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Information technology — Biometrics — Multimodal and other multibiometric fusion

Technologies de l'information — Biométrie — Fusion multimodale et autre fusion multibiométrique

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Foreword

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The committee responsible for this document is ISO/IEC JTC 1, *Information technology*, Subcommittee SC 37, *Biometrics*.

This second edition cancels and replaces the first edition (ISO/IEC/TR 24722:2007), which has been technically revised with the following changes:

— the original Clause 2 (Terminology issues) and Clause 7 (Scope and options for standardisation) are removed in this edition;

— Clause 2 (Terms and definitions) is aligned with ISO/IEC 2382-37;

— the current Clause 3, Clause 4, and Clause 5 have been technically revised in terminology, the state of arts updates, and other aspects. Such modifications have also been reflected in the bibliography.

Introduction

Some applications of biometrics require a level of technical performance that is difficult to obtain with a single biometric measure. Such applications include prevention of multiple applications for national identity cards and security checks for air travel. In addition, provision is needed for people who are unable to give a reliable biometric sample for some biometric characteristic types.

Use of multiple biometric measurements from substantially independent biometric sensors, algorithms, or characteristic types typically gives improved technical performance and reduces risk. This includes an improved level of performance where not all biometric measurements are available such that decisions can be made from any number of biometric measurements within an overall policy on accept/reject thresholds.

Of the various forms of multibiometric systems, the potential for multimodal biometric systems, each using an independent measure, has been discussed in the technical literature since at least 1974.[22][45] Advanced methods for combining measures at the score level have been discussed in Reference [15] and Reference [16]. At the current level of understanding, combining results at the score level typically requires knowledge of both genuine and impostor distributions. All of these measures are highly application dependent and generally unknown in any real system.

Research on the methods not requiring previous knowledge of the score distributions is continuing and research on fusion at both the image and feature levels is still progressing.

Given the current state of research into those questions and the highly application-dependent and generally unavailable data required for proper fusion at the score level, work on multibiometric fusion can, in the meantime, be considered mature. By intention, this Technical Report is not issued as an International Standard, in order not to force industrial solutions to conform to the methodology described herein. However, this Technical Report revision provides a mature technical description for developments of multibiometric systems. It will also provide a reference on multibiometric fusion for developers of other biometric standards and implementers.

Information technology — Biometrics — Multimodal and other multibiometric fusion

1 Scope

This Technical Report contains descriptions of and analyses of current practices on multimodal and other multibiometric fusion, including (as appropriate) references to more detailed descriptions.

This Technical Report contains descriptions and explanations of high-level multibiometric concepts to aid in the explanation of multibiometric fusion approaches including multi-characteristic-type, multiinstance, multisensorial, multialgorithmic, decision-level and score-level logic.

2 Terms and definitions

The following two categories of terms are defined here:

— terms that are specific to multimodal and multibiometric systems;

— terms that are not specific to multimodal and multibiometric systems, but are required to define the terms in the first category and not defined in the latest revision of ISO/IEC 2382-37.

For definitions of other terms in the subject field of biometrics, refer to ISO/IEC 2382-37. For the purposes of this document, the terms and definitions given in ISO/IEC 2382-37 and the following apply.

2.1
biometric data source
information channel (e.g. sensors, characteristic types, algorithms, instances or presentations) that is the origin of data (e.g. captured biometric sample, extracted features, comparison score, rank or decision) treated in fusion algorithms

2.2
biometric process
automated process using one or more biometric characteristics of a single individual for the purpose of enrolment, verification, or identification

2.3
biometric fusion
combination of information from multiple sources, i.e., sensors, characteristic types, algorithms, instances or presentations

2.4
cascaded system
system where pass/fail thresholds of biometric samples are used to determine if additional biometric samples are required to reach an overall system decision

2.5
layered system
system where individual biometric scores are used to determine the pass/fail thresholds of other biometric data processing

2.6
multialgorithmic
using multiple algorithms for processing the same biometric sample

2.7
multibiometric
uses multiple biometrics that can be combined at image, feature, score and/or decision level

Note 1 to entry: Multibiometric has five distinct subcategories: *multi-characteristic-type* (2.10), *multiinstance* (2.11), *multisensorial* (2.13), *multialgorithmic* (2.6) and *multipresentation* (2.12).

2.8
multibiometric process
biometric process (2.2) involving the use of *biometric fusion* (2.3)

2.9
multibiometrics
automated recognition of individuals based on their biological or behavioral characteristics and involving the use of *biometric fusion* (2.3)

2.10
multi-characteristic-type
multi-type
using information from multiple types of biometric characteristics

EXAMPLE Biometric characteristics types include: face, voice, finger, iris, retina, hand geometry, signature/sign, keystroke, lip movement, gait, vein, DNA, ear, foot, scent, etc.

2.11
multiinstance
using multiple biometric instances within one biometric characteristic type

EXAMPLE Iris (left) + Iris (right), Fingerprint (left index) + Fingerprint (right index).

2.12
multipresentation
using either multiple presentation samples of one instance of a biometric characteristic or a single presentation that results in the capture of multiple samples

EXAMPLE Several frames from video camera capture of a face image (possibly but not necessarily consecutive).

Note 1 to entry: Multipresentation biometrics is considered a form of *multibiometrics* (2.9), if fusion techniques are employed. Many fusion and normalisation techniques are appropriate to the integration of information from multiple presentations of the same biometric instance.

2.13
multisensorial
using multiple sensors for capturing samples of one biometric instance

EXAMPLE For face: infrared spectrum, visible spectrum, 2-D image, and 3-D image; for fingerprint: optical, electrostatic, and acoustic sensors.

2.14
sequential presentation
capturing biometric samples in separate capture events to be used for *biometric fusion* (2.3)

2.15
simultaneous presentation
capturing biometrics samples in a single capture event to be used for *biometric fusion* (2.3)

3 Overview of multimodal and other multibiometric systems

3.1 General

In general, the use of the terms multimodal or multibiometric indicates the presence and use of more than one characteristic type, sensor, instance, and/or algorithm in some form of combined use for making a specific biometric identification or verification decision. The methods of combining multiple samples, comparison scores or comparison decisions can be very simple or mathematically complex. For the purpose of this Technical Report, any method of combination will be considered a form of "fusion". Combination techniques will be covered in Clause 4.

Multimodal biometrics were first proposed, implemented and tested in the 1970s. Combining measures was seen as a necessary future requirement for biometric systems. It was widely thought that combining multiple measures could increase either security by decreasing the false acceptance rate or user convenience by decreasing the false rejection rate. These systems did not seem to advance into practical applications.

The use of fusion and related methods has been a key tool in the successful implementation of large-scale automated fingerprint identification systems (AFISs), starting in the 1980s. Until recently, multiple characteristic types have not been used in AFIS; however, most methods of fusion discussed elsewhere in this Technical Report have been successfully implemented using fingerprints alone. Some of the ways that fusion has been implemented in AFISs include the following:

— image (also known as sample) fusion in creating a single "rolled" image from a series of plain impressions on a livescan device;

— template fusion in the use of multiple feature extraction algorithms on each fingerprint image;

— multiinstance fusion in the use of fingerprints from all ten fingers;

— multipresentation fusion in the use of rolled and slap (plain) fingerprints;

— algorithm fusion for the purpose of efficiency (cost, computational complexity, and throughput rate); generally, comparators are used as a series of filters in order of increasing computational complexity. These are generally implemented as a mix of decision and score-level fusion;

— algorithm fusion for the purpose of accuracy (decreasing false accept rate and/or false reject rate, lessening sensitivity to poor-quality data); comparators are used in parallel, with fusion of resulting scores.

The use of fusion has made AFIS possible because of fusion's potential in improving both accuracy and efficiency.

Most work to date on multibiometrics has focused only on improving false acceptance and false rejection error rates. Some research work considers the use of multibiometrics to flexibly improve usability, security or accuracy.[64] Further, multibiometrics also aims at decreasing the overall failure-to-enrol rate (FTE) especially in biometric systems where user cooperation is not expected (e.g. video surveillance systems). Multibiometrics is an effort to produce a biometric decision even if only a subset of the expected biometric characteristics were captured.[66]

To further the understanding of the distinction among the multibiometric categories, Table 1 illustrates the basic distinctions among categories of multibiometric implementation. The key aspect of the category that makes it multi-"something" is shown in boldface.

Table 1 — Multibiometric categories illustrated by the simplest case of using 2 of something

Category	Characteristic type	Algorithm	Instance	Sensor
Multi-characteristic-type	2 (always)	2 (always)	2 (always)	2 (usually)[b]
Multialgorithmic	1 (always)	2 (always)	1 (always)	1 (always)
Multiinstance	1 (always)	1 (always)	2 (always)	1 (usually)[c]
Multisensorial	1 (always)	1 (usually)[a]	1 (always, and same instance)	2 (always)
Multipresentation	1	1	1	1

[a] It is possible that two samples from separate sensors could be processed by separate “feature extraction” algorithms, and then through a common comparison algorithm, making this “1.5 algorithms”, or two completely different algorithms.

[b] Exception: a multi-characteristic-type system with a single sensor used to capture two different characteristic types. For example, a high-resolution image used to extract face and iris or face and skin texture.

[c] Exception may be the use of two individual sensors to each capture one instance, for example, possibly a two-finger fingerprint sensor.

Multi-characteristic-type biometric systems take input from single or multiple sensors that capture two or more different types of biometric characteristics. For example, a single system combining face and iris information for biometric recognition would be considered a “multi-characteristic-type” system regardless of whether face and iris images were captured by different imaging devices or the same device. It is not required that the various measures be mathematically combined in anyway. For example, a system with fingerprint and voice recognition would be considered “multi-characteristic-type” even if the “OR” rule was being applied, allowing users to be verified using either of the characteristic types.

Multialgorithmic biometric systems receive a single sample from a single sensor and process that sample with two or more algorithms. This technique could be applied to any characteristic type. Maximum benefit (theoretically) would be derived from algorithms that are based on distinctly different and independent principles such as either features they extract from the biometric sample (e.g. finger minutiae versus finger pattern) or approaches to comparison (e.g. different algorithms comparing minutiae).

Multiinstance biometric systems use one (or possibly multiple) sensor(s) to capture samples of two or more different instances of the same biometric characteristic. For example, systems capturing images from multiple fingers are considered to be multiinstance rather than multi-characteristic-type. However, systems capturing, for example, sequential frames of facial or iris images are considered to be multipresentation rather than multiinstance.

Multisensorial biometric systems sample the same instance of a biometric characteristic with two or more distinctly different sensors. Processing of the multiple samples can be done with one algorithm, or some combination of multiple algorithms. For example, a face recognition application could use both a visible light camera and an infrared camera coupled with a specific frequency (or several frequencies) of infrared illumination.

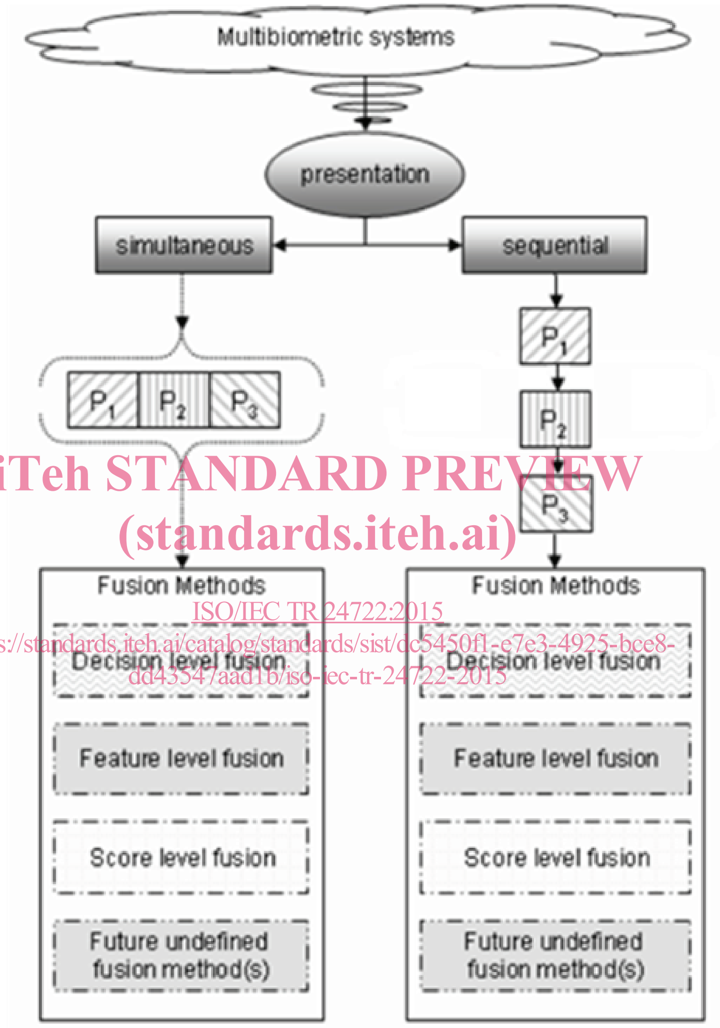
For a specific application in an operational environment, there are numerous system design considerations, and trade-offs that should be made, among factors such as improved performance (e.g. identification or verification accuracy, system speed and throughput, robustness, and resource requirements), acceptability, circumvention, ease of use, operational cost, environmental flexibility, and population flexibility.[40]

Especially for a large-scale human identification system, there are additional system design considerations such as operation and maintenance, reliability, system acquisition cost, life cycle cost, and planned system response to identified susceptible means of attack, all of which will affect the overall deployability of the system.[40]

3.2 Simultaneous and sequential presentation

3.2.1 General multibiometric system model

A general multibiometric system model is shown in Figure 1. For explanatory purposes, this model uses three biometric samples (P1, P2, P3) from three unique biometric characteristic types, except for where specified differently. At the topmost level, a subject presents their biometric characteristic(s) to the system. Dependent upon the system design, there are two methods of presenting characteristics for acquisition by the system: **simultaneous** and **sequential**.



NOTE The presentation (simultaneous or sequential) method induce or general different fusion process. The purpose of including this information is to illustrate considerations that can influence multibiometric system design.

Figure 1 — Multibiometric system model

3.2.2 Simultaneous presentation

Simultaneous presentation (with successful capture) provides biometric sample(s) from multiple characteristic types in a single event (e.g. a face and iris taken from the same camera). System designs that utilize simultaneous acquisition would tend toward high throughput applications at the expense of possible added complexity (to synchronize sample collection) or difficulty of use (dual sensor interaction, user multi-tasking).

3.2.3 Sequential presentation

Sequential capture acquires biometric sample(s) from one or multiple characteristic types in separate events. Sequential capture may be utilized in three concepts discussed in the literature. The first is multiinstance, which is the use of two or more instances within one characteristic type for a subject, i.e. Fingerprint (left index) + Fingerprint (right index). In this example, one single digit fingerprint reader is used twice in sequence. The second concept is multi-characteristic-type, which is the use of multiple different biometric characteristic types captured from one or more sensors for a subject, i.e. Hand + Face in sequence. The third concept is multisensorial, which is the use of two or more distinct sensors for capturing the same biometric feature(s) for a subject, but not at the same time. To avoid confusion with multi-characteristic-type, which may also capture biometric feature(s) from two or more distinct sensors, multisensorial can be clarified as “uni-characteristic-type multisensorial”. Examples for face recognition are infrared spectrum, visible spectrum, 2-D image, and 3-D image; for fingerprint recognition: optical, electrostatic and acoustic sensors.

3.3 Correlation

In multimodal biometric systems, the information being fused may be correlated at several different levels[56] as illustrated in the following examples.

— Correlation between characteristic types: This refers to biometric samples that are *physically related*, such as the speech and lip movement of a user.

— Correlation due to identical biometric samples: This is the case in multialgorithmic systems where the *same* biometric sample (e.g. a fingerprint image) or sub-sets of the biometric sample (e.g. voice, where an entire sample may be used by one algorithm and part of the sample by another) is subjected to different feature extraction and comparison algorithms (e.g. a minutiae-based comparator and a texture-based comparator).

— Correlation between feature values: A subset of feature values constituting the feature vectors of different characteristic types may be correlated. For example, the area of a user’s palm (hand geometry) may be correlated with the width of the face.

— Correlation among instances due to common operating procedures (e.g. common capture device and operator training).

— Correlation among instances due to subject behaviour (e.g. coloured contact lenses on both eyes).

However, in order to determine the *extent* of correlation, it is necessary to examine the comparison scores (or the ACCEPT/REJECT decision) pertaining to the comparators involved in the fusion scheme. In the multiple classifier system literature, it has been demonstrated that fusing uncorrelated classifiers leads to a significant improvement in comparison performance.[56]

For two classifiers of reasonable accuracy involved in a fusion scheme, score outputs from inputs that come from the same subject may, but need not, be correlated. Therefore it is more appropriate to consider the correlation of classifier errors as described by Reference [20]. The correlation ρ_{n_c} is given by Formula (1):

$$\rho_{n_c} = \frac{nN_c^f}{N - N_c^t - N_c^f + nN_c^f} \qquad (1)$$

where

n is the number of classifiers under test;

N is the total number of sequences;

