBS technology is particularly effective in situations where time-sensitive results are required, such as in determining the elemental composition of substances found on-site.

This research is significant as it introduces a new dimension to crime scene investigations by allowing immediate compositional analysis of materials, which is critical in making swift, evidence-based decisions. Whether it's examining residues, identifying unknown substances, or analyzing trace elements on different surfaces, LIBS enables a comprehensive analysis that provides essential clues in forensic investigations.

HOW SPECTROSCOPY ENHANCED THIS RESEARCH

LIBS operates by creating a micro-plasma on the sample's surface through a focused laser pulse, causing a small amount of material to break down into its elemental components. This plasma emits light across various wavelengths, which is then analyzed spectroscopically to identify the elements present in the sample. Because each element has a unique spectral signature, LIBS can detect and quantify elements with precision, even in complex or heterogeneous samples.
In this study, researchers demonstrated the use of LIBS for quick elemental analysis of forensic samples at crime scenes. They found that LIBS could provide immediate, reliable results for materials like gunshot residue, soil, and other trace evidence, giving investigators actionable data within minutes.

THE ROLE OF AVANTES SOLUTIONS

In this study, Avantes spectrometers were a key component in the LIBS detection system, which was configured to analyze plasma emissions with high precision across a broad spectral range.
Six compact AvaSpec-Mini spectrometers were customized for the study to cover wavelengths from 180 nm to 875 nm, with enhanced spectral resolution in the UV region—a critical range for detecting elemental signatures. Each spectrometer was calibrated for specific spectral ranges to ensure continuous coverage and unified spectral data, enabling the detection of diverse elements present in forensic samples, such as gunshot residues, soil, and trace materials.

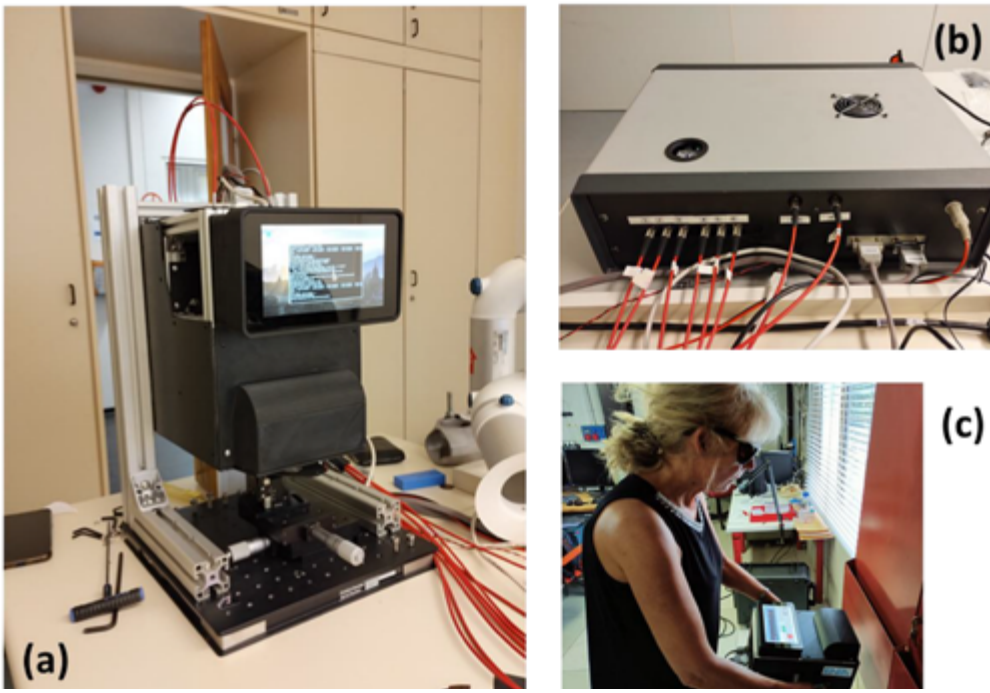

FIGURE 2: **(a)** LIBS sensor head mounted on a structure for static measurements; **(b)** the instrument box; **(c)** sensor head operated in a handheld mode.

Key features of the Avantes spectrometers in this setup included:

- **High Spectral Resolution and Sensitivity:** The AvaSpec-Mini spectrometers provided enhanced spectral resolution in the UV region, essential for distinguishing fine elemental details within multi-element samples.
- **Compact Design:** The spectrometers were compactly arranged within an instrument box, ensuring portability and ease of use at crime scenes or forensic labs.
- **Precision Data Collection and Integration:** Each spectrometer was aligned for consistent plasma emission detection, and the spectral data were processed with Avantes' Avasoft 8.14 software. This ensured precise data acquisition and enabled real-time integration of spectral readings across multiple channels.

The ability of Avantes spectrometers to perform rapid, synchronized data acquisition in this setup enabled forensic scientists to analyze elemental compositions on-site, supporting quicker, evidence-based decisions at crime scenes. This study highlights how Avantes technology, specifically the AvaSpec-Mini spectrometers, provides forensic scientists with the high-resolution, multi-channel spectral data needed for comprehensive LIBS analysis. The precise, portable design of Avantes products enhances the efficiency of forensic investigations, empowering labs and field teams to gather actionable insights with speed and accuracy.

AVANTES SOLUTIONS FOR FORENSIC RESEARCH

Avantes offers a range of high-performance spectrometers and accessories tailored to meet the precise needs of forensic scientists. In the case studies discussed, the ability of Avantes products to deliver accurate and sensitive spectral data was critical to the research outcomes, especially in applications where minute details make a significant difference. Below we discuss the successors of the discussed spectrometers that will provide an even better performance.

1. AvaSpec-VARIUS™ for High Sensitivity Analysis

The AvaSpec-VARIUS™ spectrometer, part of Avantes' UV/VIS range, is designed to provide high sensitivity and low stray light, making it ideal for detecting subtle spectral differences in forensic samples. With its compact, versatile design and USB3/Ethernet connectivity, the AvaSpec-VARIUS™ can be used both in laboratories and in mobile setups, making it an excellent choice for on-site forensic applications. Its broad spectral coverage from UV to NIR allows for detailed biochemical analysis, making it a powerful tool in biological forensic applications.

2. AvaSpec-NEXOS™ for On-Site LIBS Analysis

The AvaSpec-NEXOS™ spectrometer is suited for Laser-Induced Breakdown Spectroscopy (LIBS), which is effective in identifying elemental compositions quickly and accurately. The compact design makes it easy to integrate into a portable system. The spectrometer is designed to withstand field conditions, providing rapid on-site analysis of crime scene materials. The high-resolution spectral data capabilities are invaluable in scenarios such as those outlined in the second case study, where elemental analysis of residues and trace materials was required. The ease of use and robustness of the AvaSpec-NEXOS™ allow forensic experts to perform LIBS analysis efficiently, offering immediate insights into the elemental makeup of samples, from soil residues to metal traces.

3. AvaSoft Software for Data Precision and Analysis

Supporting both spectrometers, the AvaSoft software suite enhances data processing and visualization, allowing forensic scientists to interpret complex spectral data with precision. AvaSoft provides tools for real-time analysis and data comparison, essential for forensic labs where fast, accurate data is crucial. With features like peak analysis, integration, and customized spectral processing, AvaSoft complements Avantes' hardware solutions by streamlining the analytical workflow and improving decision-making in both case studies.

CONCLUSION

The studies reviewed here illustrate how Avantes spectroscopy solutions play an essential role in modern forensic science. From fluorescence spectroscopy for age estimation of biological stains to LIBS for elemental analysis at crime scenes, Avantes systems offer **high sensitivity, non-destructive analysis, and portability**, all of which are critical for forensic applications. By enabling accurate, immediate analysis of evidence, Avantes technology supports forensic teams in building reliable, scientifically rigorous cases.

As the demand for rapid, reliable forensic tools continues to grow, Avantes remains at the forefront, providing spectroscopic solutions that enhance the precision and effectiveness of forensic investigations. By partnering with Avantes, forensic experts are enabled to contribute significantly to the pursuit of justice and truth in criminal investigations.

For advice, feasibility studies or more information about our solutions, feel free to contact us. We are happy to help!

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CONTACT

WE'RE HAPPY TO HELP

Curious how spectroscopy will help you reveal answers by measuring all kinds of material in-line, at your production facility, in a lab, or in the field? Visit our website or contact one of our technical experts. We are happy to help you!

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