Statistical Meta-Analysis of Presentation Attacks for Secure Multibiometric Systems

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Abstract—Prior work has shown that multibiometric systems are vulnerable to presentation attacks, assuming that their matching score distribution is identical to that of genuine users, without fabricating any fake trait. We have recently shown that this assumption is not representative of current fingerprint and face presentation attacks, leading one to overestimate the vulnerability of multibiometric systems, and to design less effective fusion rules. In this paper, we overcome these limitations by proposing a statistical meta-model of face and fingerprint presentation attacks that characterizes a wider family of fake score distributions, including distributions of known and, potentially, unknown attacks. This allows us to perform a thorough security evaluation of multibiometric systems against presentation attacks, quantifying how their vulnerability may vary also under attacks that are different from those considered during design, through an uncertainty analysis. We empirically show that our approach can reliably predict the performance of multibiometric systems even under never-before-seen face and fingerprint presentation attacks, and that the secure fusion rules designed using our approach can exhibit an improved trade-off between the performance in the absence and in the presence of attack. We finally argue that our method can be extended to other biometrics besides faces and fingerprints.

Index Terms—statistical meta-analysis, uncertainty analysis, presentation attacks, security evaluation, secure multibiometric fusion.

1 INTRODUCTION

THE widespread use of biometric identity recognition systems is severely limited by security threats arising from several kinds of potential attacks [1]–[3]. In particular, the use of fake biometric traits (*e.g.*, gummy fingers [4]), also known as "direct", "spoofing" or "presentation" attacks [1], [2], [5]–[7], has the greatest practical relevance as it does not require advanced technical skills. Accordingly, the potential number of attackers is very large. Vulnerability to presentation attacks has been studied mostly for unimodal fingerprint and face recognition systems [4], [8]–[10]. Multibiometric systems have been considered *intrinsically* more secure, instead, based on the intuition that an attacker should spoof all the biometric traits to successfully impersonate the targeted client [11], [12].

This claim has been questioned in subsequent work, showing that an attacker may successfully spoof a multibiometric system even if only one (or a subset) of the combined traits is counterfeited, if the fusion rule is not designed by taking that into account [13]–[15]. From a computer security perspective, this is not surprising: it is well-known that the security of a system relies the most on the security of its *weakest link* [16]. This vulnerability of multibiometric fusion has been shown under the assumption that the fake score distribution at the output of the attacked matcher is identical to that of genuine users, without fabricating any fake trait. Under the same assumption, more secure fusion rules against presentation attacks have also been proposed.

In our recent work, through an extensive experimental analysis, we have shown that the aforementioned assumption is not representative of current face and fingerprint presentation attacks [17]–[19]. In fact, their fake score distributions do not only rarely match those of genuine users, but they can also be very different, depending on the technique, materials, and source images used to fabricate the presentation attack; *i.e.*, presentation attacks can have a different *impact* on the output of the targeted matcher. For these reasons, the methodology proposed in [13]–[15] may not only provide an overly-pessimistic security evaluation of multibiometric systems to presentation attacks, but also lead one to design secure fusion rules that exhibit a too pessimistic trade-off between the performance in the absence of attack and that under attack.

To perform a more complete analysis of the security of multibiometric systems, as shown in [17]–[21], considering only one or a few known attacks is not sufficient. One should thus face the cumbersome and time-consuming task of collecting or fabricating a large, representative set of presentation attacks (with different impact on the attacked matchers) for each biometric characteristic, and evaluate their subsequent effect on the fusion rule and on system security. However, even in this case, one may not be able to understand how multibiometric systems may behave under scenarios that are different from those considered during design, including presentation attacks fabricated with novel materials or techniques, that may produce *different*, *never-before-seen* fake score distributions at the matchers' output.

In this paper, we propose a methodology for evaluating the security of multibiometric systems to presentation at-

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Statistical Meta Information Systems

Karl A. Froeschl

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