Forensic Science International 223 (2012) 28–39

Contents lists available at SciVerse ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Review article

Hyperspectral imaging for non-contact analysis of forensic traces

G.J. Edelman [a,*], E. Gaston [b], T.G. van Leeuwen [a], P.J. Cullen [c], M.C.G. Aalders [a]

[a] Department of Biomedical Engineering and Physics, Academic Medical Center Amsterdam, The Netherlands
[b] Innovació i Recerca Industrial i Sostenible, Castelldefels (Barcelona), Spain
[c] School of Food Science and Environmental Health, Dublin Institute of Technology, Ireland

ARTICLE INFO

Article history:
Received 20 June 2012
Received in revised form 4 September 2012
Accepted 25 September 2012
Available online 23 October 2012

Keywords:
Forensic science
Hyperspectral imaging
Chemical imaging
Spectroscopic imaging
Detection
Identification
Aging

ABSTRACT

Hyperspectral imaging (HSI) integrates conventional imaging and spectroscopy, to obtain both spatial and spectral information from a specimen. This technique enables investigators to analyze the chemical composition of traces and simultaneously visualize their spatial distribution. HSI offers significant potential for the detection, visualization, identification and age estimation of forensic traces. The rapid, non-destructive and non-contact features of HSI mark its suitability as an analytical tool for forensic science. This paper provides an overview of the principles, instrumentation and analytical techniques involved in hyperspectral imaging. We describe recent advances in HSI technology motivating forensic science applications, e.g. the development of portable and fast image acquisition systems. Reported forensic science applications are reviewed. Challenges are addressed, such as the analysis of traces on backgrounds encountered in casework, concluded by a summary of possible future applications.

Contents

1. Introduction . . . 28
2. Hyperspectral imaging . . . 29
   2.1. Interaction of light and matter . . . 29
   2.2. Hypercube formation . . . 30
   2.3. System optimization for forensic science applications . . . 30
   2.4. Data analysis . . . 31
      2.4.1. Calibration . . . 31
      2.4.2. Spectral pre-processing . . . 31
      2.4.3. Spectral analysis . . . 32
      2.4.4. Image processing . . . 32
3. Forensic science applications . . . 33
   3.1. Fingermarks . . . 33
      3.1.1. Detection and enhancement of untreated fingermarks . . . 33
      3.1.2. Detection and enhancement of treated fingermarks . . . 34
      3.1.3. Detection and identification of trace contaminations in fingermarks . . . 34
4. Other traces . . . 35
5. Typical challenges . . . 37
6. Future applications . . . 37
7. Conclusion . . . 38
References . . . 38

1. Introduction

The detection and identification of forensic traces are crucial in crime scene investigations. For this purpose a wide range of techniques is available, including chemical enhancement techniques and the use of light sources with 15–30 nm bandwidths,

* Corresponding author at: Department of Biomedical Engineering and Physics, Academic Medical Center Amsterdam, P.O. Box 22700, 1100 DE Amsterdam, The Netherlands. Tel.: +31 20 566 8540.
E-mail addresses: G.J.Edelman@amc.uva.nl, gerdaedelman@gmail.com (G.J. Edelman).

0379-0738/$ – see front matter
http://dx.doi.org/10.1016/j.forsciint.2012.09.012

which increase the contrast between a trace and its background. Many of these techniques are, however, either destructive or subject to human interpretation. Hyperspectral imaging (HSI) is suitable for the non-contact identification of evidence, thus minimizing the risk of contamination and destruction of traces. HSI integrates conventional imaging and spectroscopy to obtain a three dimensional data set containing both spatial and spectral information of a specimen. In addition, analysis of the temporal behavior of spectra can give insight in the chemical changes within the specimen, which can be used for age estimation purposes. Estimation of the age of forensic traces provides investigators with valuable information, which can assist the reconstruction of the timeline of events.

HSI was originally developed for remote sensing applications utilizing satellite imaging data of the earth [1] but has since found application in such diverse fields as food science [2], pharmaceuticals [3] and medical diagnostics [4]. Hyperspectral images are analogous to a stack of images, each acquired at a narrow spectral band. Like spectroscopy, HSI can be applied in different parts of the electromagnetic spectrum, e.g. ultraviolet (UV), visible (Vis), near infrared (NIR), mid infrared (IR) or even the thermal infrared range. In these regions reflectance, transmission, photoluminescence, luminescence or Raman scattering can be recorded by hyperspectral cameras with a spectral resolution similar to miniature spectrographs. Spatial resolutions can be adapted to the application, which range from microscopic to landscapes. Advantages of HSI include speed of data acquisition, reduction of human error, no destruction of traces, no specimen preparation, and the ability to illustrate the results.

HSI is a powerful emerging tool for the analysis of forensic traces. Latent traces can be detected and visualized by using spectral differences to obtain optimal contrast between a trace and its background. Individual spectra give information about the chemical composition of the specimen, which is useful for identification and quantification purposes, and the spatial distribution of traces is simultaneously recorded. In the last decade, HSI has proven to be a valuable technique for the imaging of latent fingermarks and the detection of trace materials within these prints. HSI is also emerging in other fields of forensic science and has shown its value in comparative research of materials including fibers, paint chips, or inks, where the question arises whether two traces share common origin. The possibility of viewing spectral and spatial information side by side is advantageous in these cases.

Recent developments in HSI technology offer added potential for forensic science investigations. Because HSI systems are becoming increasingly portable, they may be used at the scene of investigation, where traces can be viewed and interpreted in the original context. The development of fast scanning systems enables investigators to scan a complete scene, which reduces the workload in forensic laboratories and quickly provides investigators with valuable information which can lead the investigation.

This paper gives an overview of the principles, instrumentation and analytical techniques involved in HSI, followed by a review of recent forensic science applications. We limited our scope to HSI applications using reflectance, photoluminescence, transmission or Raman scattering. Because forensic traces are typically encountered in many different environmental circumstances, their analysis brings specific challenges, which are also addressed. To conclude, possible future applications are summarized.

2. Hyperspectral imaging

2.1. Interaction of light and matter

The interaction between light and a specimen is determined by the optical properties of the specimen and the incident light. As hyperspectral imaging measures such interaction, it may be used to characterize the material. In practice this involves illumination of the object under investigation. Commonly, the first interaction will be on the specimen surface where part of the light will be reflected (Fig. 1a). This part contains no to little information from within the medium but is governed by the index of refraction difference between media. Upon entering the material, the light can be scattered or absorbed.

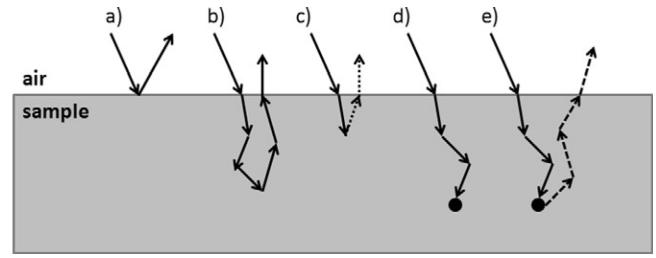

Fig. 1. The interaction of light with a specimen may lead to (a) specular reflection, (b) elastic scattering followed by diffuse reflection, (c) inelastic scattering followed by emission of Raman shifted light (dotted lines), (d) absorption, and (e) absorption followed by photoluminescence emission (dashed lines).

Scattering is the process by which light interacts with structures in a specimen and causes a change in direction of propagation, depending on the wavelength, size of the particle and index of refraction differences (Fig. 1b). The majority of light is scattered at the identical wavelength of the incident light, a process referred to as elastic scattering. There may also be a small fraction that will be inelastically scattered (Raman scattering) which will cause wavelength shifts corresponding to the vibrational states of the molecules in the specimen (Fig. 1c). Raman scattering can be measured to chemically analyze the scattering specimen.

The absorption properties of a chemical compound are wavelength dependent. Absorption in the visible wavelength range corresponds to the electronic states of the molecule, while absorption in the NIR and IR is determined by the vibrational modes. Upon relaxation, return to the ground state, the energy will be released in the form of radiation (heat or photoluminescence) or

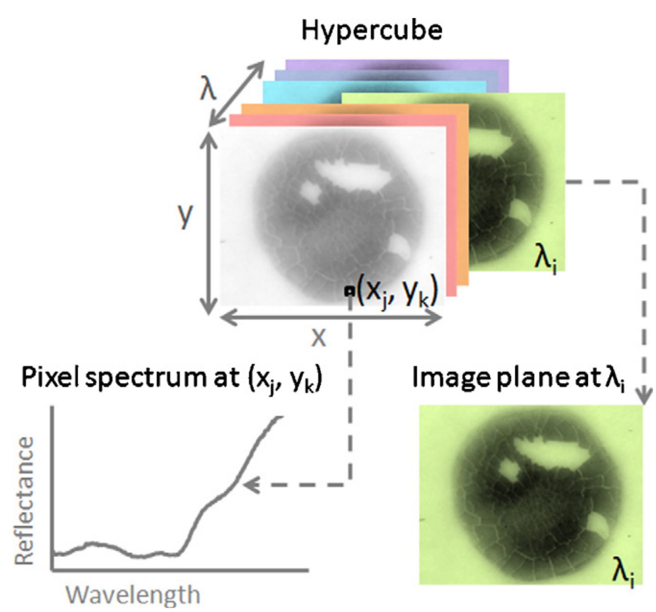

Fig. 2. Hypercube of a blood stain, with two spatial (*x*,*y*) and one wavelength (λ) dimension. From the hypercube an image plane is shown for one wavelength (λ_i) and a spectrum is obtained from one pixel (x_j,y_k).