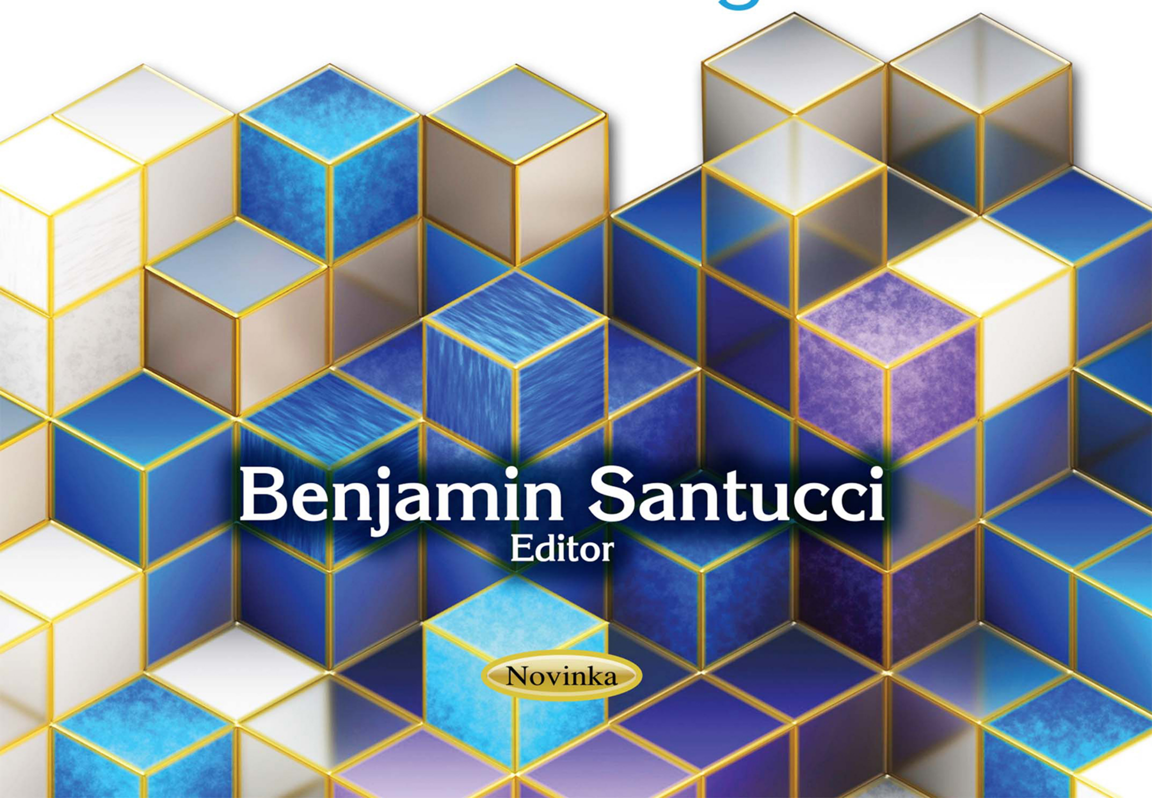
COMPUTER SCIENCE, TECHNOLOGY AND APPLICATIONS

Pattern Analysis

Methods, Applications and Challenges



Benjamin Santucci
Editor

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BENJAMIN SANTUCCI
EDITOR

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PREFACE

This book reviews methods, applications and challenges of pattern analysis. Chapter One addresses the identification problem of the printed medieval documents origin. The authors of Chapter Two perform a review on current cheiloscopic techniques, addressing the study methodology and usefulness of lip print patterns study. Chapter Three examines theoretical bases of human identification using palatal rugae pattern, and addresses the study methodology and techniques, potentialities and future usefulness of palatal rugae patterns. Chapter Four focuses on variable-scale-based pattern analysis for time series of wind speed, atmospheric pressure, and atmospheric temperature.

Chapter One - In this chapter, the authors address the identification problem of the printed medieval documents origin. To solve this task, the authors use a text mapping into equivalent script type codes. These codes form an equivalent image. Because the texture is one of the image characteristics, further analysis is performed using its texture. Feature vectors are derived from texture representation. Then, an artificial neural network is adopted for classification of the feature vectors representing fragments of documents in different historical periods. Experiment performed on a database of medieval fragments shows that fragments of documents in a given historical period can be clearly identified by using the efficient proposed framework, reaching very competitive results in terms of performance measures.

Chapter Two - Cheiloscopy is the name given to the study of lip prints. Nowadays, it is recognized that lip prints may be useful in identifying living individuals, as in certain circumstances they may be the only way to correlate an individual to a particular place or person. However, the use of lip prints in human identification is still controversial, and some authors suggest that there is insufficient evidence to conclude that the lip prints are unique for each individual, and therefore its forensic value doubtful. Recent studies on the detection of DNA, from epithelial cells present in lip prints, have opened new perspectives on this field of study. The existence of a link between a specific lip pattern and some diseases, and the individual origin and sex is also being researched. In this chapter the authors perform a review on current cheiloscopic techniques, addressing the study methodology and usefulness of lip print patterns study.

Chapter Three - Palatoscopy is the name given to the science that studies palatal furrows morphology. Palatal rugae are thought to be unique of an individual and evidence suggests that they can be used in human identification. Additionally, some studies have tried to relate the palatal rugae pattern with population affinity and sex of the individual, and results are equally promising and an increase use of this methodology is expected in the near future. Palatal rugae pattern, taking into account the anatomical location of the palatine wrinkles,is not expected to be used in linking evidence in a crime scene to a particular person. Instead, its usefulness lies in the identification of dead bodies, either by the relative stability of the palatal zone, even in situations in which facial recognition is not possible, or by the probable existence of ante mortem records. In this chapter the authors will addressed the theoretical bases of human identification using palatal rugae pattern, and will discourse about the study methodology and techniques, potentialities and future usefulness of palatal rugae patterns study.

Chapter Four - The methods introduced in this paper are designed for the analysis of strongly irregular environmental patterns, including streaming environmental data. Two different approaches to variable scale are addressed in this context. The first one focuses on the size of the “grains” handled in the data, varying data resolution; it considers time series elements to represent successive states of a dynamic system, in order to identify and characterize patterns and pattern change in the dynamic system’s behaviour. The second approach starts from an existing analysis method (Haar wavelets), which includes the scanning of a wide range of time scales. It builds on this method by adding an algorithm designed to be capable of grasping time- and time-scale-dependent pattern features, as well as making comprehensive scale-by-scale comparisons of patterns based on their scaling properties. The presented methods have a broad applicability area and are illustrated with time series corresponding to atmospheric variables: wind speed, atmospheric pressure, and atmospheric temperature time series. They can be successfully applied to studies on climate variability and implications of climate change.

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Chapter 1

IDENTIFICATION ISSUES IN PATTERN ANALYSIS

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ABSTRACT

In this paper, we address the identification problem of the printed medieval documents origin. To solve this task, we use a text mapping into equivalent script type codes. These codes form an equivalent image. Because the texture is one of the image characteristics, further analysis is performed using its texture. Feature vectors are derived from texture representation. Then, an artificial neural network is adopted for classification of the feature vectors representing fragments of documents in different historical periods. Experiment performed on a database of medieval fragments shows that fragments of documents in a given historical period can be clearly identified by using the efficient proposed framework, reaching very competitive results in terms of performance measures.

Keywords: artificial neural network, classification, medieval documents, orthography, pattern recognition, script recognition, texture analysis

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INTRODUCTION

According to Liu [1], the Sumerians began to register written information around 6,000 years ago, using clay tablets to describe commercial transactions. Since that time, the written documents have been used as a proof of civilization. Slavs, which populated the Central and Southern Europe in the early 6th century, were illiterate and pagans. In order to baptize them, it was necessary to make them literate and to translate church holy books into the language that could be understandable to them. Consequently, Greek apostles Cyril and Methodius under supervision of the Byzantine appointed to translate the church holy books from Greek to the Old Slavonic. According to that, their job included the creation of the alphabet adjusted to the Old Slavonic language. As a result of their work, the first Slavic alphabet was created. It was called Glagolitic script. Today, this type of Glagolitic script is called round Glagolitic one. It was complicated to be written. However, earliest saved documents in the round Glagolitic script dated from the 10th century in the wide region of Bulgaria in the southeast through the Moravians (Czech Republic) in the west of the Europe. Soon after, it was replaced with a more modern script created by Methodius' students, which is called Cyrillic script. However, a specific version of the old Slavonic alphabet was spread and used in Croatia. The Croatian extension of the Glagolitic alphabet was called squared or angular Glagolitic. It was transformed from the round Glagolitic alphabet, making it easier to write. Also, it was better accustomed to the carving into the parts of the stone church or stone monuments. In that period many of the church holy books were translated into the Slavonic language by writing in the angular Glagolitic script. It was a crucial event, because prior to that time the church books were allowed to be written in the Latin or Greek language only. Hence, the ancient medieval document represents one of the most valuable sources of the cultural heritage.

The end of the 15th century as well as the beginning of the 16th century represents a period of introduction and widespreading of printing process machines. After that period in Europe, the printed handwritten documents were almost vanished except handwriting ones. Essentially, all documents were machine printed. This period was identified as a very important period in spreading of printed Glagolitic documents in some parts of Croatia. During the introduction of printing process, the orthography of the Glagolitic printed documents was slightly changed. Essentially, in the hand printed Glagolitic documents all first letters in sentence were capitals. In the native Glagolitic orthography the capital letters were written as descendent letters and not ascender letters like in Latin alphabets. This rule of writing was present until the period when the documents were printed by machine and not by hands. At the beginning of the printing process introduction at the end of the 15th century, small printing factories were operated in the region of the Croatian coast, like Senj and Rijeka. In these printing factories the “old” orthography was used. Lately, in the beginning of the 16th century many of these small printing factories closed. Accordingly, the books were usually printed in the region of Italy, i.e., in Venice and Rome. If the editor of the printed book had Croatian origins, then the used orthography was the old one. In the coming decades of the 16th century, due to the influence of the Latin alphabet, the old Glagolitic orthography was changed. It was made according to the rules of the Latin alphabet. Hence, the rule of thumb for all new sentences was to begin with a capital letter, which was in these circumstances an ascender letter. It is supposed that this period begins around the middle of the 16th century.

In this way, the medieval documents are clearly mixed, but they can be discriminated according to different use of the ortography. Essentially, the discrimination of documents by their orthography can clearly identify documents’ dating and printing origin. Hence, we are proposing a system for recognition of the historical period of the medieval documents (Glagolitic documents) based on script differences identification, as well as the location of its printing.

Script recognition and discrimination techniques that have been developed can be grouped in two different analysis directions. These directions are classified as global and local ones.

Global methods take into consideration wider blocks in document images. Then, they are subjected to the statistical and/or frequency domain analysis [2]. In order to extend the method efficacy, document image blocks should be normalized. However, the prerequisites to establish a good script recognition are to have document images free of noise and given in high quality [3]. On the contrary, local methods separate document images into small pieces, which represent connected components. They contain text divided into characters, words or text lines. Furthermore, the analysis of different features, like the black pixel runs, is performed [4]. In contrast to global methods, the local methods are suitable for processing low-quality and noisy document images.

A new approach for the script recognition, which combines both techniques is proposed in [5], [6]. This approach unites local and global methods. First of all, it treats the characters in the text part of document images. Essentially, it maps each character into the corresponding script type according to its position in the text line. Secondly, the script type distribution of coded text is analyzed. Then, the text is subjected to a different type of textural analysis in order to extract the texture features needed for classification [7], [8], [9], [10], [11], [12], [13], [14]. At the end, an appropriate classification technique is used for the script discrimination and identification [6], [10], [15].

In this paper, we introduce a technique to deliberately distinguish documents which were hand or machine printed before and after the middle of the XVI century based on their ortographic rules (old or new orthography). We employ the technique previously used for script discrimination [5], [6]. Still, this method hasn't been used in any dating of the medieval documents yet. Furthermore, to the very best of our knowledge, we are the first to attempt to solve this kind of problem in the literature. Because the Glagolitic documents used a different orthography, our technique can be effectively used in solving the aforementioned problem. The method consists of three crucial stages. In the first stage, the text of the document is mapped according to the text line position of each letter. Then, in the second stage, the texture analysis of the obtained coded text is performed. At the end, the obtained results are classified according to ad-hoc artificial neural network (ANN), for identification of old or new orthography.

The paper is organized in the following manner. Section 2 describes the proposed algorithm. Section 3 presents the feature extraction method and provides an example. Section 4 introduces the classification method based on artificial neural networks. Section 5 gives the experimental results and discusses them. Section 6 draws the conclusions.

THE PROPOSED ALGORITHM

The proposed algorithm consists of three main stages. They are:

(i) mapping of the initial text,
(ii) texture analysis, and
(iii) classification for ortography identification.

Figure 1. The main steps of the proposed method.

Figure 1 shows the main steps of the procedure.

The principle of the method is based on the identification of linear patterns inside the document. These patterns correspond to sequences of consecutive codes, in which the document characters have been previously classified, based on their position in the text line. The position and frequency of the linear patterns are able to capture the ortography characteristics of the document. Hence, documents given in different ortography types will have a well-distinct disposition of these patterns, while documents given in the same ortography type will exhibit small differences in their patterns. Position and frequency of the patterns are captured by texture analysis of the coded document, corresponding to a 1-D gray scale image, for which every code is a gray level. In this way, extracted textural features present meaningful differences for different script types, useful to the artificial neural network classification method for the ortography recognition.

FEATURE EXTRACTION

Mapping of the Text

The first stage of the algorithm represents the mapping according to script types and the creation of an equivalent image pattern. Each text line can be split into three vertical zones [16], [17], [18]:

(i) upper,
(ii) middle, and
(iii) lower.

The letters in a certain script have different positions in the text line, based on their energy profile [16]. In this way, the letters are divided into:

(i) the base,
(ii) the ascender,

(iii) the descendent, and
(iv) the full letters.

Base letters (B), like the letter *a*, occupy a middle zone only. Ascender letters (A), like the letter *h*, spread over the middle and upper zones. Descendent letters (D), like the letter *g*, include the middle and lower zones. Few letters like the capital letter *lj* (in Serbian or Croatian Latin alphabet) comprise all three zones. They are classified as a full letter (F). This stage is illustrated in the Figure 2.

Then, they are mapped into the coded text. The mapping is performed as follows [19]:

(i) the base letter in 0,
(ii) the ascender letter in 1,
(iii) the descendent letter in 2, and
(iv) the full letter in 3.

Hence, any text sample is transformed into the flow of the following numerical codes: 0, 1, 2, and 3. This stage is illustrated in the Figure 3.

According to this coding, a text sample is considered as a 1-D gray scale image, where each numerical code is a gray level. Then, texture analysis is performed on the obtained 1-D image for feature extraction.

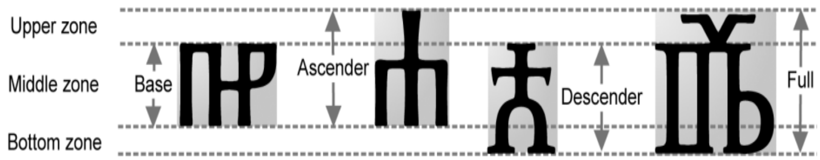


Figure 2. Script mapping according to typographical features.

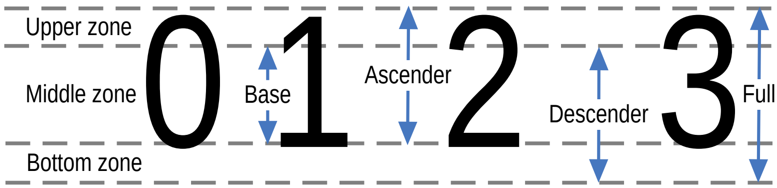


Figure 3. Script coding.

Texture Analysis

Texture is a measure of the intensity variation in the image surface [20]. Hence, the texture can be used to calculate statistical measures of the image as well as to extract suitable information for further processing. Run-length statistical analysis is used to evaluate and quantify the coarseness of a texture [21]. Let's suppose that we have an image *I* featuring *X* rows, *Y* columns and *L* levels of gray intensity. First, the run-length matrix *p(i, j)* is extracted. It is defined by specifying a direction and then counting the occurrence of runs for each gray level and length in that direction. Its number of rows corresponds to *L*, i.e., the maximum number of gray levels, while the number of columns corresponds to *N*, i.e., to the maximum run length. Run-length matrix **P** is given as:

$$\mathbf{P} = \begin{bmatrix} p(1,1) & \ldots & \ldots & \ldots & \ldots & \ldots & p(1,N) \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ p(L,1) & \ldots & \ldots & \ldots & \ldots & \ldots & p(L,N) \end{bmatrix}. \tag{1}$$

In our case, each element of the run-length matrix *p(i, j)* represents the gray level run-length of image *I* (1-D matrix) that gives the total number of occurrences of gray-level runs of length *j* and of the gray-level intensity value *i* [20]. Accordingly, a set of consecutive pixels with identical intensity values constitutes a gray level run.

Using the aforementioned matrix and vectors, the following run-length features were originally proposed in [21]:

(i) Short run emphasis (SRE),
(ii) Long run emphasis (LRE),
(iii) Gray-level nonuniformity (GLN),
(iv) Run length nonuniformity (RLN), and
(v) Run percentage (RP).

SRE measures the distribution of short runs. LRE quantifies the distribution of long runs. GLN measures the similarity of gray level values throughout the image. RLN quantifies the similarity of the length of runs throughout the image. RP measures the homogeneity and the distribution of runs of an image in a specific direction. n_r represents the total number of runs, while n_p is the number of pixels in the image *I*.

The extraction of texture features from the run-length matrix is extended by the following two measures [22]:

(i) Low gray-level runs emphasis (LGRE), and
(ii) High gray-level runs emphasis (HGRE).

LGRE takes into account the distribution of low gray level values, while HGRE measures the distribution of high gray level values.

Table 1. Eleven Run-Length Texture Measures

Measures	Definition
SRE	$SRE = \frac{1}{n_r}\sum_{i=1}^{L}\sum_{j=1}^{N}\frac{p(i,j)}{j^2}.$
LRE	$LRE = \frac{1}{n_r}\sum_{i=1}^{L}\sum_{j=1}^{N}p(i,j)\cdot j^2$
GLN	$GLN = \frac{1}{n_r}\sum_{i=1}^{L}\left(\sum_{j=1}^{N}p(i,j)\right)^2$
RLN	$RLN = \frac{1}{n_r}\sum_{j=1}^{N}\left(\sum_{i=1}^{L}p(i,j)\right)^2$
RP	$RP = \frac{n_r}{n_p}$
LGRE	$LGRE = \frac{1}{n_r}\sum_{i=1}^{L}\sum_{j=1}^{N}\frac{p(i,j)}{i^2}$
HGRE	$HGRE = \frac{1}{n_r}\sum_{i=1}^{L}\sum_{j=1}^{N}p(i,j)\cdot i^2$
SRLGE	$SRLGE = \frac{1}{n_r}\sum_{i=1}^{L}\sum_{j=1}^{N}\frac{p(i,j)}{i^2\cdot j^2}$
SRHGE	$SRHGE = \frac{1}{n_r}\sum_{i=1}^{L}\sum_{j=1}^{N}p(i,j)\cdot i^2/j^2$
LRLGE	$LRLGE = \frac{1}{n_r}\sum_{i=1}^{L}\sum_{j=1}^{N}p(i,j)\cdot j^2/i^2$
LRHGE	$LRHGE = \frac{1}{n_r}\sum_{i=1}^{L}\sum_{j=1}^{N}p(i,j)\cdot i^2\cdot j^2$

Additional four feature extraction functions gained by idea of joint statistical measure of gray level and run length are proposed in [23]. They are:

(i) Short run low gray-level emphasis (SRLGE),
(ii) Short run high gray-level emphasis (SRHGE),
(iii) Long run Low gray-level emphasis (LRLGE), and
(iv) Long run high gray-level emphasis (LRHGE).

SRLGE measures the joint distribution of short runs and low gray level values, while SRHGE takes into account the joint distribution of short runs and high gray level values. LRLGE measures the joint distribution of long runs and low gray level values, while LRHGE takes into account the joint distribution of long runs and high gray level values.

All eleven aforementioned measures are defined in Table 1.

The obtained eleven texture measures determine a feature vector representing the document in a given script.

Orthography

In the native Glagolitic orthography, the capital letters were written as descendent letters in the old document up to the half of the 16th century. However, under the influence of the Latin script after that period the capital letters in the Glagolitic documents were written as ascender letters. Hence, a clear distinction between documents written before and after that period can be made. Figures 4-5 illustrate the difference between old and new orthography in the Glagolitic documents.

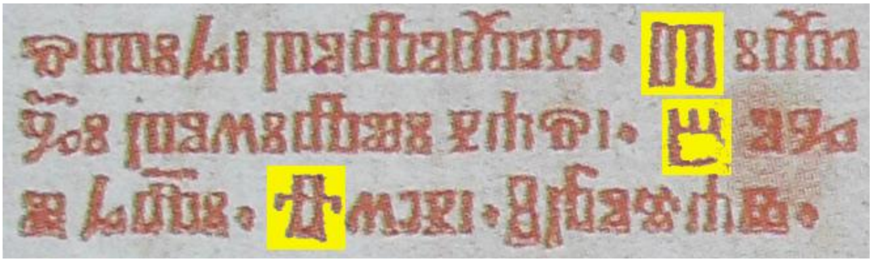


Figure 4. Old orthographic Glagolitic rule (See capital letters marked in yellow).

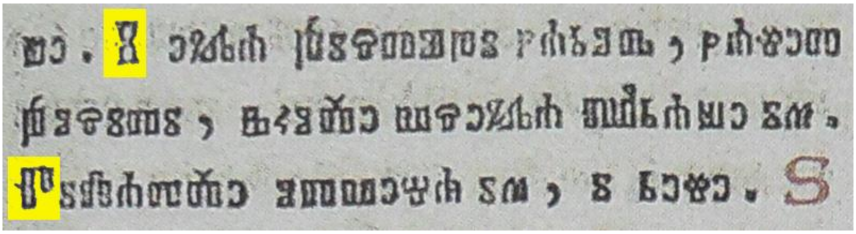


Figure 5. New orthographic Glagolitic rule (See capital letters marked in yellow).

Examples

In order to analyze the difference between old and new orthography, the text samples from Figures 4-5 are coded. The coded samples from the Figures 4-5 are given in Figures 6-7.

Also, the number of newly mapped codes is counted as well as the percentage in the text. The distribution of the script types in the coded text samples from Figures 6-7 is given in Tables 2-3, respectively.

000102010100. 201
2020001000100. 100
0110. 30000. 230010.

Figure 6. Coded text sample from Figure 4 (old orthographic rule).

00. 1 0011 3000000 01100 21000
300000 00010 000111 1000000.
1011010 000001 00 0 0000.

Figure 7. Coded text sample from Figure 5 (new orthographic rule).

Table 2. Distribution of the script types (old orthographic rule)

Mapped codes	Distribution
Base (0)	29 (63.04%)
Ascender (1)	10 (21.74%)
Descender (2)	5 (10.87%)
Full (3)	2 (4.35%)

Table 3. Distribution of the script types (new orthographic rule)

Mapped codes	Distribution
Base (0)	49 (72.06%)
Ascender (1)	16 (23.53%)
Descender (2)	1 (1.47%)
Full (3)	2 (2.94%)

If we compare the percentage of each of the script codes we can easily notice that the percentage of the code 2 is reduced from 10.87 to 1.47, which is around 7 times. According to that figure, we are going to apply our method to classify and distinct the Glagolitic document that used old and new orthography rules.

CLASSIFICATION

In order to identify a new document as given in old or new orthography, we create an ad-hoc artificial neural network, in particular a two-layer feedforward neural network, to employ on the proposed document feature vectors [24], [25]. In fact, neural networks extensively demonstrated their reliability in document retrieval and classification [26], [27], [28], in natural language processing and language classification from documents [29], and their superiority in these contexts with respect to other well-know classifiers [28], [30]. Next, we recall the main concepts underlying the adopted neural network.

It is composed of a layer of n input neurons, a hidden layer of m neurons and, because classification is binary (old or new orthography), of a layer of one output neuron o, interconnected to each other. In this network, the outputs at a given layer are forwarded to the neurons of the next layer. Also, each neuron at a given layer is fully connected to all the neurons of the next layer. The number m of neurons of the hidden layer is a critical aspect of the network, because a reduced number will produce a network with low learning ability. On the contrary, a too high number will determine a network with low generalization capacity. A weight is associated to each connection of the network, together with the weights determining the thresholding values for the neurons.

Because each document is represented by a feature vector of 11 elements, the network is composed of 11 neurons in the input layer, from which input data come from. Input neurons are represented as x_i, $i = 1...n$, where n is equal to 11 in our case. Also, an additional neuron x_0, whose value is always equal to

1, is provided as the bias to the hidden neurons. They are represented as h_j, $j = 1...m$. A connection between an input neuron x_i and an hidden neuron h_j is given as w_{ji}. Also, the input neuron x_0 is connected to all the neurons in the hidden layer, with connection weights w_{j0}, $j = 1...m$. The weight on the connection between a hidden neuron h_j and the output neuron o is represented as y_j. Also in this case, the bias hidden neuron h_0, determining a value which is always 1, is connected to the neuron o, with connection weight y_0. The output of the neurons in the hidden and output layers is the result of a thresholding sigmoid function on the weighted sum of their inputs.

Given a hidden neuron h_j, the weighted sum of its inputs is:

$$\sum_{i=1}^{n} w_{ji} x_i \ . \tag{2}$$

The employed thresholding function is the sigmoid function, determining an output between 0 and 1. Sigmoid function applied on the hidden neuron h_j is computed to obtain the output of the neuron:

$$sigmoid(a) = \frac{1}{1+e^{-a}}, \tag{3}$$

$$h_j = sigmoid(\sum_{i=1}^{n} w_{ji} x_i) = \frac{1}{1+e^{-\sum_{i=1}^{n} w_{ji} x_i}}. \tag{4}$$

The calculation of the weights for o in the output layer is similarly given as the result of the thresholding function on the weighted sum of its inputs forwarded from the hidden layer.

Given o, the weighted sum of its inputs coming from the hidden layer is given as:

$$\sum_{j=1}^{m} y_j h_j . \tag{5}$$

Because the output u of the network should be narrowed between 0 and 1, the sigmoid function is also employed on the weighted sum of o for thresholding:

$$u = sigmoid(o) = sigmoid(\sum_{j=1}^{m} y_j h_j) = \frac{1}{1+e^{-\sum_{j=1}^{m} y_j h_j}}. \tag{6}$$

Figure 8 shows the two-layer feedforward neural network model. Initially all the weights of the network assume small random values, which are modified from the training step by using the backpropagation algorithm [24]. Its aim is to "adjust" the network in order to obtain the correct output classification, given the document feature vector as input. A training set of document feature vectors in the two classes (old and new orthography) is presented multiple times as input of the network, document by document. Backpropagation algorithm repeatedly changes the network weights to obtain an output which is closer to the real class of the input documents. At the end, the network is ready to correctly classify "unseen" test document feature vectors as given in old or new orthography.

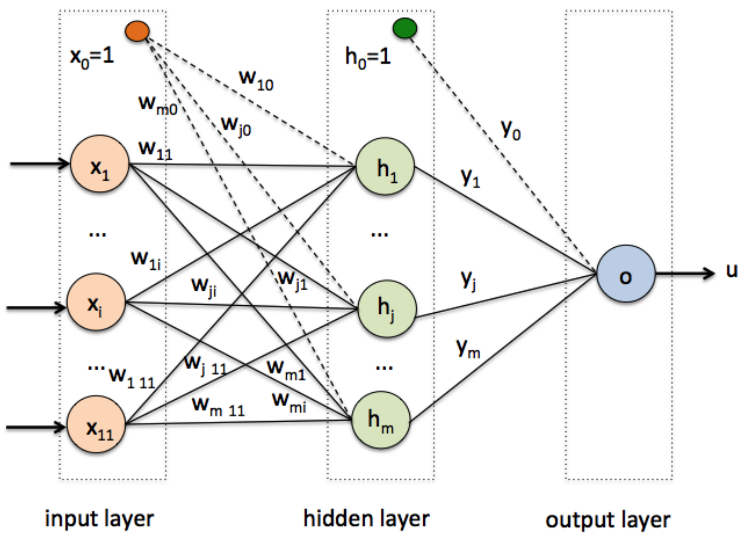


Figure 8. Two-layer feedforward neural network with 11 input neurons and one output neuron for binary classification of documents in old or new orthography.

The backpropagation algorithm updates the network weights in order to minimize the squared error between the output of the network and the class of the input document.

Specifically, the input document is propagated through the network to generate the output. Then, classification error is measured between the output and the class of the input document. Again, the weight updates are computed back to the network, for y_j, $j = 1, ..., m$, and then for w_{ji}, $i = 1, ..., n$, $j = 1, ..., m$. Finally, all the weights of the network are modified from the computed updates.

The updates of the weights y_j between hidden and output layers are computed as:

$$\Delta_{y_j} = \eta(r^t - u^t)h_j^t. \tag{7}$$

The updates of the weights w_{ji} between input and hidden layers are quantified as:

$$\Delta_{wji} = \eta(r^t - u^t)y_j h_j^t (1 - h_j^t) x_i^t. \tag{8}$$

where η is the learning rate, r^t and u^t indicate respectively the class and the output of the network for the t-th document x^t in the training set, and h^t_j and x^t_i are the outputs of the corresponding hidden and input neurons produced from x^t.

The error computed for x^t is the following:

$$E(x^t, r^t) = \frac{1}{2}(r^t - u^t)^2. \tag{9}$$

As a termination criterion, validation set is adopted. In particular, the weights of the network are updated multiple times on the training set, and sometimes, during this process, the error of the network is evaluated on the validation set. The algorithm is terminated when the error computed on this set of document feature vectors starts growing, to avoid network overfitting. At the end, the performances of the obtained classifier are evaluated on the document feature vectors composing the test set.

EXPERIMENT

The experimental part includes the application of the proposed method on a database of eleven different excerpts from different medieval documents, extracted from liturgical books, breviary, missals in Glagolitic script. Eight out of eleven documents are written according to the old orthographic rules, while the other three documents are written according to the new orthographic rules. Obviously, last eight documents dated from the period before the middle of the 16th century, while the first three documents dated later. Figure 9 shows an example of Glagolitic document from different periods, i.e., which was written according to different orthographic rules.

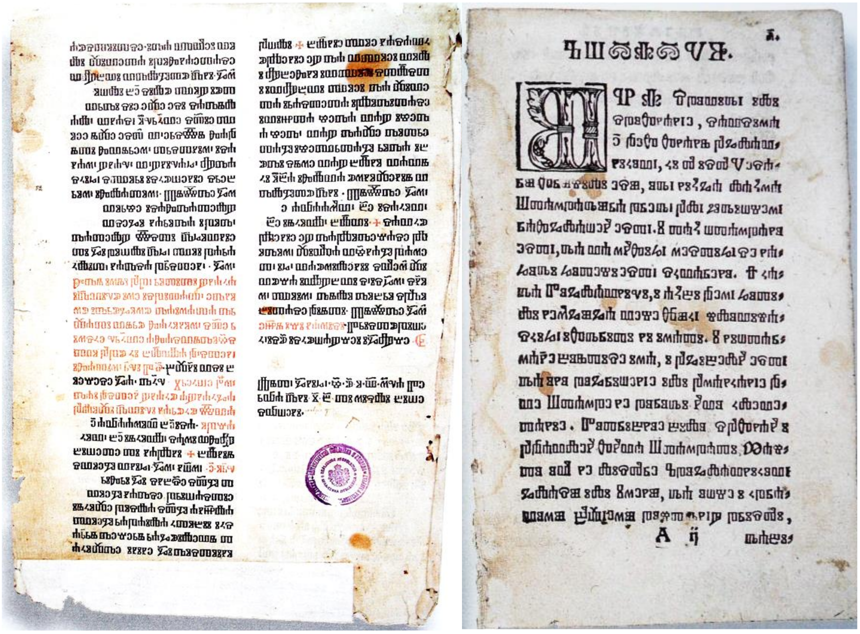
Results and Discussion

Experimentation has been performed in Matlab R2015a on a notebook quad core at 2.2 GHz, 16 GB RAM and UNIX operating system. A pre-processing phase has been employed for normalizing the document feature values of the database in a range between 0 and 1. In particular, normalization for the t-th document feature vector x^t is obtained by normalizing each value x_i^t of feature i using the following min-max method:

$$\bar{x}_i^t = \frac{x_i^t - \min_i}{\max_i - \min_i}. \tag{10}$$

where min_i is the minimum value of the feature i and max_i is the maximum value of the feature i.

Classification in old or new orthography has been performed on the aforementioned database by adopting also the Naive Bayes method [31] and the Support Vector Machine approach (SVM) [32]. Although the two methods obtain satisfactory results in classification task, demonstrating the efficacy of the proposed feature representation, the neural network showed its superiority with respect to the other classifiers in this context. Consequently, the two-layer feedforward neural network is adopted for classification of documents as given in old or new orthography.



(a) (b)

Figure 9. Glagolitic document written by: (a) the old ortographic rule, and (b) the new ortographic rule.

Cross validation method is employed for assessing the proposed approach. Specifically, the database D is randomly divided into training, validation and test set at a given percentage, by using 3 different combinations:

1. 50% of data for training, 25% for validation and 25% for test (named as D(50, 25, 25)),
2. 60% of data for training, 20% for validation and 20% for test (named as D(60, 20, 20)), and
3. 70% of data for training, 15% for validation and 15% for test (named as D(70, 15, 15)).

For each combination, the number of documents in the two classes is proportionally distributed for the training, validation and test sets. Then, to avoid dependence of the result on the selected training and validation sets, experiment is repeated 100 times for each percentage combination of training, validation and test.

Average precision, recall, and f-measure [33], together with the standard deviation, are computed for each percentage combination and each document class (old and new orthography) to evaluate the obtained results.

In order to determine the most suitable number of neurons in the hidden layer, which is a critical aspect of the network, a specific test is conducted. In particular, the network is equipped with a number of hidden neurons varying from 2 to the double of the input neurons [34], that is 2, 5, 10, 15, and 20. Each network with a certain number of hidden neurons is employed on the database randomly divided into training, validation and test sets, based on the 3 different percentage combinations, and the Mean Squared Error (MSE) is computed on the corresponding test sets.

MSE is the average squared difference between the outputs of the network and the class of the documents for the test set, and represents how much far are the outputs of the network from the true outputs. MSE computed on the test set is defined as follows:

$$MSE(x,r) = \frac{1}{T}\sum_{t=1}^{T}(r^t - u^t)^2. \tag{11}$$

where x represents the test set of size T, r^t is the class of the document t in the test set, and u^t is the output of the network for the document t in the test set. Then, for each number of hidden neurons, the average MSE, together with the standard deviation, are computed across the 3 different percentage combinations. The best number of hidden neurons is that corresponding to the minimum average MSE.

Table 4. Average MSE and corresponding standard deviation for each number of hidden neurons

	MSE_{avg}	MSE_{std}
2	0.0574	0.0995
5	0.0089	0.0154
10	0.0164	0.0117
15	0.1469	0.2544
20	0.2331	0.0578

Table 4 shows the result of this test. In particular, for each number of hidden neurons, the average MSE and corresponding standard deviation are reported. It is clear that 5 neurons in the hidden layer determine the minimum average MSE with a low standard deviation. Consequently, the two-layer feedforward neural network model is realized by including 5 hidden neurons.

Table 5 shows the classification results obtained from the two-layer feedforward neural network on the test sets of documents with old and new orthography, for each percentage combination of training, validation and test sets.

It is worth to observe that identification of documents in old or new orthography is highly reliable and accurate, also when the percentage of documents included in the training set is lowered to 50. In fact, in this case, average precision and f-measure reach a very high value of 0.99, while average recall is equal to 1.00. In the other two cases of percentage of documents in the training set equal to 60 and 70, documents in old or new orthography are perfectly identified, with an average precision, recall and f-measure of 1.00. Also, standard deviation is very low for percentage combination of 50, 25, 25, and 0 for the other two percentage combinations, demonstrating the stability of the obtained results.

In conclusion, performed experiments confirm the strong efficacy of the proposed method to successfully identify the historical period of the documents based on their different orthography.

Table 5. Classification results of the proposed method on the database of documents with old and new orthography

% combination	class	Precision	Recall	F-Measure
$D_{(50,25,25)}$	new ortography	0.9922 (0.0625)	1.0000 (0.0000)	0.9948 (0.0417)
	old ortography	1.0000 (0.0000)	0.9922 (0.0625)	0.9948 (0.0417)
$D_{(60,20,20)}$	new ortography	1.0000 (0.0000)	1.0000 (0.0000)	1.0000 (0.0000)
	old ortography	1.0000 (0.0000)	1.0000 (0.0000)	1.0000 (0.0000)
$D_{(70,15,15)}$	new ortography	1.0000 (0.0000)	1.0000 (0.0000)	1.0000 (0.0000)
	old ortography	1.0000 (0.0000)	1.0000 (0.0000)	1.0000 (0.0000)

CONCLUSION

In this study we proved that using various orthography rules, present in different historical periods, can be employed to differentiate and identify the origin of the medieval hand-printed or printed documents. The above task is solved by using specific character's mapping according to the typographical features of the document. In this way, OCR process is not mandatory and true recognition of each character in the text of document is not needed. The document mapping texture of the image is subjected to the feature extraction, by which 11 run-length characteristics were extracted. Furthermore, the classification is performed by an ad-hoc artificial neural network. The proposed algorithm was used on a database of medieval documents written in hand-printed and printed angular Glagolitic scripts. The obtained results are very accurate, promising the application of the method on other kinds of medieval documents.

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REFERENCES

[1] Liu, Z. (2008). Paper to Digital: Documents in the Information Age. Libraries Unlimited, Westport.

[2] Joshi, G. D., Garg, S. and Sivaswamy, J. (2007). A generalised framework for script identification. *International Journal on Document Analysis and Recognition* (IJDAR), *10*(2), 55-68.

[3] Busch, A., Boles, W. W. and Sridharan, S. (2006). Texture for script identification. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 27*(11), 1720-1732.

[4] Pal, U. and Chaudhury, B. B. (2002). Identification of different script lines from multi-script documents. *Image and Vision Computing, 20*(13-14), 945-954.

[5] Brodić, D., Milivojević, Z. N. and Maluckov, Č. A. (2013). Recognition of the script in Serbian documents using frequency occurrence and co-occurrence analysis. *Scientific World Journal*, 2013(896328), 1-14.

[6] Brodić, D., Milivojević, Z. N. and Maluckov, Č. A. (2015). An approach to the script discrimination in the Slavic documents. *Soft Computing*, *19*(9), 2655-2665.

[7] Brodić, D., Milivojević, Z. N. and Maluckov, Č. A. (2014). Script characterization in the old Slavic documents. In: Elmoataz A, Lezoray O, Nouboud F, Mammass D (eds) Image and Signal Processing, *LNCS*, *8509*, pp. 230-238. Springer.

[8] Brodić, D., Amelio, A. and Jevtić, M. (2015). Classification of German Scripts by Adjacent Local Binary Pattern Analysis of the Coded Text. In: Bikakis A, Zheng X (eds) Multi-disciplinary Trends in Artificial Intelligence, *LNCS*, *9426*, pp. 233-244. Springer.

[9] Brodić, D., Maluckov, Č. A., Milivojević, Z. and Draganov, I. R. (2014). Differentiation of the Script Using Adjacent Local Binary Patterns. In: Agree G (ed) Artificial Intelligence: Methodology, Systems, and Applications, *LNCS*, *8722*, pp. 162-169. Springer.

[10] Brodić, D., Milivojević, Z. N. and Amelio, A. (2015). Analysis of the South Slavic Scripts by Run-length Features of the Image Texture. *Elektronika Ir Elektrotechnika*, *21*(4), 60-64.

[11] Brodić, D. (2014). Script Recognition by Statistical Analysis of the Image Texture. *In: Proceedings of 10th International Symposium on Industrial Electronics*, (INDEL 2014), pp. 168-174.

[12] Brodić, D., Amelio, A. and Milivojević, Z. N. (2016). Identification of Fraktur and Latin Scripts in German Historical Documents Using Image Texture Analysis. *Applied Artificial Intelligence*, *30*(5), 379-395.

[13] Brodić, D., Milivojević, Z. N. and Maluckov, Č. A. (2014). Characterization of the Script Using Adjacent Local Binary Patterns. *In: Proceedings of 37th International Conference on Telecommunications and Signal Processing*, (TSP 2014), pp. 640-643.

[14] Brodić, D., Amelio, A. and Milivojević, Z. N. (2015). An Approach to the Analysis of the South Slavic Medieval Labels Using Image Texture. *In: Proceedings of 3rd Workshop on Recognition and Action for Scene Understanding*, (REACTS 2015), pp. 105-118.

[15]Brodić, D., Amelio, A. and Milivojević, Z. N. (2015). Characterization and Distinction Between Closely Related South Slavic Languages on the Example of Serbian and Croatian. In: Azzopardi G, Petkov N (eds) Computer Analysis of Images and Patterns, *LNCS*, *9256*, pp. 654-666. Springer.

[16]Brodić, D., Amelio, A., Milivojević, Z. N. and Jevtić, M. (2016). Document Image Coding and Clustering for Script Discrimination. *ICIC Express Letters*, *10*(7), 1561-1566.

[17]Zramdini, A. W. and Ingold, R. (1998). Optical font recognition using typographical features *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *20*(8), 877-882.

[18]Chaudhuri, B. B., Pal, U. and Mitra, M. (2002). Automatic recognition of printed Oriya script. *Sadhana*, *27*(1), 23-34.

[19]Damjanović, S. (2012). Slovoiskona (staroslavenska/ starohrvatskacitanka), Zagreb: Matica hrvatska.

[20]Brodić, D., Amelio, A. and Milivojević, Z. N. (2015). Classification of the Scripts in Medieval Documents from Balkan Region by Run-Length Texture Analysis. In: 22nd International Conference on Neural Information Processing, LNCS 9489, pp. 442-450. Springer Heidelberg.

[21]Galloway, M. M. (1975). Texture analysis using gray level run length. *Computer, Graphics and Image Processing*, *4*(2), 172-179.

[22]Chu, A., Sehgal, C. M. and Greenleaf, J. F. (1990). Use of gray value distribution of run lengths for texture analysis. *Pattern Recognition Letters*, *11*(6), 415-419.

[23]Dasarathy, B. R. and Holder, E. B. (1991). Image characterizations based on joint gray-level run-length distributions. *Pattern Recognition Letters*, *12*(8), 497-502.

[24]Parker, L. E. (2007). Notes on Multilayer, Feedforward Neural Networks. University of Tennessee Department of Electrical Engineering and Computer Science.

[25]Mitchell, T. (1997). Machine Learning. McGraw Hill.

[26]Li, C. H. and Park, S. C. (2007). Artificial Neural Network for Document Classification Using Latent Semantic Indexing. In*: International Symposium on Information Technology Convergence,* pp. 17-21.

[27]Zhang, Z., Zhang, S., Chen, E., Wang, X. and Cheng, H. (2005). TextCC: New Feed Forward Neural Network for Classifying

Documents Instantly. In*: Second International Symposium on Neural Networks, Proceedings*, Part II, pp. 232-237.

[28]Manevitz, L. and Yousef, M. (2007). One-class document classification via Neural Networks. *Neurocomputing*, *70*(7-9), 1466-1481.

[29]Al-Dubaee, S. A., Ahmad, N., Martinovic, J. and Snasel, V. (2010). Language Identification Using Wavelet Transform and Artificial Neural Network. In*: International Conference on Computational Aspects of Social Networks (CASoN)*, pp. 515-520.

[30]Vinodhini, G. and Chandrasekaran, R. M. (2016). A comparative performance evaluation of neural network based approach for sentiment classification of online reviews. *Journal of King Saud University - Computer and Information Sciences*, *28*(1), 2-12.

[31]Russell, S. and Norvig, P. (2003). Artificial Intelligence: A Modern Approach (2nd ed.). Prentice Hall.

[32]Cortes, C. and Vapnik, V. (1995). Support-vector networks. *Machine Learning*, *20*(3), 273-297.

[33]Performance measures for machine learning. Available online at http:// www.cs.cornell.edu/courses/cs578/2003fa/performance_measures.pdf .

[34]Karsoliya, S. (2012). Approximating Number of Hidden layer neurons in Multiple Hidden Layer BPNN Architecture. *International Journal of Engineering Trends and Technology*, *3*(6), 714-717.

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- **Journal papers**

1. Alessia Amelio. Approximate matching in ACSM dissimilarity measure. Procedia Computer Science, Elsevier, Vol. 96, pp. 1479--1488, 2016
2. Darko Brodić, Alessia Amelio, Zoran N. Milivojević. Language Discrimination by Texture Analysis of the Image Corresponding to the Text. Neural Computing and Applications, Springer, pp. 1--22, 2016
3. Alessia Amelio, Clara Pizzuti. Correction for Closeness: Adjusting Normalized Mutual Information Measure for Clustering Comparison. Computational Intelligence, Wiley, Available online, 2016
4. Alessia Amelio, Clara Pizzuti. An Evolutionary and Local Refinement Approach for Community Detection in Signed Networks. International Journal on Artificial Intelligence Tools, World Scientific, Vol. 25, Issue 4, 1650021-1--44, 2016
5. Darko Brodić, Alessia Amelio. Detecting of the Extremely Low Frequency Magnetic Field Ranges for Laptop in Normal Operating Condition or Under Stress. Measurement, Elsevier, Vol. 91, pp. 318--341, 2016
6. Darko Brodić,Alessia Amelio,Zoran N. Milivojević. Identification of Fraktur and Latin Script in German Historical Documents Using Image Texture Analysis. Applied Artificial Intelligence, Taylor and Francis, Vol. 30, pp. 379--395, 2016
7. Darko Brodić, Alessia Amelio, Zoran N. Milivojević, Milena Jevtic. Document Image Coding and Clustering for Script Discrimination. ICIC Express Letters, Vol. 10, Issue 7, pp. 1561--1566, 2016
8. Darko Brodić, Dejan Tanikić, Alessia Amelio. An approach to evaluation of the extremely low-frequency magnetic field radiation in the laptop computer neighborhood by artificial neural networks. Neural Computing and Applications, Springer, Vol. 28, pp. 1-13, 2016
9. Alessia Amelio, Clara Pizzuti. A Patch-based Measure for Image Dissimilarity. Neurocomputing, Elsevier, Vol. 171, pp. 362--378, 2016

10. Alessia Amelio, Clara Pizzuti. Evolutionary Clustering for Mining and Tracking Dynamic Multilayer Networks. Computational Intelligence, Wiley, 2016
11. Darko Brodić, Alessia Amelio. Classification of the Extremely Low Frequency Magnetic Field Radiation Measurement from the Laptop Computers. Measurement Science Review, De Gruyter, Vol. 15, Issue 4, pp. 202--209, 2015
12. Darko Brodić, Zoran N. Milivojević, Alessia Amelio. Analysis of the South Slavic Scripts by Run-Length Features of the Image Texture. Elektronika IR Elektrotechnika, Vol. 21, Issue 4, pp. 60--64, 2015
13. Alessia Amelio, Clara Pizzuti. An Evolutionary Approach for Image Segmentation. Evolutionary Computation, MIT Press, Vol. 22, Issue 4, pp. 525-557, 2014

- **Magazine papers**

1. Darko Brodić, Dejan Tanikić, Alessia Amelio. Predicting the Extremely Low Frequency Magnetic Field Radiation Emitted from Laptops: A New Approach to Laptop Design. ERCIM News, n. 107, pp. 56--57, 2016
2. Alessia Amelio. A Bottom-up Strategy for Clustering Complex Datasets with Application to Language and Script Discrimination. ERCIM News, n. 103, pp. 33--34, 2015
3. Darko Brodić, Alessia Amelio. Classification and Evaluation of the Extremely Low Frequency Electromagnetic Field Radiation Produced by Laptop Computers, ERCIM News, n. 102, pp. 36--37, 2015

- **Book chapters**

1. Alessia Amelio, Clara Pizzuti. Mining and Analyzing the Italian Parliament: Parties Structure and Evolution. Recommendation and Search in Social Networks, pp. 249--279, Lecture Notes in Social Networks, Springer, 2015
2. Alessia Amelio, Clara Pizzuti. Overlapping Community Discovery Methods: A Survey. Social Networks: Analysis and Case Studies, pp. 105--125, Lecture Notes in Social Networks, Springer, 2014

- **Conference papers**

1. Darko Brodić, Alessia Amelio. Analysis of the Human-Computer Interaction on the Example of Image-based CAPTCHA by Association Rule Mining. In proceedings of 5th International Workshop on Symbiotic Interaction (Symbiotic), 29-30 September 2016, Padua, Italy (In press)
2. Darko Brodić, Alessia Amelio, Ivo R. Draganov. Time Analysis of Text-based CAPTCHA by Association Rules. In proceedings of 17th International Conference on Artificial Intelligence: Methodology, Systems, Applications (AIMSA), 7-10 September 2016, Varna, Bulgaria, Lecture Notes in Computer Science 9883, Springer, pp. 78-88
3. Darko Brodić, Alessia Amelio, Zoran N. Milivojević. A New Image Analysis Framework for Latin and Italian Language Discrimination. In proceedings of 1st International Workshop on Modeling, Learning and Mining for Cross/Multilinguality (MultiLingMine), 20-23 March 2016, Padua, Italy, CEUR Workshop Proceedings 1589, pp. 46--55
4. Darko Brodić, Alessia Amelio, Milena Jevtić. Classification of German Scripts by Adjacent Local Binary Pattern Analysis of the Coded Text. In proceedings of 9th Multi-Disciplinary International Workshop on Artificial Intelligence (MIWAI), 13-15 November 2015, Fuzhou, Fujian Province, China, Lecture Notes in Computer Science 9426, Springer, pp. 233--244
5. Darko Brodić, Alessia Amelio, Zoran N. Milivojević. Classification of the Scripts in Medieval Documents from Balkan Region by Run-length Texture Analysis. In proceedings of 22nd International Conference on Neural Information Processing (ICONIP), 9-12 November 2015, Istanbul, Turkey, Lecture Notes in Computer Science 9489, Springer, pp. 442--450
6. Darko Brodić, Alessia Amelio, Zoran N. Milivojević. An Approach to the Analysis of the South Slavic Medieval Labels Using Image Texture. In proceedings of 3rd Workshop on Recognition and Action for Scene Understanding (REACTS), 5 September 2015, Valletta, Malta, arXiv:1509.01978
7. Darko Brodić, Alessia Amelio, Zoran N. Milivojević. Characterization and Distinction Between Closely Related South Slavic Languages on the Example of Serbian and Croatian. In proceedings of 16th International Conference on Computer Analysis of Images and Patterns (CAIP), 2-4 September 2015, Valletta, Malta,

Lecture Notes in Computer Science, Part I, 9256, Springer, pp. 654--666

8. Alessia Amelio, Clara Pizzuti. Analysis of the Italian Tweet Political Sentiment in 2014 European Elections. In proceedings of the 27th IEEE International Conference on Tools with Artificial Intelligence (ICTAI), 9-11 November 2015, Vietri sul Mare, Italy, IEEE CS Press, pp. 713--720
9. Alessia Amelio, Clara Pizzuti. Is Normalized Mutual Information a Fair Measure for Comparing Community Detection Methods?. In proceedings of the IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM), 25-28 August 2015, Paris, France, IEEE CS Press, pp. 1584--1585
10. Alessia Amelio, Clara Pizzuti. An Evolutionary Dynamic Optimization Framework for Structure Change Detection of Streaming Networks. In proceedings of 6th IEEE International Conference on Information, Intelligence, Systems and Applications (IISA), 6-8 July 2015, Corfu, Greece, IEEE CS Press, pp. 1--6
11. Alessia Amelio, Clara Pizzuti. Community Detection in Multidimensional Networks. In proceedings of the IEEE International Conference on Tools with Artificial Intelligence (ICTAI), 10-12 November 2014, Limassol, Cyprus, IEEE CS Press, pp. 352--359
12. Alessia Amelio, Clara Pizzuti. A Cooperative Evolutionary Approach to Learn Communities in Multilayer Networks. In proceedings of the 13th International Conference on Parallel Problem Solving from Nature (PPSN), 13-17 September 2014, Ljubljana, Slovenia, Lecture Notes in Computer Science 8672, Springer, pp. 222--232
13. Alessia Amelio, Clara Pizzuti. Evaluating the Average Common Submatrix measure for the Similarity of Real-World Images. In proceedings of the 22nd Italian Symposium on Advanced Database Systems (SEBD), 16-18 June 2014, Sorrento Coast, Italy, pp. 303--310
14. Alessia Amelio, Clara Pizzuti. A New Evolutionary-based Clustering Framework for Image Databases. In proceedings of the 6th International Conference on Image and Signal Processing (ICISP), 30 June - 2 July 2014, Cherbourg-Octeville, France, Lecture Notes in Computer Science 8509, Springer, pp. 322--331
15. Alessia Amelio, Clara Pizzuti. Uncovering Communities in Multidimensional Networks with Multiobjective Genetic Algorithms. Genetic and Evolutionary Computation Conference (GECCO

Companion), 12-16 July 2014, Vancouver, BC, Canada, ACM Proceedings, pp. 75--76

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1. D. Brodić, A. Amelio: Detecting of the Extremely Low Frequency Magnetic Field Ranges for Laptop in Normal Operating Condition or Under Stress, Measurement, ISSN 0263-2241, Vol. 91, No. September, pp. 318 - 341, 2016, [Impact factor (IF) 1.742/2016]
2. D. Brodić, D. Tanikić, A. Amelio: An approach to evaluation of the extremely low-frequency magnetic field radiation in the laptop computer neighborhood by artificial neural networks, Neural Computing and Applications, ISSN 0941-0643, pp.1-11, 2016, [Impact factor (IF) 1.492/2015]
3. D. Brodić, A. Amelio, M. Z. N. Milivojević: Language discrimination by texture analysis of the image corresponding to the text, Neural Computing and Applications, ISSN 0941-0643, pp. 1-13, 2016, [Impact factor (IF) 1.492/2016]
4. D. Brodić, Z. N. Milivojević: Text Line Segmentation with the Parametric Water Flow Algorithm, Information Technology And Control, ISSN 1392–124X, Vol. 45, No. 1, pp. 52 - 61, 2016, [Impact factor (IF) 0.633/2015]
5. D. Brodić: Analysis of the Extremely Low Frequency Magnetic Field Emission from Laptop Computers, Metrology and Measurement Systems, ISSN 0860-8229, Vol. 23, No. 1, pp. 143 - 154, 2016, [Impact factor (IF) 1.140/2015]

6. D. Brodić, A. Amelio, Z. N. Milivojević: Identification of Fraktur and Latin Script in German Historical Documents Using Image Texture Analysis, Applied Artificial Intelligence, ISSN 0883-9514, Vol. 30, No. 5, pp. 379 - 395, 2016, [Impact factor (IF) 0.540/2015]
7. D. Brodić, Z. N. Milivojević, Č. A. Maluckov: An approach to the script discrimination in the Slavic documents, Soft Computing, ISSN 1432-7643, Vol. 19, No. 9, pp. 2655 - 2665, 2015, [Impact factor (IF) 1.630/2015]
8. D. Brodić: Text Line Segmentation with Water Flow Algorithm Based on Power Function, Journal of Electrical Engineering - Elektrotechnický časopis, ISSN 1335-3632, Vol. 66, No. 3, pp. 132 - 141, 2015, [Impact factor (IF) 0.378/2014]
9. D. Brodić, Z. N. Milivojević: Approach to the Estimation of Global and Local Text Skew in Historical Printed Documents, Journal of Control Engineering and Applied Informatics, ISSN 1454-8658, Vol. 17, No. 2, pp. 99 - 109, 2015, [Impact factor (IF) 0.449/2015]
10. D. Brodić, Č. A. Maluckov, L. Peng: Statistics Oriented Preprocessing of Document Image, Computing and Informatics, ISSN 1335-9150, Vol. 34, No. 2, pp. 383 - 401, 2015, [Impact factor (IF) 0.524/2015]
11. D. Brodić, A. Amelio: Classification of the Extremely Low Frequency Magnetic Field Radiation Measurement from the Laptop Computers, Measurement Science Review, ISSN 1335-8871, Vol. 15, No. 4, pp. 202 - 209, 2015, [Impact factor (IF) 0.969/2015]
12. D. Brodić, Z. N. Milivojević, A. Amelio: Analysis of the South Slavic Scripts by Run-length Features of the Image Texture, Elektronika Ir Elektrotechnika, ISSN 1392-1215, Vol. 21, No. 4, pp. 60 - 64, 2015, [Impact factor (IF) 0.389/2015]
13. D. Brodić, C. A. B. Mello, Č. A. Maluckov, Z. N. Milivojević: An Approach to Skew Detection of Printed Documents, Journal of Universal Computer Science, ISSN 0948-695X, Vol. 20, No. 4, pp. 488 - 506, 2014, [Impact factor (IF) 0.466/2014]
14. Z. N. Milivojević, D. Brodić, M. Milivojević: The Effects of the Active Hypoxia to the Speech Signal Inharmonicity, Radioengineering, ISSN 1210-2512, Vol. 23, No. 2, pp. 665 - 670, 2014, [Impact factor (IF) 0.653/2014]
15. Z. N. Milivojević, D. Brodić, D. Blagojević: The Impact of the Acute Hypoxia to Speech Inharmonicity, Elektronika Ir Elektrotechnika, ISSN 1392-1215, Vol. 20, No. 5, pp. 136 - 143, 2014, [Impact factor (IF) 0.561/2014]

- **Journal papers (Scopus)**

1. Darko Brodić, Alessia Amelio, Zoran N. Milivojević, Milena Jevtic. Document Image Coding and Clustering for Script Discrimination. ICIC Express Letters, Vol. 10, Issue 7, pp. 1561-1566, 2016
    A. Popova, J. Garcia, N. Neshov, I. Draganov, D. Brodić: Finding URLs in images by text extraction in DCT domain, recognition and matching in dictionary, International Journal of Reasoning-based Intelligent Systems, ISSN 1755-0556, Vol. 7, No. 1/2, pp. 78 - 92, 2015
2. D. Brodić: Measurement of the extremely low frequency magnetic field in the laptop neighborhood, Revista Facultad de Ingeniería, ISSN 0120-6230, Vol. 76, pp. 39 - 45, 2015
3. D. Tanikić, M. Manić, S. Ranđelović, D. Đenadić, D. Brodić: Determination of the characteristic transformation temperatures of the biocompatible shape memory alloys, International Journal of Research in Engineering and Technology, ISSN 2321-7308, Vol. 3, No. 17, pp. 1 - 6, 2014

- **Magazine papers**

1. D. Brodić, D. Tanikić, A. Amelio: Predicting the Extremely Low frequency Magnetic field Radiation Emitted from Laptops: A New Approach to Laptop design, ERCIM News, ISSN 0926-4981, Vol. 107, No. 107, pp. 56 - 57, 2016
2. D. Brodić, A. Amelio: Classification and Evaluation of the Extremely Low Frequency Electromagnetic Field Radiation Produced by Laptop Computers, ERCIM News, ISSN 0926-4981, Vol. 102, No. 102, pp. 36 - 37, 2015

- **Conference papers**

1. Darko Brodić, Alessia Amelio. Analysis of the Human-Computer Interaction on the Example of Image-based CAPTCHA by Association Rule Mining. In proceedings of 5th International

Workshop on Symbiotic Interaction (Symbiotic), 29-30 September 2016, Padua, Italy (In press)

2. D. Brodić, A. Amelio, I. Draganov: Response Time Analysis of Text-Based CAPTCHA by Association Rules, Editors: Christo Dichev and Gennady Agre, Publisher: Springer International, Printed by Springer International Publishing Switzerland, ISBN 978-3-319-44748-3, pp. 78 - 88, 2016
3. D. Brodić, A. Amelio, Z. N. Milivojević: A New Image Analysis Framework for Latin and Italian Language Discrimination, First Workshop on Modeling, Learning, and Mining for Cross/Multilinguality (MultiLingMine 2016) co-located as a part of ECIR 2016, Padova, Italy, 2016, pp. 46 - 55
4. D. Brodić, A. Amelio, Z. N. Milivojević: Characterization and Distinction Between Closely Related South Slavic Languages on the Example of Serbian and Croatian, Editors: G. Azzopardi and N. Petkov, Publisher: Springer-Verlag, Printed by Springer International Publishing Switzerland, ISBN 978-3-319-23191-4, pp. 654 - 666, 2015
5. D. Brodić, A. Amelio, M. Jevtić: Classification of German Scripts by Adjacent Local Binary Pattern Analysis of the Coded Text, Editors: Bikakis, Antonis, Zheng, Xianghan, Publisher: Springer-Verlag International, Printed by Springer International Publishing, ISBN 978-3-319-26181-2, pp. 233 - 244, 2015
6. D. Brodić, A. Amelio, Z. N. Milivojević: Classification of the Scripts in Medieval Documents from Balkan Region by Run-length Texture Analysis, Editors: Arik, S., Huang, T., Lai, W.K., Liu, Q., Publisher: Springer-Verlag International, Printed by Springer International Publishing Switzerland, ISBN 978-3-319-26532-2, pp. 442 - 450, 2015
7. D. Brodić, A. Amelio, Z. N. Milivojević: An Approach to the Analysis of the South Slavic Medieval Labels Using Image Texture, REACTS 2015, Valetta, Malta, 2015, pp. 105 - 118
8. D. Brodić, D. Tanikić, M. Jevtić, I. Draganov: An Approach to Establishing Models for the EMF Emission of the Laptops by ANN, 10th International Conference on Communications, Electromagnetics and Medical Applications (CEMA'15), Sofia, Bulgaria, 2015, pp. 27 - 30

    I. Draganov, O. Boumbarov, D. Brodić: Personal Data Protection for Medical Assistive System Used by Motor

Disabled Patients Based on MPEG-21 Schemas, 10th International Conference on Communications, Electromagnetics and Medical Applications (CEMA'15), Sofia, Bulgaria, 2015, pp. 22 - 26

9. D. Brodić, Z. N. Milivojević, I. Draganov, V. Tasić: Comparison of Different Methods for the Estimation of Text Skew, L International Conference on Information, Communication and Technologies, Sofia, Bulgaria, 2015, pp. 50 - 53

I. Draganov, N. Neshov, D. Brodić: Testing Oculus Rift Virtual Reality Headset Applicability to Medical Assistive Systems, L International Conference on Information, Communication and Technologies, Sofia, Bulgaria, 2015, pp. 54 - 57

10. B. Prlincević, Z. N. Milivojević, P. Spalević, D. Brodić: Comparative Analysis of the MSD and MSDM Watermarking Algorithms Based on the Schur Decomposition, L International Conference on Information, Communication and Technologies, Sofia, Bulgaria, 2015, pp. 258 - 261
11. M. Andjelić, V. Tasić, M. Pavlov-Kagadejev, D. Brodić, I. Stojković: Development of Data Acquisition Module Based on PIC18F4550 Microcontroller, L International Conference on Information, Communication and Technologies, Sofia, Bulgaria, 2015, pp. 361 - 364
12. D. Brodić, M. Jevtić, Z. N. Milivojević, V. Tasić: Text Skew Estimation Based on the Horizontal Entropy Calculation, 2015 38th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, 2015, pp. 1488 - 1491
13. V. Tasić, M. Pavlov-Kagadejev, V. Despotović, D. Brodić, M. Anđelić, I. Stojković: Process Control System of the Converters Plant in the RTB Bor Company, Serbia, 50th International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST 2015), Sofia, Bulgaria, 2015, pp. 353 - 356
14. V. Tasić, M. Pavlov-Kagadejev, V. Despotović, D. Brodić, I. Lazović: Process control system in the district heating plant in Bor, 47th International October Conference, Bor Lake, Serbia, 2015, pp. 469 - 472
15. D. Brodić, M. Jevtić: The analysis of the laptop characteristics with the impact to the laptop magnetic field emission, International

Scientific Conference UNITECH 2015, Gabrovo, Gabrovo, Bulgaria, 2015, pp. 253 - 256

16. D. Brodić, Z. N. Milivojević, Č. A. Maluckov: Script Characterization in the Old Slavic Documents (Image and Signal Processing, Lecture Notes in Computer Science 8509), Editors: Abderrahim Elmoataz, Olivier Lezoray, Fathallah Nouboud, Driss Mammass, Publisher: Springer-Verlag, Printed by Springer International Publishing, ISBN 978-3-319-07998-1; 978-3-319-07997-4, ISSN: 0302-9743, pp. 230 - 238, 2014
17. D. Brodić, Č. A. Maluckov, Z. N. Milivojević, I. Draganov: Differentiation of the Script Using Adjacent Local Binary Patterns (Artificial Intelligence: Methodology, Systems, and Applications, Lecture Notes in Artificial Intelligence 8722), Editors: Gennady Agre, Pascal Hitzler, Adila A. Krisnadhi, Sergei O. Kuznetsov, Publisher: Springer-Verlag, Printed by Springer International Publishing, ISBN 978-3-319-10553-6, 978-3-319-10554-3, ISSN: 0302-9743, pp. 162 - 169, 2014
18. K. Riesen, D. Brodić, Z. N. Milivojević, Č. A. Maluckov: Graph Based Keyword Spotting in Medieval Slavic Documents – A Project Outline (Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection, Lecture Notes in Computer Science 8740), Editors: Marinos Ioannides, Nadia Magnenat-Thalmann, Eleanor Fink, Roko Žarnić, Alex-Yianing Yen, Ewald Quak, Publisher: Springer-Verlag, Printed by Springer International Publishing, ISBN 978-3-319-13694-3, 978-3-319-13695-0, ISSN: 0302-9743, pp. 724 - 731, 2014
19. D. Brodić: Script Recognition by Statistical Analysis of the Image Texture (Invited paper)., 10th International Symposium on Industrial Electronics, Banja Luka, Bosnia and Herzegovina, 2014, pp. 168 - 174
20. D. Brodić, Z. N. Milivojević, Č. A. Maluckov, M. Jevtić: Discrimination between Serbian and Slovenian language by texture analysis, MIPRO, Opatija, Croatia, 2014
21. V. Tasić, M. Pavlov, D. Brodić, V. Despotović, D. Milivojević: The Use of the Internet and Wireless Communications in the Monitoring and Control of Industrial Processes, 37th International Convention on Information and Communication Technology, Electronics and Microelectronics MIPRO 2014, Opatija, Croatia, 2014, pp. 993 - 996

22. B. Prlinčević, Z. N. Milivojević, D. Brodić: MIPFD Algorithm for Image Fire Detection, 37th International Scientific Conference on Information, Communication and Energy Systems and Technological Applications (ICEST 2014), Niš, Serbia, 2014, pp. 373 - 376
23. D. Brodić, Z. N. Milivojević, Č. A. Maluckov: Characterization of the Script Using Adjacent Local Binary Patterns, 37th International Conference on Telecommunications and Signal Processing (TSP 2014), Berlin, Germany, 2014, pp. 640 - 643
24. D. Brodić, Z. N. Milivojević: Optimization of the Entropy Based Algorithm for Text Skew Detection, 14th International Scientific Conference UNITECH'14, Gabrovo, Bulgaria, 2014, pp. 318 - 322
25. B. Prlinčević, Z. N. Milivojević, D. Brodić: The Efficiency of MDB Algorithm for Elimination of Impulse Noise at Images with Watermark Inserted by DCTSVD Algorithm, 14th International Scientific Conference UNITECH'14, Gabrovo, Bulgaria, 2014, pp. 89 - 94
26. Z. N. Milivojević, B. Prlinčević, D. Brodić: Performanse of DDS Algorithm for Insertion of Double Watermark, 14th International Scientific Conference UNITECH'14, Gabrovo, Bulgaria, 2014, pp. 122 - 127
27. D. Tanikić, M. Manić, S. Ranđelović, D. Đenadić, D. Brodić: Determination of the characteristic transformation temperatures of the biocompatible shape memory alloys, International Academic Conference on Engineering, Internet and Technology, Prague, Czech Republic, 2014, pp. 35 - 40

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1. **Journal papers (Web of Science)**

1. D. Brodić, A. Amelio, M. Z. N. Milivojević: Language discrimination by texture analysis of the image corresponding to the text, Neural Computing and Applications, ISSN 0941-0643, pp. 1-13, 2016, [Impact factor (IF) 1.492/2016]
2. D. Brodić, Z. N. Milivojević: Text Line Segmentation with the Parametric Water Flow Algorithm, Information Technology And Control, ISSN 1392–124X, Vol. 45, No. 1, pp. 52 - 61, 2016, [Impact factor (IF) 0.633/2015]
3. D. Brodić, A. Amelio, Z. N. Milivojević: Identification of Fraktur and Latin Script in German Historical Documents Using Image Texture Analysis, Applied Artificial Intelligence, ISSN 0883-9514, Vol. 30, No. 5, pp. 379 - 395, 2016, [Impact factor (IF) 0.540/2015]
4. D. Brodić, Z. N. Milivojević, Č. A. Maluckov: An approach to the script discrimination in the Slavic documents, Soft Computing, ISSN 1432-7643, Vol. 19, No. 9, pp. 2655 - 2665, 2015, [Impact factor (IF) 1.630/2015]
5. D. Brodić, Z. N. Milivojević: Approach to the Estimation of Global and Local Text Skew in Historical Printed Documents, Journal of Control Engineering and Applied Informatics, ISSN 1454-8658, Vol. 17, No. 2, pp. 99 - 109, 2015, [Impact factor (IF) 0.449/2015]
6. D. Brodić, Z. N. Milivojević, A. Amelio: Analysis of the South Slavic Scripts by Run-length Features of the Image Texture, Elektronika Ir Elektrotechnika, ISSN 1392-1215, Vol. 21, No. 4, pp. 60 - 64, 2015, [Impact factor (IF) 0.389/2015]
7. D. Brodić, C. A. B. Mello, Č. A. Maluckov, Z. N. Milivojević: An Approach to Skew Detection of Printed Documents, Journal of Universal Computer Science, ISSN 0948-695X, Vol. 20, No. 4, pp. 488 - 506, 2014, [Impact factor (IF) 0.466/2014]
8. Z. N. Milivojević, D. Brodić, M. Milivojević: The Effects of the Active Hypoxia to the Speech Signal Inharmonicity, Radioengineering, ISSN 1210-2512, Vol. 23, No. 2, pp. 665 - 670, 2014, [Impact factor (IF) 0.653/2014]
9. Z. N. Milivojević, D. Brodić, D. Blagojević: The Impact of the Acute Hypoxia to Speech Inharmonicity, Elektronika Ir Elektrotechnika, ISSN 1392-1215, Vol. 20, No. 5, pp. 136 - 143, 2014, [Impact factor (IF) 0.561/2014]

2. **Journal papers (Scopus)**

1. Darko Brodić, Alessia Amelio, Zoran N. Milivojević, Milena Jevtic. Document Image Coding and Clustering for Script

Discrimination. ICIC Express Letters, Vol. 10, Issue 7, pp. 1561-1566, 2016

3. **Conference papers**

1. D. Brodić, A. Amelio, Z. N. Milivojević: A New Image Analysis Framework for Latin and Italian Language Discrimination, First Workshop on Modeling, Learning, and Mining for Cross/Multilinguality (MultiLingMine 2016) co-located as a part of ECIR 2016, Padova, Italy, 2016, pp. 46 - 55
2. D. Brodić, A. Amelio, Z. N. Milivojević: Characterization and Distinction Between Closely Related South Slavic Languages on the Example of Serbian and Croatian, Editors: G. Azzopardi and N. Petkov, Publisher: Springer-Verlag, Printed by Springer International Publishing Switzerland, ISBN 978-3-319-23191-4, pp. 654 - 666, 2015
3. D. Brodić, A. Amelio, Z. N. Milivojević: Classification of the Scripts in Medieval Documents from Balkan Region by Run-length Texture Analysis, Editors: Arik, S., Huang, T., Lai, W.K., Liu, Q., Publisher: Springer-Verlag International, Printed by Springer International Publishing Switzerland, ISBN 978-3-319-26532-2, pp. 442 - 450, 2015
4. D. Brodić, A. Amelio, Z. N. Milivojević: An Approach to the Analysis of the South Slavic Medieval Labels Using Image Texture, REACTS 2015, Valetta, Malta, 2015, pp. 105 - 118
5. D. Brodić, Z. N. Milivojević, I. Draganov, V. Tasić: Comparison of Different Methods for the Estimation of Text Skew, L International Conference on Information, Communication and Technologies, Sofia, Bulgaria, 2015, pp. 50 - 53
6. B. Prlincević, Z. N. Milivojević, P. Spalević, D. Brodić: Comparative Analysis of the MSD and MSDM Watermarking Algorithms Based on the Schur Decomposition, L International Conference on Information, Communication and Technologies, Sofia, Bulgaria, 2015, pp. 258 - 261
7. D. Brodić, Z. N. Milivojević, Č. A. Maluckov: Script Characterization in the Old Slavic Documents (Image and Signal Processing, Lecture Notes in Computer Science 8509), Editors: Abderrahim Elmoataz, Olivier Lezoray, Fathallah Nouboud, Driss Mammass, Publisher: Springer-Verlag, Printed by Springer International Publishing, ISBN 978-3-319-07998-1; 978-3-319-07997-4, ISSN: 0302-9743, pp. 230 - 238, 2014

8. D. Brodić, Č. A. Maluckov, Z. N. Milivojević, I. Draganov: Differentiation of the Script Using Adjacent Local Binary Patterns (Artificial Intelligence: Methodology, Systems, and Applications, Lecture Notes in Artificial Intelligence 8722), Editors: Gennady Agre, Pascal Hitzler, Adila A. Krisnadhi, Sergei O. Kuznetsov, Publisher: Springer-Verlag, Printed by Springer International Publishing, ISBN 978-3-319-10553-6, 978-3-319-10554-3, ISSN: 0302-9743, pp. 162 - 169, 2014
9. K. Riesen, D. Brodić, Z. N. Milivojević, Č. A. Maluckov: Graph Based Keyword Spotting in Medieval Slavic Documents – A Project Outline (Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection, Lecture Notes in Computer Science 8740), Editors: Marinos Ioannides, Nadia Magnenat-Thalmann, Eleanor Fink, Roko Žarnić, Alex-Yianing Yen, Ewald Quak, Publisher: Springer-Verlag, Printed by Springer International Publishing, ISBN 978-3-319-13694-3, 978-3-319-13695-0, ISSN: 0302-9743, pp. 724 - 731, 2014
10. D. Brodić, Z. N. Milivojević, Č. A. Maluckov, M. Jevtić: Discrimination between Serbian and Slovenian language by texture analysis, MIPRO, Opatija, Croatia, 2014
11. B. Prlinčević, Z. N. Milivojević, D. Brodić: MIPFD Algorithm for Image Fire Detection, 37th International Scientific Conference on Information, Communication and Energy Systems and Technological Applications (ICEST 2014), Niš, Serbia, 2014, pp. 373 - 376
12. D. Brodić, Z. N. Milivojević, Č. A. Maluckov: Characterization of the Script Using Adjacent Local Binary Patterns, 37th International Conference on Telecommunications and Signal Processing (TSP 2014), Berlin, Germany, 2014, pp. 640 - 643
13. D. Brodić, Z. N. Milivojević: Optimization of the Entropy Based Algorithm for Text Skew Detection, 14th International Scientific Conference UNITECH'14, Gabrovo, Bulgaria, 2014, pp. 318 – 322
14. B. Prlinčević, Z. N. Milivojević, D. Brodić: The Efficiency of MDB Algorithm for Elimination of Impulse Noise at Images with Watermark Inserted by DCTSVD Algorithm, 14th International Scientific Conference UNITECH'14, Gabrovo, Bulgaria, 2014, pp. 89 - 94
15. Z. N. Milivojević, B. Prlinčević, D. Brodić: Performanse of DDS Algorithm for Insertion of Double Watermark, 14th International Scientific Conference UNITECH'14, Gabrovo, Bulgaria, 2014, pp. 122 - 127

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Chapter 2

CHEILOSCOPY AND HUMAN IDENTIFICATION: A REVIEW

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ABSTRACT

Cheiloscopy is the name given to the study of lip prints. Nowadays, it is recognized that lip prints may be useful in identifying living individuals, as in certain circumstances they may be the only way to correlate an individual to a particular place or person. However, the use of lip prints in human identification is still controversial, and some authors suggest that there is insufficient evidence to conclude that the lip prints are unique for each individual, and therefore its forensic value doubtful. Recent studies on the detection of DNA, from epithelial cells present in lip prints, have opened new perspectives on this field of study. The existence of a link between a specific lip pattern and some diseases, and the individual origin and sex is also being researched. In this chapter the authors perform a review on current cheiloscopic techniques, addressing the study methodology and usefulness of lip print patterns study.

1. Introduction

Cheiloscopy, from the Greek words cheilos (lips) and skopein (to see) (Molano, Gil, Jaramillo and Ruiz, 2002) is the name given to the study of lip prints (Sivapathasundharam, Prakash and Sivakumar, 2001). The first reference to a lip prints study dates from 1902 (Caldas, Magalhaes and Afonso, 2007; Sivapathasundharam et al., 2001), however, it wasn't until 1930 that studies focusing on human identification were developed (Thomas and van Wyk, 1988). In 1932, Edmond Locard, the French famous criminologist, recognized the usefulness of lip print patterns in forensic investigations (Thomas and van Wyk, 1988), and later on, in 1950, Le Moyer Snyder referred to the use of lip print patterns in human identification (Snyder, 1950). Cheiloscopy is important in human identification because lip print patterns seem to be unique to an individual, except, perhaps, in monozygotic twins (Neville, Damm, Allen and Bouquot, 2002; Pueyo, Garrido and Sánchez, 1994; Sivapathasundharam et al., 2001; Tsuchihashi, 1974). Ragab and collegues stated that the specificity of Egyptian lip prints was verified in their study, as no two subjects showed absolutely similar lip print patterns; in fact, every person had a unique mixture of lip grooves. Moreover, pattern differences were observed even in twins and family relatives (Ragab, El-Dakroory and Rahman, 2013). These results agree with those from other authors, namely those obtained by El Domiaty and collegues who also reported that throughout the whole study, performed on 966 Saudi subjects, no identically similar lip print patterns were found (El Domiaty, Al-gaidi, Elayat, Safwat and Galal, 2010). Similar reports of lip print patterns singularity were made concerning Indian populations (Jeergal, Pandit, Desai, Surekha and Jeergal, 2016).

Furthermore, like fingerprints, lip print patterns rarely display any alterations to their original features, resisting many afflictions, such as herpetic lesions. In fact, only those pathologies that inflict permanent damage to the lip tissue, such as burns, seem to be able to alter the cheiloscopic pattern (Molano et al., 2002). Suzuki and Tsuchihashi also reported lip prints singularity, and observed lip response to trauma, stating that after healing, the lip pattern was restored to its original features (Suzuki and Tsuchihashi, 1971; Tsuchihashi, 1974).

Another important aspect of lip print patterns is its prompt formation: lip grooves can be identified in human beings as early as the sixth week of in uterine life (Sadler, 2012), meaning that they can be used for forensic purposes since birth.

2. Anatomical Aspects

Lips are mobile folds, with skin, muscle, glands and mucous membrane. They surround the mouth and form the anterior boundary of the oral cavity. Anatomically, the surface that forms the oral sphincter is called the lip area. The upper lip outspreads from under the nose, extending laterally toward the cheek to the nasolabial sulcus; the lower lip is bounded inferiorly by the labiomental sulcus. Both lips join at the corners of the mouth – the commissures – and are separated by the buccal fend (Warwick and Williams, 1979).

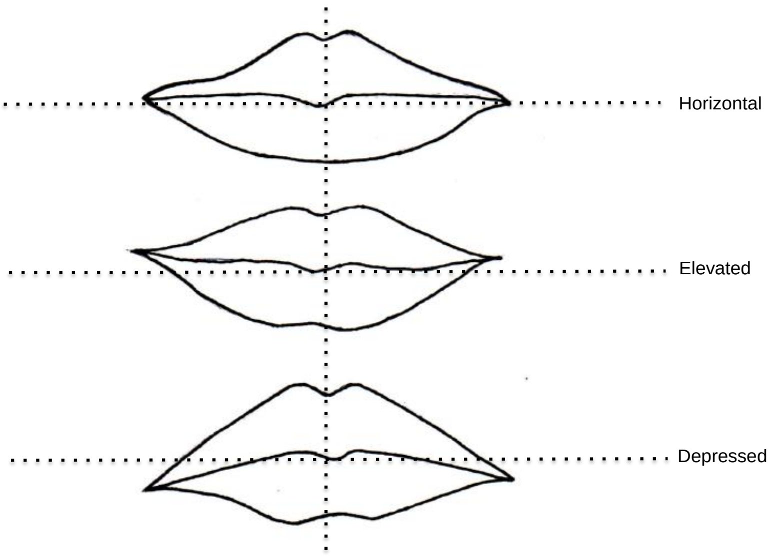

Figure 1. Lip commissures placement.

Lips are covered by skin and mucosa, which meet at the labial cord, a white wavy line. The space between the upper and lower labial cord is known as the Klein area, and it is covered with wrinkles and grooves that form the distinctive lip print pattern (Pueyo et al., 1994; Sivapathasundharam et al., 2001).

It should be noticed that besides lip print patterns, other lip features have been used in forensic human identification. Commissures placement, for instance, is of the utmost importance in facial recognition, making the lip shape look horizontal, elevated or depressed (Figure 1) (Molano et al., 2002; Pueyo et al., 1994). Lips have also been classified according their width, and it has been refereed that thin lips are common in European, medium lips show no ancestry preference, as they are very common, thick lips (with an inversion of the labial cord) are common in Africans, and mixed lips are usually seen in Asians (Chiu and Clark, 1992; Molano et al., 2002; Pueyo et al., 1994).

3. Lip Print Patterns Classifications

A forensic identification process is considered useful when it meets five key parameters, which will influence its degree of scientific reliability. These five key parameters are (França, 2011; Pereira, 2012; Pinheiro, 2008):

- Uniqueness or singularity: the condition of being impossible to find two individuals who share the same set of personal characteristics, i.e., each subject has only certain elements that individualize him. Nowadays, this concept has been challenged, and some authors claim that singularity is not only impossible to prove, but also not a fundamental request. If a feature has known prevalence and discriminative capacity it meets the request (Page, Taylor and Blenkin, 2011);
- Immutability: defined as the inviolability of individualizing characteristics throughout the individual's life;
- Permanence: principle which states that certain organic elements do not vary from those that arise during intrauterine life, remaining unchanged until advanced stages of putrefaction;
- Feasibility: the ease with which the process can be applied in the forensic routine;

- Classification methodology: it regards methodology storage and file sorting, so that the records are easily located whenever required.

The first three criteria have already been explored previously, in the introduction chapter, whereas the feasibility principle will be discussed further ahead. For now, we will address the classification methodology of lip print patterns, describing several classification practices used in this context.

3.1. Martín Dos Santos Classification

Lip grooves are divided into two groups: (1) simple, when formed by only one element and (2) compound, when composed by several elements. Simple elements can be a straight line (R-1), a curve (C-2), an angular form (A-3) or sinusoidal (S-4); conversely, compound grooves can be bifurcated (B-5), trifurcated (T-6) or anomalous (An-7) (Figure 2) (Santos, 1967).

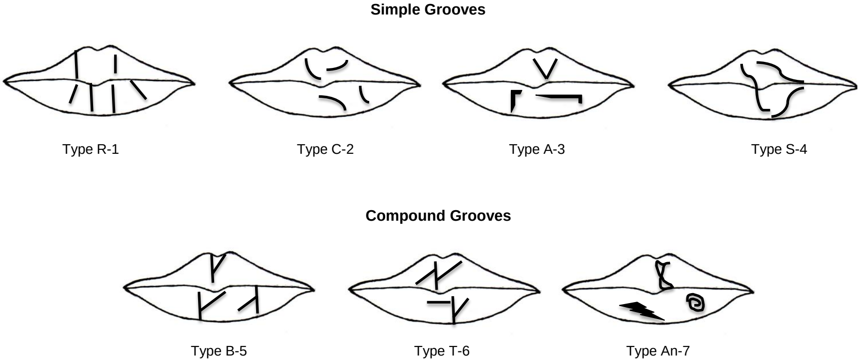

Figure 2. Martín dos Santos classification.

There are no references to the use of this classification, other than the one made by its author in his paper. This is due, perhaps to the lack of instructions to build a cheiloscopic formula that allows for lip print patterns classification.

3.2. Suzuki and Tsuchihashi Classification

These authors contemplated six different types of furrows (Suzuki and Tsuchihashi, 1971), as seen in Table 1 and in Figure 3.

Table 1. Suzuki and Tsuchihashi classification

CLASSIFICATION	FURROW TYPE
I	Complete vertical
I’	Incomplete vertical
II	Branched
III	Intersected
IV	Reticular pattern
V	Irregular

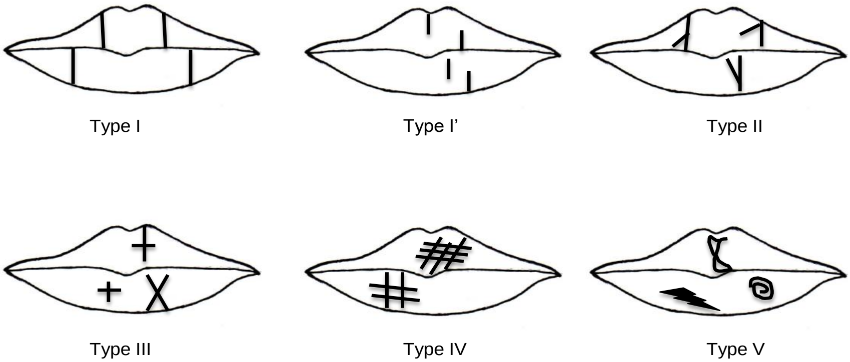

Figure 3. Suzuki and Tsuchihashi classification

Lip print patterns should be divided into four quadrants by a horizontal axis passing through both labial commissures dividing the upper and lower lip, and another axis perpendicular to the first one, coinciding with the median sagittal plane dividing the lips in right and left halves; each sulcus is classified, by writing its type in the area adjacent to the lip print itself.

Like the previously described classification, this methodology does not recommend the development of any cheiloscopic formula, which may hamper the comparative examination and also the registration process. With regard to its use, this is probably the most widely used method, being cited by several authors (Augustine, Barpande and Tupkari, 2008; Costa and Caldas, 2012; Devi et al., 2015; Mohamed, Shenoy and Vijaya, 2009; Ramakrishnan, Bahirwani and Valambath, 2015; Randhawa, Narang and Arora, 2011).

3.3. Renaud Classification

This is, without doubt, the most complete classification. The lips are studied in separated halves (left and right), and every groove has a number (Table 2), according to its form (Figure 4). A cheiloscopic formula is then elaborated using capital letters to describe the upper lip left (L) and right (R) sides, and small letters to classify each groove; in the lower lip, it is done the other way around, using capital letters to classify the grooves, and small letters to separate left from right sides. Furrows are classified as complete if they intersect the totally of the lip (from the labial cord to the oral sphincter) and incomplete, if not (Renaud, 1973).

Despite its obvious advantages, only a few researchers have used this classification (El Domiaty et al., 2010; Ragab et al., 2013).

Table 2. Renaud classification

CLASSIFICATION	FURROW TYPE
A	Complete vertical
B	Incomplete vertical
C	Complete bifurcated
D	Incomplete bifurcated
E	Complete branched
F	Incomplete branched
G	Reticular pattern
H	X or coma
I	Horizontal
J	Other forms (ellipse, triangle)

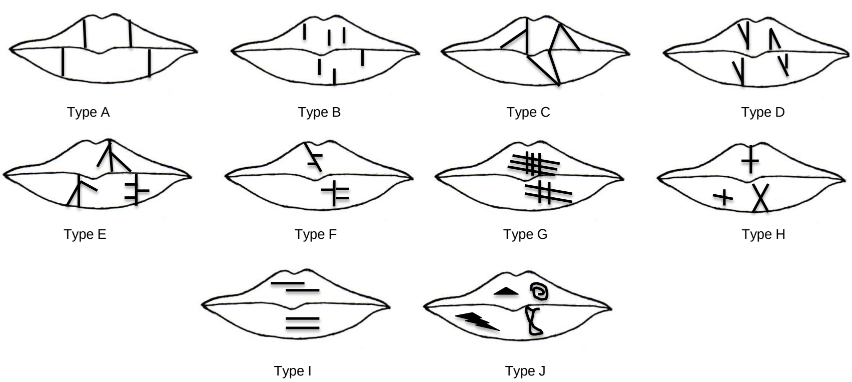

Figure 4. Renaud classification.

3.4. Afchar-Bayart Classification

This classification, dated from 1979, is inspired in the Suzuki and Tsuchihashi classification, and divides lip furrows in a seven-type classification (Afchar-Bayar, 1978), as seen in Table 3 and Figure 5.

Table 3. Afchar-Bayart classification

CLASSIFICATION	FURROW TYPE
A1	Vertical and straight, covering the whole lip
A2	Like the former, but without covering the whole lip
B1	Straight branched grooves
B2	Angulated branched grooves
C	Converging grooves
D	Reticular pattern
E	Other forms

Like the Suzuki and Tsuchihashi classification, this methodology does not provide a cheiloscopic formula. Furthermore, some of the anatomical types described are not easy to interpret, as sketches illustrating each furrow type are not provided. Due perhaps to the above reasons, this classification is only referred by its author in the paper used to present it (Afchar-Bayar, 1978).

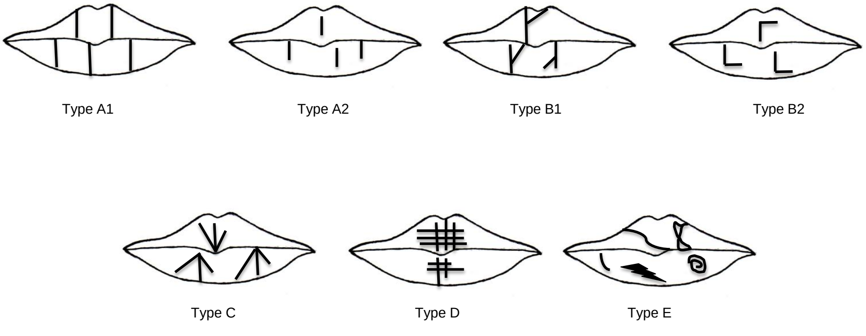

Figure 5. Afchar – Bayart classification.

3.5. Domingos, Romero and Capilla Classification

This is another classification based on the one made by Suzuki and Tsuchihashi. In the grooves classified as Type II of Suzuki and Tsuchihashi, the author and his co-workers observed, with some frequency, a slight variation: they observed that branched grooves often divided upwards in the upper lip, and downwards in the lower, as reported by Suzuki and Tsuchihashi; but they also realized that some grooves, the so called II' type, branched the other way around (Dominguez, Romero and Capilla, 1975). The types of lip furrows described in this classification are depicted in Table 4 and Figure 6.

Table 4. Domingos, Romero and Capilla classification

CLASSIFICATION	FURROW TYPE
I	Vertical complete
I'	Vertical incomplete
II	Bifurcated, upwards in the upper lip, and downwards in the lower lip
II'	Bifurcated, downwards in the upper lip, and upwards in the lower lip
III	Converging grooves
IV	Reticular pattern
V	Other forms

As with the Suzuki and Tsuchihashi classification, this methodology does not provide a cheiloscopic formula. Once more, this classification is only referred in the paper used to present it.

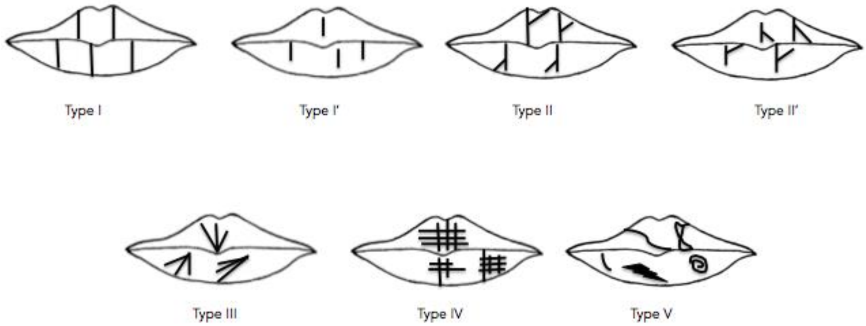

Figure 6. Domingos, Romero and Capilla classification.

3.6. Oviedo and Meira classification

This classification, once again inspired in the Suzuki and Tsuchihashi classification, adds the analyses of the groove depth to the morphologic features (Oviedo and Meira, 1988). This feature can, of course, be difficult to assess, particularly when studying photographs. It also does not lead to a cheiloscopic formula elaboration, and no references, besides the paper where it was presented, can be found in the literature. The types of lip furrows described in this classification are depicted in Table 5.

Table 5. Oviedo and Meira classification

CLASSIFICATION	FURROW TYPE
A	Vertical or horizontal grooves
B	Branched or bifurcated grooves
C	Lobulations

Type A furrows can still be divided in complete or incomplete, being the latter subdivided in external and internal. Similarly, type C furrows can also be divided in horizontal or vertical grooves, reticular pattern, converging or diverging grooves (Figure 7).

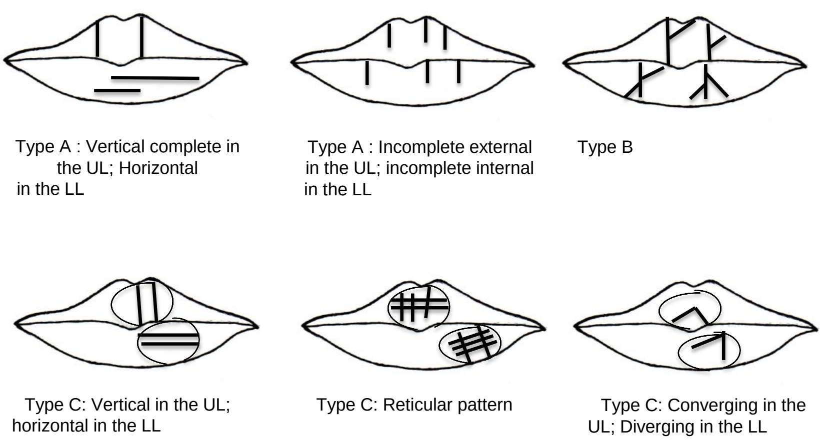

Figure 6. Oviedo and Meira classification (Upper lip – UL; Lower lip- LL).

4. Types of Lip Prints

Searching for prints in a crime scene investigation can be extremely important, since lip prints can link a subject to a specific location, and can be found in various items, such as clothes, glasses, cups or even cigarettes' buts (Ball, 2002; A.; Castelló, Alvarez, Miguel and Verdú, 2002; Ponce, Segui, Muñoz and Verdú Pascal, 2003)

Lip prints can be divided in three different types. When visible to the naked eye, lip prints are called visible or patent (Caldas et al., 2007). Lipsticks account for the majority of these prints (Webb, Egan and Turbett, 2001). Lipsticks are complex substances, which have in their constitution, several compounds, namely oils or waxes (Ponce et al., 2003; Webb et al., 2001). The color of the lipsticks is due to organic inks and inorganic pigments (Webb et al., 2001). Still, prints left in blood, dirt, paint, grease or any other substance that reveals it immediately, are other examples of visible lip prints (Caldas et al., 2007).

Modeled lip prints are visible lip prints that allow for lip furrows observation, but also record the lip anatomy. They usually result from the contact of the lips with soft surfaces, such as plaster, clay or wax (Caldas et al., 2007).

As stated previously, most lip prints are seen as lipstick smears (Webb et al., 2001). However, all lip prints are important, even the ones that are not visible (Castelló, Alvaréz-Seguí and Verdú, 2000; Ponce et al., 2003). In fact, the forensic cheiloscopic study is not restricted to visible prints, including also the latent ones (Ponce et al., 2003). The vermillion border of the lips has minor salivary and sebaceous glands, which, together with the moisturizing done by the tongue, leads to the possibility of the existence of latent lip prints (Ball, 2002). Additionally, not all lipstick smears are colored, and the cosmetic industry has developed lipsticks which do not leave a visible smear or mark - these are called persistent lipsticks (Seguí, Feucht, Ponce and Pascual, 2000).

5. Collecting and Processing Lip Print Patterns

Observation, using white and ultraviolet light sources, is the first step when processing lip prints (Caldas et al., 2007). Photographs should also be made, and prior to any processing in order to protect the evidence (U.S. Department of Justice Federal Bureau of Investigation Laboratory Division, 2001). Photographing latent prints is a complex process and, according to FBI guidelines, latent prints should be photographed individually with an identification label and a scale; furthermore, each step in the processing sequence must be photographed. (U.S. Department of Justice Federal Bureau of Investigation Laboratory Division, 2001).

If lipstick is present, the lipstick itself should be analyzed and its constitution determined. In fact, although about 65% of lipsticks share the same ingredients, differences in the remaining ingredients may provide the identification of the lipstick manufacturer (Ehara and Marumo, 1998).

If lip prints are located on a non-porous surface, they can be photographed and enlarged (Ball, 2002), and using transparent overlays, it is possible to make an overlay tracing (Ball, 2002; Pueyo et al., 1994).

In some circumstances, lip prints can be covered with processing agents which allow direct observation and photography (Molano et al., 2002; Pueyo et al., 1994). These substances are called developers or processing agents.

Hence, developers are pure substances or mixtures capable, physically or chemically, to reveal latent prints (Castelló, Alvaréz and Verdú, 2004; Dominguez et al., 1975; Ponce et al., 2003; Schulz and Reichert, 2002; Seguí et al., 2000). The choice of developer to use in each situation depends essentially on three factors (Katz, 1994):

- The color of the support in which the lip print is found;
- The nature of the support (porous or non-porous);
- The age of the lip print, since the lipid and water contents decrease over time.

There are two types of developers (Katz, 1994):

- Chemical substances or physic methods are able to develop a print without the occurrence of chemical reaction between the developer and the product perspiration. This is a purely physical phenomenon where the developer adheres to the perspiration on the latent print. They may be chemical developers (such as lead carbonate, ivory black, carbon black or aluminum powder) or physic methods (for example, oblique visible light and ultraviolet light).
- Chemical reagents are simple or compound substances, which react with certain constituents of perspiration products in the lip print, thus making it visible. Examples include iodine vapor, 5% silver nitrate solution, osmium tetroxide, and ninhydrin.

As stated, several substances can be used as processing agents, such as aluminium powder, silver metallic powder, silver nitrate powder, plumb carbonate powder, fat black aniline dyer or cobalt oxide (Ehara and Marumo, 1998; Seguí et al., 2000). Additionally, and because all lip prints contain lipids, their development, is also possible by using lysochrome dyes (such as Sudan III, Oil Red O, Sudan Black) (Ponce et al., 2003). When the color of the surface where the lip print lies on is multi-colored, or when the print is old, fluorescent developers can be useful (Castelló et al., 2002; Castelló et al., 2000; Ponce et al., 2003).

Plumb carbonate, a white powder, can be used using a brush, over smooth, polished, metallic or plastic surfaces. Its only limitation is its use over white surfaces (Ponce et al., 2003). In such circumstances, marphil black powder or fat black aniline dye are better choices since they both have a dark color (Ponce et al., 2003). Silver nitrate can lead to positive results on difficult surfaces, such as untreated wood or cardboard (Trozzi, Schwartz and Hollars, 2001).

Other examples of chemical reagents used on porous surfaces are DFO (1,8-Diazafluoren-9-one) (Trozzi et al., 2001). On plastic or waxed surfaces, on vinyl gloves or photographs, cyanoacrylate dye is the developer of choice (Trozzi et al., 2001).

Finally, another option for the development of latent lip prints is the use of aluminum powder or magnetic powder, due to a marked affinity for lipstick pigments (Seguí et al., 2000).

After processing a lip print, subsequently detailed observation with white light and/or alternative sources of light (such as ultraviolet light), the pattern should be photographed, always with a metric reference scale (Castelló et al., 2002; A.; Castelló et al., 2004; Castelló et al., 2000; Dominguez et al., 1975; Ponce et al., 2003; Seguí et al., 2000; Singh, Brave and Khanna 2010).

6. DNA AND LIP PRINT PATTERNS

The sensitivity of modern molecular biology techniques has had great impact on forensic analysis. In fact, because only a few cells are needed to obtain a DNA profile, usually a wide range of biological evidence for collection is available in crime scenes. The most common samples are blood, semen, hair (with root) and saliva (Goodwin, Linacre and Hadi, 2011). Yet, nowadays it is possible to extract and study DNA of invisible or latent prints (Castelló et al., 2004).

When an object is touched, epithelial cells may deposit. The amount of biological material recovered depends on (Goodwin et al., 2011):

a) The contact duration of the skin with the target object;
b) The amount of pressure exerted;
c) The presence of fluid that can mediate the transfer.

Since it is possible to obtain a DNA profile from fingerprints, it is conceivable that the lip prints can also be used as a source of genetic material. The theoretical limitations include the number of cells recovered and the material used for developing lip prints, as it can interfere with the extraction, amplification and DNA detection (Balogh et al., 2003; Schulz and Reichert, 2002). Yet, some studies indicate that it is possible to obtain DNA from lipsticks (Webb et al., 2001) and labial latent prints, stained with Sudan Black (Castelló et al., 2004).

Still, due to the limited number of studies, there is currently no reliable information or consensus on the best protocol to be used for DNA extraction and profiling from lip prints, which may explain why this procedure is not routinely used in forensic investigations. Thus, it is of crucial importance to conduct follow-up studies to determine the best conditions to obtain DNA profiles effectively, and to determine which developers should be used in these cases.

7. OTHER USES OF CHEILOSCOPY

Apart from the possibility to relate lip prints patterns with an individual, some authors have suggested that lip prints can also be related with ancestry (Costa and Caldas, 2012; Devi et al., 2015; El Domiaty et al., 2010; George et al., 2016; Koneru et al., 2013; Prasad and Vanishree, 2011) and sex (Bansal, Sheikh, Bansal and Pallagati, 2013; Kaul, Padmashree, Shilpa, Sultana and Bhat, 2015; Sharma, Ingle, Kaur and Yadav, 2014). If possible, this would be extremely interesting since it would allow the use of lip prints patterns without requiring previously established data.

In terms of ancestry, some populations have shown a tendency to exhibit morphologically similar types of lip prints: for example, Prabhu and colleagues stated that the Suzuki and Tsuchihashy type V was the most common in the population they studied (Goa, India) (Prabhu, Dinkar and Prabhu, 2012). This was also the most predominant lip print type found in a

Nigerian population (Adamu et al., 2015). Conversely, in a Portuguese population, Suzuki and Tsuchihashy type II was the most prevalent type of lip print (Costa and Caldas, 2012). Using Renaud's classification, Ragab and colleagues reported that the most predominant type of lip furrow on an Egyptian population was type I (Ragab et al., 2013). Yet, in an Egyptian population the most common lip furrows were type J (El Domiaty et al., 2010).

The existence of an inheritance pattern of lip prints has also been reported. According to Schnuth, cited by Adamu et al. (Adamu et al., 2015), hereditary plays an important role in lip prints development, and similarities between parents and their children are expected. Ghalaut et al. reported a 83.3% of strong lip print resemblance between parents and their offspring (Ghalaut, Bhagwath and Saxena, 2013). These data agree with those reported by Augustine and co-workers (Augustine et al., 2008). Yet, the results of another investigation revealed a lesser lip print pattern similitude (58.6%) between parents and their offspring, pointing out the need of more studies concerning lip print pattern inheritability (George et al., 2016).

With regard to sex estimation, several authors have reported statistically significant differences between sexes regarding the morphology of lip prints (Costa and Caldas, 2012; Prasad and Vanishree, 2011). El Domiarty and colleagues reported that the Renaud's horizontal lip furrow type was only found in Egyptian females (El Domiaty et al., 2010). Sex differences on lip print morphology were also reported by other authors (Krishnan, Thangavelu, Rathnavelu and Narasimhan, 2016). Jeerger and colleagues also referred that males and females displayed statistically significant differences in lip print patterns in particular lip sites: lower medial lip, as well as upper and lower lateral segments. On the upper medial lip segment, no statistically significant differences were found in lip print pattern between males and females (Jeergal et al., 2016). This suggests that the distribution of lip prints according to lip segment should be considered in sex estimation.

However, there are also conflicting results: Prabhu and colleagues, for example, reported no differences in the lip print pattern according to sex (Prabhu et al., 2012). Similarly, Ragab and colleagues also stated that sex could not be determined from patterns of lip prints in their study (Ragab et al., 2013).

Some investigators have tried to find out if certain patterns of lip prints can be related with individuals, or with their parents, in cases of congenital anomalies. Saad and colleagues referred that a specific lip print type, named type 0, an area devoid of grooves, was significantly higher in parents of cleft lip and palate patients (Saad, Kamel, Hassan and Elotiefy, 2005). Similar results were found by Saujanya and colleagues, that besides the increased frequency of type 0 pattern, also found branched grooves more common in parents of children with cleft lip and palate, referring that these could be genetic markers for transmission of this deformity (Saujanya et al., 2016). Other authors have referred to other lip print types, namely a whorl pattern, and an increase number of lip furrows count in the parents of cleft lip and/or palate children, supporting the idea of using lip print patterns as genetic markers of some conditions (Manasa Ravath, Girish, Murgod, Hegde and Savita, 2014).

8. Limitations of Lip Print Patterns Study in the Forensic Field

Lip prints are produced by a movable portion of the lip, which means that the same person may produce different lip prints, according to the pressure direction and harvesting method used in the lip prints (Caldas et al., 2007).

Another problem is subjectivity, particularly evident in the manual performed overlays. To avoid error, the person that performs the overlays should also process and interpret all remaining data (Ball, 2002).

An essential problem of analysis of the lip prints is the existence of conditions that preclude cheiloscopic analyses. Lymphangiomas, congenital labial fistulas, Merkelson-Rosenthal syndrome, syphilis, scleroderma, among others, are some examples of such conditions (Caldas et al., 2007).

Postmortem examination of the labial tissues should also be done with caution since significant changes in the produced lip prints are expected (Utsuno, Kanoh, Tadokoro and Inoue, 2005).

Finally, pre-established data regarding a cheiloscopic formula only exist on very specific circumstances, so it is a technique that aims primarily to relate lip prints with the lips that produced them, rather than for necro-identification (Caldas et al., 2007).

Conclusion

There are several classifications for lip print patterns in the literature; Suzuki and Tsuchihashi classification is probably the most widely used, however Renaud classification is considered the most complete. Further analysis and discussion in the forensic community is essential in order to clarify which classification would be more useful in forensic cases, taking into account that many of the resulting prints are incomplete.

A considerable amount of DNA from epithelial cells can be recovered on lip prints, which, depending of the circumstances, could help obtaining a genetic profile. Nevertheless, since the presence of lipstick and/or material used for developing lip prints can interfere with DNA profiling, more studies are still necessary to design a guideline to help the forensic specialist implement the best procedure in each case.

The possibility to relate lip prints to ancestry or sex is promising, taking in account the studies recently published in the literature. Finally, concerning the existence of an inherited pattern of lip prints, more studies with larger populations are needed in order to evaluate the availability of this forensic tool to relate a suspect with the family lineage.

REFERENCES

[1] Adamu, L. H., Taura, M. G., Hamman, W. O., Ojo, S. A., Dahiru, A. U., Sadeeq, A. A. and Umar, K. B. (2015). Study of lip print types among Nigerians. *Homo*, 66(6), 561-569.

[2] Afchar-Bayar, M. (1978). Determination de l'identité par les empreintes des lévres chez les femmes de Iran [Identification using lip prints in Iranian women]. *Societé de Médicine Legale*, 589-592.

[3] Augustine, J., Barpande, S. R. and Tupkari, J. V. (2008). Cheiloscopy as an adjunct to forensic identification: a study of 600 individuals. *J Forensic Odontostomatol*, 26(2), 44-52.

[4] Ball, J. (2002). The current status of lip prints and their use for identification. *J Forensic Odontostomatol*, 2, 43-46.

[5] Balogh, M. K., Burger, J., Bender, K., Schneider, P. M. and Alt, K. W. (2003). STR genotyping and mtDNA sequencing of latent fingerprint on paper. *Forensic Sci Int*, 137(2-3), 188-195.

[6] Bansal, N., Sheikh, S., Bansal, R. and Pallagati, S. (2013). Correlation between lip prints and finger prints in sex determination and pattern predominance in 5000 subjects. *J Forensic Odontostomatol*, 31(1), 8-14.

[7] Caldas, I. M., Magalhaes, T. and Afonso, A. (2007). Establishing identity using cheiloscopy and palatoscopy. *Forensic Sci Int*, 165(1), 1-9.

[8] Castelló, A., Alvarez, M., Miguel, M. and Verdú, F. (2002). Long-lasting lipsticks and latent prints. *Forensic Science Communications* [online], April.

[9] Castelló, A., Alvaréz, M. and Verdú, F. (2004). Just lip prints? No: there could be something else. *FASEB J*, 18, 615-616.

[10] Castelló, A., Alvaréz-Seguí, M. and Verdú, F. (2000). Use of fluorescent dyes for developing latent lip prints. *Color Technol*, 120(4), 184-187.

[11] Chiu, C. S. and Clark, R. K. (1992). The facial soft tissue profile of the southern Chinese: Prosthodontic considerations. *J Prosthet Dent*, 68(5), 839-850.

[12] Costa, V. A. and Caldas, I. M. (2012). Morphologic patterns of lip prints in a Portuguese population: a preliminary analysis. *J Forensic Sci*, 57(5), 1318-1322.

[13] Devi, A., Astekar, M., Kumar, V., Kaur, P., Singh, N. and Sidhu, G. K. (2015). The study of inheritance analysis and evaluation of lip prints in individuals. *J Forensic Dent Sci.*, 7(1), 49-53.

[14] Dominguez, J. M., Romero, J. L. and Capilla, M. J. (1975). Aportación al estudio de las huellas labiales [Contribution to the study of lip prints]. *Rev Esp Med Legal*, 2(5), 25-32.

[15] Ehara, Y. and Marumo, Y. (1998). Identification of lipstick smears by fluorescence observation and purge-and-trap gas chromatography. *Forensic Sci Int*, 96, 1-10.

[16] El Domiaty, M. A., Al-gaidi, S. A., Elayat, A. A., Safwat, M. D. and Galal, S. A. (2010). Morphological patterns of lip prints in Saudi Arabia at Almadinah Almonawarah province. *Forensic Sci Int*, 200(1-3), 179 e171-179.

[17] França, G. V. (2011). *Medicina Legal* [Legal Medicine]. Rio de Janeiro: Guanabara Koogan.

[18] George, R., Nora Afandi, N. S., Zainal Abidin, S. N., Binti Ishak, N. I., Soe, H. H. and Ismail, A. R. (2016). Inheritance pattern of lip prints among Malay population: A pilot study. *J Forensic Leg Med*, 39, 156-160.

[19] Ghalaut, P., Bhagwath, S. and Saxena, S. (2013). An assessment of inheritance pattern of lip prints in North Indian population. *Indian J Dent Sci*, 1, 37-39.

[20] Goodwin, W., Linacre, A. and Hadi, S. (2011). *An Introduction to Forensic Genetics* (2nd ed.). Sussex: Willey-Blackwell.

[21] Jeergal, P. A., Pandit, S., Desai, D., Surekha, R. and Jeergal, V. A. (2016). Morphological patterns of lip prints in Mangaloreans based on Suzuki and Tsuchihashi classification. *J Oral Maxillofac Pathol,* 20(2), 320-327.

[22] Katz, D. (1994). Fingerprinting. Retrieved 2016-09-13, from http://www.
chymist.com/FINGERPRINTING.pdf.

[23] Kaul, R., Padmashree, S. M., Shilpa, P. S., Sultana, N. and Bhat, S. (2015). Cheiloscopic patterns in Indian population and their efficacy in sex determination: A randomized cross-sectional study. *J Forensic Dent Sci*, 7(2), 101-106.

[24] Koneru, A., Surekha, R., Nellithady, G. S., Vanishree, M., Ramesh, D. and Patil, R. S. (2013). Comparison of lip prints in two different populations of India: Reflections based on a preliminary examination. *J Forensic Dent Sci*, 5(1), 11-15.

[25] Krishnan, R. P., Thangavelu, R., Rathnavelu, V. and Narasimhan, M. (2016). Gender determination: Role of lip prints, finger prints and mandibular canine index. *Exp Ther Med*, 11(6), 2329-2332.

[26] Manasa Ravath, C. J., Girish, H. C., Murgod, S., Hegde, R. B. and Savita, J. K. (2014). Lip prints and inheritance of cleft lip and cleft palate. *J Clin Diagn Res,* 8(7), 28-32.

[27] Mohamed, S., Shenoy, P. G. and Vijaya, H. (2009). Cheiloscopy - Can it be a tool for sex determination? *Med Leg Update*, 9(2), 30-32.

[28] Molano, M. A., Gil, J. H., Jaramillo, J. A. and Ruiz, S. M. (2002). Estudio queiloscópico en estudiantes de la facultad de odontología de la Universidad de Antíoquia [Cheiloscopic study of the students in Antíoquia University]. *Rev. Fac. Odontol*. Univ. Antioquia, 14(1), 26-33.

[29] Neville, B., Damm, D., Allen, C. and Bouquot, J. (2002). *Oral and Maxillofacial Pathology* (2nd ed.). Philadelphia: WB Saunders Company.

[30] Oviedo, C. O. and Meira, R. A. (1988). Determinación de la identidad por médio de las impressiones labiales [Human identification using lip prints]. *Rev Esp Med Legal*, 15, 54-57.

[31] Page, M., Taylor, J. and Blenkin, M. (2011). Uniqueness in the forensic identification sciences-fact or fiction? *Forensic Sci Int*, 206(1-3), 12-18.

[32] Pereira, C. P. (2012). *Medicina Dentária Forense* [Forensic Dental Medicine]. Lisboa: LIDEL.

[33] Pinheiro, M. F. T. (2008). *CSI Criminal* [Criminal CSI]. Porto: Edições Universidade Fernando Pessoa.

[34] Ponce, A. C., Segui, M. A., Muñoz, M. C. N. and Verdú Pascal, F. A. (2003). Revelado de huellas labiales invisibles con reactivos fluorescentes [Processing invisible lip prints with fluorescent reagents]. *Cuadernos Med* Leg For, 34, 43-47.

[35] Prabhu, R. V., Dinkar, A. and Prabhu, V. (2012). A study of lip print pattern in Goan dental students - A digital approach. *J Forensic Leg Med*, 19(7), 390-395.

[36] Prasad, P. and Vanishree. (2011). A comparison of lip prints between Aryans-Dravidians and Mongols. *Indian J Dent Res*, 22(5), 664-668. doi: 10.4103/0970-9290.93453.

[37] Pueyo, V. M., Garrido, B. R. and Sánchez, J. A. S. (1994). *OdontologÍa Legal y Forense* [Legal and forensic odontology]. Barcelona: Masson.

[38] Ragab, A. R., El-Dakroory, S. A. and Rahman, R. H. (2013). Characteristic patterns of lip prints in Egyptian population sample at Dakahlia Governorate. *Int J Legal Med*, 127(2), 521-527.

[39] Ramakrishnan, P., Bahirwani, S. and Valambath, S. (2015). Assessment of cheiloscopy in sex determination using lysochrome - A preliminary study. *J Forensic Dent Sci.*, 7(3), 195-200.

[40] Randhawa, K., Narang, R. S. and Arora, P. C. (2011). Study of the effect of age changes on lip print pattern and its reliability in sex determination. *J Forensic Odontostomatol*, 29(2), 45-51.

[41] Renaud, M. (1973). L'identification chéiloscopique en médicine légale [Cheiloscopic identification in legal medicine]. *Le chirurgien dentiste de* France, October, 65-69.

[42] Saad, W. M., Kamel, A. H., Hassan, F. Z. and Elotiefy, M. A. (2005). Genetic studies on the inheritance of lip prints in-cleft lip and palate. *Egypt J Plast Reconstr Surg,* 29, 9-12.

[43] Sadler, T. W. (2012). *Langman's medical embriology* (12th ed.). Baltimore: Wolters Kluwer/ Lippincott Williams and Wilkins.

[44] Santos, M. (1967). Queiloscopy, A supplementary stomatological means of identification. *Int Microform J Leg Med,* 2, 66.

[45] Saujanya, K., Prasad, M. G., Sushma, B., Kumar, J. R., Reddy, Y. S. and Niranjani, K. (2016). Cheiloscopy and dermatoglyphics as genetic markers in the transmission of cleft lip and palate: A case-control study. *J Indian Soc Pedod Prev Dent,* 34(1), 48-54.

[46] Schulz, M. M. and Reichert, W. (2002). Archived or directly swabbed latent fingerprints as a DNA source for STR typing. *Forensic Sci Int,* 127(1-2), 128-130.

[47] Seguí, M. A., Feucht, M. M., Ponce, A. C. and Pascual, F. (2000). Persistent lipsticks and their lip prints: new hidden evidence at the crime scene. *Forensic Sci Int,* 112, 41-47.

[48] Sharma, V., Ingle, N. A., Kaur, N. and Yadav, P. (2014). Identification of sex using lip prints : A clinical study. *J Int Soc Prev Community Dent,* 4(Suppl 3), S173-177.

[49] Singh, N. N., Brave, V. R. and Khanna, S. (2010). Natural dyes versus lysochrome dyes in cheiloscopy: A comparative evaluation. *J Forensic Dent Sci,* 2(1), 11-17.

[50] Sivapathasundharam, B., Prakash, P. A. and Sivakumar, G. (2001). Lip prints (Cheiloscopy). *Ind. J. Dent. Res.,* 12(4), 234-237.

[51] Snyder, L. M. (1950). *Homicide Investigation*. Springfield: Thomas.

[52] Suzuki, K. and Tsuchihashi, Y. (1971). A new attempt of personal identification by means of lip print,. *Can Soc Forensic Sci J,* 4, 154-158.

[53] Thomas, C. J. and van Wyk, C. W. (1988). The palatal rugae in identification. *J Forensic Odontostomatol*, 6(1), 21-25.

[54] Trozzi, T. A., Schwartz, R. L and Hollars, M. L. (2001). Processing Guide for Developing Latent Prints. Retrieved 2016/09/07, from http://www.fbi.gov/hq/lab/fsc/backissu/Jan2001/lpu.pdf.

[55] Tsuchihashi, Y. (1974). Studies on personal identification by means of lip prints. *Forensic Sci.,* 3, 233-248.

[56] U.S. Department of Justice Federal Bureau of Investigation Laboratory Division. (2001). Processing Guide for Developing Latent Prints. Retrieved 2016/09/07, from https://archives.fbi.gov/archives /about-us/lab/forensic-science-communications/fsc/jan2001/lpu.pdf.
[57] Utsuno, H., Kanoh, T., Tadokoro, O. and Inoue, K. (2005). Preliminary study of post mortem identification using lip prints. *Forensic Sci Int*, 149(2-3), 129-132.
[58] Warwick, R. and Williams, P. L. (1979). *Gray's Anatomy* (35th ed.). Rio de Janeiro: Guanabara Koogan.
[59] Webb, L. G., Egan, S. E. and Turbett, G. R. (2001). Recovery of DNA for forensic analysis from lip cosmetics. *J Forensic Sci,* 46(6), 1474-1479.

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2. Sampaio-Maia B, Caldas IM, Pereira ML, Pérez-Mongiovi D and Araújo R. The oral microbiome in health and its implication in oral and systemic diseases. In: Advances in Applied Microbiology, Volume 97, Elsevier. 2016. http://dx.doi.org/10.1016/bs.aambs.2016.08.002 ISSN 0065-2164 [In press].
3. Caldas IM, Teixeira A, Pérez-Mongiovi A, Afonso A and Magalhães T. Identificação por queiloscopia e palatoscopia. [Identification using cheiloscopy and palatoscopy]. In: Corte-Real A and Vieira DN. Medicina Dentária Forense na Investigação. [Forensic Dentistry in Investigation]. 2015. Coimbra: Imprensa da Universidade de Coimbra.
4. Caldas IM. A Medicina Dentária Forense na Identificação Humana In: Pinheiro MF. Ciências Forenses ao Serviço da Justiça. [Forensic sciences serving Justice]. Porto: PACTOR, 2013 (pp.223-52). ISBN: 978-989-693-039-4

Full papers:

1. Cardoso HFV, Caldas IM and Andrade M. Dental and skeletal maturation as simultaneous and separate predictors of chronological age in post-pubertal individuals: A preliminary study in assessing the probability of having attained 16 years of age in the living. Aust J Forensic Sci 2016. In press: DOI: 10.1080/00450618.2016.1237548.
2. Braga S and Caldas IM. Study of Palatal Rugae following orthodontic treatment. Aust J Forensic Sci 2016; 48(3): 305 – 311.

3. Alves MJ, Manita C, Caldas IM, Fernández-Martinez E, Gomes da Silva A and Magalhães T.
4. Evolution and Analysis of Cultural and Cognitive Factors Related With Domestic Violence Against Women. J Interpers Violence. 2016 May 2. pii: 0886260516645570. [Epub ahead of print].
5. Silva AM, Pereira ML, Gouveia S, Tavares JN, Azevedo A and Caldas IM. A new approach to sex estimation using the mandibular canine index. Med Sci Law 2016,56(1) 7–12.
6. Pérez-Mongiovi D, Teixeira A &Caldas IM. The radiographic visibility of the root pulp of the third lower molar as an age marker. Forensic Sci Med Pathol 2015,11(3): 339-44.
7. Carneiro JL, Caldas IM, Afonso A and Cardoso HFV. Is Demirjian's original method really useful for age estimation in a forensic context? Forensic Sci Med Pathol. 2015;11(2):216-21.
8. Marques MR, Pereira ML and Caldas IM. Forensic age estimation using the eruption of the second permanent mandibular molar: determining age over 14 years-old. Aust J Forensic Sci 2015;47(3):306-12.
9. Carneiro JL, Santos A, Magalhães T, Afonso A and Caldas IM, Human identification using dental techniques: A case report. Med Sci Law 2015; 55(2): 78-81.
10. Dourado- Sequeira C, Teixeira A, Caldas IM, Afonso A and Pérez-Mongiovi D. Age estimation using the radiographic visibility of the periodontal ligament in lower third molars in a Portuguese population. J Clin Exp Dent 2014; 6(5), 546-50.
11. Bouchardet F, Cortes MISG, Bastos JV, Caldas IM, Franco A and Vieira DN. The impact of tooth avulsion on daily life performance using the Brazilian OIDP index in children and young adults. J Forensic Odontostomatol 2014; 32(1):9-14.
12. Martins H, Assunção L, Caldas IM and Magalhães T. Victims of intimate partner violence - The physician's intervention in the Portuguese National Health Service. J Fam Violence 2014; 29(3): 315-22.
13. Simões RJ, Cardoso HFV and Caldas IM. Prevalence of talon cusps in a Portuguese population: Forensic identification significance of a rare trait. Dent Res J 2014;11(1):45-8.

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Full papers:

1. Pérez-Mongiovi D, Teixeira A, Caldas IM. The radiographic visibility of the root pulp of the third lower molar as an age marker. Forensic Sci Med Pathol 2015;11(3): 339-44.
2. Dourado- Sequeira C, Teixeira A, Caldas IM, Afonso A and Pérez-Mongiovi D. Age estimation using the radiographic visibility of the periodontal ligament in lower third molars in a Portuguese population. J Clin Exp Dent 2014; 6(5), 546-50.
3. Bastos-Aires D, Azevedo A, Pereira ML, Pérez-Mongiovi D and Teixeira A. Preliminary study of micronuclei levels in oral exfoliated cells from patients with periodontitis. J Dent Sci 2013; 8(2):200-4.
4. Souto-Lopes M, Azevedo A, Teixeira A, Bastos-Aires D, Lordelo J and Pérez-Mongiovi D. Cytotoxicity of acrylic based resin compounds in a human gingival fibroblast cell line. Rev Port Estomatol Med Dent Cir Maxilofac 2013; 54(2):99-102.
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2. Sampaio-Maia B, Caldas IM, Pereira ML, Pérez-Mongiovi D and Araújo R. The oral microbiome in health and its implication in oral and systemic diseases. In: Advances in Applied Microbiology, Volume 97, Elsevier. 2016 http://dx.doi.org/ 10.1016/bs.aambs.2016.08.002 ISSN 0065-2164 [In press]
3. Caldas IM, Teixeira A, Pérez-Mongiovi A, Afonso A, Magalhães T. Identificação por queiloscopia e palatoscopia. [Identification using cheiloscopy and palatoscopy]. In: Corte-Real A, Vieira DN. Medicina Dentária Forense na Investigação. [Forensic Dentistry in Investigation]. 2015. Coimbra: Imprensa da Universidade de Coimbra.

Full papers:

1. Pérez-Mongiovi D, Teixeira A, Caldas IM. The radiographic visibility of the root pulp of the third lower molar as an age marker. *Forensic Sci Med Pathol* 2015;11(3): 339-44.
2. Dourado- Sequeira C, Teixeira A, Caldas IM, Afonso A and Pérez-Mongiovi D. Age estimation using the radiographic visibility of the periodontal ligament in lower third molars in a Portuguese population. *J Clin Exp Dent* 2014; 6(5), 546-50.
3. Areias C, Macho V, Coelho A, Pereira L, Andrade D, Pérez-Mongiovi D &Sampaio-Maia B. Clinical approach of Down syndrome children in the dental office. Av. *Odontoestomatol* 2014; Vol 30 (6): 289-95.
4. Sousa TFA, Aniceto MC, Amorim CG, Souto-Lopes M, Pérez-Mongiovi D, Montenegro MCBSM and Araújo AN. Vortex-assisted liquid–liquid micro-extraction and high-performance liquid chromatography for a higher sensitivity methyl methacrylate

determination in biological matrices. *Biochemical Chromatography* 2013 (Wiley Online library). DOI: 10.1002/bmc.3089.

5. Bastos-Aires D, Azevedo A, Pereira ML, Pérez-Mongiovi D and Teixeira A. Preliminary study of micronuclei levels in oral exfoliated cells from periodontitis patients. *J Dental Sci* 2013; 8: 200 – 4.

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Chapter 3

PALATOSCOPY IN HUMAN IDENTIFICATION: A REVIEW

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ABSTRACT

Palatoscopy is the name given to the science that studies palatal furrows morphology. Palatal rugae are thought to be unique of an individual and evidence suggests that they can be used in human identification. Additionally, some studies have tried to relate the palatal rugae pattern with population affinity and sex of the individual, and results are equally promising and an increase use of this methodology is expected in the near future. Palatal rugae pattern, taking into account the anatomical location of the palatine wrinkles,is not expected to be used in linking evidence in a crime scene to a particular person. Instead, its usefulness lies in the identification of dead bodies, either by the relative stability of the palatal zone, even in situations in which facial recognition is not possible, or by the probable existence of ante mortem records. In this chapter the authors will addressed the theoretical bases of human identification using palatal rugae pattern, and will discourse about the study methodology and techniques, potentialities and future usefulness of palatal rugae patterns study.

1. INTRODUCTION

Palatoscopy, or palatal rugoscopy, is the name given to the study of palatal rugae in order to establish a person's identity (Caldas et al., 2007; Gilbert Calabuig, 1998).

Palatoscopy has consolidated its value as a scientific technique that can be used with success in comparative methodologies aiming human identification. Indeed, many investigators have studied the palatal rugae pattern as a phenotypic feature that is unique to each individual (Caldas et al., 2007; Jain and Chowdhary, 2014), meaning that as the dental profile, fingerprints and DNA, palatal rugae pattern can also be used in personal identification with conclusive results.

Kuppler, in 1897, was, perhaps, the first person to study palatal anatomy to relate its features with ancestry (Carrera Carbajo). Palatal rugoscopy for identification purposes was first proposed in 1932, by a Spanish investigator named Trobo Hermosa (Pueyo et al., 1994).

The interest of palatal rugae patterns in forensic sciences relates mainly with 3 factors:

a. The palatal rugae pattern is permanent. Palatal rugae are formed in the 3rd month in utero from the connective tissue that covers the maxilla

(Sadler, 1990). From that moment on, they persist throughout the individual's life, and even postmortem, as these tissues seem to take much more time to decompose, resisting decomposition changes for up to seven days after death (Muthusubramanian et al., 2005).

b. The palatal rugae pattern is immutable, at least in shape. Studies on the thermal effects on the palatal rugae pattern of burn victims with panfacial third degree burns have concluded that most victims did not sustain any palatal rugae pattern changes, and when changes were noted, they were less pronounced than in other tissues generalized body state (Muthusubramanian et al., 2005). Furthermore, once formed, palatal rugae pattern does not undergo any changes, except in length and relative position, due to normal growth (Almeida et al., 1995) and dental alterations. Not even diseases, chemical aggression or trauma seem to be able to change palatal rugae form (Pueyo et al., 1994). Some authors have reported changes, but mainly in palatal rugae size and position, secondary to extreme finger sucking in infancy, tooth loss, periodontal surgery, and persistent pressure due to orthodontic treatment (Kapali et al., 1997). Finger sucking alterations are of little importance, since they are produced early in the child's life, and the pattern will persist from that moment on. As for dental extractions and periodontal surgery, they can in fact produce a local effect on the direction of the rugae (Bowles, 2005). Some authors pointed out that rugae medial points should be preferred when assessing the palatal rugae pattern, as they show increased stability over the lateral points (Almeida et al., 1995; Bailey et al., 1996; Bowles, 2005; Hoggan and Sadowsky, 2001). Others believed that the more posterior ruga is less susceptible to changes with tooth extraction, being the third palatal rugae pair in particular the most stable reference (Abdel-Azizz and Sabet, 2001; Bowels, 2005; Lysell, 1955). Other studies however, point out that the first ruga is the most stable (Bailey et al., 1996). We believe further studies are needed in order to define which ruga is the most stable when teeth extractions are performed. In patients who underwent orthodontic treatment, the first right ruga had significant differences in size before and after the treatment in females, but there was no morphological changes in any rugae for both sexes (Braga and Caldas, 2016). In agreement, Ali and colleagues also stated the shape of rugae can be used as a reliable forensic marker in subjects undergoing orthodontic treatment, but palatal rugae length must be used with caution (Ali et al., 2016).

c. The palatal rugae pattern is exclusive. This concept relates to the uniqueness or singularity of the evidence, one of the five parameters a forensic identification process should meet to be considered trustworthy (França, 2011; Pereira, 2012; Pinheiro, 2008). Basically, it states it should be impossible to find two individuals who share the same set of personal characteristics, i.e., in this case, the same palatal rugae pattern. Even though this concept has been challenged, and claims were made that singularity is not only impossible to prove, but also not a fundamental request (Page et al., 2011), most authors agree the palatal rugae pattern is, in fact, exclusive (Dawasaz and Dinkar, 2013; De Angelis et al., 2012; English et al., 1988; Gondivkar et al., 2011; Kotrashetti et al., 2011; Patil et al., 2008; Santos and Caldas, 2012; Shetty et al., 2015; Suhartono et al., 2016; Thabitha et al., 2015).

2. ANATOMICAL ASPECTS

The oral mucosa surface is mostly flat and smooth without grooves or crests, except for (Warwick and Williams, 1979):

a. the back of the tongue, which is covered with papillae and
b. the anterior portion of the palatal mucosa, having a dense system of rugae, firmly attached to the underling bone.

Palatal rugae are irregular, asymmetric ridges of mucous membrane extending lateral from the incisive papilla and the anterior part of the median palatal raphe (Abdel-Aziz and Sabet, 2001; Kapali et al., 1997; Simmons et al., 1987).

In the palate, there is a thin central groove, bordered, on each side, by a crest: the palatal raphae; from this crest, latterly, three to seven smaller crests emerge: the palatal rugae (Pueyo et al., 1994; Warwick and Williams, 1979).

The development and differentiation of rugae seems more advanced in other animals, such as rats, than humans and while they are probably involved in oral function in some animals, rugae seem to be attenuating in humans (Kapali et al., 1997; Thomas and Rossouw, 1991). Their functions appear to be related with food transportation through the oral cavity, preventing loss of food from the mouth and to participate in the chewing process (Buchtová et al., 2003). The modern diet is essentialy soft, and doesn´t have the same requirements in terms of chewing, which can explain why palatal rugae seem to exhibit a lesser development. Their functions associated with taste and tactile perception, once fundamental to recognize poisons (Buchtová et al., 2003), are also less required.

Generally, there is no bilateral symmetry in the rugae number or in their distribution from the midline in humans. It has been found that there are slightly more rugae in males and on the left side in both sexes (Simmons et al., 1987). We will address sex differentiation through palatal rugae pattern, further ahead.

3. Palatal Rugae Patterns Classification

Like other patterns (lip prints and fingerprints, for example), there are several proposed classifications for palatal rugae patterns. Due to the subjective nature of palatal rugae morphology and its pattern interpretation, researchers have found the task of classification a very difficult one. According to Bhullar and colleagues (Bhullar et al., 2011), the first system of classification was developed in 1911 by Goria and was quite rudimentary. Palatal rugae pattern was classified by specifying the number of rugae and the extent of the rugal zone relative to the teeth. Lysell, in 1955, developed a widely used system for palatal rugae classification based on the shape, length, direction and unification of palatal rugae (Abdel-Aziz and Sabet, 2001; Bowles, 2005; Kapali et al., 1997). This system provides a fairly extensive description of the palatal rugae pattern and has inspired several classifications systems. In this chapter, we have chosen to describe the most known ones for their application or historical reference.

3.1. Thomas and Kotze classification

This classification, dating from 1983, divides palatine wrinkles according their length, morphology, placement, number and the extent of the rugal zone (Bhullar et al., 2011; Caldas et al., 2007; Jibi et al., 2011).

Regarding length, there are three types of palatal rugae:

- Type A - 5 to 10 mm long;
- Type B - more than 10 mm long and
- Secondary - 3 to 5 mm in length.

According to their morphology, palatal rugae can be classified as:

- Fragments (size inferior to 3 mm);
- Curved;
- Sinuous;
- Lines and
- Circular.

The number of each rugae morphologic type should also be noted, as well as the area occupied by the palatal rugae pattern. This is made using palatal photography.

This classification presents several problems. On one hand, it doesn't lead to the elaboration of a rugogram, i.e., a formula that depicts palatal rugae pattern. This poses a problem, since forensic evidence, to be useful, needs to be classifiable, so that the comparative examination may be straightforwardly carried out and the records easily located and stored (França, 2011; Pereira, 2012; Pinheiro, 2008). On the other hand, several authors have discouraged the use of palatal rugae length as criteria for classification, since length may vary due to dental treatments (Abdel-Aziz and Sabet, 2001; Ali et al., 2016; Almeida et al., 1995; Bailey et al., 1996; Braga and Caldas, 2016). Yet, despite these limitations, some references to this classification can be found in the literature (Ali et al., 2016; Kotrashetti et al., 2011; Rajan et al., 2013; Saraf et al., 2011; Savita et al., 2016).

3.2. Carrea Classification

In this classification, palatal rugae are divided into four different types, as seen in Figure 1 and Table 1. Rugae are classified according their direction and no rugogram is created (Caldas et al., 2007; Carrea, 1937).

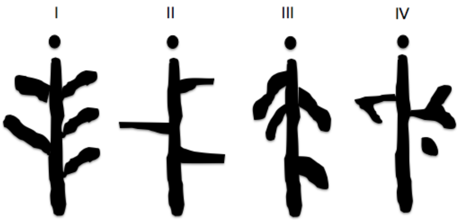

Figure 1. Carrea Classification.

Table 1. Carrea classification

Classification	Rugae Type
I	Posterior-anterior directed rugae
II	Rugae perpendicular to the raphae
III	Anterior-posterior directed rugae
IV	Rugae with several directions

Regarding this classification, like with size, rugae direction may not be a stable marker (Kapali et al., 1997).

3.3. Martins dos Santos Classification

This classification bases on the form and position of each palatal ruga. As shown in the example depicted in Figure 2, the classification respects the following rules (Matins-dos-Santos, 1946):

- The most anterior wrinkle on the right side is represented by a capital letter and is termed initial rugae;
- All other right side rugae are called complementar rugae and are represented by numbers;
- The most anterior left side wrinkle is also represented by a capital number and is named sub-initial rugae;
- All other left side rugae are designated sub-complementar rugae and are denoted by numbers.

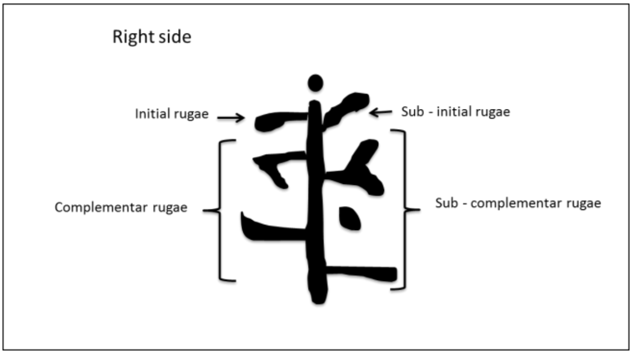

Figure 2. Martins dos Santos Classification

Table 2. Martins dos Santos classification

Classification	Rugae Type	
	Anterior Position	Other Position
Point	P	0
Line	L	1
Curve	C	2
Angle	A	3
Circle	C	4
Sinuous	S	5
Bifurcated	B	6
Trifurcated	T	7
Interrupt	I	8
Anomaly	AN	9

The numbers and letters attributed to rugae relate to its form and are depicted in Table 2.

Once again, it is not an easy classification to use, since there are no instructions to elaborate a rugogram. Additionally, curves and circles are classified equally in anterior position rugae. Also, it is not clear how to distinguish between points and circles, or between angles and bifurcated rugae.

3.3. López de Léon Classification

Dating from 1924, this classification has only historic relevance. The author proposed the existence of a link between a person's personality and palatal rugae morphology, as depicted in Table 3 (Caldas et al., 2007; Simmons et al., 1987).

Table 3. López de Léon classification

Classification	Rugae Type
B	Bilious personality rugae
N	Nervous personality rugae
S	Sanguinary personality rugae
L	Lymphatic personality rugae

The rugogram is built using the predominant type of rugae, on each side, written in capital letters, followed by the identification of the palate side, using “l” and “r” lower case letters, followed by the number of the most predominant morphologic palatal rugae on each side. For instances, a possible rugogram would be Br6; Bl8 (Caldas et al., 2007; Pueyo et al., 1994).

3.4. da Silva Classification

In this classification, palatal rugae are divided into two groups: simple palatal rugae, composed by a single element (see Table 4 and Figure 3) and compound, resulting from the union of two or more simple rugae (Caldas et al., 2007; Pueyo et al., 1994; Thomas and van Wyk, 1988).

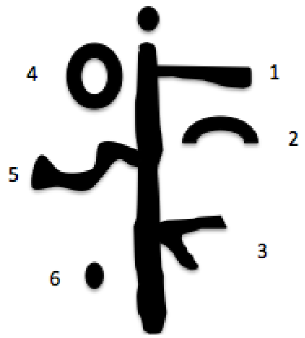

Figure 3. da Silva Classification.

Table 4. da Silva classification

Classification	Rugae Type
1	Line
2	Curve
3	Angle
4	Circle
5	Sinusoid
6	Point

The classification process is made in two distinct stages:

- The structural classification of the rugae, identifying each of its components; for example, if a palatal rugae is a point, a line and an angle, the classification will be 1 3 6.
- Quantitative numbering, counting in each side of the palate, the number of the several morphologic types found; for example, the right side has 5 lines, 3 curves and 2 angles, the classification will be 3 5 2; on the left side there are 3 lines and 3 curves, the classification will be 3 3.

This is a methodology difficult to apply since it is not clear how to apply the two-steps classification in building the rugogram.

3.5. Trobo Classification

This classification considers simple (Table 5 and Figure 4) and compound rugae pattern, the last being two or more simple palatal rugae fused. The rugogram is made describing each pattern, beginning in the principal rugae (the one closest to the incisive papilla), which is classified with a capital letter; the following rugae are described using lower case letters, and the palate right side is categorized first (Caldas et al., 2007; Pueyo et al., 1994; Trobo y Hermosa, 1932).

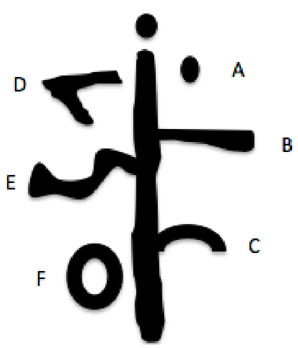

Figure 4. Trobo Classification.

Table 5. Trobo classification

Classification	Rugae Type
A	Point
B	Line
C	Curve
D	Angle
E	Sinusoid
F	Circle

3.6. Basauri Classification

Like the previous one, this is a very easy to use classification. It distinguishes between the principal ruga, the more anterior one (labeled with letters), and the accessory rugae, concerning all the remaining rugae (labeled with numbers), as seen in Table 6 and Figure 5. The rugogram is elaborated beginning from the right side of the palate (Pueyo et al., 1994).

The rugogram is built, starting on the right side, from the principal to the accessory rugae.

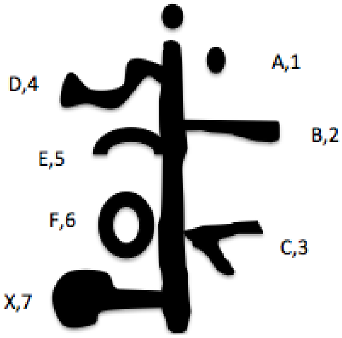

Figure 5. Basauri Classification (If principal rugae, label using letters, if accessory, label with number).

Table 6. Basauri classification

Classification	Rugae Type	
	Principal rugae	Acessory rugae
Point	A	1
Line	B	2
Angle	C	3
Sinuous	D	4
Curve	E	5
Circle	F	6
Polymorphic	X	7

3.7. Cormoy System

This system classifies palatal rugae according to their length in: (1) principal rugae (over 5 mm); (2) accessory rugae (ranging from 3 to 4 mm); (3) fragmental rugae (with less than 3 mm length). The morphologic aspect (line, curve, and angle), origin of the medial extremity and direction of each rugae are also described. Ramifications are also scored. Additionally, rugae with the same origin, interrupted rugae and the incisive papilla are described as well. It is a very complete classification system of palatal rugae pattern (Pueyo et al., 1994). Yet, the rugogram elaboration process is not explained, which makes the managing and processing of data difficult, and is based on the palatal rugae length that may not be a stable marker (Kapali et al., 1997).

4. Palatal Rugae Patterns Analyses

The first step on palatal rugae patterns analyses is the direct observation of the palate. This can be done directly, or using a mirror, but no definitive conclusions should be made regarding the rugogram elaboration. In this step, a full oral examination of the mouth should be performed. Missing teeth should be registered, since, as discussed previously, teeth extractions can alter rugae positions. Similarly, evidence of previous orthodontic treatment should be recorded, since some authors have described alterations in palatal rugae length following this type of treatment (Abdel-Aziz and Sabet, 2001; Ali et al., 2016; Almeida et al., 1995; Bailey et al., 1996; Braga and Caldas, 2016). It should be noticed that since identification using palatal rugae is, in theory, a necro-identification process, evidence of previous orthodontic treatment can be found in clinical records or even in the direct examination of the mouth (for instance, bilateral absence of the first or second premolars in a perfectly aligned maxillary arch). Maxillary prosthetic devices should also be listed, since they can also raise some doubts in the palatoscopic assessment, leading to an exclusion of identity. In fact, occasionally, palatal rugae are added to prosthetic devices to improve speech patterns (Gitto et al., 1999). In these cases, if prosthetic devices are considered as source of pre-established data, a false exclusion of identity may occur due to misleading *antemortem* data.

Intraoral inspection is probably the most used and also the easiest and the most affordable technique. Nonetheless, if a comparative exam is required, a more detailed and exact study is needed (Pueyo et al., 1994; Thomas and van Wyk, 1988). In these cases, oral photography or oral impressions should be made (Caldas et al., 2007; Pueyo et al., 1994). These exams allow for a more detailed observation. In this step, a rugogram should be made, selecting one of the classifications described, considering the limitations previously explained. Calcorrugoscopy, or the overlay print of palatal rugae in a maxillary cast (Figure 6), can be used to facilitate the comparative analysis (Pueyo et al., 1994). In this technique, using maxillary casts, palatal rugae pattern is highlighted and then photographed. Pre-established data are treated the same away, and both pictures are developed in transparent foils and matched to determine the overlap. Although effective, one must count for the possibility of distortion in any of the steps of this methodology (impressions, photography, etc.).

Figure 6. Calcorrugoscopy.

Stereoscopy is another complex technique, by which a three dimensional image of the palatal rugae anatomy can be obtained (Caldas et al., 2007; Pueyo et al., 1994). Sterophotogrammetry allows for an accurate determination of the length and position of every single palatal rugae (Caldas et al., 2007; Pueyo et al., 1994).

Rai and Kapur (Rai and Kaur, 2013) described a new method for palatal rugae analysis, using a software called *Palatal Rugae Comparison Software* (PRCS Version 2.0). This software relies on the correspondence of several points (the initiation and termination point of each rugae, the tip and base of the incisive papilla) and the images are plotted together. The plotted points are then processed, and the possible match is assessed. The main advantage of this software is the possibility of working as a database, as it allows comparisons with previous loaded photographs.

Still, due to its simplicity, price and reliability, direct observation and the study of maxillary dental casts are the most used techniques (Pueyo et al., 1994).

5. Other Uses of Palatoscopy

In the last years, several studies have pointed out the use of palatal rugae pattern in human identification, namely in sex and ancestry estimation (Caldas et al., 2007; Saraf et al., 2011).

5.1. Ancestry Estimation

In terms of ancestry estimation, several population-specific studies have been published expressing an enthusiastic new approach that can be of the utmost importance in human positive identification. As a matter of fact, different parts of the world have demonstrated particular biometric features among palatal rugae pattern, such as in Portugal, Indonesia, Egypt, Nigeria, Australia, India or Jordan (Azab et al., 2016; Eboh, 2012; Kapali et al., 1997; Kotrashetti et al., 2011; More et al., 2015; Mustafa et al., 2014; Santos and Caldas, 2012; Suhartono et al., 2016).

In their 1997 publication, Kapali and colleagues reported differences among Australian Aborigines and Caucasians, in palatal rugae number, shape and unification type (Kapali et al., 1997). They've found a higher number of primary rugae (categorized as A – 5 to 10mm; B- 10mm or more) in

Australian Aborigines, although Caucasians tended to show a higher proportion of rugae longer than 10mm. Qualitative differences were also found, and straight rugae were more common in Caucasians, and sinusoid patterns were more frequent in the Australian Aborigines. In the Aboriginal sample, unifications (classified as diverging and converging, depending if two rugae join at their origin or termination) were found to be less common, suggesting that different ethnic groups have a tendency to exhibit both qualitatively and quantitatively palatal rugae variations. Interestingly, these authors have tried to find an explanation to their results, suggesting that the differences in the pattern and in the length of the rugae could be explain by the existence of broader palates, generally an anatomical feature found in Aborigines. Yet, it remains unclear why Caucasians were found to have more rugae longer than 10mm compared with Aborigines (Kapali et al., 1997).

The palatal rugae pattern of a Portuguese population has also been characterized, and the straight rugae type was the most prevalent (Santos and Caldas, 2012). These results differ from those of Kapali and colleagues in the Caucasian Australians (Kapali et al., 1997), where straight rugae were the less common pattern, suggesting differences among populations.

Azab and colleagues (Azab et al., 2016), in a sample of adult Egyptians, showed that the sinusoid type was the most common palatal rugae pattern, followed by the straight, curved and circular types. The most frequent direction was the forward one, and unification wise, converging palatal rugae had a higher incidence than diverging rugae. Once more, inter-racial differences in palatal rugae were identified (Azab et al., 2016).

Later on, in 2014, Mustafa and colleagues (Mustafa et al., 2014) stated that the Jordanian population has a tendency to express a specific rugae type. To date, this study is the first to describe the morphometric features of palatal rugae in Jordan, representing also the first study enrolling a larger sample (n=327 dental casts) when compared with previous published studies. Conversely to the Portuguese population (Santos and Caldas, 2012), in the Jordanian population sinusoid rugae type were predominant, followed by diverging, straight and curved, converging and circular. These investigators have also found that rugae with length over 5mm were more common type among the Jordanians (Mustafa et al., 2014).

Likewise, Indonesian population’s rugae patterns have been characterized for forensic purposes. Despite the diversity among Indonesians (including, Javanese, Sundanese, Indonesian Chinese, Bataks and Malays), the authors stated that the sample was representative of the whole population. The most common palatal rugae were the straight, sinuous and curve types, representing together about 83% of all palatal rugae patterns. These outcomes substantiate a difference among palatal rugae patterns in different populations (Suhartono et al., 2016).

Several studies carried out in India in different regions, suggested that the palatal rugae pattern can possibly vary geographically in subpopulations, which can, perhaps, be explained by the migration phenomenon, particularly from Nepal, Taiwan, Bhutan, Bangladesh and other countries (Gondivkar et al., 2011; Kotrashetti et al., 2011; Nayak et al., 2007).

In 2011, investigators found that two ethnic groups of Indians from different regions (Maharashtra and Karnataka state) exhibited a significant difference among wavy, straight, circular and divergent type and they also had verified that the mean rugae number was greater among Maharashtra group when compared to the other studied population (Kotrashetti et al., 2011). Still according to the rugae shapes, Maharashtra state group was found to have more straight type, whereas Karnataka state population showed a greater number of wavy forms.

Comparing Indian and Nepalese population, More and colleagues (More et al., 2015) have concluded that the rugae shape in all the participants (100 Indians and 100 Nepalese) are quite similar, but the location of palatal rugae differ among them representing a distinctive feature in both groups. In Indians, rugae were located between posterior edge of incisive papilla and distal surface of canine on both sides of the palate. On the other hand, Nepalese participants were found to have rugae placed between distal surface of lateral incisor and distal surface of second premolar, on either side of palatal raphae, remaining the pre-maxillary region unfilled of rugae. Nevertheless this interesting finding, more studies are required to better understand if the uniqueness of palatal rugae pattern associated to a specific population have a potential distinctive not only among several studied variables (such as, type or number) but also in the location.

5.2. Sex Estimation

The use of palatal rugae for sex estimation has been explored for many authors and the results are not consistent regarding the usefulness of this tool to discriminate between sexes.

In two Australian populations (Aborigines and Caucasians), the average number of rugae in the Aboriginal participants had no significant differences between the sexes, being 5.0 and 4.9 for males and females, respectively.

Additionally, no statistically significant difference in number of rugae between right and left sides was evident for either sex (Kapali et al., 1997).

Further studies were carried out and, in 2007, Nayak and colleagues characterized the differences in the palatal rugae shape in two populations of India. Wavy and curved were the most prevalent rugae shape in both sexes, followed by straight rugae. Unifications were few and circular rugae were not observed. No significant differences between sexes were observed. However, the authors stated in their conclusions that the results should consider that the data were obtained with a small simple size and further work on larger samples was required to validate the findings (Nayak et al., 2007).

In 2013 Shetty and collaborators designed a study aimed to analyze the palatal rugae pattern in two populations in South India (Kodovas and Malayalees) and evaluate the rugae pattern between sexes within each group. A significant difference between males and females for straight rugae pattern among Malayalees was found (Shetty et al., 2015), suggesting that the ruga shape can be used in sex estimation.

Also in an Indian based study, Jibi and co-workers, in 2011 designed an investigation that aimed to identify and compare the rugae pattern between males and females of two different communities in the city of Davangere, Karnataka, India (Jibi et al., 2011). Their findings revealed that rugae features showed no significant differences between right and left sides for either communities or sex. However, regarding shape and unification, females showed a significantly higher diverging rugae pattern while males had a significant number of circular and converging type of rugae, suggesting that the rugae pattern can be an additional method of differentiation in forensic sciences together with the other methods such as visual, fingerprints, and dental characteristics.

These findings are supported by those of Saraf and colleagues that, in 2011, found statistically significant results regarding rugae shape between sexes. The converging type was more frequent in females whilst the circular types were greater in number in males. The use of logistic regression allowed sex estimation with a high accuracy (>99%) suggesting that this statistical method can be a useful and an additional tool of analyses when palatal rugae are used to discriminate sex. However, no significant difference in the total number and length measurements of rugae was found between sexes (Saraf et al., 2011).

Also in 2011, Barath and co-workers, in a sample of one hundred males and females, equally distributed, of coastal Andhra population, found that differences in unification pattern among males and females were statistically different. Inversely, the total number of the rugae was not significantly different between sexes. The association between rugae length and shape with sex determination was calculated using discriminant analysis, which enabled sex differentiation with an accuracy of 78%. Yet, apart from these results, and based in the methodology used (sample size and classification system), the authors stated the need of further investigations (Bharath et al., 2011).

Once more, regarding palatal rugae number, Eboh, in a study aiming to describe palatal rugae patterns among Urhobo ethnic nation resident in Abraka, Delta State, South-Southern, Nigeria, found that females have more rugae compared to males, despite not being a statistically significant difference. Even this can suggest a tendency, more studies with larger samples are required to assess if the number of palatal rugae is sex-specific (Eboh, 2012). Similar conclusions were reached by Nagalaxmi and co-workers (Nagalaxmi et al., 2014).

In 2015, a study in a sample of 100 maxillary casts of Sudanese Nubians students from various universities located in Khartoum, was used to determine the prevalence of palatal rugae different biometric characteristics, exploring the existence of asymmetry, and to determine their effectiveness in correctly identifying sex using logistic regression (Ahmed and Hamid, 2015). The authors recommended when palatal rugae are the only tool available to discriminate sex they shouldn't be used in the Sudanese Nubian population since the obtained predictive value was 60%, and current orientations recommend a predictive value of 65% when using only ruga shapes.

Recent studies support that palatal rugae pattern may not be a useful tool for sex estimation, particularly if used alone. For instance, a 2015 study conducted in a pediatric Indian population hypothesizes that rugae are important in human identification since no two palates showed similar type of rugae in either sexes (Thabitha et al., 2015). However, as no significant difference between sexes existed, the authors conclude that rugae pattern contributes minimally towards sex determination. The same conclusions were reached by Muhasilovic and collaborators, in 2016 (Muhasilovic et al., 2016), who did not determine statistically significant differences in the total number of palatal rugae between the sexes, in a population sample from Bosnia and Herzegovina (Sarajevo Canton). Using logistic regression analysis the authors concluded this statistical method was more successful in classifying males, 69% of them, while for women the success rate was significantly lower with only 41%. In total, 55% of subjects were correctly classified. The authors concluded that regarding palatal rugae and sex prediction, logistic regression analysis could be used as an additional tool for differentiation method for the population of Bosnia and Herzegovina.

6. Limitations of Palatoscopy

The major difficulty of palatoscopy is the lack of a universal consistent classification method of palatal rugae. Indeed, the subjective nature of the interpretation intra and inter-observer, resulting in ambiguous definitions of palatal rugae pattern, has been reported in many studies (Caldas et al., 2007; Jain and Chowdhary, 2014; Patil et al., 2008; Suhartono et al., 2016). As stated in the forensic literature, there are several classifications (Caldas et al., 2007; Pueyo et al., 1994), and misinterpretation related to a given shape type can occur. For instance, in Trobo, Basauri or Thomas and Kotze classifications, the supporting example drawings from wavy/sinuous do not differ significantly from line/straight shape of others classifications. The same can be assessed to angled and curved shapes, which has not been clear explained, which can lead, naturally to deviations in classification (Suhartono et al., 2016). So, it is of the utmost importance to establish a standard and universal classification, which can critically modify the existing paradigm.

Many researchers stated that there are several external factors that can modify the original palatal rugae patterning, as orthodontic treatment, dental extractions, periodontal surgery, cleft palate surgery or even forced eruption of impacted canines, which can change the length or the direction of palatal rugae (Caldas et al., 2007; Jain and Chowdhary, 2014). It is also reported that finger sucking in childhood can produce a local effect in palatal rugae position (Caldas et al., 2007; Eboh, 2012; Jain and Chowdhary, 2014). Furthermore, proliferative benign and malignant lesions can affect directly palatal mucosa and/or the bone beneath, resulting in a significant loss of palatal characteristics depending on the extension of the disease.

Among criminal scenarios, palatoscopy doesn’t represent the ideal tool to establish a linking between a suspect and a crime scene, because it is not expect that, due their anatomical position, palatal rugae evidence can be found and be useful in biological criminalistics expertise (Caldas et al., 2007).

Forensic literature has explored new fields, particularly regarding to human identification. In fact necro-identification can be assessed with unusual scientific techniques, as palatoscopy. Therefore, it is recognized that palatal rugae pattern is unique to each individual, remaining unchanged during life and possessing postmortem resistance (Caldas et al., 2007; Jain and

Chowdhary, 2014; Mustafa et al., 2014; Patil et al., 2008). Furthermore, several studies have been bringing insights about this feature as a potential discriminator between different ancestries (Azab et al., 2016; Eboh, 2012; Gondivkar et al., 2011; Kapali et al., 1997; Kotrashetti et al., 2011; More et al., 2015; Mustafa et al., 2014; Nayak et al., 2007; Santos and Caldas, 2012; Suhartono et al., 2016). Further investigations are required with larger samples and accurate representation of the analyzed population. To date, the existing forensic results have demonstrated that a specific rugae pattern can be influenced by ethnicity, which can aid as a supplementary tool to the reconstruction of the biological profile in the complex and challenging human identification process.

Following this argument, it is also source of consensus among forensic investigators that the lack of more studies remains inevitably one of the problems of palatoscopy. But we consider that all the research that has been carried out represents a motivating future to this area. Every published data can encourage more investigators to contribute in all the different surprising and interesting forensic targets, namely ethnicity and sexual dimorphism.

CONCLUSION

In recent years it has become increasingly clear that palatoscopy is a valuable forensic technique within both reconstructive and comparative methodologies aiming human identification, given that the palatal rugae pattern is permanent, exclusive, and remains immutable throughout life (with small exceptions that may cause changes in rugae length and position). This forensic methodology is particularly valuable in necro-identification as palatal rugae resist decomposition changes for up to seven days after death. In this sense, it should be promoted the collection, storage and database creation of palatal rugae photography or impression, among dentist and other oral health professionals.

Currently the main difficulty in palatoscopy is the lack of a universal consistent classification method of palatal rugae. This chapter describes seven different classification methodologies, although others can be found. The available methodology varies from simple, but with lack of rigor, to complex, but difficult to apply. In our opinion the best available methods are the Basauri or Trobo classifications (which are quite similar). Still, guidelines should be developed by the scientific community promoting the creation of a simple, yet complete and rigorous method to classify palatal rugae.

Besides necro-identification by comparison to previous established data, palatal rugae are being investigated for ancestry and sex estimation. In ancestry estimation wise, palatoscopy seems promising, given that many studies conducted in different populations appear to find significant differences between populations and ethnicities. However, international comparative studies should be conducted to define reliable population-specific palatal rugae patterns. The studies using palatoscopy for sex estimation, however, are not consensual. For example, we've found studies stating that females have more converging rugae pattern whereas others found that females presented higher diverging rugae pattern in comparison to males. Thus, further studies, with higher number of participants, should be performed.

In conclusion, palatoscopy is a growing area in forensic sciences, and represents currently an innovative complementary tool in human identification.

REFERENCES

[1] Abdel-Aziz HM, Sabet NE: Palatal rugae area: a landmark for analysis of pre- and post-orthodontically treated adult Egyptian patients. *East Mediterr Health J* 2001;7:60-66.

[2] Ahmed AA, Hamid A: Morphological Study of Palatal Rugae in a Sudanese Population. *Int J Dent* 2015;http://dx.doi.org/ 10.1155/2015/650648.

[3] Ali B, Shaikh A, Fida M: Stability of Palatal Rugae as a Forensic Marker in Orthodontically Treated Cases. *J Forensic Sci* 2016;doi: 10.1111/1556-4029.13129. [Epub ahead of print].

[4] Almeida MA, Phillips C, Kula K, Tulloch C: Stability of the palatal rugae as landmarks for analysis of dental casts. *Angle Orthodont* 1995;65:43-48.

[5] Azab SMS, Magdy R, Sharaf El Deen MA: Patterns of palatal rugae in the adult Egyptian population. *Egyptian Journal of Forensic Sciences* 2016;6:78-83.

[6] Bailey LJ, Esmailnejad A, Almeida MA: Stability of the palatal rugae as landmarks for analysis of dental casts in extraction and nonextraction. *Angle Orthodont* 1996;66:73-78.

[7] Bharath ST, Kumar GR, Dhanapal R, Saraswathi T: Sex determination by discriminant function analysis of palatal rugae from a population of coastal Andhra. *J Forensic Dent Sci* 2011;3:58-62.

[8] Bhullar A, Kaur RP, Kamat MS: Palatal Rugae – an Aid in Clinical Dentistry. *J Forensic Res* 2011;2:3.

[9] Bowles RG: First premolar extraction decisions and effects [Thesis]; Graduate Studies Council, Health Science Center. Graduate Studies Council, Health Science Center, University of Tennessee, USA, 2005.

[10] Braga S, Caldas IM: Study of palatal rugae pattern following orthodontic treatment. *Aust J Forensic Sci* 2016;48:305-311.

[11] Buchtová M, Tichy F, Putnová I, Misek I: The development of palatal rugae in the European pine vole, Microtus subterraneus (Arvicolidae, Rodentia). *Folia Zoo* 2003;52:127-136.

[12] Caldas IM, Magalhaes T, Afonso A: Establishing identity using cheiloscopy and palatoscopy. *Forensic Sci Int* 2007;165:1-9.

[13] Carrea JU: La identificación humana por las rugosidades palatinas [Human identification by palatal rugae]. *Ortodoncia* 1937;1:141-161.

[14] Carrera Carbajo I: Identificación de cadáveres y aspectos forenses de los desastres [Necro-identification and forensic aspects of mass disasters]. https://www.administraciondejusticia.gob.es/paj/PA_WebApp_SGNTJ_NPAJ/descarga/Identificacion de cadaveres.pdf?idFile=a69bcd77-cfa7-4e9a-bdbf-b95e96c6c4f6.

[15] Dawasaz AA, Dinkar AD: Rugoscopy: predominant pattern, uniqueness, and stability assessment in the Indian Goan population. *J Forensic Sci* 2013;58:1621-1627.

[16] De Angelis D, Riboli F, Gibelli D, Cappella A, Cattaneo C: Palatal rugae as an individualising marker: reliability for forensic odontology and personal identification. *Sci Justice* 2012;52:181-184.

[17] Eboh DEO: Palatal Rugae Patterns of Urhobos in Abraka, South-Southern Nigeria. *Int J Morphol* 2012;30:709-713.

[18] English WR, Robinson SF, Summitt JB, Oesterle LJ, Brannon RB, Morlang WM: Individuality of human palatal rugae. *J Forensic Sci* 1988;33:718-726.

[19] França GV: Medicina Legal [Legal Medicine]. Rio de Janeiro, Guanabara Koogan, 2011.

[20] Gilbert Calabuig JA: Medicina Legal y Toxicologia [Legal medicine and toxicology]. Barcelona, Masson, 1998.

[21] Gitto CA, Exposito SJ, Draper JM: A simple method of adding palatal rugae to a complete denture. *J Prosthet Dent* 1999;81:237-239.

[22] Gondivkar SM, Patel S, Gadbail AR, Gaikwad RN, Chole R, Parikh RV: Morphological study of the palatal rugae in western Indian population. *J Forensic Leg Med* 2011;18:310-312.

[23] Hoggan BR, Sadowsky C: The use of palatal rugae for the assessment of anteroposterior tooth movements. *Am J Ortho Dentofacial Orthop* 2001;119:482-488.

[24] Jain A, Chowdhary R: Palatal rugae and their role in forensic odontology. *Journal of investigative and clinical dentistry* 2014;5:171-178.

[25] Jibi PM, Gautam KK, Basappa N, Raju OS: Morphological pattern of palatal rugae in children of Davangere. *J Forensic Sci* 2011;56:1992-1997.

[26] Kapali S, Townsend G, Richards L, Parish T: Palatal rugae patterns in Australian aborigines and Caucasians. *Aust Dent J* 1997;42:129-133.

[27] Kotrashetti VS, Hollikatti K, Mallapur MD, Hallikeremath SR, Kale AD: Determination of palatal rugae patterns among two ethnic populations of India by logistic regression analysis. *J Forensic Leg Med* 2011;18:360-365.

[28] Lysell I: Plica palatinae transverse and papilla incisive in man. A morphological and genetic study, *Act Odont Scand* 1955;13(Suppl 18): 5-137.

[29] Matins-dos-Santos G: Ficha odonto-rugopalatina [Odonto-palatine rugae regist]. *Revista Brasileira de Odontologia*, 1946;4:36-42.

[30] More CB, Patel PT, Peter R: Analysis of Palatal Rugae Pattern in Indian and Nepalese Population - a comparative study. *Journal of Oral Medicine, Oral Surgery, Oral Pathology and Oral Radiology* 2015;1:108-113.

[31] Muhasilovic S, Hadziabdic N, Galic I, Vodanovic M: Analysis of palatal rugae in males and females of an average age of 35 in a population from Bosnia and Herzegovina (Sarajevo Canton). *J Forensic Leg Med* 2016;39:147-150.

[32] Mustafa AG, Allouh M, Tarawneh I, Alrbata R: Morphometric analysis of palatal rugae among Jordanians: further evidence of

worldwide palatal rugae individuality. *Aust J Forensic Sci* 2014;46:53-63.

[33] Muthusubramanian M, Limson KS, Julian R: Analysis of rugae in burn victims and cadavers to simulate rugae identification in cases of incineration and decomposition. *J Forensic Odontostomatol* 2005;23:26-29.

[34] Nagalaxmi V, Sridevi U, Naga Jyothi M, Lalitha C, Kotya NM, Srikanth K: Cheiloscopy, Palatoscopy and Odontometrics in Sex Prediction and Discrimination - a Comparative Study. *The Open Dentistry Journal* 2014;8:269-279.

[35] Nayak P, Acharya AB, Padmini AT, Kaveri H: Differences in the palatal rugae shape in two populations of India. *Arch Oral Biol* 2007;52:977-982.

[36] Page M, Taylor J, Blenkin M: Uniqueness in the forensic identification sciences--fact or fiction? *Forensic Sci Int* 2011;206:12-18.

[37] Patil MS, Patil SB, Acharya AB: Palatine rugae and their significance in clinical dentistry: a review of the literature. *J Am Dent Assoc* 2008;139:1471-1478.

[38] Pereira CP: Medicina Dentária Forense [Forensic Dental Medicine]. Lisboa, LIDEL, 2012.

[39] Pinheiro MFT: CSI Criminal [Criminal CSI]. Porto, Edições Universidade Fernando Pessoa, 2008.

[40] Pueyo VM, Garrido BR, Sánchez JAS: OdontologÍa Legal y Forense. Barcelona, Masson, 1994.

[41] Rai B, Kaur J: Evidence-Based Forensic Dentistry. Berlin Heidelberg, Springer -Verlag, 2013.

[42] Rajan VP, John JB, Stalin A, Priya G, Abuthagir AK: Morphology of palatal rugae patterns among 5-15 years old children. *J Pharm Bioallied Sci* 2013;5:S43-47.

[43] Sadler TW: Langman's Medical Embryology, ed 6th. Baltimore, Williams and Wilkins, 1990.

[44] Santos C, Caldas IM: Palatal rugae pattern in a Portuguese population: a preliminary analysis. *J Forensic Sci* 2012;57:786-788.

[45] Saraf A, Bedia S, Indurkar A, Degwekar S, Bhowate R: Rugae patterns as an adjunct to sex differentiation in forensic identification. *J Forensic Odontostomatol* 2011;29:14-19.

[46] Savita JK, Yathindra Kumar BN, Satish G, Divya KT, Ranjitha J, Pujari RK: Prevalence of palatal rugae shapes in Karnataka and Kerala population: A cross-sectional study. *J Int Soc Prev Community Dent* 2016;6:230-233.

[47] Shetty DK, Mali S, Divakar HD, Amit P, Dhairaysheel E, Harsh U: Palatal Rugae Patterns as a Bioindicator for Forensic Identification in Kodava and Tibetan Populations of India. *J Int Oral Health* 2015;7:57-59.

[48] Simmons JD, Moore RN, Erickson LC: A longitudinal study of anteroposterior growth changes in the palatine rugae. *J Dent Res* 1987;66:1512-1515.

[49] Suhartono AW, Syafitri K, Puspita AD, Soedarsono N, Gultom FP, Widodo PT, Luthfi M, Auerkari EI: Palatal rugae patterning in a modern Indonesian population. *Int J Legal Med* 2016;130:881-887.

[50] Thabitha RS, Reddy RE, Manjula M, Sreelakshmi N, Rajesh A, Kumar VL: Evaluation of palatal rugae pattern in establishing identification and sex determination in Nalgonda children. *J Forensic Dent Sci* 2015;7:232-237.

[51] Thomas CJ, Rossouw RJ: The early development of palatal rugae in the rat. *Aust Dent J* 1991;36:342-348.

[52] Thomas CJ, van Wyk CW: The palatal rugae in identification. *J Forensic Odontostomatol* 1988;6:21-25.

[53] Trobo y Hermosa P: El aparato dentario del hombre prehistorico. (Dental apparatus in the prehistoric man). in. Madrid, Universidad Complutense, 1932, vol PhD Thesis.

[54] Warwick R, Williams PL: Gray’s Anatomy, ed 35th. Rio de Janeiro, Guanabara Koogan, 1979.

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Chapter 4

VARIABLE-SCALE-BASED PATTERN ANALYSIS FOR TIME SERIES OF WIND SPEED, ATMOSPHERIC PRESSURE, AND ATMOSPHERIC TEMPERATURE

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ABSTRACT

The methods introduced in this paper are designed for the analysis of strongly irregular environmental patterns, including streaming environmental data. Two different approaches to variable scale are addressed in this context. The first one focuses on the size of the "grains" handled in the data, varying data resolution; it considers time series elements to represent successive states of a dynamic system, in order to identify and characterize patterns and pattern change in the dynamic system's behaviour. The second approach starts from an existing analysis method (Haar wavelets), which includes the scanning of a wide range of time scales. It builds on this method by adding an algorithm designed to be capable of grasping time- and time-scale-dependent pattern features, as well as making comprehensive scale-by-scale comparisons of patterns

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based on their scaling properties. The presented methods have a broad applicability area and are illustrated with time series corresponding to atmospheric variables: wind speed, atmospheric pressure, and atmospheric temperature time series. They can be successfully applied to studies on climate variability and implications of climate change.

Keywords: wind speed, atmospheric pressure, atmospheric temperature, pattern analysis, scaling, dynamic systems

INTRODUCTION

The urgent need to better understand and address environmental systems has led to ample monitoring programs, which have been producing increasingly large quantities of fast streaming data. Larger data volumes and enhanced data quality are valuable to the study of complex environmental issues, but only if they are complemented by powerful analysis methods. The latter are expected to capture useful information on complex systems, to offer unambiguous answers to key questions, and to better support decision making. Such methods should thus be capable of grasping essential features of the studied systems, which often involve nonlinear relationships dominating different temporal and spatial scales.

The methodology for pattern analysis dedicated to natural processes has been developing fast. Numerous methods have been specifically dedicated to the temporal behaviour of complex natural systems, as reflected in time series (Malamud and Turcotte, 1999; Kantz and Schreiber, 2004; Donner and Barbosa, 2008; Mudelsee, 2010). However, no single method can exhaustively describe the patterns produced by natural systems, with their specific, time-dependent irregularities expressed on a wide range of temporal scales. Therefore, new methods are created in order to address specific challenges raised by the study of complex systems.

The methodology introduced in this paper is designed for the analysis of strongly irregular environmental patterns, including streaming environmental data. Two different approaches to scale are addressed in this context: the first one varies the size of the “grains” handled in the data (“data granularity” or “resolution”). The second one varies the size of the time scales involved in the data analysis algorithm. Both of these approaches include pattern change detection and characterization among their targets. While the applicability area of the presented methodology is broad, both of the approaches are applied in this paper to time series corresponding to atmospheric variables. Concrete application examples are meant to offer a better understanding of the time series properties that can be grasped with the proposed methodology in new ways.

Historically, surface air temperature has been one of the best represented atmospheric variables worldwide. Compared to other aspects of the atmosphere, it could be easily recorded in a relatively reliable way. For this reason, for some locations we benefit today from temperature records of considerable length (ranging from decades to one or two centuries), longer than for other atmospheric variables. The available instrumental record lengths are not ideal for climate change studies (the latter thus rely on a wealth of other sources of information), but they can be useful for the exploration of aspects of climate variability on such temporal scales. Data concerning atmospheric pressure and wind speed, on the other hand, are more difficult to find as uninterrupted long records. However, technological progress has made reliable, high-sampling-rate, affordable data acquisition possible: therefore, for certain locations the reduced length in terms of recorded time intervals is complemented by increased overall time series length due to a superior sampling rate.

The remarkable advantages of wind energy compared to other energy sources – the non-renewable ones, or even some of the renewable ones – have led to a surge in research efforts concerning this resource (Juhlin et al., 2014) to address the challenges it involves. A key aspect of these challenges are related to uncertainties: on one hand, we do not yet have effective ways of storing the energy acquired from wind, so that the temporal pattern of wind energy conversion is reflected in the energy availability pattern; on the other hand, wind is characterized by intermittency, which is expressed on a wide range of time scales. In this context, a better understanding of the uncertainties involved in temporal aspects of energy availability is particularly important. Although reliable methodological instruments have been developed for this purpose, there are still important gaps concerning key features of wind patterns. For instance, the widely used wind speed distributions, while useful, do not reflect the effects that the actual sequence of the time series values have on the wind turbine and consequently on the power that is eventually made available (Leahy and McKeogh, 2012). Likewise, the wind speed patterns involve a wide range of scales, and their properties vary across the scale spectrum (Kirchner-Bossi et al., 2015; Archer and Jacobson, 2013); moreover, scale-dependent pattern characteristics change over time. It is therefore important for the analysis to capture the scaling aspects in the pattern, but also to describe their scale-by-scale temporal behavior. The methodological approaches presented here address the goals discussed in this chapter.

A VARIABLE GRANULARITY APPROACH

The key goals of the method introduced below concern the identification and quantitative characterization of properties of patterns and pattern change, based on time series analysis of variables that reflect the dynamics of the studied system. The method considers the elements of time series as discrete outputs of a dynamic system subject to transitions from one state to another, for example from A_i to A_j, where the states A_i and A_j are elements of the set of accessible states of the system over the analyzed time interval. These states are represented in the time series by the values a_i and a_j, respectively, of the monitored variable. Each element in the succession of values in the time series can thus be considered to represent a transition from one available state to another available state in the framework of the system dynamics. To study the system dynamics in terms of the transitions that make up a time series segment, we can use a matrix representation of all possible transitions. For this approach, the key parameter for the construction of the matrix is data granularity or resolution. In this paper, the granularity r is defined as the smallest possible difference between two distinct time series elements:

$$r = \min(|a_i - a_j|), \quad \forall i, j, \quad a_i \neq a_j \tag{1}$$

Based on the resolution r and on the smallest value a_{min} and the largest value a_{max} in the studied time series segment, we establish the set of accessible states as the set of all the values between a_{min} and a_{max} with a step equal to r. The set of L values corresponding to the accessible states is used to define the L lines and L columns in the transition frequency matrix. In this way, every possible transition among the accessible states corresponds to one element in the matrix (Figure 1; grey cells represent transitions that have frequency of occurrence zero in the studied time series segment).

All the pairs of successive values in the time series are then counted and represented in the matrix: the total number of transitions from state i to state j will thus be found in the matrix cell $t_{i,j}$. One should note that the transition frequency matrix does not have to be symmetric, since the number of transitions from state i to state j may or may not have be the same with the one for transitions from state j to state i; nor do its diagonal elements $t_{i,i}$ all have to have one and the same value, since the situations in which the system can be found in the same state in successive time snapshots can differ from one time series value to another. We should also note that the matrix does not correspond to a Marcov process, which would have endowed it with special properties: the processes we study are typically characterized by long-range correlations, and the transition to a new state would not be history-independent.

	A_1	A_2	A_3	A_4	...
A_1		$t_{1,2}$	$t_{1,3}$		...
A_2	$t_{2,1}$	$t_{2,2}$		$t_{2,4}$	...
A_3		$t_{3,2}$	$t_{3,3}$	$t_{3,4}$	...
A_4		$t_{4,2}$			...
...	...	...	...	...	...

Figure 1. Example of a transition frequency matrix: e.g., the system has suffered $t_{1,2}$ times a transition from state A_1 to state A_2, and has never experienced the same state A_1 in successive snapshots.

One may find that the system undergoes some of the transitions many times during a given time interval. In this context we are looking for the number of transitions in the matrix that have occurred at least once during the studied time interval. We thus count all the non-zero cells in the transition frequency matrix and determine the proportion of such cells out of the set of all cells in the matrix:

$$N(r) = \frac{1}{L^2} \sum_{i,j=1}^{L} H(t_{i,j}) \tag{2}$$

where

$$H(x) = \begin{cases} 0, x \leq 0 \\ 1, x > 0 \end{cases} \tag{3}$$

In order to characterize the temporal evolution of the dynamic system, one could now follow the variation in the number of distinct transitions, *N*, over time. However, this procedure would not offer a rigorous approach to the dynamics reflected in the time series. First, the transition frequency matrix would strongly depend on granularity, and data granularity or resolution represents an arbitrary choice (for example, it can be based on technological criteria, i.e., on the characteristics of the data acquisition instrument). Second, the results would depend on the total number of accessible states, which can also vary arbitrarily: for instance, if a time series is subject to a trend, the total number of accessible states varies with the length of the analyzed time series segment.

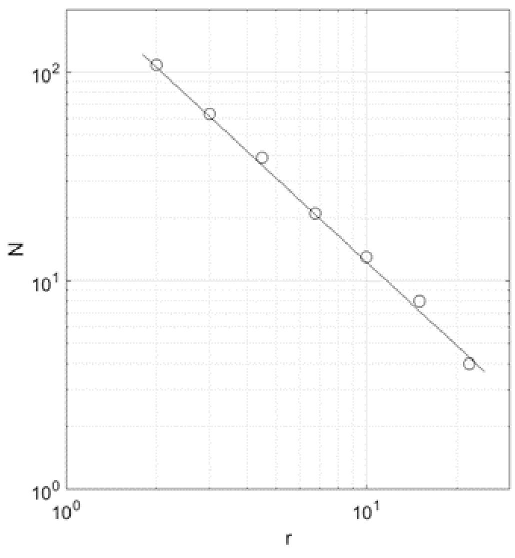

Figure 2. Relation between granularity (r) and the number of distinct transitions (N).

Consequently, we will not rely on the number of transitions or on a certain granularity value. Instead, we study the way in which the number of distinct transitions depends on granularity, whith the latter covering a range of granularity values:

$$r_u = \{r_1, r_2, ..., r_n\} \tag{4}$$

While the number of distinct transitions still depends on granularity:

$$N = N(r_u) \tag{5}$$

we do not rely on any of these individual values, but on the relationship between *N* and *r*. If this relationship turns out to be a power law (Figure 2) for a given time interval θ:

$$N(r,\theta) \propto r^{-g(\theta)} \tag{6}$$

then the exponent *g* characterizes the system dynamics from the point of view of its transition frequencies associated with its accessible states. We will call *g* the *granularity exponent*.

For the reasons described in the preceding chapter, the method will address questions that are important for a better understanding of atmospheric variables, which are also key to wind power studies; it will first be illustrated using time series of atmospheric variables recorded by the weather station of the Department of Environmental Science and the Department of Astronomy and Physics at Saint Mary`s University in Halifax, Canada. The analyzed time series represent wind speed, atmospheric temperature, and atmospheric pressure, recorded with a ten minute sampling rate (Figure 3). Atmospheric variable records may look as if they were separate series of data, to be considered in isolation; their meaning is not always explored using an integrated approach to all the available variables. For instance, wind speed, atmospheric pressure and atmospheric temperature records all reflect the dynamics of one and the same system as "seen" from one location through the lens of a set of instruments characterized by a certain resolution, a certain sampling rate, etc. It is thus important to learn in what way and to what extent the different time series recorded simultaneously reflect features of the dynamic behaviour of the system.

The application of the steps described above led to the power law relation shown in Eq. (6) for all the studied variables and time segments. Figure 2 illustrates this power law, obtained in this case for wind speed. The presence of the power law given in Eq. (6) is an important feature of such natural time series. It reveals self-similarity properties in the pattern, which can be more easily seen by analyzing the transition frequency matrix: indeed, the matrix is similar to itself when viewed on different scales, and in this case when using different values of granularity. The self-similar structure is characterized by the granularity exponent *g*, which is established over a certain scale range.

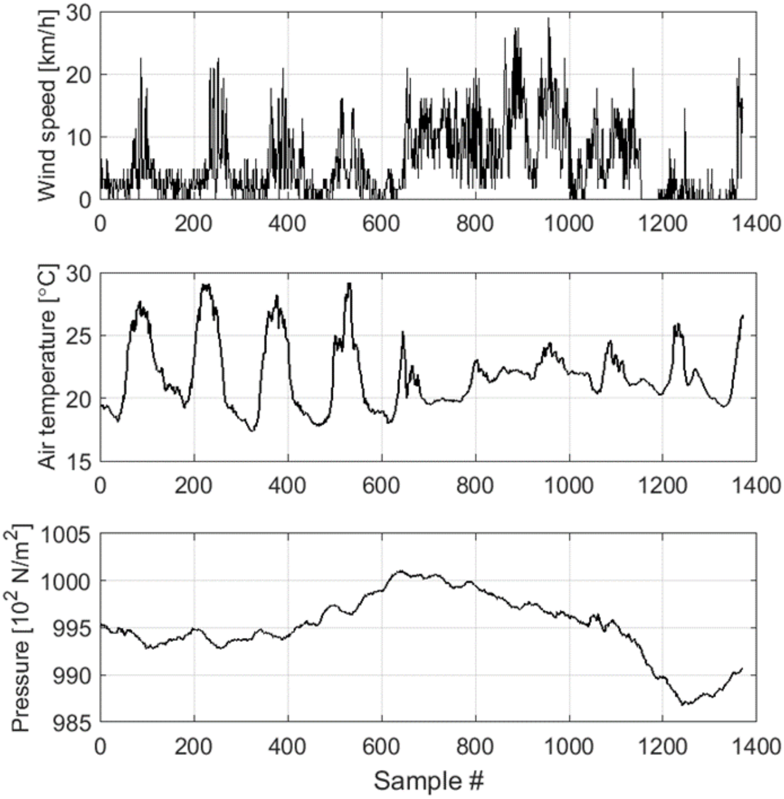

Figure 3. Time series corresponding to the analyzed atmospheric variables.

This property of the matrix is particularly useful from a methodological point of view. In fact, repeatedly constructing the transition frequency matrix for each value of the granularity can be time consuming, thus decreasing the effectiveness of the method in circumstances in which the analysis should be performed in a strictly limited time (as is the case when one addresses streaming environmental data). Due to the self-similarity that characterizes the matrix, a procedure-accelerating algorithm can be designed. The algorithm comprises the following steps: (i) the smallest available granularity size is selected; (ii) the transition frequency matrix is then constructed for this granularity value, as described above; (iii) the number of distinct transitions characterizing the pattern for that particular granularity is determined; (iv) the data granularity is increased, and the procedure is repeated starting with point (iii) above. If the successive granularity values are chosen to be multiples of the initial, smallest granularity, phase (iii) can be performed very fast. In this way, the transition frequency matrix is generated only once, after which the numbers $N(r)$ can be immediately obtained for other values of r by the mere addition of the values in adjacent cells: for every new value r_i, each cell is equivalent to the sum of the smaller cells corresponding to r_{i-1}. In this procedure, one can thus recognize the box-counting algorithm (Feder, 1988), which is a reliable and fast method widely used for the determination of the fractal dimension of highly irregular patterns. In other words, the procedure to be followed according to the proposed methodology consists of (a) determining the transition frequency matrix only once, as shown above, for the smallest granularity value to be studied, and (b) applying the box-counting method to the existing transition matrix. The latter phase can be performed very fast, given the nature of the method, as well as the existence of rapid box-counting algorithms (Jiménez and de Miras, 2012). The problem related to the most time-consuming part of the procedure involved multiple matrix generation phases possibly hindering the application of the method to streaming data. With this technique, the issue is eliminated, and the method can be applied even when the processing time is critical.

The described procedures were applied to the three time series mentioned above and shown in Figure 3. The power law given in Eq. (6) was found in each case, with a correlation coefficient higher than 99%. The resulting g-values for each analyzed time segment are shown in Figure 4.

The values of the g-exponent vary from one variable to another, which is not surprising considering the nature of the variables. However, since all the three variables – wind speed, atmospheric temperature, and atmospheric pressure – are an expression of one and the same dynamic system, their patterns might reflect their common origin. However, the graphical representation of the time series (Figure 3) shows how different the temporal patterns of the three variables are. In spite of this diversity, one can notice similarities among the g-value graphs in Figure 4, more so than among the graphs of the variables themselves (Figure 3): for instance, in all three graphs in Figure 4 there are minimum or low value points on day 4, and a higher value interval on days 6 and 7, followed by a decrease on day 8. Of course, the level of detail in the g-graphs is lower than in the original variable graphs, since the latter correspond to the acquisition sampling interval (10 minutes), while the former represent each day by one point on the graph. Even after taking this distinction in consideration, one can still identify the parallels among the g-graphs for time series that look very different from each other, which suggests that the method captures features of the system dynamics, even if common properties of the dynamics are less visible in the time series graphs.

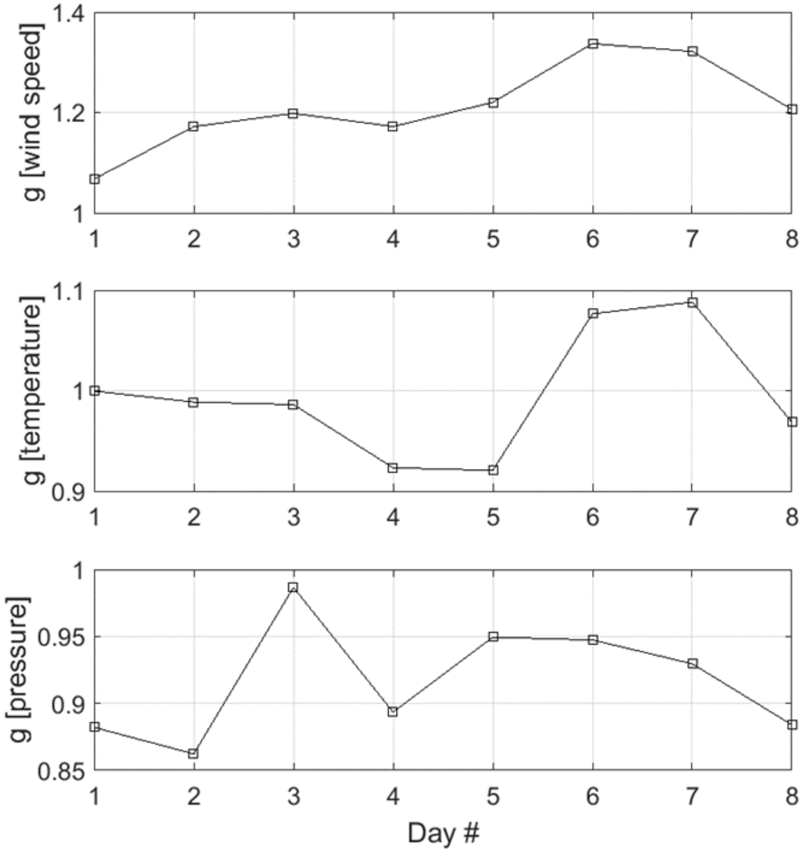

Figure 4. The granularity exponents determined for the time series presented in Figure 3. The lines connecting the points are only meant to guide the eye.

We have also applied this method to different sets of data, to check its outcomes on a longer time scale (decades rather than days) and to compare them to a different way of capturing the variability in the dataset – a statistical measure of dispersion. The dataset consists of maximum daily surface air temperature recorded in Vardø, a high-latitude northern station located in Norway (more details about this station are provided in the next chapter). Due to the richness of this dataset, the presented methodology can be applied to produce a more detailed picture than the one obtained above. Intervals of 5 years shifted for each point by one year were analyzed, and for each interval the standard deviation *s* and the granularity exponent *g* were determined.

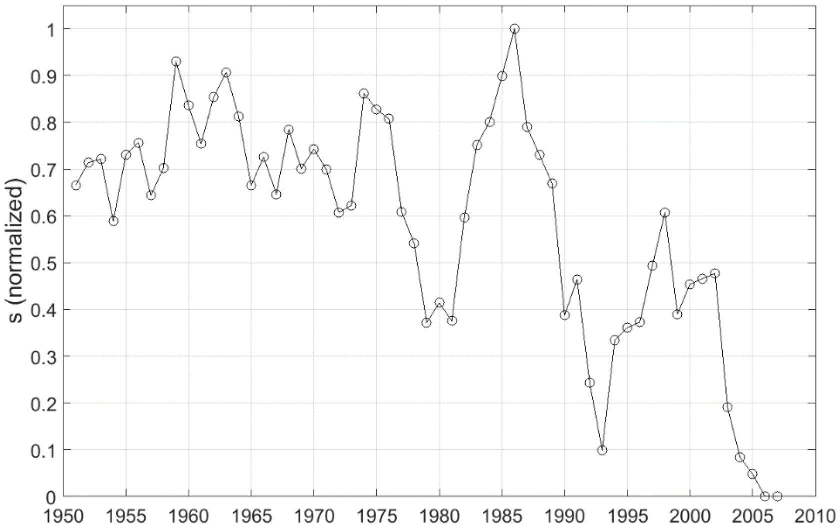

Figure 5. Normalized standard deviation values for successive segments of maximum surface air temperature records from Vardø.

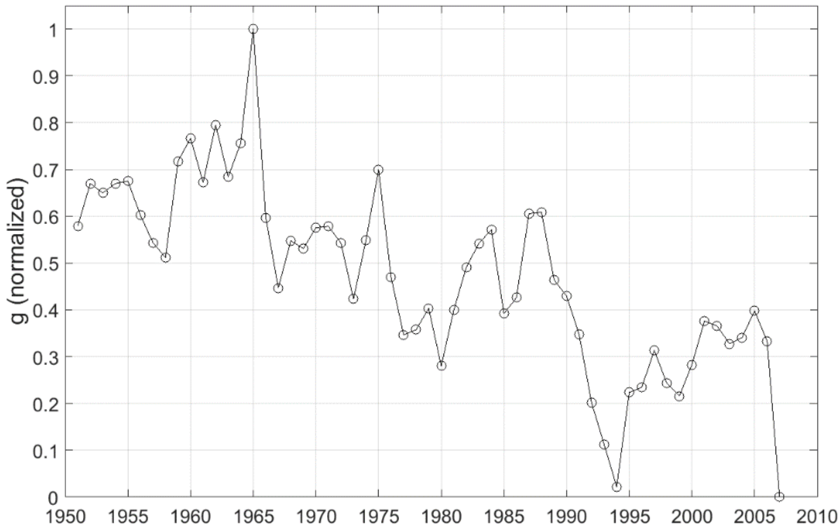

Figure 6. Normalized granularity exponent (*g*-values) for the same time series segments as in Figure 5.

The resulting values were normalized in order to cover the interval [0,1], facilitating the comparison between the two ways of describing the different time segments. The resulting graphs are shown in Figures 5 and 6. One can notice in both graphs a decreasing tendency between the eighties and the first years of the new millennium. However, unlike the standard deviation, the granularity exponent shows a steady decrease throughout the whole studied interval, whereas the standard deviation presents a plateau for the first decades of the record. Moreover, a periodic oscillation fingerprint can be more clearly noticed on the *g*-value graph. One can thus see that the two ways of describing the pattern capture distinct features, emphasizing the idea that different methods (relying on different principles) see the pattern from different angles, and together they may offer us information that is not available from any of the individual approaches.

Both applications show that the variable granularity method can identify scaling properties of the pattern referring to the transitions of the system among its available states, as well as quantitatively evaluating the variability of the pattern related to the dynamics it expresses through such transitions. The method can thus reveal a scaling property of time series that is related to, but goes beyond those identified with the methodology that is currently applied (Malamud and Turcotte, 1999): this self-similarity fingerprint is revealed due to the effects of variable resolution. The proposed approach can fruitfully complement the current methods dedicated to the characterization of patterns in time series.

A Variable Time Scale Approach

A relevant assessment of temporal change in atmospheric variability requires a set of methods capable of characterizing various aspects of the studied variables. Among the latter, air temperature is by far the one most widely studied. Reports of Arctic communities concerning a growing variability of weather patterns and their diminishing prediction capability based on local knowledge have led to scientific studies regarding changes in temperature pattern variability. However, these studies have not produced convergent results: the various methods have led to different conclusions concerning the problem of changing variability (Suteanu, 2015a). This is not surprising, considering that (a) weather variability perception may rely on factors that are different from air temperature patterns, and (b) surface air temperature patterns themselves enjoy a range of properties, some of which are quantitatively captured by the methodology applied in various studies, but no set of methods can identify "all" the aspects of such patterns of change. New methods, especially if they rely on novel analysis principles, could uncover pattern properties that have not been previously identified, contributing to our picture of the complexity of environmental dynamics. The method presented below will therefore address atmospheric temperature datasets from meteorological stations located at high northern latitudes, focusing on particularly important pattern features: long term correlations. In fact, time series of natural variables such as wind speed and surface air temperature have been found to be characterized by long-range correlations (Fraedrich et al., 2009; Lovejoy and Schertzer, 2013; Suteanu, 2015b, Fortuna et al., 2016). In other words, their autocorrelation function is characterized by a slow, gradual decrease, which does not follow an exponential function, but a power law. The accurate assessment of time series with such properties require adequate tools. These can, for instance, establish the relation between the average size of the fluctuation and the time scale corresponding to the evaluation window of the fluctuation, while scanning a range of temporal scales for the analysis window. The most widely applied methods in this category are Detrended Fluctuation Analysis and Wavelets Analysis. Most importantly, these methods are capable of accurately addressing the typically nonstationary nature of such time series. In this study we apply wavelets, which offer an elegant and powerful approach to natural time series characterized by strong irregularity on multiple scales (Holschneider, 1995; Nason and von Sachs, 1999). We focus in particular on Haar wavelets, a tool characterized by simplicity and effectiveness with respect to the evaluation of time series such as those considered here (Lovejoy et al., 2012).

The method is applied to time series representing daily minimum and maximum surface air temperature in two coastal locations at the northern edge of Norway (Klein Tank et al., 2002): Vardø (coordinates: 70.37N, 31.08E, altitude: 14m) and Fruholmen Fyr (coordinates: 71.09N, 24.00E, altitude: 13m). The processing starts with the seasonal detrending of the time series, by computing the average temperature for each day of the year over the whole dataset, after which this average temperature is subtracted from each daily value. This step is followed by the normalization of the resulting time series. The outcome is a time series $h(i)$ with an average of zero and a standard deviation equal to 1. The time series $h(i)$ is then divided into sections of v successive elements, and the average size of the fluctuation F in temporal windows of size v is calculated as follows:

$$F^2(v) = \left\langle \sum_{i=x}^{x+v/2} h^2(x) - \sum_{i=x-v/2}^{x} h^2(x) \right\rangle_x \quad (7)$$

where the subscript x means that the average of this expression is taken for all values of x. Subsequently, we check the presence of a power law relation between the temporal length or "time scale" v and the average size of the fluctuation F over that time scale:

$$F(v) \propto v^K \quad (8)$$

The exponent K in this equation characterizes the time series persistence (or its degree of "smoothness") over the range of scales covered by Eq. (8). When applied to the integral of the time series rather than to the time series itself, the method produces exponent values that are larger by 1 than those corresponding to the actual time series: the method indeed leads to outcomes that are very close to the theoretical relationships between these two sets of exponents.

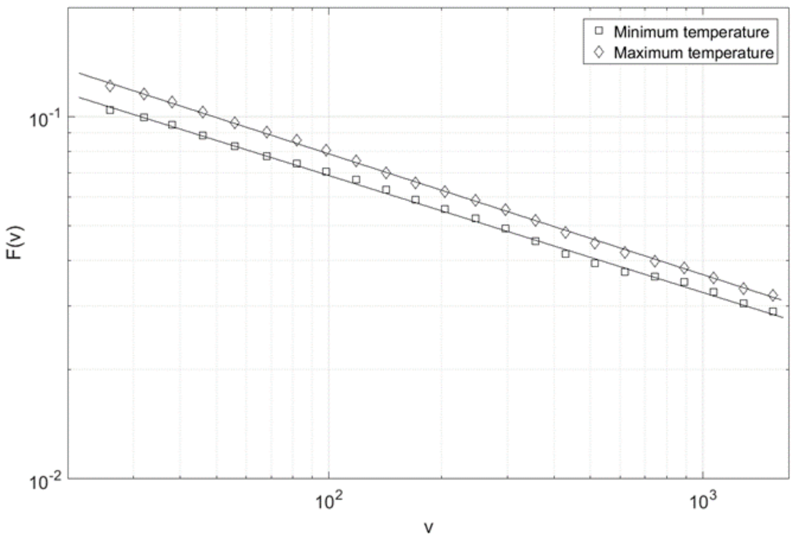

Figure 7. Time scale (v) vs. average size of the fluctuation (F) for the minimum and maximum temperature records in Fruholmen Fyr, in the framework of Haar wavelet analysis.

Examples of scaling relations like the one given in Eq. (8) are shown in Figure 7. While such time series are nonstationary, one can divide the analyzed dataset in windows, and characterize each window in order to get an image of the way in which the pattern is changing over time (Nason and von Sachs, 1999). This approach has led to the detection of pattern similarities regarding the change of *K* over time in different locations, and to the suggestion of Suteanu and Mandea (2012) to define atmospheric dynamics regions based on pattern change similarities in various locations.

This methodology can be extended to provide information on the pattern properties as a function of temporal scale, as well as on the way in which these properties vary over time. Indeed, instead of assessing the "overall persistence" for the whole scale range, we can assess and represent persistence for each scale interval. The relevance of the scale-by-scale detailed behaviour of the graph that leads to the identification of Eq. (8) was underlined by Maraun et al. (2004), who proposed to look at the successive slopes of graphs like those in Figure 7, and to represent them as a function of scale (see also Figure 6 in Suteanu, 2015a).

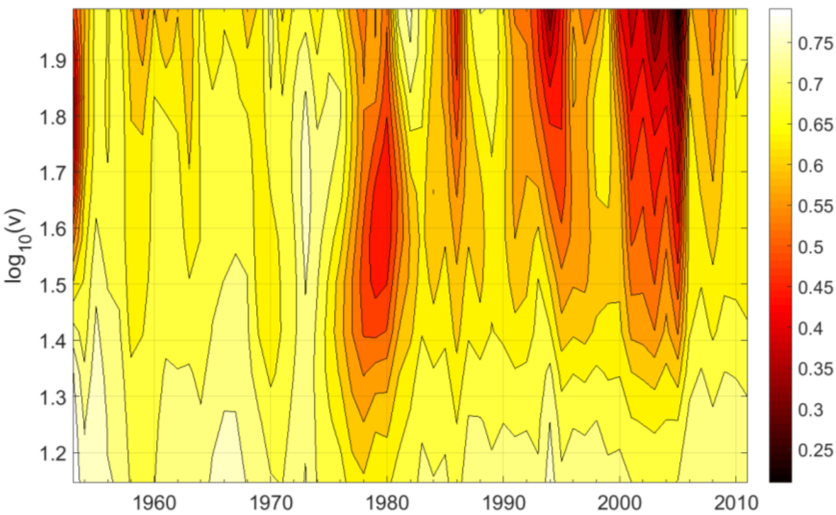

Figure 8. Time-scale vs. time diagram for minimum temperature records, Fruholmen Fyr.

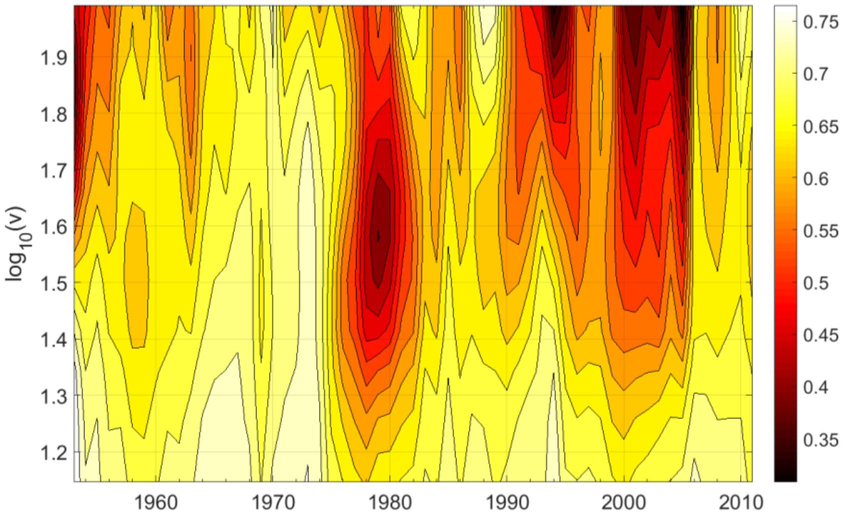

Figure 9. Time-scale vs. time diagram for maximum temperature records, Fruholmen Fyr.

To accomplish the above-mentioned objectives, the extension of the method involves several additional operations, as well as a different type of graphical representation. We rotate the graph resulting from the scale-dependent assessment of the successive slopes by 90 degrees. Furthermore, instead of showing the graph for only one temporal interval, we horizontally align the graphs for all the successive analyzed time windows. In this way we obtain a new type of diagram, in which the horizontal axis corresponds to time, and the vertical axis shows the time scales, while the slope values corresponding to successive scale intervals are represented according to a colour code.

The diagram (like those presented in Figure 8 and Figure 9) can be seen as a “time vs. time-scale” isopersistence map. This representation offers the advantage of showing the temporal development of the pattern, by bringing together results that arise from a multitude of graphs and by showing for each interval the slopes for each scale range. One can see in Figures 8 and 9 that there are time intervals for which the persistence is higher and covers a relatively wide scale interval, whereas for other time intervals the diagram colours indicate less strong persistence.

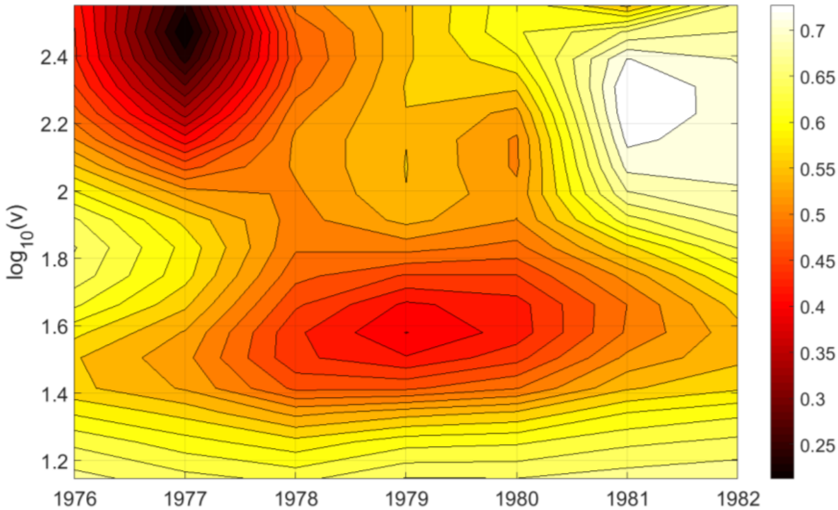

Figure 10. Zooming into the time-scale vs. time diagram from Figure 9.

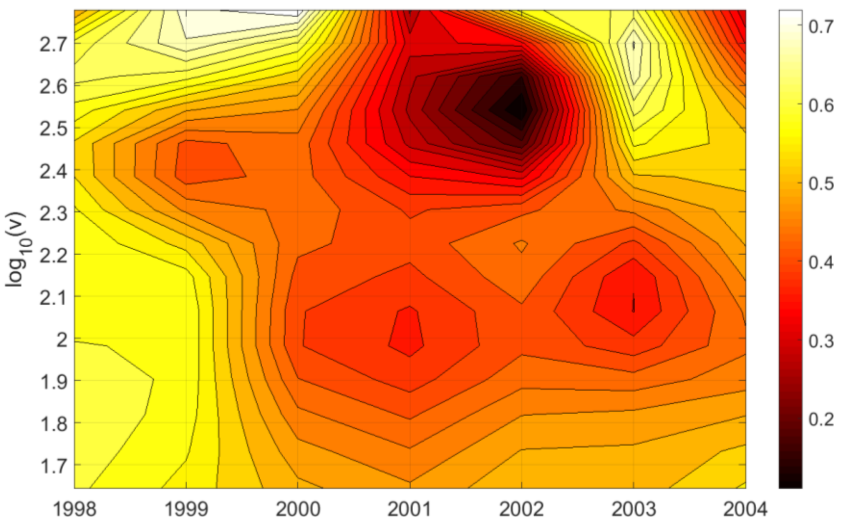

Figure 11. Zooming into another zone of the time-scale vs. time diagram from Figure 9.

With the help of such diagrams, questions concerning changes in variability over time can be answered in a more nuanced way than through a graph showing a persistence value for each time interval. One can notice in the diagrams that changes in variability occur, over time, for different time scale intervals in different ways, and associating only one number to each interval (as other methods do) implies a strong simplification, which is not always helpful. Moreover, the described method allows us to zoom in, zoom out, and move the focus of our exploration in the "time-scale vs. time" plane as needed. Examples of diagram details obtained by zooming in (i.e., by changing the time scale interval and the temporal interval selected for the diagram) are presented in Figures 10 and 11. One can notice that the upper end of the time scale is changed from 100 days to more than 300 and more than 600 days, respectively, while the time scale for the diagram is reduced to 6 years.

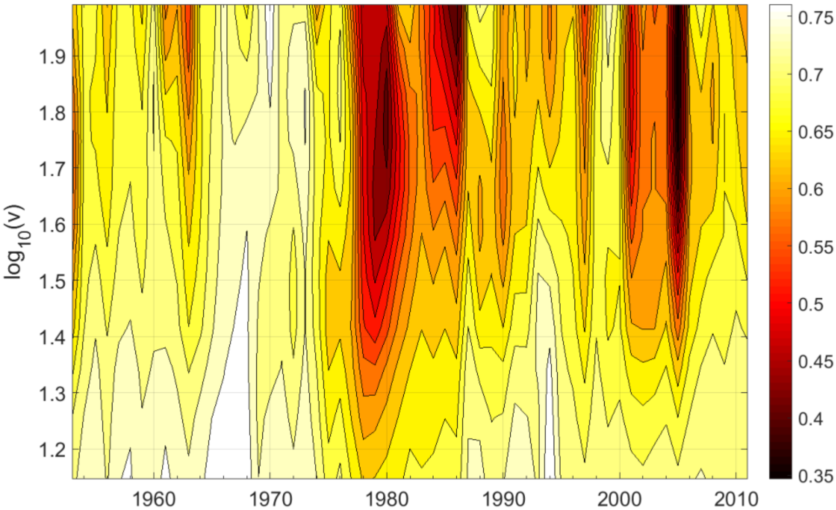

Figure 12. Time-scale vs. time diagram for maximum temperature records from Vardø.

Figures 12 and 13 present the diagrams for the maximum temperature records in Vardø, and a map detail produced by zooming into the time interval corresponding to the first seven years of the third millennium, respectively. Figures 10, 11, and 13 show that zooming operations, although straightforward and fast to accomplish with the proposed methodology, can reveal pattern structures and details of time-scale vs. time features that are not easy to identify with the help of other methods. Such diagrams also show that temporal changes in variability cannot be merely represented by a single line on a graph, since such changes occur in time-scale-specific ways. These results also provide an explanation for the difficulties encountered with respect to the question whether variability of weather patterns is actually changing over time: it is in fact difficult to tell what aspects of the complex variable patterns are mostly affecting people's perception of change. The presented methodology can thus be effectively applied to studies on climate variability and implications of climate change.

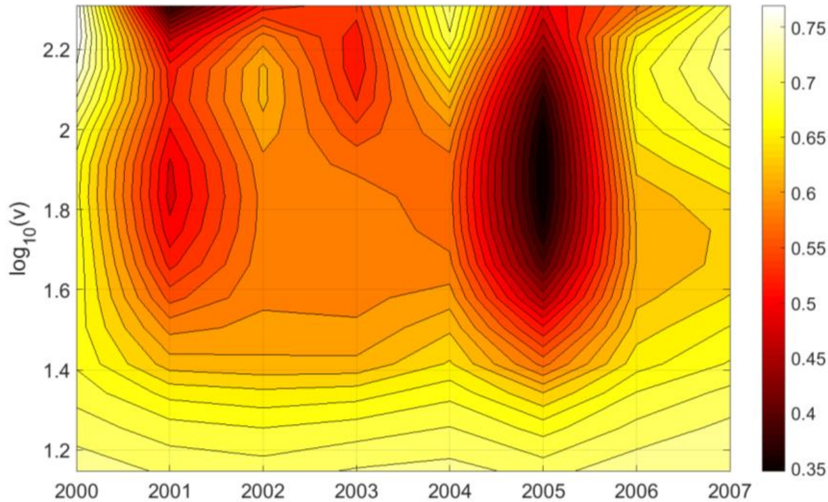

Figure 13. Zooming into the time-scale vs. time diagram from Figure 12.

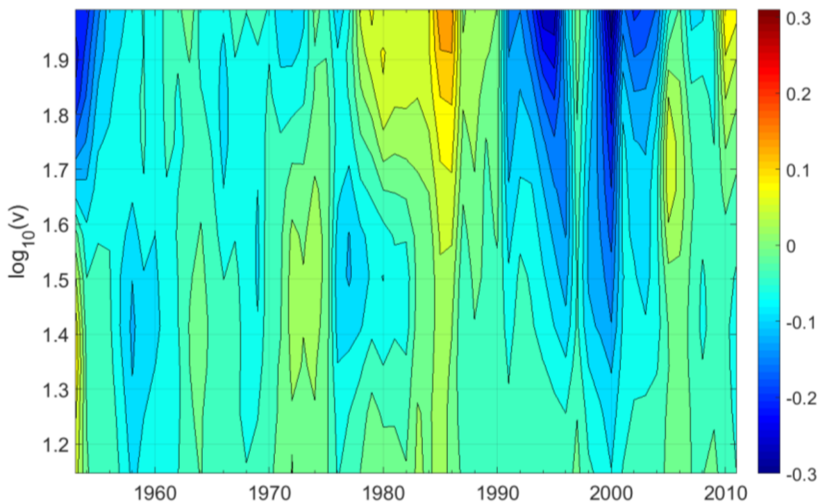

Figure 14. Isopersistence-based comparison between the maximum temperature records from Fruholmen Fyr and Vardø, respectively.

The methodology supports comprehensive comparisons of patterns. For instance, it offers the tools to produce diagrams representing scale-by-scale comparisons of variability patterns corresponding to different locations; this is particularly useful when regions are defined by the way in which temporal variability changes take place in distinct locations (Suteanu and Mandea, 2012). Figure 14 presents the outcome of a comparison of daily maximum temperature patterns in the two studied locations. One can distinguish the time periods emphasizing the strongest similarities among the patterns from the two stations, as well as the time scale intervals affected by stronger or weaker change. For example, one can see in Figure 14 that dissimilarities are particularly notable for time scales longer than $\log_{10}(v) = 1.5$, i.e., for time scales longer than one month; in terms of time flow, a time interval that stands out regarding pattern difference is 1984-1986, which is by far not an exceptional interval in the individual diagrams that are compared (Figures 9 and 12). Similarly, the methodology can be used for detailed, scale-related comparisons involving patterns from the same location, but corresponding to different time periods, offering new instruments to study implications of climate change.

While easy to implement and fast to run, the method leading to time-scale vs. time diagrams avoids the involvement of arbitrary time intervals; it addresses variability on all time scales available in the data, producing diagrams that are easy to read and to interpret. This approach can therefore be successfully used for the characterization of location-specific features and the reliable detection of temporal fingerprints of the pattern.

CONCLUSION

The pattern analysis methods presented in this paper represent tools for the identification and quantitative characterization of patterns and pattern change. They are designed for the analysis of strongly irregular environmental patterns, including streaming environmental data.

Both methods involve variable-scale-based algorithms. The first one focuses on the scale at which we consider the data, varying their resolution. The second method starts from Haar wavelets analysis and incorporates a novel algorithm capable of grasping time- and time-scale-dependent pattern features. The presented methodology has a broad applicability area and is illustrated here with examples of time series of atmospheric variables: wind speed, atmospheric pressure, and atmospheric temperature time series.

The two approaches provide mutually complementary information regarding pattern characterization. They should thus be selected as a function of the questions asked and the data types to be addressed. These methods can be applied in conjunction with current approaches in order to contribute to a more detailed and reliable picture of the studied systems. While easy to implement and fast to run, the presented methods can be successfully applied to the study of a range of aspects of climate variability and climate change.

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REFERENCES

[1] Archer, C. L.; Jacobson, M. Z. *Appl Geogr* 2013, 45, 119-130.

[2] Donner, R. V., Barbosa, S. M., Editors, *Nonlinear Time Series Analysis in the Geosciences -Applications in Climatology, Geodynamics, and Solar-Terrestrial Physics*; Lecture Notes in Earth Sciences; Springer: Berlin, 2008.

[3] Feder, J. *Fractals;* Plenum: New York, 1988.

[4] Fortuna, L.; Nunnari, G.; Nunnari, S., *Nonlinear Modeling of Solar Radiation and Wind Speed Time Series*, Springer Briefs in Energy; Springer: New York, NY, 2016.

[5] Fraedrich, K.; Blender, R.; Zhu, X. *Int J Mod Phys B* 2009, 23, 5403-5416.

[6] Holschneider, M. *Wavelets: An Analysis Tool*; Clarendon Press: Oxford, 1995.

[7] Jiménez, J.; de Miras, R. J. *Comput Methods Programs Biomed* 2012, 108(3):1229-42.
[8] Juhlin, C.; Hangx, S.; Ask, M.; Bruckman, V. *Energy Procedia* 2014, 59, 440-444.
[9] Kantz, H.; Schreiber, Th. *Nonlinear Time Series Analysis*; Cambridge University Press: Cambridge, 2004.
[10] Kirchner-Bossi, N; Garcia-Herrera, R.; Prieto, L.; Trigo, R.M. *Int J Climatol* 2015, 35(9), 2635-2646.
[11] Klein Tank, A. M. G. et al. Int *J Climatol* 2002, 22, 1441-1453.
[12] Leahy, P.; McKeogh, E. *Wind Energ* 2012, 16(4), 575-586.
[13] Lovejoy, S.; Schertzer, D. *The Weather and Climate: Emergent Laws and Multifractal Cascades*; Cambridge University Press: Cambridge, 2013.
[14] Lovejoy, S; Schertzer, D.; Stanway, J. D. *Nonlinear Proc Geophys* 2012, 19, 513-527.
[15] Malamud, B. D.; Turcotte, D.L. *Adv Geophys* 1999, 40, 1-90.
[16] Maraun, D.; Rust, H. W.; Timmer, J. *Nonlinear Proc Geoph* 2004, 11, 495-503.
[17] Mudelsee, M. *Climate Time Series Analysis: Classical Statistical and Bootstrap Methods;* Atmospheric and Oceanographic Sciences Library 51; Springer: Dordrecht, 2010.
[18] Nason, G. B.; von Sachs, R. *Phil Trans R Soc Lond A* 1999, 357(1760), 2511-2526.
[19] Suteanu, C. *Pure Appl Geophys* 2015a, 172(7), 2057-2073.
[20] Suteanu, C. *Energy Procedia* 2015b, 76, 200-206.
[21] Suteanu, C.; Mandea, M. *Meteorol Atmos Phys* 2012, 118(3-4), 179-188.

BIOGRAPHICAL SKETCH

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His courses include Environmental Pattern Analysis and Modeling, Environmental Information Management, as well as Statistics, Natural Hazards, and graduate and post-doc courses on nonlinear approaches to natural complex systems.

Publications:

1. C. Suteanu (2016), Operating on symmetry and scale to address environmental variability, *Noema* XV, 145-164.
2. C. Suteanu (2016) Book review of “Environmental Sciences—A Student's Companion” by Kenneth J. Gregory, Ian G. Simmons, Anthony J. Brazel, John W. Day, Jr., Edward A. Keller, Arthur G. Sylvester, and Alejandro Yanez-Arancibia, SAGE, London; *The Canadian Geographer* 60, 1, 6–7.
3. C. Suteanu (2015) A methodology for the time-scale-sensitive evaluation of wind speed and direction variability. *Energy Procedia* 76, 200–206.
4. C. Suteanu (2015) Statistical variability and persistence change in daily air temperature time series from high latitude Arctic stations, *Pure and Applied Geophysics*, 172, 7, 2057-2073.
5. L. Liucci, L. Melelli, C. Suteanu (2015) Scale-invariance in the spatial development of landslides in the Umbria Region (Italy), *Pure and Applied Geophysics*, 172, 7, 1959-1973.
6. C. Suteanu (2015) Book review of “The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences” by R. Kitchin, SAGE, Los Angeles; *Geographical Research* 53, 3, 340-342.
7. C. Suteanu (2014) Pattern variability in Arctic air temperature records, *Surveys in Geophysics*, 35, 5, 1215-1242.
8. C. Suteanu, L. Campbell, T. Charles, J. Clyburne, J. Lundholm, A. Wiacek (2014), Cutting-edge science for the real world, in K.Vaidya (ed.), *Environmental Science and Studies for the Curious: Top Professors' Perspectives on College/University Major, Scholarships,*

Research Issues, and Career Options, The Curious Academic Publishing, ISBN 978-1-925128-60-4.

9. C. Suteanu (2013) The causal network of in-betweenness, *Biocosmology—Neo-Aristotelism*, 3, 4, 608-618.
10. C. Suteanu (2013) Identifying change in the variability of surface air temperature patterns, *Pattern Recognition in Physics*, 1, 1, 135-142.
11. P. Horne, C. Suteanu, D. Van Proosdij, G.Baker (2013) Elevation-dependent multi-scale analysis of a complex inter-tidal zone, *Journal of Coastal Research* 29, 3, 631-641.

Organization of Scientific Events in the Last 3 Years

1. *9th International Symposium on Digital Earth*, Halifax, Canada, 5-9 October 2015. Member of the Local Organizing Committee.
2. *European Geosciences Union General Assembly*, Vienna, Austria, 12-17 April 2015. Session: NP1.5: *Geocomplexity and Scales*. Co-convener.
3. *European Geosciences Union* General Assembly, Vienna, Austria, 27 April – 2 May 2014. Session: NP3.1/CL6.12/SSS0.6: *Scales, Scaling and Extremes in the Geosciences*. Co-convener.
4. *5th International Conference on Fractals and Dynamic Systems in Geoscience*, Perugia, Italy, 26 September – 3 October 2013. Member of the Scientific Committee.
5. *European Geosciences Union General Assembly*, Vienna, Austria, 7-12 April 2013. Session: NP3.2/AS4.17/GM6.6/HS7.7/SM1.7: *Geocomplexity: patterns, processes, scaling and extremes in the geosciences* (co-organized). Convener.

***Reviewer for**:* Hydrological Sciences Journal; Journal of Volcanology and Geothermal Research; Journal of Structural Geology; Journal of Complex Systems; Journal of Regional Science; Natural Hazards; Natural Hazards and Earth Systems Science; Nonlinear Processes in Geophysics; Pure and Applied Geophysics; Quaternary International; Surveys in Geophysics; Humanities; International Journal of the Humanities; Theory, Culture and Society.

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