

UNIVERSITY OF PITEȘTI
FACULTY OF MATHEMATICS AND COMPUTER SCIENCE



PhD THESIS
Signal Processing Methodologies
– SUMMARY –

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Autoevaluation

The main objective of our thesis (*Signal Processing Methodologies*) is the study of digital signal processing methods with applications in *Iris Recognition*. The practical examples considered most often throughout the thesis come from this field, whereas the signals that we are working with are those encoded in the iris texture of the human eye, or signals derived therefrom.

Consequently, the digital signal processing methods discussed in this thesis cover the needs of this practical example, all of them belonging in either one of the following fields: *computer vision* (eye image segmentation, i.e. pupil and iris detection), *feature extraction and encoding* (binary encoding of the iris texture and of the digital identities, or custom encoding of the digital identities), *feature matching* (iris matching), *artificial intelligence* and *data understanding* (programming intelligent agents used to discover new processing methods or to improve existing ones; computer aided design for large scale intelligent biometric systems) and *formal modeling* for biometric systems (formal theories of signal similarity detection). In the later direction, we succeeded to formalize non-paradoxical self-referentiality in binary logic, *Consistent Biometry*, and *Turing-Zadeh paradigm* of intelligent recognition, all of them used to design the newly proposed paradigm of *Intelligent Iris Verifier* systems.

Regarding the iris segmentation, encoding and matching, we succeeded to give our own original solutions and to prove that the iris recognition results obtained by using them are at least comparable with the best iris recognition results documented in IREX 1 report. On the other hand, it is exemplified in this thesis that the use of recently proposed *Intelligent Iris Verifier* systems (which are evolutionary systems endowed with strong logical formal support) allowed us to give the best iris recognition results obtained and announced so far for the test database (Bath Database) and much more important, allowed us to advance from *statistical biometric safety* toward *absolute (logical) biometric safety*, from *fuzzy bimodal biometric decision* to *crisp binary biometric decision*.

In terms of experimental work, this thesis is supported by over 10,000 exhaustive iris recognition tests (each counting between 500,000 and 60,000,000 one-to-one comparisons), all of them performed on the public dataset *University of Bath Iris Image Database* and resulting in original conclusions and new results, some of them being published already [44] - [58], others following to be published soon (Chapter 5.1 - *Turing-Zadeh paradigm* of intelligent recognition / classification, for example).

Motivation

The topic explored in this thesis has two facets: one practical, with immediate applicability in the current technology of iris recognition, and one theoretical (yet), regarding the deep understanding of iris recognition as a subject of Artificial Intelligence, as a problem of encoding a concept (the digital identity) from known hypostases (binary iris codes). The stake in the second case is to achieve a logically coherent computational modeling of an intelligent agent endowed with suitable means that should enable it to prove an artificial understanding of similarity between the signals encoded within the iris texture - in particular, or similarity between other species of data – in general.

Choosing iris recognition as the main research subject of this thesis came from our belief (now confirmed by new results) that this branch of signal processing is still a pioneering area that provides the passionate researcher with a variety of unexplored paths, topics and views. We build this thesis toward these unexplored areas by searching for questions and answers (not necessarily in equal numbers) enabled to change the horizons of iris recognition (and those of the related domains) to the new coordinates of *logically consistent and intelligent iris recognition*.

From now on, starting with this thesis, the classical paradigm of statistical iris recognition finally has a better alternative, namely that of iris recognition practiced on evolutionary intelligent biometric systems (*Intelligent Iris Verifier*) in which the new biometric-decisional model is no longer bimodal (statistical), being a binary one instead, being one with absolute safety rates, one strongly cointensive with the reality of iris recognition objectively recorded by interrogating a human agent during a Turing test of iris recognition.

A Turing test shows that the recognition decisions given by a human agent are binary, crisp and correct (unconfused), whereas those usually given by a software agent (at the current state of the art stage) are bimodal, fuzzy and statistically confused. In other words, there is not enough *cointension* between the *human-oriented precisiation* and the *machine-oriented precisiation* of iris recognition, the *m-precisiation* (the meaning) of recognition practiced on artificial agents is not that of a human agent. Moreover, each of them is supposed to represent well (with cointension) the same event, namely the iris recognition. In short, this is the major contradiction within the current horizon of iris recognition and the main issue that this thesis aims to treat.

Outline

The complexity of the issues addressed in the thesis gradually increases to its final part, in tandem with the quality of the recognition results. In this thesis, the point at which the investigation of iris recognition begins, and also the point where all recognition results return for validation, is quite unexpected: the Turing test [71]. It is a relatively simple routine, which as will be noted throughout the thesis, has the power to bring a welcomed change of perspective in iris recognition: from a statistical theory of similarity, to a theory of intelligent recognition based on new and original soft computing models (Turing-Zadeh models for iris recognition) in which the concept of *cointensivity* plays the central role.

The research begins in **Chapter 2**, which illustrates the current state of research in the field of iris recognition. Chapter 2 contains a description of the pioneering phase of iris recognition (Flom, Safir, Daugman, Wildes), followed by a description of the current performance standard (*the state of the art*) in iris recognition as it is illustrated in the latest independent (and public) evaluation of iris recognition undertaken in 2007 by N.I.S.T. (National Institute for Standards and Technologies, USA) and recorded in the so called IREX 1 Report, [22]. On this occasion we show that the *test dataset* (University of Bath Iris Image Database, [72]) and the *test methodology* (*exhaustive iris recognition tests* based on *all-to-all comparisons*) adopted in the thesis is relevant for estimating the performance of iris recognition on *standard images* (as defined in IREX 1 Report, [22]).

Chapter 3 presents new *segmentation methods* (*RLE-FKMQ Based Pupil Finder*, *Circular Fuzzy Iris Segmentation*) and a new *encoding method* (*Hilbert Encoder*), techniques that we called *primary techniques* because they are obtained with no artificial intelligence support and they fits into a new but still *classical* approach to iris recognition in which the *biometric decision is still bimodal*, or in other words, they are new means for designing new iris recognition system but without exceeding the classical paradigm of *statistical iris recognition*. However, as it is outlined almost throughout the entire thesis (but especially in Chapter 4.2, Chapter 5 and Chapter 6), the bimodal biometric decision assumed in the theory of statistical iris recognition (initially proposed by Daugman [13], [16]) is not very much cointensive (or better saying, is not cointensive in values nor in meaning) with the *realistic biometric decision model* illustrated by recording the recognition decisions given by a human agent during a Turing test.

The primary techniques presented along the third chapter (*RLE-FKMQ Based Pupil Finder*, *Circular Iris Fuzzy Segmentation* and *Hilbert Encoder* or *Gabor Analytic Iris Texture Binary Encoder*) allowed us to obtain relatively quickly iris recognition results which are (at least) comparable with the results recorded in the report 'IREX 1 for *state of the art* recognition algorithms proposed by *Cambridge University*, *Cogent Systems*, *Crossmatch Technologies*, *Honeywell*, *Iritech*, *L1 Identity Solutions*, *LG*, *Neuro-technology*, *Reticle Systems* and *Sagem*. Thousands of exhaustive iris recognition tests undertaken while perfecting the techniques described in Chapter 3 gave us a correct understanding of the current horizons in iris recognition and this happened mainly because our tests were organized as Turing tests and because we always compared the automatic biometric decisions given by a simulated iris recognition system (an artificial agent) to those given by a human agent. By doing this way we accumulated a critical level of practical experience which further allowed us to formalize the Turing test as meta-theories of iris recognition (see the *Extended Turing-Zadeh Formal Model associated to an iris recognition Turing test* in Section 5.1.10) in which any given possible iris recognition theory (any iris recognition system explicitly known as a set of computation rules) can be compared to a realistic model of iris recognition which is implicitly known through examples of biometric decisions given by the human agent and formalized as a set of *cognitive implications* (Section 4.1).

An essential element found while doing Turing tests of iris recognition is that the statistical theory of iris recognition guarantees non-empty support for the *Liar Paradox*, (there are genuine/imposter pairs of iris codes which tell about themselves that *aren't* genuine/imposter pairs) whereas in the recorded practice of the human agent this does not happen at all: all pairs are recognized correctly as being *imposter* or *genuine* pairs without any kind of intermediary nuances between these two concepts. Clarifying the logical inconsistency situation revealed by the appearance of the *Liar Paradox* in the internal logic of a biometric system was made possible by creating a new formalization of binary logic - *Computational Cognitive Binary* (CCBL, introduced in **Chapter 4**) which hosts the *Cognitive Dialect* as a form of non-contradictory, well-formed and native self-referential logical discourse written *with* and *about* the propositional variables of (Classical) *Propositional Logic*. The principle of objectivity is set out here and provides necessary support for the computational substantiation of self-consciousness (self-awareness), for logically formalized artificial intelligent agents in general, and for smart biometric systems in particular. Chapter 4 then continues with the study of two fuzzy

logics that can describe the operation of a biometric system: a 2-valent inconsistent (confused) fuzzy logic induced by EER criterion, and an 8-valent fuzzy logic that hosts a *3-Valent Disambiguated Fuzzy Model* of iris recognition. To clarify logical aspects related to biometric verification and biometric identification, Section 4.3 outlines that in Consistent Biometry they are logically equivalent. The *Principle of Consistent Biometry* and the *Fundamental Theorem of Consistent Biometry* illustrate that verification and identification both carry the same semantic charge, namely the recognition of an individual.

Chapter 5 presents iris recognition as a topic of *Artificial Intelligence* and *Soft Computing*. The *Turing-Zadeh Formal Models* (TZM) of iris recognition are defined and proposed here. The relations between two such models are further expressed as a *Qualitative Sugeno Model* written in *Cognitive Dialect*. A TZM formally describing an iris recognition biometric system is a point in the formal meta-theory of iris recognition, is *a possible theory of iris recognition* more or less *cointensive* with the reality. An AFKD (Automatic Formal Knowledge Discovery) problem is further defined as being the problem of identifying through an informed search a new theory (of iris recognition, in this case) somewhere inbetween a perfectible TZM of iris recognition *precisiated* by a software agent (the start point of the search) and a precise (realistic) TZM of iris recognition *precisiated* by a human agent (the depiction of an ideal iris recognition theory known by examples). The *compatibility principle*, the *principle of efficient computational Turing-Zadeh modeling* and the *principle of reasonable speed-precision negotiation* are further formulated in order to avoid the possibility of building computationally *intractable TZMs of iris recognition* and/or *inconsistent formal theories of iris recognition*.

Chapter 6 is dedicated to a new paradigm of approaches to signal processing and iris recognition. Neural or neuro-evolutionary methods are used here in order to optimize existing primary techniques, to encode digital identities and to learn a formal theory of iris recognition. Efficient processing methods of signals derived from the iris image are identified as solutions to search/optimization problems addressed by applying AFKD techniques. Examples of this kind are: the optimized segmentation procedure (CFIS2 – the second version of *Circular Fuzzy Iris Segmentation*), the optimized binary encoders of the iris texture (*Wavelet-Hilbert*, *Multiscale Hilbert*, *Haar - Multiscale Hilbert*, the combined encoder *Log-Gabor & Haar - Multiscale Hilbert*) and the procedures for encoding stationary or evolutionary neural memories (discriminant directions or, more

generally, digital identities) needed for *Intelligent Iris Verifier* systems. Chapter 6 covers all of these topics.

The complex formal apparatus described in the thesis is a suitable context for identifying new iris recognition theories that are strongly cointensive with the reality objectively recorded during the Turing tests of iris recognition. This is why, as separation between the classes of scores, the results obtained by simulating IIV systems (with or without stored digital identities) and presented in Chapter 6 are now the number one among the top iris recognition results obtained on the same test database, at a comfortable distance from what is now considered to be a '*state of the art*' iris recognition result.

Some questions mentioned in **Chapter 7** illustrate the open problems in iris recognition: template aging, consistency and soundness of iris recognition, and iris recognition on non-standard images (recognition in unconstrained acquisition scenarios). They prescribe the limits up to which the thesis can conclude (**Chapter 8**).

The *list of main personal contributions* proposed in this thesis can be found at page 223 as **Apendix 6**.

The *bibliograpy* includes *only* titles cited in the thesis. The articles marked in bibliography with **bold** are our articles. They were written between 2008 and 2011, in direct connection to this thesis.

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