MINUTIAE MANIPULATION FOR BIOMETRIC ATTACKS

Simulating the Effects of Scarring and Skin Grafting

NOVETTA

Minutiae Manipulation for Biometric Attacks

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INTRODUCTION

Secure applications of biometric systems require vulnerability assessments against realistic attacks. One type of attack is a physical spoofing attack; an impostor fingerprint is presented to the sensor instead of a genuine presentation. Spoofing attacks have been reported at border crossing checkpoints and in employee time keeping systems [1] [2].

This study evaluates the impact on biometric performance for two spoofing attacks encountered in the field involving manipulated fingerprints: intentional scarring and skin grafting. These spoofing attacks are emulated using altered artefacts to simulate the effects of scarring and skin grafting. Three types of artefacts were tested:

- Unaltered artefacts
- Artefacts with simulated scarring, added by etching
- Artefacts with simulated skin grafting, accomplished by combining two fingerprints

This study provides greater insight into the capabilities of biometric matching algorithms to withstand these spoofing attacks. Conducting spoofing studies is one of Novetta's many approaches to vulnerability testing.

SPOOFING ATTACKS AND ENGINEERING CONTROLS

Fingerprint sensors are used extensively at border crossings and for physical and logical access. Denied person lists often exist for these systems to restrict entry or access to users for prior violations. These lists use 1:N identification, often in conjunction with 1:1 verification. Biometric systems utilizing denied person lists are targets for physical spoofing attacks: Both identity fraud (matching someone else) and identity concealment (not matching yourself).

Highly publicized cases, including that of Jose Arechiga Gamboa, show the extreme measures attackers will use to cross borders undetected. Gamboa used a deceased man's name, a fraudulent passport, facial plastic surgery, and fingerprint alteration surgery to cross the US-Mexico border [3].

In addition, doctors sell fingerprint alteration and skin grafting services on the black market. Several documented cases exist featuring purposefully altered fingerprints, including fingerprint obfuscation through scarring [5].

Spoofing attacks, such as fingerprint obfuscation through scarring and skin grafting, have been encountered in the field.

One doctor was charged with conspiracy to conceal illegal aliens after selling fingerprint alteration services for $4,500 [6]. A 2009 case, discovered due to the presence of surgical scars (rather than the collected biometric data), involved a woman switching her right and left fingerprints via skin graft surgery [2] [4]. Authorities have found these surgeries fairly common among individuals desperate to gain entrance into Japan.

These documented attacks remind biometric system developers of potential system vulnerabilities. Engineering controls can be used to minimize some of these vulnerabilities including:.

Attended presentations

Attended biometric systems allow the attendant to detect unusual scarring on a user's fingerprints.

Software or hardware based liveness detection

Liveness detection software and hardware facilitate distinguishing between living and nonliving tissue.

Altered fingerprint detection algorithms

Altered fingerprint detection algorithms use known information about genuine fingerprints, such as minutiae density and ridge flow, to detect unusual features in captured fingerprint images. Studies have shown this technique is capable of detecting several types of fingerprint alterations and that alterations detected in five or more digits is a strong indication of deliberately altered prints. A ridge flow analysis can achieve a true detection rate of up to 92% [7] [8].

Multimodal biometrics

Multimodal biometric systems combine the verification (and/or identification) results from multiple biometric modalities. This makes spoofing the system more difficult, as all modalities used must be spoofed.

FABRICATION OF TESTED ARTEFACTS

Artefacts were fabricated using a cooperative mold in all cases. For comparison purposes, all artefacts were of the same genuine finger and all types of artefacts were made of the same material - breathable latex paint. Three types of artefacts were tested:

- Unaltered artefacts
- Artefacts with simulated scarring added by etching
- Artefacts with simulated skin grafting, accomplished by combining two fingerprints: the original print and the added print

Artefacts simulating scarring were fabricated through a two-step molding and casting process. A positive was cast from the original cooperative mold then defaced to introduce scar-like notches obscuring some genuine minutiae. A second mold was then created from the defaced positive. This second mold was used to fabricate scarred artefacts.

Simulating skin grafting was more difficult than simulating scarring. Simulating skin grafting involved combining the pattern from two different fingerprints. The fabrication process did not combine two molds directly as this would introduce potential misalignment and gapping issues. Instead, a mold was made of the added print and cut into quarters. A single quarter was used to mask a portion of the original finger. The original finger, with added mask, was then cast into a single, combined mold. The combined mold was used to fabricate grafted artefacts.

ARTEFACT TESTING

Measures were taken to eliminate inherent biases. Simulated scarring and simulated skin grafting artefacts were fabricated concurrently over several days. For each artefact type, twelve samples were fabricated and tested with 10 replicate presentations per sample. Biometric presentations were collected over a one month period in randomized order.

An optical fingerprint sensor (CrossMatch's Guardian R) was used to capture all biometric presentations, due to its use at US border crossings. Neurotechnology VeriFinger software was used for fingerprint enrollment and matching.

All presentations were compared to an enrolled genuine biometric reference. The matching threshold was set at 80.

In addition to analyzing the effect on biometric performance of simulated scarring and simulated skin grafting, collected fingerprint images were visually inspected. Visual inspection provided insight into the impact of different alteration characteristics.

Representative biometric images of each artefact type are shown in Figure 1 thru Figure 3. The unaltered artefact (Figure 1) shows a continuous fingerprint pattern with inherent horizontal creases most often attributed to dryness. These creases are typically treated as noise within the presentation by the algorithms and filled in without impact on minutiae points.

Artefacts simulating scarring (Figure 2) show a discontinuous pattern with etch marks that are of similar size or larger, compared to creases in the unaltered print. The length, width, position, and angle relative to the localized ridge flow of introduced etching vary. Artefacts simulating skin grafting (Figure 3) show a continuous fingerprint pattern with ridge flow inconsistencies around the edge between the original and added fingerprint.

Figure 1: Example biometric presentation of unaltered artefact

Figure 2: Example biometric presentation of simulated scarring artefact

Figure 3: Example biometric presentation of simulated skin grafting artefact

TEST RESULTS: EFFECT OF SIMULATED SCARRING

Simulated scarring introduced the following changes:

- Ridge flow distortion
- Minutiae changes
- Empty spaces within the fingerprint presentation

The level of efficacy of this alteration technique depends on the properties of the simulated scars and their relation to the genuine fingerprint pattern. Introduced scar length and width, overall scar count, and angle of scars were less important than the number of impacted minutiae.

In general, thin scars less than 0.01" in width were ineffective; minutiae detection filled in the missing ridge flow data for thin scars, as for naturally occurring creases. Thick scars in close clustering were more effective at lowering match scores than sporadic long, thin scars, as thick, closely clustered scars introduced a greater degree of ridge flow disturbance.

The impact of simulated scarring on match score distribution is shown in Figure 4. Match scores of unaltered artefacts are shown for comparison. The two distributions have minimal overlap, indicating significant match score reduction due to simulated scarring. On average simulated scarring reduced match scores by 60%. However, despite significant match score reduction, only ~ 2% of simulated scarring samples had match scores below the matching threshold of 80.

The impact of simulated scarring on match scores was found to be related to three primary factors which describe the impact of simulated scarring on minutiae points:

- Number of genuine minutiae removed
- Number of genuine minutiae remaining
- Number of altered or introduced minutiae due to simulated scarring

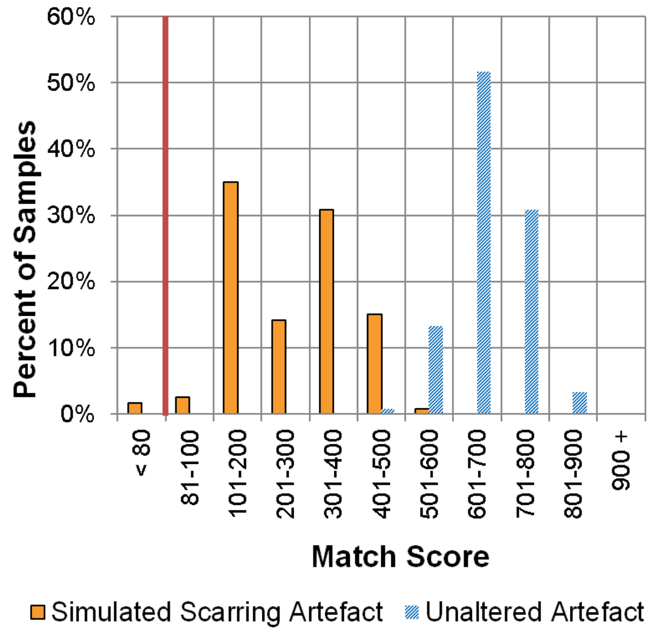

Figure 4: Match score distributions for unaltered and simulated scarring artefacts

Genuine minutiae remaining within the scarred artefact presentation increased match scores. Genuine minutiae removed through simulated scarring were caused by scars introduced at more crucial points in the ridge flow pattern. The absence of these minutiae contributed as much as altered or introduced minutiae to reduction of match scores.

The impact of minutiae changes of on match scores of simulated scarring artefacts is shown in Figure 5. The quantity of removed genuine minutiae and quantity of altered or introduced minutiae have a similar, positive relationship with decreasing match score.

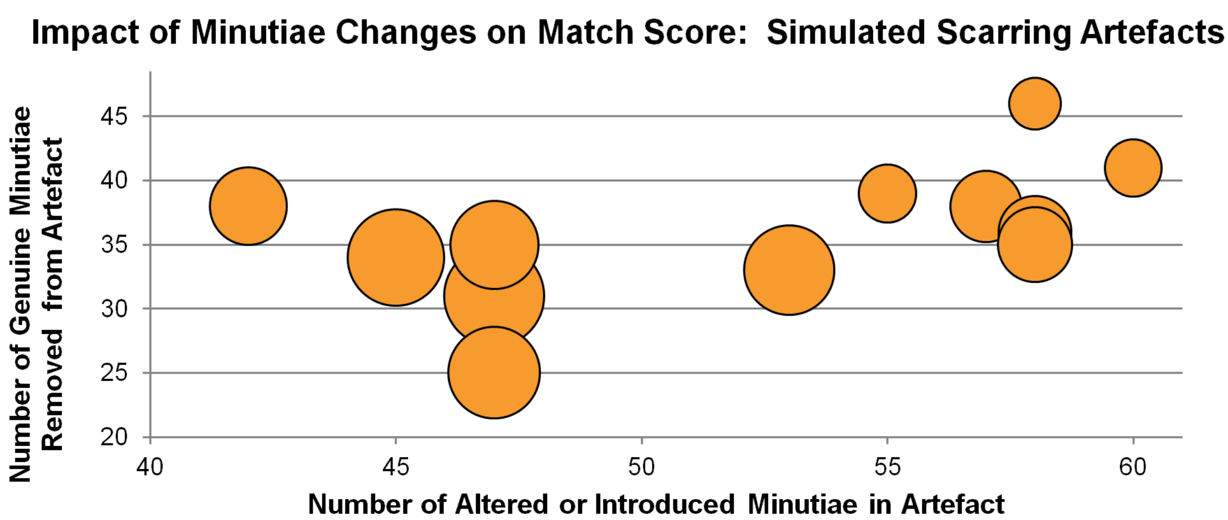

Figure 5: Impact of minutiae changes in simulated scarring artefacts on match score (depicted by data point size)

Although both unaltered and simulated scarring artefacts contained several genuine creases, the genuine creases had minimal to no impact of matching for unaltered artefacts. However, the genuine creases, possibly due to a compounded effect with introduced scarring did occasionally result in introduced minutiae within simulated scarring artefacts.

TEST RESULTS: EFFECT OF SIMULATED SKIN GRAFTING

Simulated skin grafting introduced the following changes within all presentations:

- Predominantly consistent ridge flow with a minor mismatching region
- Missing genuine minutiae
- Introduced minutiae at the original fingerprint-added fingerprint interface
- Disrupted core region

The impact of simulated skin grafting on match score distribution is shown in Figure 6. Match scores of unaltered artefacts are shown for comparison. The two distributions have overlap, indicating less pronounced match score reduction due to simulated skin grafting. On average simulated skin grafting reduced match scores by 40%.

Although all 12 simulated skin grafting artefacts matched the original fingerprint, 3 also matched the added fingerprint. These 3 artefacts had match scores around 100 for both the original and added fingerprints. Additionally, ~40% of the presentations for these 3 artefacts generated match scores below the match threshold (80).

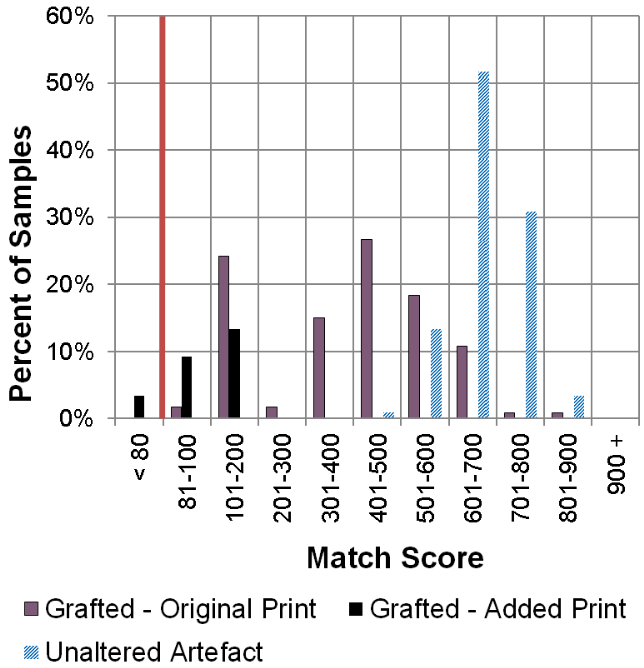

Figure 6: Match score distributions for unaltered and simulated skin grafting artefacts.

In general, simulated skin grafting artefacts had lower match scores if the core was distorted. Of the alteration parameters examined, percentage of added print visible within the presentation (i.e. grafted area) and number of changed minutiae had the most pronounced impact on match score, as shown in Figure 7.

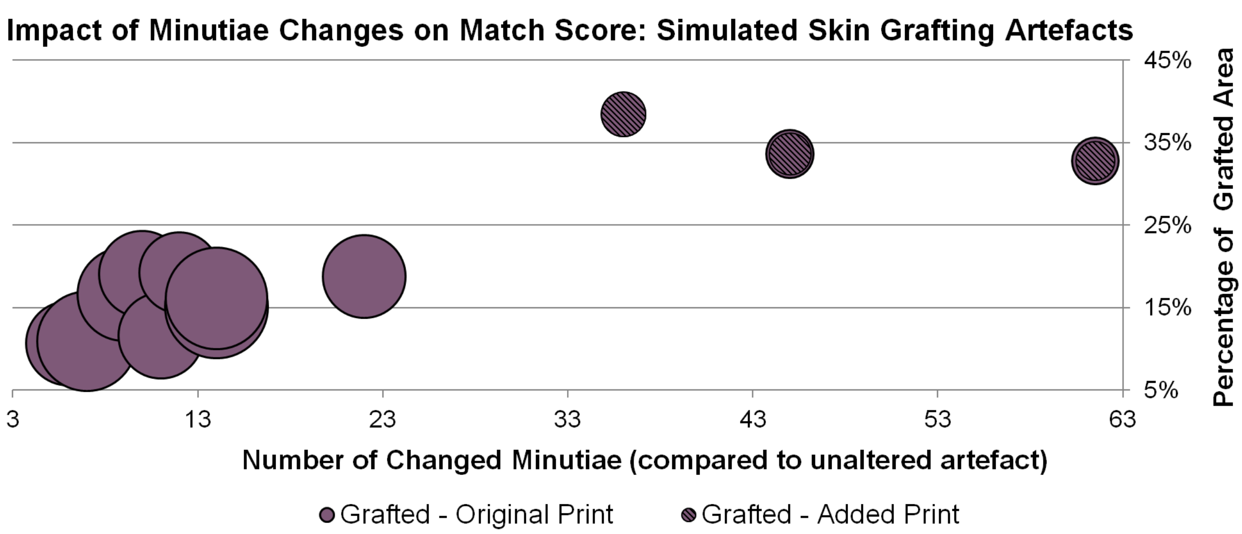

Figure 7: Impact of changed minutiae and size of grafted area in simulated skin grafting artefacts on match score (depicted by data point size)

CONCLUSIONS

This study investigated the impact of fingerprint alterations in biometric sensor attacks on match scores. Fingerprint manipulations encountered in the field were simulated using two artefact types:

1.) Simulated scarring
2.) Simulated skin grafting

These simulated alterations have shown how match scores are impacted by altered minutiae data. Both alteration methods reduced match scores; however, most samples still scored above the match threshold. Initial findings show that simulated scarring is less effective than simulated skin grafting at lowering match scores.

Simulated scarring resulted in an average match score reduction of 60%. Scar placement was determined to be vital to match score reduction: scars that removed genuine minutiae or induced more false minutiae were the most effective at lowering match scores.

Compared to simulated scarring artefacts, more simulated skin grafting artefacts scored below the match threshold. The impact of simulated skin grafting on match score depended on the percentage of grafted area in the biometric presentation and the number of changed minutiae. Twenty-five percent of the tested simulated skin grafting artefacts matched both the original and added fingerprint. These results open the possibility of a biometric attack where a reference biometric is comprised of two genuine fingerprints, thereby granting access to two different individuals at verification.

Physical attacks using altered fingerprints can be carried out by those with enough time and resources. Understanding these attacks and how they impact biometric performance can influence the development and implementation of more robust systems.

KEY POINTS

- **Simulated scarring and simulated skin grafting both significantly lower match scores**
- **Scar length, width, and count have less impact on match score than minutiae changes**
- **Simulated skin grafting lowers match scores more as grafted area increases and more minutiae change; especially when the core is impacted**
- **The skin grafting technique tested can produce artefacts which match multiple system users**

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