Digital Jawi Palaeography: Studies from the Perspective of Computer Science

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Abstract— Malay artefacts in the form of manuscripts and inscribed stones have high historical values to the Malay civilization, and to the Islamic world. These artefacts contain explicit and implicit information that can unlock ancient information. For example, a manuscript offers explicit information based on the written text, but palaeography study can uncover implicit information, such as who was the author, where did the author came from, the number of authors, date, and the manuscript's authenticity can also be validated. Palaeography uses the decorations and the type of writings on manuscripts or on inscribed stones as the medium of study. Palaeography experts retrieve information from these mediums by comparing the decorations and type of writings on manuscripts of known origin with manuscripts of unknown origin. The methodology used by palaeography experts is applied in digital palaeography. Digital Jawi palaeography studies types of calligraphy that are on manuscripts, since the Arabic calligraphy has its own history, as much as its birth and development when adopted in certain places. This current study has introduced a new method in the field of image processing based on triangle geometry. This method is based on three key coordinates, which taken from each alphabet. Each alphabet is matched with the model in the Qalam al-Sittah to determine every calligraphy type. This type of calligraphy will become the input to determine palaeography information. Tests were also conducted to determine the validity of the proposed method. Additionally, the Inscribed Stone of Terengganu (IST) was used in preliminary experiments.

Index Terms— Palaeography, Arabic Calligraphy, Triangle Geometry, Feature Extraction

I. Introduction

Beautiful brilliance, exquisite language and writing techniques that depict the artistic aspect of Malay civilization have made the Malay manuscripts, in the form of books, letters as well as inscribed stones, retain high values from the perspective of the materials, and even higher values from the historical perspective.

An estimated 7,789 Malay manuscripts are stored in Malaysia. A comprehensive study can be done on the aspects of the history, language, philology, and palaeography. From this number, 3,699 of them are at the National Library of Malaysia, 307 manuscripts are at the University of Malaya Library, the Tun Sri Lanang Library stores 57, Dewan Bahasa dan Pustaka kept 226, while the Islamic Arts Museum of Malaysia kept 3,500.

Although a large number of manuscripts are kept in this country, some of them do not have information regarding the author(s), dates, and the origin. Mohammad Jajuli [11] proved this situation in a study on manuscripts of Malay laws. It was found that some of the manuscripts do not contain the name(s) of the author(s), the date they were written, and the number of authors. Othman and Abdul Halim [16] obtained similar findings when they studied the Inscribed Stone of Terengganu. They found that the name of the engraver was not inscribed on the stone, nor was its origin. Even though a date was specified on the inscribed stone, different dates were estimated due to erosion and aging factor. This factor is supported by Sitti Rachmawati et al. [18] in a study on old Malay manuscripts. The Catalogue of Malay Manuscripts by Kamariah Abu Samah and Wan Salhah Megat Ahmad [7], published by Dewan Bahasa dan Pustaka, also contains manuscripts without dates and without the names of the authors. These problems have created study opportunities to track who the author was, where it came from, when it was written, how many authors were involved, and even the authenticity of the manuscript can be determined. This type of studies is known as palaeography.

Palaeography is defined as the study of ancient handwritten manuscripts [22]. Bischoff [3] defined palaeography as the art of seeing and understanding. Brown [4] on the other hand, provided a detailed study of the history of scripts, which included acronyms, and the punctuations, as well as their interpretations. Meanwhile, Witkam [20] claimed palaeography to be the science of identifying the dates of old documents. Similarly, Arabic palaeography is the study of the development of Arabic scripts through time and place. According to Just Witcam [20], the western world's palaeography can be applied to conduct Arabic palaeography. These definitions are based on paper-based documents.

Although the definitions given above are related to paper-based manuscripts, palaeography is also focused on the analytical descriptions of the form of the alphabets, such as initials, punctuations, and the type of calligraphy used, to determine the manuscript's date and place of origin [10][22][5].

Therefore, palaeography is not only confined to paper-based manuscripts, but also to any materials that have writings and decorations. This is further validated by Anabel Teh Gallop [1], who studied the word, 'Bismillah', the letter kaf "ك", as well as the decorations that decorated numerous old Malay manuscripts.

II. Arabic Calligraphy And Palaeography

The Jawi script is derived from the Arabic alphabets [8][12]. It was reported that the Jawi script was first used in Malaya with the discovery of the Inscribed Stone of Terengganu. According to Othman and Abdul Halim [16], this stone was carved on February 22, 1303. The Jawi script was extensively used by the Malacca Sultanate, from 1400 to 1511; the old Johor Sultanate, from 1511 to 1728; and in Johor Riau, from 1728 to 1824.

Interestingly, Jawi script had not only adapted the Arabic alphabets, it has also applied the calligraphy.

In a study of Islamic civilisation, the different forms of handwriting, or calligraphy, also have a category of their own [12][13]. Popular types of calligraphy include Kufic, Riqa, Naskh, Diwani, Diwani al Jali, and Raihani. Each type of calligraphy was introduced at different times, and places. Kufic calligraphy was created in Kufa, and was used as the standard script in the Qur'an in the 8th century, which lasted for almost 300 years. Meanwhile, the Naskh calligraphy was developed in the 10th century, and was streamlined in Turkey in the 16th century. Subsequently, this script became the standard script to write the Qur'an. The Nasta'liq or Pharisees calligraphy was discovered in the 14th and 15th centuries in Iran. Each calligraphy was uniquely created in different eras, and are used and developed in different places.

In Malaysia, the study done on the Merong Mahawangsa manuscript had led to the discovery that the slant and skew in Jawi script can be linked to the types of scripts used [12]. In fact, these Jawi manuscripts may even contain different types of scripts, such as Naskh, Thuluth, and Riqa. His findings could provide useful input to the palaeography of Jawi script.

This relationship is further strengthened by a discovery in the book of the Malay Laws. According to Mohammad Jajuli [11], this book was written by three different authors, based on the different types of calligraphy on pages 1-10, 11-16, and 17-32. In the first part, which was pages 1-10, the calligraphy used was different from the standard Naskh, or Thuluth. Apparently, the script was more rounded in shape, and shorter, akin to Javanese script, or Sanskrit. The second part has elements of the Thuluth calligraphy, while in the third part, the shapes of the script had changed to being more rectangular.

Findings related to the dates, and the places where these types of calligraphy were developed, are widely used and developed. The influence of calligraphy in these manuscripts [12][13] can be used as a guide in palaeography. In fact, the technical characteristics (codicology) of the calligraphy can be used as indicators to determine the type, and the age of the script involved [20]. These calligraphy features can clearly help in the development of Digital Jawi Palaeography.

III. Background Of Paleography

Numerous palaeography have been conducted, but the digital form of palaeography only began in 1999 [2][5][10], which was a study on the Roman domain. Some researchers are currently conducting palaeography in the digital form. However, these studies are focused on Roman, Hebrew, and Hindi domain. The first digital palaeography system was developed in 1999 by researchers from the University of Pisa, known as "System for Palaeography Inspector". Nevertheless, this system was not completed, and cannot be used by the university's Department of History [5]. This system had used the centroid as well as the tangent method. The features used by the researcher were insufficient, and cannot be tested because the system did not support Windows XP operating system [5].

In 2004, Yosef et al. [22] conducted a preliminary study of the Hebrew manuscripts. This study had only taken into account five Hebrew alphabets, but no justifications were offered over the choice of the five alphabets. The applied technique revolved around the range of spaces within the alphabets.

Moalla et al. [10] applied a global approach, which a statistical method was based on the Haralick characteristics to obtain 12 features that were used to identify the types of Roman script. However, this method can only declare the dominant script in Roman manuscripts. Limitations of the methods used by the previously mentioned researchers demand a different method that can identify the type of calligraphy used, and the origin of the script. A method, known as the Triangular Geometric Model was introduced by Mohd Sanusi et al. [14][15] to recognize digit image and Jawi handwriting. This study is being conducted by the Pattern Recognition Research Group, at Universiti Kebangsaan Malaysia.

IV. Developing The Framework For Digital Paleography

Digital Jawi palaeography was initiated in 2010 with reports of discoveries, and paper publications at the national and international level [8] [12] [14] [15]. The earliest phase in the development of the Digital Jawi Palaeography framework was to develop a theoretical framework, and a specific framework. The theoretical framework is shown in Figure 1.

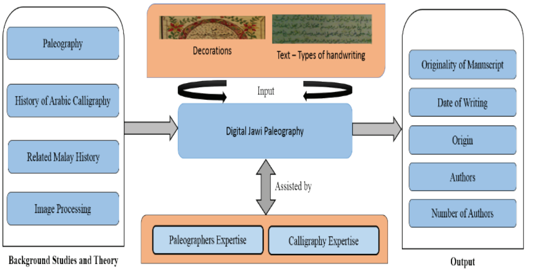

Fig. 1. Theoretical framework for digital jawi paleography.

According to Figure 1, palaeography requires background searches on the basic knowledge of palaeography, basic knowledge of Arabic calligraphy, related Malay history, and an expansive knowledge of digital image processing. The input for this framework was the decorations on the manuscripts, and Jawi texts obtained from old Malay manuscripts. The decorations and texts must be in the form of images. Digital Jawi palaeography was assisted by palaeography experts, and calligraphy experts. They offered recommendations for the developed algorithm, and confirmed the findings from experiments. The output of the Digital Jawi Palaeography is the authenticity of the manuscript, dating, the origin of the author(s), the identity of the author(s), and the number of author(s).

Following the development of the theoretical framework, a specific framework in the domain of computer science was developed. The specific framework is shown in Figure 2.

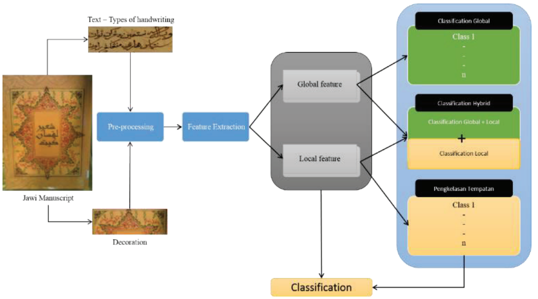

Fig. 2. Specific framework for digital jawi palaeography.

Figure 2 shows how the images of the decorations, and the Jawi texts from Malay manuscripts were processed by the computer. The first phase included the pre-processing, followed by feature extraction. In this pre-processing phase, images in the Malay manuscripts will be segmented, and undergo format conversion to the binary format. Feature extraction is divided into two parts, namely global features and local features. This current study applied the local features based on the Triangle Model [8] [9] [14] [15]. The global features and local features were known as an approach in object recognition. Global features have potential to generalize an entire object with a single vector. Thus, their work in standard classification techniques is upfront. The example of global features is local binary patterns (LBP) which are grayscale and rotation invariant texture operators local [19]. Meanwhile, local features are calculated at multiple points in the image and more robust to obstruction and clutter. This might need specialized classification algorithm to manage cases in variable number of feature vectors per image. Next, classifications were executed either using the local classification, or global, or even a hybrid. The classification process will determine the types of calligraphy found in the Malay manuscript. This study did not use images of the decorations, but was focused on the Jawi text.

V. Malay Manuscript In The Domain Of Image Processing

The processing of Jawi manuscripts was conducted based on the triangle geometry model, as proposed by Mohd Sanusi et al. [14],[15], and Khairuddin et al. [8]. The processes involved in image processing can be divided into:

a. Data collection
b. Pre-processing
c. Processing text images into binary form
d. Feature Extraction and the suggested methods.
e. Classifications using the Supervised Machine Learning and Unsupervised Machine Learning.

A. Data Collection

Data collection is necessary for the development of algorithms, and for the experimental phase. Data are required for the validation of algorithms, as well as used as models in algorithms. Verifying the accuracy of the algorithm requires the standard data used by image processing researchers. This standard data is designated as the standard dataset.

The main problem in Digital Jawi Palaeography is the absence of standard datasets for specific types of script for Arabic calligraphy. The only Arabic calligraphy that were taken into consideration included the “Diwani”, “Thuluth”, “Naskh”, “Riqa”, and “Pharisees”. These selections were based on studies by Khairuddin Omar [8] that found that the Arabic calligraphy can be categorised into six types, known as the “Qalam al-Sittah”. However, this study did not include the Kufic calligraphy.

B. Pre-processing

Jawi script in Jawi manuscripts are connected, and are ligatures [8]. In this pre-processing phase, images in the Malay manuscripts will be segmented, and undergo format conversion to the binary format. This process corresponds to the specific framework in Figure 2. The pre-processing phase provides images for the feature extraction phase.

Segmentation is performed on images of the Malay manuscripts to turn them into a singular form. The segmentation was performed manually according to Yosef et al. [22]. Images from the standard dataset were not segmented because this dataset is already in the singular form.

After the segmentation process was completed, format conversion to the binary format was performed, which applied the Otsu’s method. This method is often used for character recognition. The benefit of using Otsu’s method includes the ability to determine threshold values dynamically according to the circumstances of each image. Khairuddin et al. [9] compared the use of threshold values on a regular basis with threshold values obtained using the Otsu’s method. Figure 3 shows a Jawi image that has been converted into a binary format.

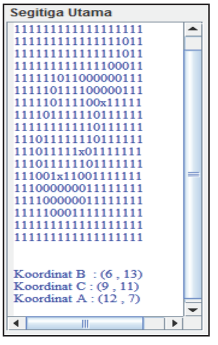

Fig. 3. An image in the binary format.

C. Feature Extraction

Feature extraction in this study was based on [13]. Six features were extracted using the proposed triangle model. However, this model has been improved by dividing the image into four zones. Figure 4 shows the division of the image into four zones.

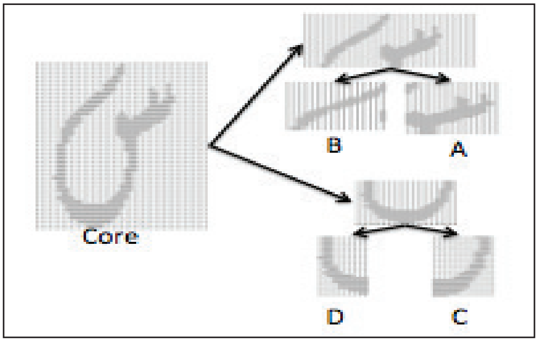

Fig. 4. A Jawi image was divided into four zones.

The division of the image into four zones was based on the gravity point of the black image. Each zone, including the main zone, was extracted to obtain the coordinates of the triangle. Label “x” in Figure 4 shows the coordinates of the triangle for each zone.

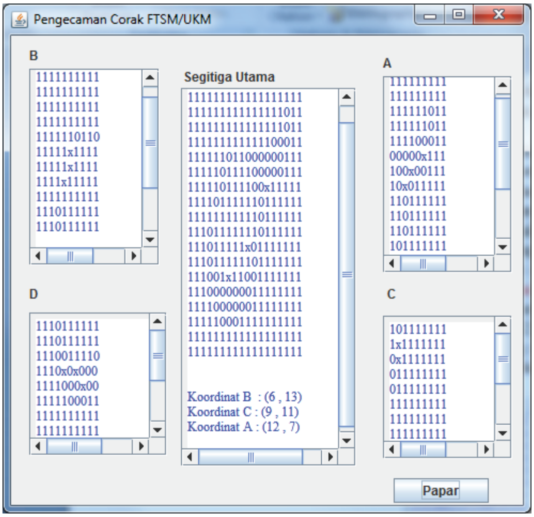

Fig. 5. Triangle coordinates in four zones.

The coordinates obtained from Figure 5 were based on studies done by Khairuddin et al. [8], and Mohd Sanusi et al. [15]. These coordinates represent the vertices of a triangle. Next, features were extracted based on the following Figure 6, which shows how to calculate the sides of the vertices of the triangle to obtain the sides. The sides of this triangle were obtained using the Pythagorean Theorem.

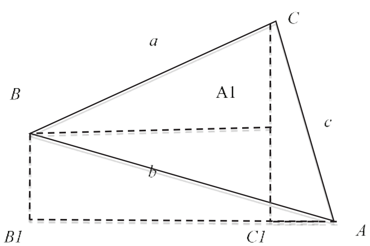

Fig. 6. Calculating the sides of the triangle.

The sides and the coordinates of the triangle that were extracted from Figure 5 and Figure 6 were used to obtain the features listed in the following Table 1.

TABLE 1
PROPOSED FEATURE FROM THE TRIANGLE GEOMETRY

No. of Feature	Name of Feature	Description
1	c/a	Value of c divided by a
2	a/b	Value of a divided by b
3	b/c	Value of b divided by c
4	A	Angle A
5	B	Angle B
6	C	Angle C
7	ΔBA	Gradient from B to A
8	ΔBC	Gradient from B to C
9	ΔCA	Gradient from C to A

The sides of the triangle: “a”, “b”, and “c” were obtained using the following equations:

$$a^2 + b^2 = c^2 \tag{1}$$

$$a = \sqrt{((A1(y) - C(y))^2) + ((A1(x) - B1(x))^2)} \tag{2}$$

$$b = \sqrt{((B1(y) - B(y))^2) + ((A(x) - B1(x))^2)} \tag{3}$$

$$c = \sqrt{((C1(y) - C(y))^2) + ((A(x) - C1(x))^2)} \tag{4}$$

Features 1-3 from Table 1 were obtained by dividing the values of the sides using the equations stated in the same table. Next, the angles for A, B, and C were obtained using the following equations:

$$A = arccos\frac{b^2+c^2-a^2}{2bc} \tag{5}$$

$$B = arccos\frac{a^2+c^2-b^2}{2ac} \tag{6}$$

$$C = arccos\frac{a^2+b^2-c^2}{2ab} \tag{7}$$

Meanwhile, gradients were obtained by using the A, B, and C coordinates. Equations that can be used to determine the gradients stated in Table 1 are as follows:

$$GraBC = \frac{B(y)-C(y)}{B(x)-C(x)} \tag{8}$$

$$GraBA = \frac{B(y)-A(y)}{B(x)-A(x)} \tag{9}$$

$$GraCA = \frac{B(y)-C(y)}{B(x)-C(x)} \tag{10}$$

The features obtained from the extraction of the triangle-based model were used in the classification of the types of calligraphy, and the determination of the calligraphy used in manuscripts. The purpose of palaeography can be expounded from the type of calligraphy used.

VI. Experimental And Findings

The experiments were divided into two parts: the first part of the experiments was conducted to determine the accuracy of the proposed algorithm. Experiments in this part can also be divided into experiments based on Supervised Machine Learning (SML), and Unsupervised Machine Learning (UML) Neural Networks by using the Mean Average Precision (MAP) method. For the second part, experiments will be conducted using the calligraphy dataset that were previously developed, and also the experimental Jawi script dataset, which was the Inscribed Stone of Terengganu (IST).

In the following Table 2, the algorithm based on the Triangle Geometry Model was tested using the HODA dataset. Experimental data for each class totaled to 2,000 data. The experimental results showed that the proposed algorithm based on the Triangle Geometry Model was able to produce the highest accuracy of 87.671 using the UML for the top 5 runs. On the other hand, experiments for the SML have produced the second highest results. The findings for each class showed that the Hoda4 class had produced the lowest accuracy.

TABLE 2
Findings From Experimentations Using The Standard Hoda Dataset (Khosravi & Kabir, 2007) [6]

Type	SML-MLP	UML-MV			UML-MAP		
Class\ Rank	Not applicable	Top 5	Top 10	Top 20	Top 5	Top 10	Top 20
Hoda0	92.45	89.62	88.365	86.705	93.728	92.459	90.759
Hoda1	96.45	95.65	95.07	94.72	96.924	96.511	95.972
Hoda2	88.20	83.83	82.56	81.5425	88.075	86.834	85.257
Hoda3	70.35	66.85	64.675	62.2925	76.671	73.861	70.374
Hoda4	73.1	49.9	47.71	44.6275	62.275	59.812	55.812
Hoda5	88.35	89.19	88.43	87.545	92.077	91.541	90.624
Hoda6	86.05	80.34	78.56	76.2375	86.454	84.550	82.241
Hoda7	90.6	91.5	90.47	89.9225	93.726	92.976	92.026
Hoda8	96.75	95.14	94.455	93.7025	96.757	96.276	95.611
Hoda9	88.2	85.87	84.895	83.695	90.018	88.982	87.604
Average	**87.05**	**82.789**	**81.519**	**80.099**	**87.671**	**86.380**	**84.628**

Having determined the accuracy of the algorithm, it was tested using the previously developed Arabic calligraphy dataset. This dataset was tested using examples from old manuscripts. An example of the manuscripts used in this study is the Inscribed Stone of Terengganu (IST). Examples of the images of the alphabets found on the IST are shown in the following Figure 7. Experimental findings using the Inscribed Stone of Terengganu are as shown in Table 3.

Fig. 7. Experiment data from the IST.

TABLE 3
Findings Of Experiments Using The Inscribed Stone Of Terengganu

Types of Calligraphy	MAP (0.4)
Diwani	3.3333
Pharisees	3.3333
Naskh	20
Riqa	3.3333
Thuluth	70

As seen in Table 3, experiments were conducted using the SML based on the MAP classifier. According to the findings from these experiments, Thuluth calligraphy was identified to dominate the IST. Thus, the MAP classifier has shown that the inscribed stone was inclined to Thuluth calligraphy style. However, experiments using the UML based on MAP were still in the experimental stage. Experiments for other Malay manuscripts are yet to be implemented because at this point, this study is still in the experimentation, and algorithm validation phase.

VII. Conclusion

Digital Jawi Palaeography is a study that aims to assist palaeography experts. Their expertise as well as the Arabic calligraphy became the input for Digital Jawi Palaeography. This study has proposed a new method that can be used to identify the types of Arabic calligraphy. Based on Arabic calligraphy, old manuscripts and inscribed stones will be categorised into the specified percentages of the types of calligraphy, which include Thuluth, Naskh, Riqa, and Diwani calligraphy. This percentage will determine the origin of the manuscript, the original author(s), as well as being able to identify the author if the author had previously written in other manuscripts.

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