Minutiae Template Conformance and Interoperability Issues

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Abstract: Minutiae features extracted from finger images are widely used for automated fingerprint recognition. The conformance of minutiae templates to standardised data interchange formats and the interoperability of minutiae extraction and comparison subsystems from multiple suppliers are important to prevent proprietary lock-in. Based on the work performed within the European research project on minutiae template interoperability testing, this paper summarises conformance and interoperability issues that have arisen and proposes solutions.

1 Motivation for minutiae template interoperability testing

Most fingerprint systems compare minutiae, i.e. characteristic points of the dermal ridges, rather than full fingerprint images. A minutia is characterised by its location, the direction of the tangent to the ridge skeleton at this point, and its type (ridge ending, ridge bifurcation, or other). To help ensure interoperability between minutiae extraction and comparison subsystems from different suppliers, an international standard for finger minutiae data interchange formats has been developed [ISO/IEC 19794-2], based on earlier national standards such as [ANSI INCITS 378, DIN V 66400].

However, in order to ensure global interoperability, the current machine-readable travel document (MRTD) specifications of the International Civil Aviation Organization (ICAO), for instance, require the storage of complete finger images, if fingerprint data is to be used in addition to a digitally stored face image, and allow minutiae data as additional option only. The use of minutiae templates instead of finger image templates would enable solutions to be memory and time saving and more privacy sensitive. If minutiae extraction and comparison subsystems from multiple suppliers are shown to be interoperable, i.e. to work well together, there could be a move from storing finger images as reference data to storing the more compact minutiae templates, even in open systems such as MRTD systems.

This paper summarises issues observed within the European minutiae template interoperability testing (MTIT) project to have an impact on the interoperability of minutiae extraction and comparison subsystems from multiple suppliers and draws lessons from this. Section 2 of this paper outlines the method used for testing the conformance of minutiae templates to [ISO/IEC 19794-2] and deals with conformance issues that have been observed. Section 3 outlines the method used for testing the interoperability of subsystems and deals with interoperability issues that have been observed. Section 4 contains concluding remarks.

2 Conformance to ISO/IEC 19794-2

2.1 Conformance requirements

In order to improve the chances of interoperability through standardisation, the individual subsystems within a heterogeneous system must conform to the established standards. In this spirit, conformance to standards is a prerequisite, though not a guarantee, for interoperability.

[ISO/IEC 19794-2] defines several minutiae data format types. For each format type, it specifies both

- syntactic requirements, characterising the structure of conforming minutiae templates, and

- semantic requirements, characterising relations among fields in conforming minutiae templates or between fields in conforming minutiae templates and the underlying input finger image(s).

A minutiae template conforms to a format type defined in [ISO/IEC 19794-2] only if it satisfies the relevant normative syntactic and semantic requirements for the claimed format type. A minutiae extraction subsystem is considered to conform to a format type defined in [ISO/IEC 19794-2] as long as all templates that it generates conform to that format type.

2.2 Conformance testing

Conformance testing is the process of checking that a test object satisfies the conformance requirements.

For an individual minutiae template as test object, conformance testing includes

- format and internal consistency checking, for assessing whether the minutiae template's fields have valid values and relate to each other as required (for instance, whether the actual length of a data field is equal to the length indicated in the corresponding length field), and

– contents checking, for assessing whether the minutiae template's fields relate to the underlying finger image(s) as required (for instance, whether minutiae are placed at the points where the dermal ridges end or bifurcate).

For a minutiae extraction subsystem as test object, conformance testing involves conformance testing of the minutiae templates generated by this subsystem. The format and internal consistency checking has been conducted automatically for each minutiae template generated by the subsystem under test. This step has been conducted using decoder software that parses a minutiae template and checks it against the relevant conformance requirements. The contents checking, on the other hand, has been conducted manually for a subset of the minutiae templates generated by the subsystem under test. This step has been carried out using a minutiae visualisation tool that takes the underlying finger image as input in addition to a minutiae template. To automate also the contents checking of minutiae templates would require

– a minutiae extraction reference implementation producing minutiae that are always acceptable as "ground-truth" (but there is a risk of biasing towards the chosen algorithm) or at least a database of finger images (preferably of high quality as there are no provisions for minutiae placement in low-quality images anyway) annotated with "ground-truth" reference minutiae and

– a minutiae comparison reference implementation to automatically compare the minutiae templates generated by the subsystem under test with the "ground-truth" reference minutiae.

2.3 Conformance issues

Conformance issues are deviations of implementations from what is required in the underlying standards.

Context checking allows revealing conformance issues that would remain undetected by just format and internal consistency checking. For instance, not each minutiae extraction algorithm sets the ridge endings at the positions required by the claimed format type. Depending on the format type [ISO/IEC 19794-2] requires ridge endings to be placed either at valley bifurcation points or at ridge skeleton end points.

Figure 1 shows dispersion patterns of minutiae found by four different minutiae extraction algorithms. All minutiae templates passed the format and internal consistency checking, but contents checking reveals (see Figure 1a) that the minutiae extraction algorithms place the ridge endings inconsistently (they should be placed at valley bifurcation points in the record format type). Even though minutiae comparison algorithms are quite robust against small variations, this conformance issue has a detrimental effect on the interoperability performance.

Contents checking also showed that different minutiae extraction algorithms may disagree over the type of minutiae (ridge ending or ridge bifurcation) that they all find, especially in blurred fingerprint regions (see Figure 1b). Depending on the threshold

(a) Agreement over minutiae type (b) Disagreement over minutiae type

Figure 1 Dispersion patterns from four minutiae extraction subsystems
(Legend: ridge ending, ridge bifurcation)

used in converting a gray-scale image into a black/white image, a separating valley between a ridge ending and an adjacent ridge may appear or disappear. If different minutiae extraction algorithms disagree over the type of a minutia, then they consequently also disagree over its exact location. In low-quality regions even the “manual” discrimination of ridge endings and bifurcations is hard. The worse the finger image quality, the less “ground truth” is known.

Another conformance issue that can be detected, if present, by contents checking, but not by format and internal consistency checking, is a deviation from the required position of the origin of the coordinate system and from the required direction of the coordinate axes. [ISO/IEC 19794-2] requires the origin of the coordinate system to be the upper left corner of the finger image, x to increase to the right, and y to increase downward. Deviations from these requirements are possible in legacy implementations because [DIN V 66400] required the origin of the coordinate system to be the lower left corner of the finger image and y to increase upward.

3 Interoperability of subsystems

3.1 Cross-subsystem performance tests

The test objects in the MTIT project were minutiae extraction and comparison subsystems from four different suppliers. The interoperability testing has been carried out offline, using pre-existing and specially collected databases of finger images, as a set of technology evaluations [ISO/IEC 19795-2] for combinations of minutiae extraction and comparison subsystems [ISO/IEC 19795-4]. Because minutiae extraction and comparison algorithms from the same supplier are often bundled together, each minutiae comparison subsystem has always been combined with the minutiae extraction subsystem from the same supplier. The other minutiae templates to be compared came from each of the other minutiae extraction subsystems.

The performance of combinations where all subsystems are from the same supplier and exchange proprietary templates has also been tested. Such cases provide a benchmark for assessing performance degradations due to minutiae template interoperability issues.

3.2 Interoperability criteria

A combination of minutiae extraction and comparison subsystems is considered interoperable if the subsystems are able to work effectively together to achieve a required level of performance.

What level of performance is required to consider a combination of subsystems interoperable? The original ILO criterion of interoperability [ILO05] was an FRR of 1% or less at an FAR of 1% (i.e., an EER below 1%). The MINEX test [NISTIR 7296] did not apply a fixed interoperability criterion, but looked at a variety of interoperability criteria. The minutiae template interoperability tests using different databases have shown that the performance of the same combination of subsystems depends on the database used, but that the relative performance loss compared to the benchmark performance of proprietary systems tested with the same database is consistent across databases. Therefore, a maximum admissible performance loss compared to the benchmark performance of proprietary systems tested with the same database is a better interoperability criterion than a fixed target performance. This finding should still be added to [ISO/IEC 19795-4].

3.3 Interoperability issues

3.3.1 Overview

As it may have been be expected, the tests within the MTIT project have confirmed that the performance of proprietary systems using two fingers is better than the performance of multi-supplier systems using two fingers, which in turn is better than the performance of proprietary systems using only one finger, which is better than the performance of multi-supplier systems using one finger only [BM07]. Also, the performance of single-supplier systems using minutiae templates is mostly better than the performance of multi-supplier systems using minutiae templates. The better the quality of the finger images used for testing, the better is the recognition performance throughout all systems. Here we discuss possible reasons for the performance degradations that occur when exchanging minutiae templates within multi-supplier systems.

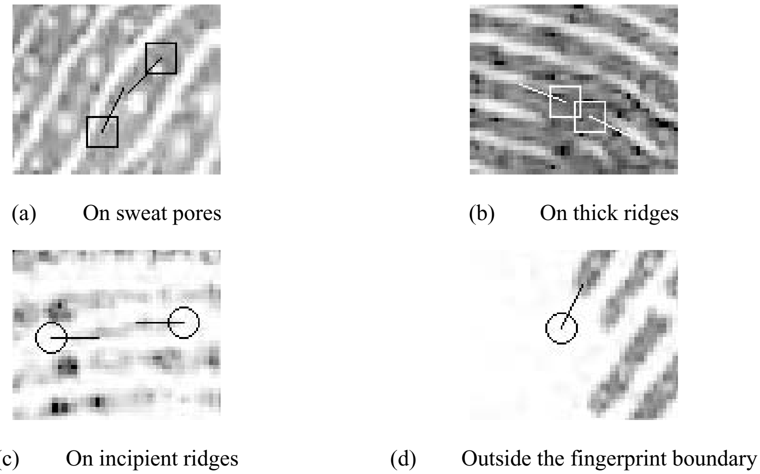
Interoperability issues are such issues where different implementations deviate from each other, but the current edition of the underlying standard does not yet specify unambiguously what is required.

3.3.2 Minutiae detection strategy

Contents checking of minutiae templates has shown that different minutiae extraction algorithms not only disagree over the exact location, the direction, and the type of those minutiae that they all find, but that they also detect different numbers of minutiae in the same finger image. Some minutiae extraction algorithms use a “liberal” minutiae detection strategy and detect a large number of minutiae (among them false minutiae), while other minutiae extraction algorithms use a more “conservative” minutiae detection strategy and detect fewer minutiae. Different minutiae detection strategies are suspected of having a strong effect on the interoperability of subsystems. In the following, we list interoperability issues and propose a common minutiae detection strategy as a remedy.

False minutiae may be placed, for instance, at sweat pores (see Figure 2a), at points where thick ridges converge (see Figure 2b), on incipient ridges (very short and thin ridges found between the normal ridges and not part of the normal ridge flow pattern, see Figure 2c), along creases (accidental interruptions of originally continuous ridges), outside the fingerprint boundary (see Figure 2d), and below the first phalange. To avoid obtaining divergent minutiae patterns from the same finger image, it should be standardised that minutiae should not be set at sweat pores, at points where thick ridges converge, on incipient ridges, at creases, outside the fingerprint boundary, and below the first phalange.

Some minutiae extraction algorithms place false minutiae at cores and deltas. Cores and deltas are special points inside a fingerprint used for general classification of pattern types (loop, whorl, arch etc.). They are "singularities" of high curvature in the ridge direction field. No minutia should be set at a core or delta since the direction angle could not be properly defined. Information about cores and deltas can be expressed in a standardised way in the extended data block [ISO/IEC 19794-2].



(a) On sweat pores

(b) On thick ridges

(c) On incipient ridges

(d) Outside the fingerprint boundary

Figure 2 Examples of false minutiae
(Legend: ridge ending, ridge bifurcation)

3.3.3 Minutia quality

The one-per-minutia minutia quality field in the record format is intended to express the confidence in the characteristics and in the actual presence of a minutia. Its use may improve the recognition performance. However, because there is no guaranteed relationship between minutia quality values assigned by different suppliers, the minutiae comparison subsystems under test did not make use of the minutia quality fields, even though these fields had been filled using supplier-specific algorithms. To be useful for interoperable matching, the meaning of the minutia quality field should be specified in more detail.

3.3.4 Large finger images and compact-size card format

In the compact-size card format, minutiae coordinates are coded in 8 bits, using a resolution of 10 pixels per millimetre. Therefore, dealing with minutiae from finger images that are greater than 2.55 centimetres in either direction is a problem when the compact-size card format is used. [ISO/IEC 19794-2] contains provisions for peeling off minutiae from the convex hull of the minutiae set and for coordinate extension in either x or y direction. However, if different suppliers chose different remedies, the interoperability performance will suffer. Therefore, it should be specified in more detail how to deal with large images when the compact-size card format is used.

4 Summary and outlook

The importance of conformance testing for ensuring interoperability has been shown. After checking the format and internal consistency of the minutiae templates generated by a minutiae extraction subsystem, also the contents of at least some generated templates should be checked against the underlying finger image(s) to detect any bias of the minutiae extraction subsystem.

In order to achieve interoperability between subsystems from multiple suppliers, it is important that the individual minutiae extraction algorithms yield comparable minutiae sets. For this, the minutiae detection strategy should be clarified.

In interoperability performance testing, a maximum admissible performance loss compared to the benchmark performance of proprietary systems tested with the same database is a more robust criterion for interoperability than a fixed target performance because the performance measured for the same combination of subsystems depends on the database used for testing.

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