DIGITISATION PROCESSING AND RECOGNITION OF OLD GREEK MANUSCIPTS (THE *D-SCRIBE* PROJECT)

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Abstract: *After many years of scholar study, manuscript collections continue to be an important source of novel information for scholars, concerning both the history of earlier times as well as the development of cultural documentation over the centuries. D-SCRIBE project aims to support and facilitate current and future efforts in manuscript digitization and processing. It strives toward the creation of a comprehensive software product, which can assist the content holders in turning an archive of manuscripts into a digital collection using automated methods. In this paper, we focus on the problem of recognizing early Christian Greek manuscripts. We propose a novel digital image binarization scheme for low quality historical documents allowing further content exploitation in an efficient way. Based on the existence of closed cavity regions in the majority of characters and character ligatures in these scripts, we propose a novel, segmentation-free, fast and efficient technique that assists the recognition procedure by tracing and recognizing the most frequently appearing characters or character ligatures.*

Keywords: *Handwriting Recognition, Character Recognition, Binarization, Segmentation-free, Feature Extraction, Historical Document Recognition, Old Manuscript Recognition.*

Introduction

Recognition of old Greek manuscripts is essential for quick and efficient content exploitation of the valuable old Greek historical collections. D-SCRIBE (http://iit.demokritos.gr/cil/dscribe/) is a Greek GSRT-funded R&D project which aims to support and facilitate current and future efforts in manuscript digitization and processing. It strives toward the creation of a comprehensive software product, which can assist the content holders in turning an archive of manuscripts into a digital collection using automated methods. Our final product will give memory institutions the opportunity to:

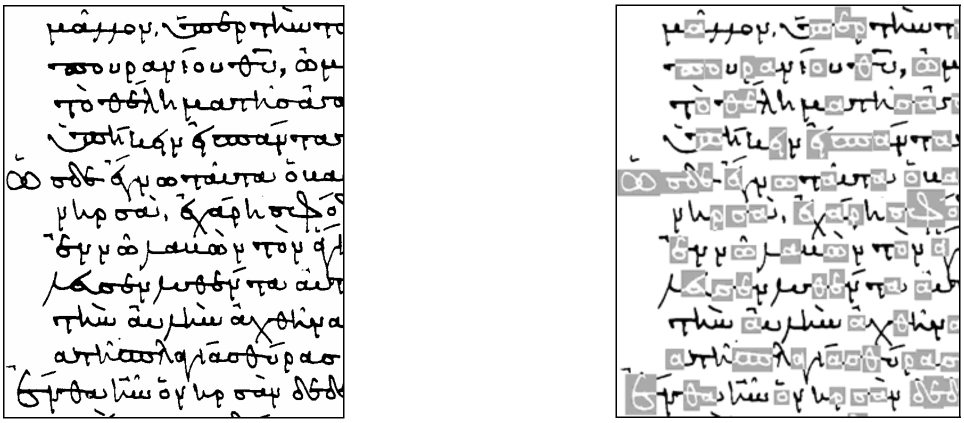
- Digitize their manuscript collections according to quality metrics, leveraging existing material with state-of-the-
- art technical feasibility.
- Produce varying digital objects for varying purposes, e.g. access vs. preservation.
- Automate the transliteration of manuscripts, by employing manuscript-tuned OCR modules.
- Manage their content in the form of a digital library, by using a powerful document management system.
- Facilitate and expand the study of paleography, by providing self-study tools which will help students and
- researchers in coping with large volumes of data.

In the framework of D-SCRIBE, the system STUD-IOS will be developed. This system is constituted by two sub-systems. The first sub-system aims to cover the need for self-instruction of D-SCRIBE users for the digitization and treatment of Greek manuscripts. It will be developed after the completion of the D-SCRIBE platform, and its current planning forecasts its operation in the form of friendly support (windows help), during the operation of the D-SCRIBE platform. The second sub-system comes to cover the cognitive object of paleography, on theoretical issues, e.g. types of writings, faculties of paleography, materials used for the paleography, techniques of paleography. Furthermore, it supports teaching and develops the faculty of transcription of manuscripts in modern Greek.

In this paper, we focus on the problem of recognizing early Christian Greek manuscripts. Specifically, our principal concern constitutes the Sinaitic Codex Number Three, which contains the Book of Job, one of the best Greek manuscripts and one of the major masterpieces of world literature (see Fig. 1a). Written in Hebrew initially, the Book was translated into Greek approximately the 3rd century B.C. for the sake of the Hellenized Hebrews of

Alexandria. We propose a novel digital image binarization scheme for low quality historical documents allowing further content exploitation in an efficient way. Based on the existence of closed cavity regions in the majority of characters and character ligatures in these scripts, we propose a novel, segmentation-free, fast and efficient technique that assists the recognition procedure by tracing and recognizing the most frequently appearing characters or character ligatures.

In the field of handwritten character recognition a great progress has occurred during the past years [Vinciarelli, 2002]. Many methods were developed for a variety of applications like automatic reading of postal addresses [Lu, 2002], fax forms [Hirano, 2001] and bank checks [Xu, 2001], form processing, etc. In the literature, two main approaches can be identified: the global approach [Suen, 1993] and the segmentation approach [Kavallieratou, 2002]. The global approach entails the recognition of the whole word while the segmentation approach requires that each word has to be segmented into letters. Some approaches that do not involve any segmentation task are based on concepts and techniques that have been used in object recognition with occlusions [Chen, 2003]. According to these approaches, significant geometric features such as short line segments, enclosed regions and corners are extracted from a fully unsegmented raw document bitmap by methods like template matching [Duda, 1973], peephole method [Mori, 1992], n-tuple feature [Jung, 1996] and hit-or-miss operator [Gonzalez, 1992].



(a) Early Christian Greek manuscript

(b) Identified characters or character ligatures that contain closed cavities

Fig. 1.

Traditional techniques for handwriting recognition cannot be applied to early Christian Greek manuscripts written in lower case letters, since continuity between characters of the same or consecutive words does not permit character or word segmentation. Furthermore, the aforementioned manuscripts entail several unique characteristics as in the following:

- High script standardization. Although, we refer to handwritten manuscripts, the corresponding characters are highly standardized since the manuscripts are immediate predecessors of early printed books.
- Frequent appearance of character ligatures
- Frequent appearance of closed cavities in the majority of character and character ligatures. As shown in Fig. 1b, closed cavities appear in letters “α”, “ο”, “σ”, “ε”, “δ”, “ω”, “π”, “θ”, “φ” as well as in letter ligatures “σπ”, “εσ” etc. These constitute 60% of complete character set used in a typical old Greek manuscript.

The continuity between characters of the same or consecutive words guided us to develop a segmentation-free recognition technique as a fundamental assistance to Old Greek handwritten Manuscript OCR. Based on the existence of closed cavities in the majority of characters and character ligatures, we propose a technique for the detection and recognition of characters that contain closed cavities. It is a novel method whose originality is based on two aspects. First, a novel segmentation-free approach based on the detection of the closed cavities. This aids toward the proposed character representation since the hole regions exist in the majority of characters and character ligatures. Second, novel features are used that are based on the protrusions in the outer contour of the connected components that contain closed cavities.

The proposed methodology consists of several distinct stages. First, we apply a binarization and image enhancement technique to get an improved quality black and white (b/w) image. Second, we trace closed cavities that exist in character bodies. We suggest a novel fast algorithm based on processing the white runs of the initial b/w image. This algorithm permits the extraction of the character closed cavities but rejects closed cavities of larger dimension, such as closed cavities inside frames, diagrams, etc. In the next step, all closed cavities in characters are initially grouped into several categories based on their spatial proximity and topology. In this way, character closed cavities are classified as: a single closed cavity, two horizontal neighboring closed cavities, three horizontal neighboring closed cavities, four horizontal neighboring closed cavities, two vertical closed cavities and two vertical neighboring patterns that consist of a single closed cavity and two neighboring closed cavities (see Table 1). The final stage of our approach concerns classification of the aforementioned closed cavity patterns into a character or a ligature. It is based on the protrusions that appear in the outer contour outline of the connected components which contain the character closed cavities. The proposed novel recognition methodology, as well as the initially applied binarization and image enhancement tasks are fully described in the following sections.

Table 1. The proposed dictionary for closed cavity patterns.

Pattern ID	1	2	3	4	5	6
Pattern	o	o o	o o o	o o o o	o o	o o o
Characters or character ligatures	(α), (o) (ε), (σ) (ρ), (δ)	(π), (ω), (εσ)	(σπ), (επ)	(απο)	(θ)	(φ)

Image Binarization and Enhancement

Binarization is the starting step of most document image analysis systems and refers to the conversion of the gray-scale image to a binary image. Since historical document collections are most of the times of very low quality, an image enhancement stage is also essential. In the literature, the binarization is usually reported to be performed either globally or locally. The global methods (global thresholding) use a single threshold value to classify image pixels into object or background classes [Otsu, 1979], whereas the local schemes (adaptive thresholding) can use multiple values selected according to the local area information [Kim, 1996]. Most of the proposed algorithms for optimum image binarization rely on statistical methods, without taking into account the special nature of document images [Niblack, 1986]. Global thresholding methods are not sufficient for document image binarization since document images usually have poor quality, shadows, nonuniform illumination, low contrast, large signal-dependent noise, smear and strains. Instead, adaptive to local information techniques for document binarization have been developed [Sauvola, 2000].

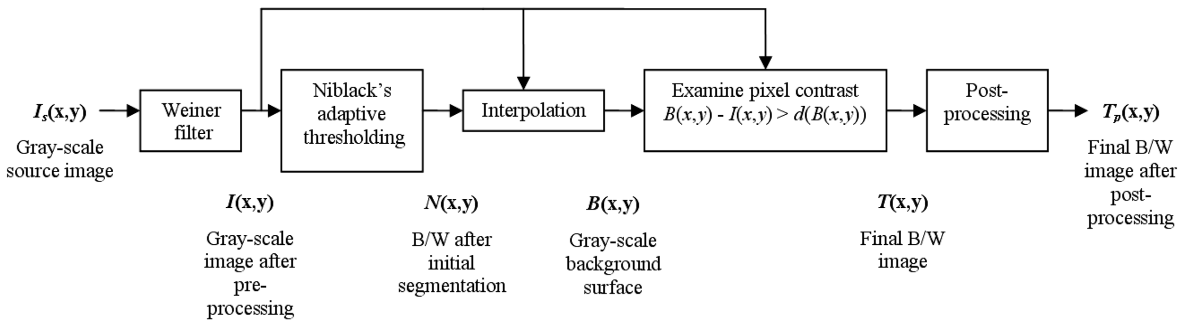
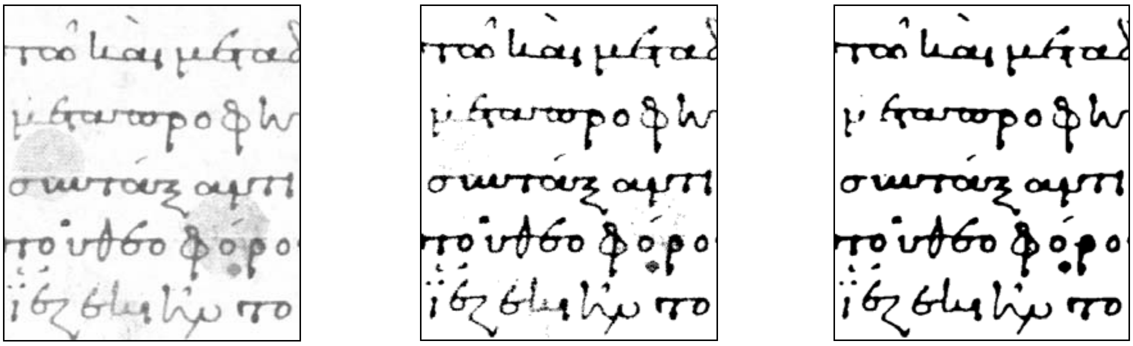


Fig. 2. Block diagram of the proposed methodology for low quality historical document text preservation.

The proposed scheme for image binarization and enhancement is described in [Gatos, 2004] and consists of five distinct steps (see Fig. 2): a pre-processing procedure using a low-pass Wiener filter, a rough estimation of foreground regions using Niblack's approach [Niblack, 1986], a background surface calculation by interpolating neighboring background intensities(see Fig. 3), a thresholding by combining the calculated background surface with the original image and finally a post-processing step that improves the quality of text regions and preserves stroke connectivity. An example of the image binarization and enhancement result is demonstrated in Fig 4.

(a) Original image (b) Background surface *B*

Fig. 3. Background surface estimation



(a) Original gray scale image (b) B/W image resulting after binarization (c) Final image after image enhancement

Fig. 4. Image binarization and enhancement example

Character Closed Cavity Detection

Several closed cavity detection algorithms exist, mainly based on contour following techniques that distinguish the external from internal contours [Xia, 2003]. We suggest a novel fast algorithm for closed cavity detection based on processing the white runs of the b/w image. In the following, a step-by-step description of the proposed algorithm, is given.

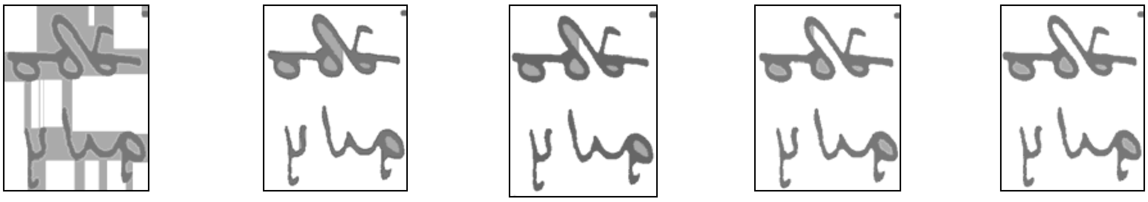
Step 1. All horizontal and vertical image white runs that neighbor with image borders or have a length greater than *L,* get flagged, where *L* denotes a typical length which reflects character size. The proposed algorithm for closed cavity detection extracts only the character closed cavities and not other closed cavities of larger dimension, with white run length greater than *L*, such as closed cavities inside frames, diagrams etc.;

Step 2. All horizontal and vertical white runs of non-flagged pixels that neighbor with the flagged pixels of step 1, get flagged as well;

Step 3. Repeat step 2 until no pixel remains to be flagged;

Step 4. All remaining white runs of non-flagged pixels belong to image closed cavities. Closed cavities with very small area are ignored.

An example of the proposed closed cavity detection algorithm is demonstrated in Fig.5.



(a) (b) (c) (d) (e)

Fig. 5. Closed cavity detection algorithm: (a)-(e) Resulting image after 1,2,3,4 and 5 iterations, respectively.

In early Christian Greek manuscripts, a single character or character ligature may contain more than one closed cavities. Therefore, it is imperative to examine whether the detected closed cavities can be grouped together. This is done by taking into account their spatial proximity and topology leading to the construction of a dictionary. Table 1 shows the proposed dictionary structure. At the last row of this Table, we indicate the corresponding characters and character ligatures.

Feature Estimation

Feature extraction is applied to characters that contain one or more closed cavities. The proposed method for character isolation creates a bounding box around the character guided by the spatial relationship between the contours of the closed cavity and the outer contour of the connected component. The feature estimation stage identifies all segments that belong to a protrusion in the outer contour of each isolated character. It is applied in two consecutive modes: a vertical and a horizontal mode. The vertical mode is used to describe the protrusible segments that may exist either at the top or at the bottom of the character while the horizontal mode is used to describe the protrusible segments that may exist on the right side of the character. The feature set which is composed of 9 features F ={f1, f2,…, f9} expresses the probability of a segment being part of a protrusion. Features {f1, f2, f3} describe the protrusible segments that may appear on the top of the character, features {f4, f5, f6} describe the protrusible segments that may exist at the bottom of the character and features {f7, f8, f9} describe the protrusible segments that may exist on the right side of the character. We have not taken into account segments that may belong to left protrusions, due to our observation that in all cases they correspond to a letter ligament rather than the main body of a character. An example of the estimated features is given in Fig. 6. One may observe a set of nine (9) cells which enable the visualization of feature values. Each cell position corresponds to the position of the respective protrusible segment in the set F.

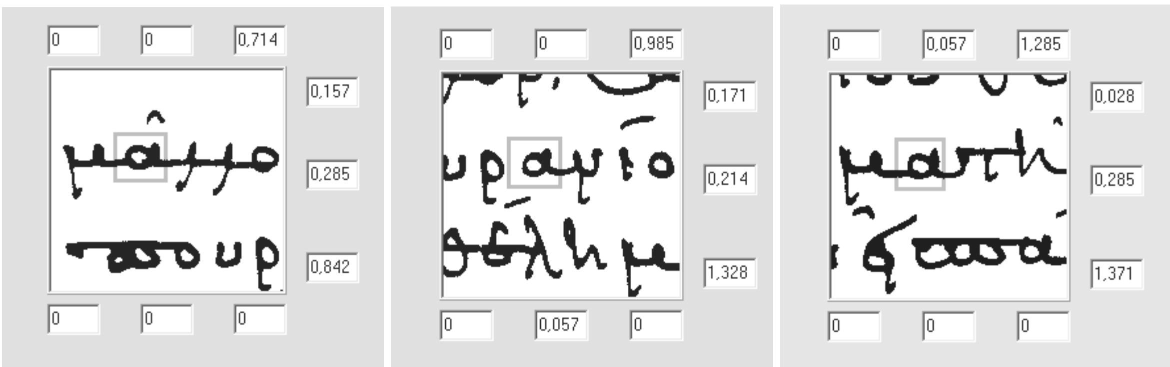


Fig 6. Feature estimation example for characters “α”

Experimental Results

The purpose of the experiments was to test the classification performance of the handwritten manuscripts with respect to the proposed closed cavity detection and feature extraction techniques. The overall experimental samples originate from three different writers of the Book of Job collection, manually labeled with the correct answers. We have built a dictionary of closed cavity patterns that contains a total of 967 characters and character ligatures. A detailed distribution of the underlying patterns along with their spatial configuration, is shown in Table 2. We mention that the majority of characters are classified as having one or two adjacent closed cavities. Furthermore, as it is shown at Table 1, it is worth noticing that since patterns with ID 4-6 correspond to a unique character or character ligature, detection leads directly to the classification of the corresponding characters.

Table 2. The dictionary of closed cavity patterns including the number of pattern occurrences.

Pattern ID	1	2	3	4	5	6
Pattern	o	o o	o o o	o o o o	o o	o o o
Occurrences	786	130	7	3	30	11

The first set of experiments tested the performance of the closed cavity pattern detection algorithm. We recall that the dataset involved in our experiments have been preprocessed with a binarization and image enhancement algorithm. Due to this, we have worked on images of improved quality (see Figure 4).

The closed cavity detection algorithm requires no training and all of the available labeled samples were used as a test set. Table 3 shows the results obtained by applying the algorithm, indicating the recall and the precision rates for each one of the closed cavity patterns. Recall is the number of correct closed cavities found divided by the total number of existing closed cavities. Precision is the number of correct closed cavities found divided by the total number of closed cavities found. As seen from Table 3, the performance on both recall and precision is satisfactory.

Table 3. Recall / Precision for the characters or character ligatures in each of the closed cavity patterns.

ID	Recall (%)	Precision (%)
1	95,81	97,42
2	94,61	86,62
3	100,00	53,85
4	100,00	100,00
5	84,37	96,43
6	87,50	100,00

The second set of experiments evaluates the performance of the proposed character and character ligature recognition approach by measuring the classification performance of state-of-the-art classification algorithms. The experiments focus on characters and character ligatures that correspond to patterns with ID 1-2 (Table 1), since these patterns appear in a great variety of characters. Furthermore, patterns with ID 4-6 correspond to a unique character or character ligature and its subsequent detection implies a direct classification. The experiment involved two steps: the training and testing of a statistical classifier. The focus of the experiments was on testing suitability of the extracted features.

To that end, characters and character ligatures coming from 3 different writers (referenced as wr1, wr2 and wr3, respectively – Table 4) were gathered into two different datasets CL1 and CL2. CL1 dataset corresponds to Pattern ID 1, while CL2 dataset corresponds to Pattern ID 2 (Table 1). In Table 4, in the columns that concern the Training and Test set, we clearly indicate the percentage of the corresponding characters used in the experiment. More specifically, for the training stage, we use different percentages of the complete character set from writers wr1 and wr2, while for the Testing stage, we use the remaining percentages for the complete character set for either the case of writer wr1 and wr2 or the case or writer wr3. Within each dataset, the feature extraction algorithm was applied to each character or character ligature. To measure the generalization performance of the trained classifiers, a splitting of data is necessary. Thus, a series of different scenarios with various ways of splitting has been constructed. Table 4 lists the scenarios for CL1 and CL2.

Table 4. Training set / Test set configuration for the CL1 and CL2 datasets

ID	Samples	Training	Test
CL1-1	754	70 (10% wr1, wr2)	684 (90% wr1, wr2)
CL1-2	754	147 (20% wr1, wr2)	607 (80% wr1, wr2)
CL1-3	479	147 (20% wr1, wr2)	332 (100% wr3)
CL1-4	402	70 (10% wr1, wr2)	332 (100% wr3)
CL1-5	1086	754 (100% wr1, wr2)	332 (100% wr3)
CL2-1	123	12 (10% wr1, wr2)	111 (90% wr1, wr2)
CL2-2	123	24 (20% wr1, wr2)	99 (80% wr1, wr2)
CL2-3	73	12 (10% wr1, wr2)	61 (100% wr3)
CL2-4	85	24 (20% wr1, wr2)	61 (100% wr3)
CL2-5	184	123 (100% wr1, wr2)	61 (100% wr3)

The classification step was performed using two well known classification algorithms, K-NN and Support Vector Machines (SVM) [Theodoridis, 1997]. K-NN was used in two variants, with L1 norm and L2 norm. Moreover, exhaustive search took place in order to determine the value of neighbors (k) that gave the best score. On the other hand, SVM was used in conjunction with the Radial Basis Function (RBF) kernel, a popular, general-purpose yet powerful kernel. Again, a grid search was performed in order to find the optimal values for both the variance parameter (γ) of the RBF kernel and the cost parameter (c) of SVM. The results for CL1 and CL2 datasets along with the optimal parameter values are listed in Table 5 and Table 6, respectively. The scores that were achieved in both datasets were very high even in cases where the samples were few. This particular aspect is very encouraging, since it proves the good generalization performance of the algorithms. Furthermore, the fact that the algorithms were able to generalize so well, is also due to the robust feature extraction scheme.

Table 5. Algorithmic performance for the CL1 dataset. Numbers in parenthesis represent the parameters used for achieving the optimal scores. The ID column corresponds to the different scenarios as shown in Table 4. For the SVM kernel, the number of support vectors found is also given.

ID	KNN-L1	KNN-L2	SVM-rbf
CL1-1	90.49 (k=1)	90.78 (k=1)	93.42 (γ=0.94, c=50, SVs=45)
CL1-2	94.06 (k=1)	93.73 (k=1)	95.05 (γ=0.98, c=50, SVs=62)
CL1-3	97.89 (k=2)	97.59 (k=2)	97.89 (γ=0.04, c=50, SVs=63)
CL1-4	94.27 (k=1)	96.08 (k=1)	97.28 (γ=0.2, c=100, SVs=42)
CL1-5	98.19 (k=10)	98.19 (k=4)	98.49 (γ=0.8, c=1, SVs=216)

Table 6. Algorithmic performance for the CL2 dataset. Numbers in parenthesis represent the parameters used for achieving the optimal scores. The ID column corresponds to the different scenarios as shown in Table 4.

ID	KNN-L1	KNN-L2	SVM-rbf
CL2-1	95.49 (k=1)	93.69 (k=1)	94.59 (γ=0.1, c=10, SVs=9)
CL2-2	93.93 (k=1)	92.92 (k=1)	94.94 (γ=0.1, c=20, SVs=10)
CL2-3	100.0 (k=1)	100.0 (k=1)	100.0 (γ=0.1, c=10, SVs=9)
CL2-4	98.36 (k=6)	95.99 (k=1)	100.0 (γ=0.1, c=10, SVs=11)
CL2-5	96.72 (k=1)	98.36 (k=1)	100.0 (γ=0.1, c=10, SVs=24)

Conclusion

D-SCRIBE project aims to support and facilitate current and future efforts in manuscript digitization and processing. In this paper, we focus on the problem of recognizing early Christian Greek manuscripts. We propose a novel digital image binarization scheme for low quality historical documents allowing further content exploitation in an efficient way. Additionally, we present a novel methodology that assists recognition of early Christian Greek manuscripts. We strive toward an assessment of the recognition procedure by tracing and recognizing the most frequently appearing characters or character ligatures, using a segmentation-free, quick and efficient approach. Based on the observation that closed cavities appear in the majority of characters and character ligatures, we propose a recognition technique that consists of several distinct stages. Experimental results show that the proposed method gives highly accurate results that offer a great assistance to old Greek handwritten manuscript interpretation.

Future work involves the detection and recognition of the remaining old Greek handwritten character and character ligatures that do not include closed cavities, as well as the testing of the performance of the proposed technique for other types of old handwritten historical manuscripts.

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MINERVA – THE MINISTERIAL NETWORK FOR VALORISING ACTIVITIES IN DIGITISATION TOWARDS AN AGREED EUROPEAN PLATFORM FOR DIGITISATION OF CULTURAL AND SCIENTIFIC HERITAGE

Giuliana De Francesco

Abstract. MINERVA is a project funded by the European Commission IST Programme within the 5th Framework Programme. It created a network of EU Ministries and other agencies in charge of cultural policies and programmes, which is open to enlargement to new countries and new sectors of the civil society. The network discusses, correlates and harmonises the activities carried out in the field of digitisation of cultural and scientific heritage, aiming at creating a common European platform made up of agreed recommendations, guidelines, standards. The network acts also to foster collaboration between European Commission and Member States, to ensure awareness of European policies at national level, to exchange good practice, to coordinate national programmes in order to embed in national digitisation activities the technical results achieved by the network. Some main outcomes of the activities are presented.