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Review article

Modern statistical models for forensic fingerprint examinations: A critical review

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ABSTRACT

Over the last decade, the development of statistical models in support of forensic fingerprint identification has been the subject of increasing research attention, spurned on recently by commentators who claim that the scientific basis for fingerprint identification has not been adequately demonstrated. Such models are increasingly seen as useful tools in support of the fingerprint identification process within or in addition to the ACE-V framework.

This paper provides a critical review of recent statistical models from both a practical and theoretical perspective. This includes analysis of models of two different methodologies: Probability of Random Correspondence (PRC) models that focus on calculating probabilities of the occurrence of fingerprint configurations for a given population, and Likelihood Ratio (LR) models which use analysis of corresponding features of fingerprints to derive a likelihood value representing the evidential weighting for a potential source.

Contents

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1. Introduction

Fingerprints have been widely used throughout the world as a means of identification for forensic purposes. Forensic experts have extensively relied on the premises that fingerprint characteristics are highly discriminatory and immutable amongst the general population. For the majority of the 20th century, the forensic identification of fingerprints has had near unanimous acceptance as robust forensic evidence, where testimonies provided by fingerprint experts were rarely challenged and the philosophical foundations of such testimonies were rarely questioned. However, in recent times, there has been a number of questions raised regarding the scientific validity of forensic fingerprint identification [1–4].

The current wave of scrutiny in North America is largely associated with the Daubert decision [5] by the Supreme Court in the USA, concerning expert evidence admissibility. In the 1993 case of Daubert v. Merrell Dow Pharmaceuticals [6] a ruling was made that outlined criteria concerning the admissibility of scientific expert testimony, based somewhat on criteria used in the broader scientific community. The criteria for a valid scientific method were stated as being as follows:

- must be based on testable and falsifiable theories or techniques,
- must be subjected to peer-review and publication,
- must have known or predictable error rates,
- must have standards and controls concerning its applications, and
- must be generally accepted by a relevant scientific community.

The guidelines for expert testimony admissibility from Daubert have since influenced international jurisdictions, with the UK Law Commission's recent expert evidence consultation paper [7] also prescribing similar standards (with an emphasis on scientific method more so than falsifiability).

Fingerprint identification via the ACE-V (Analysis, Comparison, Evaluation, and Verification) framework [9] has been subjected to scrutiny from a number of academics and legal commentators, who have cited the following objections [8]:

- the unfounded and unfalsifiable theoretical foundations of fingerprint feature discriminability,
- the 'unscientific' absolute conclusions of identification in testimonies (i.e., either identification, exclusion, or inconclusive), and
- the contextual bias of experts for decisions made within the ACE-V framework.

While contextual bias is primarily concerned with influences on accuracy and consistency of practitioners within the ACE-V process [10–12], the remaining criticisms can be restated as the non-existence of a scientifically sound probabilistic framework for fingerprint evidential assessment, that has the consensual approval from the forensic science community.

The traditional theoretical foundations of fingerprint identification primarily rest on observational science, where a high discriminability of feature characteristics exists. However, there is a lack of consensus regarding quantifiable error rates for a given pair of 'corresponding' feature configurations [13]. Some critics have invoked a more traditional interpretation for discriminability [14,15], claiming that an assumption of 'uniqueness' is used. This clearly violates the falsifiable requirement of Daubert. However, more and more experts do not necessarily associate discriminability with uniqueness [16]. Nevertheless, a consensus framework for calculating accurate error rates for corresponding fingerprint features needs to be established.

The conclusions of identification [20] made by fingerprint practitioners have historical influence from Edmond Locard's *tripartite rule* [21]. The tripartite rule is as follows:

- Positive identifications are possible when there are more than 12 minutiae within sharp quality fingermarks.
- If 8–12 minutiae are involved, then the case is borderline. Certainty of identity will depend on additional information such as finger mark quality, rarity of pattern, presence of the core, delta(s), and pores, and ridge shape characteristics, along with agreement by at least 2 practitioners.
- If a limited number of minutiae are present, the fingermarks cannot provide certainty for an identification, but only a presumption of strength proportional to the number of minutiae.

In a holistic sense, the tripartite rule can be viewed as a probabilistic framework, where the successful applications of the first and second rules are analogous to a statement with certainty that the mark and the print share the same source, whereas the third rule covers the probability range between 0% and 100%. While some jurisdictions only apply the first rule to set a numerical standard within the ACE-V framework, other jurisdictions (such as Australia, UK, and USA [22]) adopt a holistic approach, where no strict numerical standard or feature combination is prescribed. Nevertheless, current fingerprint practitioner testimony is largely restricted to conclusions that convey a statement of certainty, ignoring the third rule's probabilistic outcome.

A probabilistic framework for fingerprint identification has not been historically popular and was even previously banned by professional bodies (see [23]). In recent times however, a probabilistic framework for fingerprint identification has had more favourable treatment within the forensic community. It was suggested in [24] that a probabilistic framework is based on strong scientific principles unlike the traditional numerical standards. In