Forensic Science in the 21st Century - Will Trace Evidence Ever Reach the Next Level?

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Abstract

The key role of a forensic scientist is to assist in determining whether a crime has been committed, and if so, assist in the identification of the offender. The analytical component of any procedure is a crucial step, along with the development of hypotheses and the interpretation of results in the context of the case. Most forensic analyses and comparisons are essentially a reduction process whereby the scientist aims at distinguishing between different sources of the same sample or substance. In this context, it is widely recognised that some forms of forensic evidence are more valuable than others, fingerprints and DNA being at the top end of this spectrum. However, analytical sciences have seen extraordinary developments in recent years. Some questions remain: Will trace evidence ever reach a similar level? And, perhaps more importantly, is such extreme discrimination really the most significant feature for trace evidence? It is argued that trace evidence is a value-added source of information for the reconstruction of a case, and that this kind of information is rarely obtained with other types of forensic evidence. This gives intrinsic value to a

type of evidence that may appear to have less indentification power or to be less economically viable than other types of forensic evidence.

This paper will discuss these topics and also review recent technological advances that may impact on forensic science in the near future. It will focus on techniques that have been recently at the core of collaborative research between the University of Technology, Sydney and the Australian Federal Police: hyperspectral imaging (or chemical imaging), isotope ratio mass spectrometry and lab-on-a-chip devices. All these techniques have demonstrated some promise for forensic applications and may soon find a place in routine forensic science.

Introduction

Historically, trace evidence is at the core of forensic science, having played a crucial role in the development of forensic science in the 20th century, prompted by the seminal work of pioneers such as Gross, Reiss and Locard [1-3]. However, the face of trace evidence changed dramatically in the last 20 years. The global adoption of DNA as forensic evidence has been the catalyst, if not the main driver of these changes. Forensic science processes and laboratory infrastructures and organisations had to be significantly modified to embrace the “DNA revolution”. DNA profiling has become increasingly sensitive and selective, as well as extremely valuable in leading investigations through the advent of DNA databases. During this time, trace evidence, as a discipline, had to adapt and learn to live with less funding and a downgraded status.

It is widely recognised that some forms of forensic evidence are more valuable than others, fingerprints and DNA being at the top end of this spectrum. There is little doubt that, in most cases, trace evidence is of less identifying value than these two other types of forensic evidence. In addition, the examination of trace evidence is a costly exercise compared to routine DNA analysis or fingerprint detection. This apparent cost-benefit issue prompted some discussions from various authors in recent years. It is beyond the scope of this paper to present them all here. However, Figure 1 presents a visual summary of the situation.

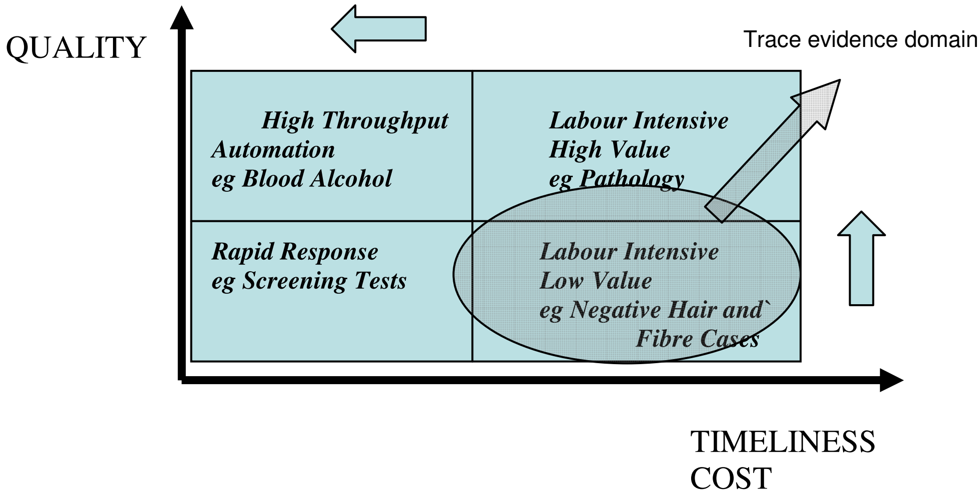


Figure 1: Quality, timeliness and cost of various forensic science procedures (courtesy of Dr. Hilton Kobus, adapted from [4])

In reality, these two dimensions are often intertwined and a two-dimensional model may appear simplistic to some readers. However, it identifies two ways to improve the overall benefit of trace evidence (Figure 1):

1. To improve the value of the information provided by trace evidence; and
2. To reduce the time and cost of trace evidence examination.

These aims present significant challenges for the trace evidence discipline, and such a debate is unavoidable. It also offers opportunities to re-shape the face of trace evidence. Some arguments are presented in this paper, along with recent technological advances that may impact on forensic science in the near future.

Improving the Value of Trace Evidence

Most forensic analyses, and in particular trace evidence comparisons, are essentially a reduction process whereby the scientist aims at distinguishing between different sources of the same sample or substance. If no meaningful differences could be found, then it can be inferred that the two samples *could come from the same source*. It must be recognised that such a conclusion is not sufficient as it does not evaluate the strength of the apparent associative link (i.e. the '*could have* *come from*' statement is seen as independent of the circumstances, which is rather misleading). There is some uncertainty attached to this link and, further, this level of uncertainty can be widely variable depending on a number of objective and subjective parameters. Being more informative and more accurate in the conclusion would undoubtedly improve the value of trace evidence.

In accordance with Ribaux and Margot [5] individualisation [6] and identification (or, more accurately, inference of identity of source [7]) are essential concepts. Further, the application of a coherent model based on subjective probabilities (Bayesian framework [8-10] has become standard practice in a number of forensic science disciplines, especially DNA [11]. However, such a model is less widely applied in trace evidence, mainly because of the lack of background data that are needed for its effective application. One notable exception is glass evidence [12] and to a lesser extent fibres [13]. It is argued here that these efforts in designing research to produce relevant and reliable statistical data should be significantly expanded to most, if not all, types of trace evidence. This will eventually improve the value of trace evidence.

The discussion above focused on the traditional use of trace evidence in court. However, it is well known and accepted that the application of forensic science, including trace evidence, starts at the scene. In other words, the value of trace evidence does not only reside in it ability to support the proposition that, say, *60 fibres come from a given jumper*, but also to give investigative leads in the absence of comparative material. This is in addition to assisting in reconstructing the scene or a series of events, identifying links between different cases or, more broadly, systematically analysing large scale criminal phenomena. The value of integrating traditional forensic evidence with other dimensions of the investigative process has recently been highlighted by research in an area known as forensic intelligence [14-17]. In our opinion, although rapidly growing, this novel application of forensic science data is still under-exploited. When this potential is fully realised, the value of trace evidence will also be upgraded because it can be seen as a crucial source of information in an investigative or intelligence framework.

Reducing the Time and Cost of Trace Evidence Examination

One of the novel forensic science approaches whose implementation has been accelerated by tragic events such as September 11 or the Bali bombings is the shift of analytical procedures from the laboratory to the crime scene [18]. By doing so, modern forensic science is able to provide a quick, if not real-time response. The benefits for law enforcement and national security are obvious. But, in general, these benefits come at the cost of less confidence in the analytical results. In other words, the need for a quicker forensic response is somewhat traded off against the reliability of the results. Results obtained this way are certainly acceptable in an intelligence or tactical context, but still require confirmatory laboratory tests to stand up in court. It is believed that current and future technological advances will fill the gap and an increasing number of tests with an acceptable degree of reliability will be applied at the scene in the near future.

Unfortunately, most forensic science laboratories are still faced with the following problems that hinder this approach:

- Most forensic testing is done in the laboratory;
- The equipment tends to be large and expensive;
- A large amount of laboratory space is required;
- It takes time to transport samples to the laboratory;
- It takes time to process each sample and produce a result;
- Most laboratories work with significant backlogs; so
- Often the analytical results are not available until the police investigation is nearly (or is already) completed.

Analytical sciences have seen extraordinary developments in recent years. To some extent, they also drove, or at least sped up, recent significant technology transfers into forensic science. However, there is a real risk of falling into a 'gadgetry' trap if the following conditions are not met:

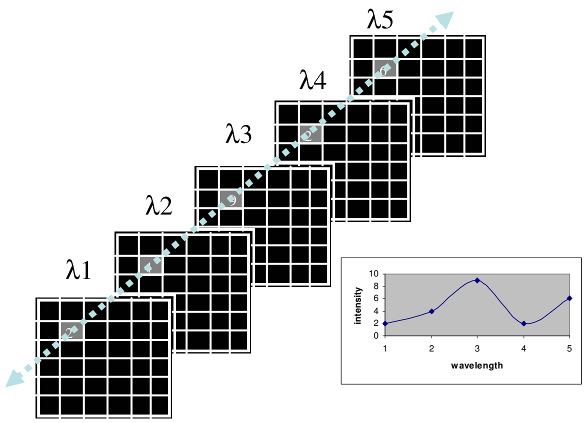
- The technology must be fit for purpose and must remain a tool;

- Technology transfer and adoption must occur with prime consideration of the forensic context (i.e. holistic forensic science approach from the detection of evidence to the interpretation of results).

Techniques that have recently been at the core of collaborative research between the University of Technology, Sydney, and the Australian Federal Police are presented below as examples of promising emerging technologies.

Hyperspectral Imaging

Hyperspectral imaging (chemical imaging) combines molecular spectroscopy and digital imaging, providing both spatial and spectral information of materials (Figure 2). Chemometric processes, such as principal components analysis (PCA), can be applied to the raw data, allowing for information to be extracted from the large data sets that are generated. This technology is applicable in various spectral ranges (vis–NIR and mid-IR regions) and magnifications.



Exline, D. L.; Nelson, M. P.; Smith, R. D.; Treado, P. J.; "Forensic Examination of Synthetic Fibers Using Raman Chemical Imaging"; Presented at The Pittsburgh Conference, New Orleans, LA, March 2001

Figure 2: Schematic summarising the principles of chemical imaging. Light intensity is recorded as a function of both wavelength and location. The resulting data set can be seen as a full image at each λ or as a full spectrum at each pixel.

The potential for the use of visible and near infrared chemical imaging in forensic applications has been demonstrated previously in the areas of fingerprint detection, ink analysis, and bruise age estimation [19-22]. A paper presented at the current Trace Evidence Symposium investigated the potential use of fluorescence chemical imaging for the detection and analysis of firearm propellants [23].

Significant work has also been undertaken in the mid-IR range [24-26]. Another paper presented at the present conference highlights applications in the area of automotive paint chips, bicomponent fibres and the detection of illicit substances in fingerprints [27].

The reader is invited to read [23, 27] to see detailed examples of application.

Isotope ratio mass spectrometry

Stable isotope ratio mass spectrometry (IRMS) is based on the precise and accurate measurement of variations in the natural isotopic abundance of light stable isotopes. The underlying principle is that if the isotopic compositions of two samples are indistinguishable, and isotopic fractionation can be excluded from having occurred during handling, analysis, etc., then the two samples are likely to have originated from the same source. A difference may indicate that the two samples originated from different sources. Amongst a large number of applications, those related to forensic science include: explosives, ignitable liquids, drugs and most types of trace/physical evidence [28].

The Australian Federal Police (AFP) is in the process of developing and validating methods for the analysis of explosives using IRMS. A range of different explosives are being analysed from manufacturers in the region. Field experiments have been conducted and post-blast samples will be analysed by IRMS for comparison with pre-blast samples. The overall aim is to create an explosives database incorporating products manufactured in Australia and in the South-East Asian region.

Preliminary results based on carbon and nitrogen isotope ratios show that IRMS has the potential to discriminate samples from different PETN manufacturers (Figure 3). Methods and procedures for the measurement of oxygen and hydrogen isotope ratios are currently being validated.

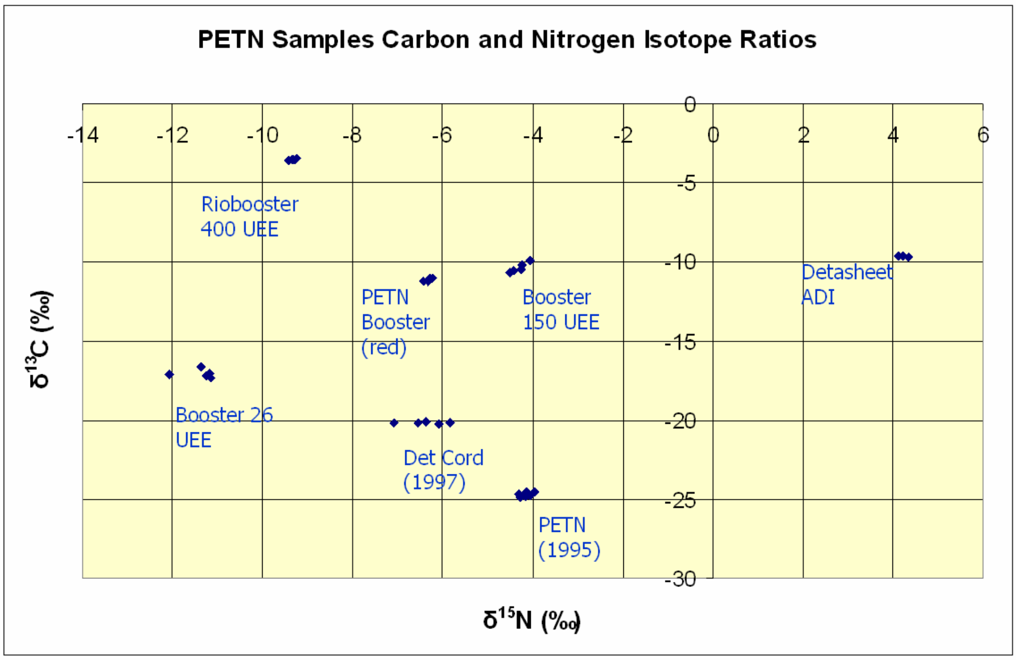


Figure 3: Preliminary results showing the potential of IRMS to differentiate between different sources of the same substance (PETN) [29]

Lab-On-A-Chip

The miniaturisation of chemical instrumentation using micro-fabrication technology is an emerging area of analytical research that has been developed over the past ten years. These so-called lab-on-a-chip (LOC) devices dramatically downscale the analytical processes and can incorporate a wide variety of separation and detection methodologies. The main advantage of LOC devices is their amenability to field detection of DNA, illicit drugs and explosive residues. By doing so, they blur the artificial boundary between the scene and the laboratory. They also allow modern forensic science to provide a quick, if not real-time response with little trade-off in terms of discrimination and reliability.

Figures 4 and 5 present fast separations of organic explosives obtained using an Agilent Bioanalyser 2100 platform as part of a collaborative research project in the area of counter-terrorism [30].

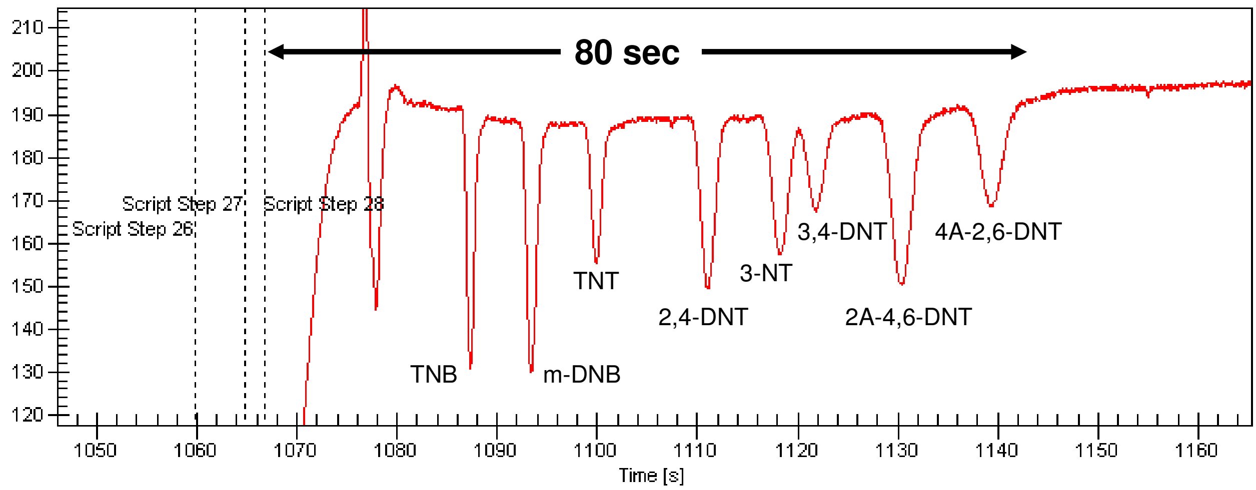


Figure 4: Separation obtained using an Agilent Bioanalyser 2100 platform. Electrolyte: 50mM SDS & 50mM Borate with 1.5% AgilentTM Dye (v/v).

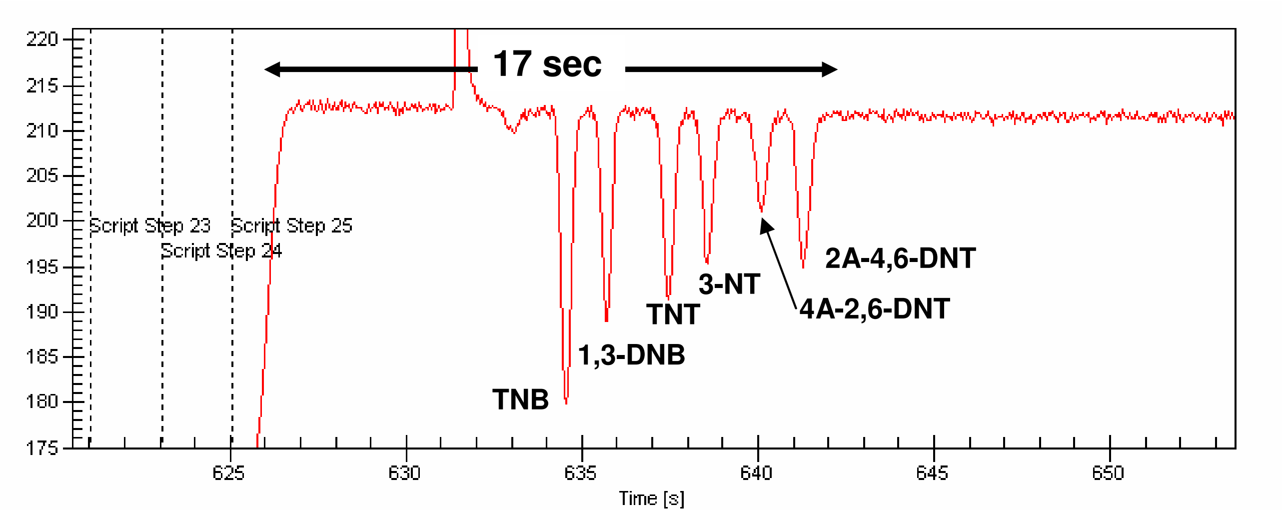


Figure 5: Separation obtained using an Agilent Bioanalyser 2100 platform. Electrolyte: 50mM Borate & 25mM SDS with 1.5% Agilent DNATM Dye (v/v).

Discussion and Conclusions

Economic realities and the change of status of trace evidence undoubtedly present significant challenges for this discipline. There is little doubt that it has become necessary to re-assess the place and shape of the trace evidence discipline, as well as the need to think about new models applicable to trace evidence. As usual, challenges also bring opportunities. The successful re-emergence of trace evidence in the 21st Century will depend on:

- *The end of ultra-specialisation (eg. glass expert as opposed to paint expert, etc), and a return to the generalist approach*: This may be driven by funding considerations. It could also be seen as a paradox considering the rapid technological developments requiring increasingly specialised personnel. However, successfully managing this change will remove artificial silos and deliver significant benefits to forensic science. Trace evidence experts with a holistic view of forensic science will optimise the value that can be drawn from trace evidence, both from court and intelligence viewpoints.

- *The successful implementation of relevant emerging technologies*: This will blur the boundaries between lab and field forensic science. It will also streamline the analytical process leading to quicker results. It will also free up the forensic scientist who can in turn have more time to spend on difficult cases, background surveys assisting evidence interpretation, etc., leading to more meaningful trace evidence results.
- *The realisation that discrimination is not the most significant feature for trace evidence*: Trace evidence is a value-added source of information for the reconstruction of a case, or, more broadly, for investigative purposes. This kind of information is rarely obtained with other types of forensic evidence, especially those focusing on identification only. In other words, the trace evidence discipline should not be shy of this apparent shortcoming. The combination of trace evidence with 'identifying evidence' can deliver the key to the famous questions "what happened?" and "who dun it?".
- *A more general engagement with the DNA and the fingerprint disciplines*: These two other types of evidence are essentially trace evidence in nature. They rely on the transfer, persistence, detection, collection and successful examination of material – biological material for DNA and a complex mixture of human secretions and external contaminations for fingerprints. As a result, many of the issues, and also solutions, are very similar for all three disciplines. Unfortunately, artificial boundaries still exist because of different historical developments and pathways. A more coherent approach will benefit all three disciplines and, in turn, forensic science as a whole.

Overall, the future of trace evidence is much brighter than one might think. It is up to those involved in this discipline to face the challenges, seize the opportunities and convince the stakeholders that trace evidence plays a crucial role in law enforcement and in the administration of justice. Implementing the right strategic directions will not only 'save' trace evidence, but also prompt its re-emergence.

Acknowledgments

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