Learning Meters of Arabic Poems with Deep Learning

A Thesis Presented to the Faculty
of
Nile University

In Partial Fulfillment
of the Requirements for the Degree
of Master of SCIENCE

By
Moustafa Alaa Mohamed
July 2018

CERTIFICATION OF APPROVAL

Learning Meters of Arabic Poems with
Deep Learning

By
Moustafa Alaa Mohamed

Dr. Samhaa El-Beltagy (Chair) — Date
Professor of Electrical and Computer Engineering

Dr. Waleed Yousef — Date
Professor of Computer Science

ACKNOWLEDGMENT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

People can easily determine whether a piece of writing is a poem or prose, but only specialists can determine the class of poem.

In this thesis, we built a model that can classify poems according to their meters; a forward step towards machine understanding of Arabic language.

A number of different deep learning models are proposed for poem meter classification. As poems are sequence data, then recurrent neural networks are suitable for the task. We have trained three variants of them, LSTM, GRU with different architectures and hyper-parameters. Because meters are a sequence of characters, then we have encoded the input text at the character-level, so that we preserve the information provided by the letters succession directly fed to then models. Besides, We introduce a comparative study on the difference between binary and one-hot encoding regarding their effect on the learning curve. We also introduce a new encoding technique called *Two-Hot* which merges the advantages of both *Binary* and *One-Hot* techniques.

Deep Learning models, shows its ability to understand the text and can achieve an outstanding accuracy regarding text classification. In addition to, the new techniques discovered such as LSTM to solve the long sequence dependency problem. In this thesis, we will explain how to use the deep learning to classify the Arabic poem to classes. Also, explain in details the feature of Arabic poem and how to deal with this features.

Chapter 1

INTRODUCTION

Thesis Outline

The coming chapters are arranged as follows:

Chapter 1: presents some basic introduction and background knowledge as regards the Arabic Poem and its definitions. Also, it contains details about the Arabic language and some feature used during our work.

Chapter 2: introduces the essential pre-processing steps, and the justification for their need. Pre-processing steps are data extraction, data cleansing and data format.

Chapter 3: introduces the data encoding techniques used and the effect of each one. Also, it contains some comparisons between the three techniques used.

Chapter 4: presents the model's details and how we chose the model and the architecture and hyper-parameters details.

Chapter 5: Results and discussion.

Chapter 6 : Conclusion and future work

Arabic is the fifth most widely spoken language[1]. It is written from right to left. Its alphabet consists of 28 primary letters, and there are 8 more derived letters from the basic ones, so the total count of Arabic characters is 36 characters. The writing system is cursive; hence, most letters join to the letter that comes after them, a few letters remain disjoint.

Each Arabic letter represents a consonant, which means that short vowels are not represented by the 36 characters, for this reason, the need of *diacritics* rises. *Diacritics* are symbols that comes after a letter to state the short vowel accompanied by that letter. There are four diacritics ◌َ ◌ُ ◌ِ ◌ْ which represent the following short vowels /*a*/, /*u*/, /*i*/ and *no-vowel* respectively, their names are *fat-ha, dam-ma, kas-ra and sukun* respectively. The first three symbols are called *harakat*. Table **??** shows the 4 diacritics on a letter.

Diacritics	*without*	*fat-ha*	*kas-ra*	*dam-ma*	*sukun*
Shape	د	دَ	دِ	دُ	دْ

Table 1.1: *Diacritics on the letter* د

There are two more sub-diacritics made up of the basic four to represent two cases:

Definition 1 ***Shadaa***

*to indicate the letter is doubled. Any letter with shaddah ( ) the letter should be duplicated: first letter with a constant (sukoon) and second letter with a vowel (haraka) [**?**]; Table **??** shows the dal with shadda and the original letters.*

[1] *according to the 20th edition of Ethnologue, 2017*

Diacritics	*letter with Shadda*	*letters without shadaa*
Shape	دَّ	دْدَ

Table 1.2: *Shadaa diacritics on the letter* د

Definition 2 ***Tanween***

is doubling the short vowel, and can convert Tanween fathah, Tanween dhammah or Tanween kasrah by replacing it with the appropriate vowel (dhammah, fathah or kasrah) then add the Noon letter with constant to the end of the word [?]. Table **??** *shows the difference between the original letter and the letter with Tanween*

Diacritics	*letter with tanween*	*letters without tanween*
Tanween Dam-ma	دٌ	دُ+نْ
Tanween Kas-ra	دٍ	دِ+نْ
Tanween Fat-ha	دً	دَ+نْ

Table 1.3: *Tanween diacritics on the letter* د

Arabs pronounce the sound /*n*/ accompanied *sukun* at the end the indefinite words, that sound corresponds to this letter نْ, it is called *noon-sakinah*, however, it is just a phone, it is not a part of the indefinite word, if a word comes as a definite word, no additional sound is added. Since it is not an essential sound, it is not written as a letter, but it is written as *tanween* ◌ٍ ◌ً ◌ٌ. *Tanween* states the sound *noon-sakinah*, but as you have noticed, there are 3 *tanween* symbols, this because *tanween* is added as a diacritic over the last letter of the indefinite word, one of the 3 harakat*harakat* accompanies the last letter, the last letter's *harakah* needs to be stated in addition to the sound *noon-sakinah*, so *tanween* is doubling the last letter's *haraka*, this way the last letter's *haraka* is preserved in addition to stating the sound *noon-sakinah*; for example, نْ + رَجُلُ is written رَجُلٌ and نْ + رَجُلِ is written رَجُلٍ.

Those two definition, Definition **??** and Definition **??** will help us to reduce the dimension of the letter's feature vector as we will see in *preparing data* section.

Diacritics makes short vowels clearer, but they are not necessary. Moreover, a phrase without full diacritics or with just some on some letters is right linguistically, so it is allowed to drop them from the text.

In Unicode, Arabic diacritics are standalone symbols, each of them has its own unicode. This is in contrast to the Latin diacritics; e.g., in the set *{ê, é, è, ë, , , }*, each combination of the letter *e* and a diacritic is represented by one unicode.

1.1 Arabic Poetry

Arabic poetry الشعر العربي is the earliest form of Arabic literature. It dates back to the sixth century. Poets have written poems without knowing exactly what rules which make a collection of words a poem. People recognize poetry by nature, but only talented ones can write poems. This was the case until *Al-Farahidi* (718 786 CE) has analyzed the Arabic poetry, then he came up with that the succession of consonants and vowels produce patterns or *meters*, which make the music of poetry. He has counted them fifteen meters. After that, a student of *Al-Farahidi* has added one more meter to make them sixteen. Arabs call meters بحور which means "*seas*".

Definition 3 ***Meter***

*Poetic meters define the basic rhythm of the poem. Each meter is described by a set of ordered feet which can be represented as ordered sets of consonants and vowels [**?**].*

ولد الهدى فالكائنات ضياء *** وفم الزمان تبسم وثناء انشاء
الروح والملأ الملائك حوله *** للدين والدنيا به بشراء

Definition 4 ***Arabic Verse***

refers to "poetry" as contrasted to prose. Where the common unit of a verse is based on meter or rhyme, the common unit of prose is purely grammatical, such as a sentence or paragraph [2]. A verse know as Bayt in Arabic بيت

Definition 5 ***Shatr***

A verse consists of two halves, each of them is called shatr and carries the full meter. We will use the term shatr to refer to a verse's half; whether the right or the left half.

[2] *https://en.wikipedia.org/wiki/Verse_(poetry).*

Feet	Scansion
فَعُولُنْ	0/0//
فَاعِلُنْ	0//0/
مُسْتَفْعِلُنْ	0//0/0/
مَفاعِيلُنْ	0/0/0//
مَفْعُولاَت	0//0///
فَاعِلاَتُنْ	0/0//0/
مُفَاعَلَتُنْ	0///0//
مُتَفَاعِلُنْ	0//0///

Table 1.4: The eight feet. Every digit represents the corresponding diacritic over each latter in the feet. / If a letter has got *harakat* (◌َ ◌ُ ◌ِ), 0 if a letter has got *sukun* (◌ْ). Any *mad* (و, ا, ى) is equivalent to *sukun*.

Definition 6 ***Poem***

is a set of verses has the same meter and rhyme.

Definition 7 ***al-arud*العروض**[3]*;*

it is the study of poetic meters, in which he has laid down rigorous rules and measures, with them we can determine whether a meter of a poem is sound or broken. A meter is an ordered sequence of feet. Feet are the basic units of meters, there are eight of them. A Foot consists of a sequence of consonant and vowels. Traditionally, feet are represented by mnemonic words called tafa'il (تفاعيل). According to al-Farahidi and his student, there are sixteen combinations of tafa'il. A meter appears in a verse twice; each shatr carries the same complete meter.

For example, the following *shatr* وَيُسأَلُ في الحَوادِثِ ذو صَوابٍ is equivalent to the *meter* مفاعلتن مفاعلتن فعول, which means it belongs to *Al-Wafeer* meter. We can get the pattern of the *sukun* and *harakat* by replacing each feet by the corresponding code in table **??**, which produces the following pattern that should be read from right to left:

[3]it is often called the *Knowledge of Poetry*.

Meter Name	**Meter** *feet combination*
al-Wafeer	مُفَاعَلَتُن مُفَاعَلَتُن فَعُولُن
al-Taweel	فَعُوْلُنْ مَفَاْعِيْلُنْ فَعُوْلُنْ مَفَاْعِلُنْ
al-Taweel	فَعُوْلُنْ مَفَاْعِيْلُنْ فَعُوْلُنْ مَفَاْعِلُنْ
al-Kamel	مُتَفَاْعِلُنْ مُتَفَاْعِلُنْ مُتَفَاْعِلُنْ
al-Baseet	مُسْتَفْعِلُنْ فَاْعِلُنْ مُسْتَفْعِلُنْ فَاْعِلُنْ
al-Khafeef	فَاْعِلاتُنْ مُسْتَفْعِلُنْ فَاْعِلاتُنْ
al-Rigz	مُسْتَفْعِلُنْ مُسْتَفْعِلُنْ مُسْتَفْعِلُنْ
al-Raml	فَاْعِلاتُنْ فَاْعِلاتُنْ فَاْعِلاتُنْ
al-Motakarib	فَعُوْلُنْ فَعُوْلُنْ فَعُوْلُنْ فَعُوْلُنْ
al-Sar'e	مُسْتَفْعِلُنْ مُسْتَفْعِلُنْ مَفْعُوْلاتُ
al-Monsafeh	مُسْتَفْعِلُنْ مَفْعُوْلاتُ مُسْتَفْعِلُنْ
al-Mogtath	مُسْتَفْعِلُنْ فَاْعِلاتُنْ فَاْعِلاتُنْ
al-Madeed	فَاْعِلاتُنْ فَاْعِلُنْ فَاْعِلاتُنْ
al-Hazg	مَفَاْعِيْلُنْ مَفَاْعِيْلُنْ
al-Motadarik	فَاْعِلُنْ فَاْعِلُنْ فَاْعِلُنْ فَاْعِلُنْ
al-Moktadib	مَفْعُوْلاتُ مُسْتَفْعِلُنْ مُسْتَفْعِلُنْ
al-Modar'e	مَفَاْعِيْلُنْ فَاْعِلاتُنْ مَفَاْعِيْلُنْ
al-Kamel	مُتَفَاْعِلُنْ مُتَفَاْعِلُنْ مُتَفَاْعِلُنْ
al-Baseet	مُسْتَفْعِلُنْ فَاْعِلُنْ مُسْتَفْعِلُنْ فَاْعِلُنْ

Table 1.5: *The sixteen Arabic poem meters*

`0/0// 0///0// 0///0//`

This is a very brief introduction to *Arud*, many details are reduced.

1.2 Thesis Objectives

Chapter 2

BACKGROUND AND LITERATURE REVIEW

Chapter 3

DATASET

We have scrapped the Arabic dataset from two big poetry websites: الديوان[1], الموسوعة الشعرية[2]. Both are merged into one large dataset. It is important to note that the verses' diacritic states are not consistent, this means that a verse can carry full, semi diacritics or it can carry nothing. The total number of verses is 1,862,046 poetic verses; each verse is labeled by its meter, the poet who wrote it, and the age which it was written in. There are 22 meters, 3701 poets and 11 ages; and they are Pre-Islamic, Islamic, Umayyad, Mamluk, Abbasid, Ayyubid, Ottoman, Andalusian, era between Umayyad and Abbasid, Fatimid and modern. We are only interested in the 16 classic meters which are attributed to *Al-Farahidi*, and they are the majority of the dataset with a total number of 1,722,321 verses[3].

3.1 Preparing Data

3.1.1 Data Cleaning

[1] *aldiwan.net*
[2] *poetry.tcaabudhabi.ae*
[3] https://wwww.github.com/tahamagdy

Chapter 4

DATA ENCODING

4.0.1 Arabic Poem Encoding

4.0.1.1 One-Hot encoding

4.0.1.2 Binary Encoding

4.0.1.3 Two-Hot encoding

Chapter 5

MODEL TRAINING

Chapter 6

RESULTS AND DISCUSSION

Chapter 7

CONCLUSION AND FUTURE WORK

7.1 Future Work

REFERENCES

[1] THOMAS A. CIULLA, ARMANDO G. AMADOR, BERNARD ZINMAN, "Diabetic Retinopathy and Diabetic Macular Edema," DIABETES CARE, VOL. 26, NO. 9, SEPTEMBER 2003.

[2] "Classification of Diabetic Retinopathy from Fluorescein Angiograms," Journal OPTHALMOLOGY, vol. 98, 1991.

[3] R. Theodore Smith, Carol M. Lee, Howard C. Charles, Marilyn Farber, and Jose G. Cunha-Vaz, "Quantification of Diabetic Macular Edema," Arch Opthalmol, VOL. 105, Feb. 1987.

[4] S. Dithmar and F. G. Holz 2008. Fluorescence Angiography in Opthalmology. Springer.

[5] Frank ter Haar, "Automatic localization of the optic disc in digital colour images of the human retina," Master Thesis, Utrecht University, December 2005.

[6] www.vitrualmedicalcentre.com

[7] Elia Duh 2008. Diabetic Retinopathy. Humana Press, Totowa, USA.

[8] G. E. Lang 2007. Diabetic Retinopathy. Karger, Switzerland.

[9] Lisa Gottesfeld Brwon, "A survey of Image Registration techniques," ACM Computing Surveys VOL. 24, pp. 326–376, 1992.

[10] Min Xu, Hao Chen, and Pramod K. Varshney, "Ziv−Zakai Bounds on Image Registration," IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 57, NO. 5, MAY 2009.

[11] Hassan Foroosh (Shekarforoush), Josiane B. Zerubia, and Marc Berthod, "Extension of Phase Correlation to Subpixel Registration," IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE, VOL. 10, NO. 1, JANUARY 2006.

[12] Georgios Tzimiropoulos, Vasileios Argyriou, Stefanos Zafeiriou, and Tania Stathaki, "Robust FFT-Based Scale-Invariant Image Registration with Image Gradients," IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE, VOL. 32, 2010.%bibitemsurvey Barbara Zitova, and Jan Flusser, "Image registration methods: a survey," Image and Vision Computing VOL. 21, pp. 977−1000, 2003.

[13] W. E. Hart and M. H. Goldbaum, "Registering retinal images using automatically selected control point pairs," in Proc. IEEE Int. Conf. Image Processing, VOL. 3, pp. 576−580, Nov. 1994.

[14] Douglas E. Becker, Ali Can, James N. Turner, Howard L. Tanenbaum, and Badrinath Roysam, "Image Processing Algorithms for Retinal Montage Synthesis, Mapping, and Real-Time Location Determination," IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, VOL. 45, NO. 1, JANUARY 1998.

[15] F. Zana and J. C. Klein, "A Multimodal Registration Algorithm of Eye Fundus Images Using Vessels Detection and Hough Transform," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 18, NO. 5, MAY 1999.

[16] D. Lloret, J. Serrat, A. M. Lopez, A. Soler, and J. J. Villaneuva, "Retinal image

registration using creases as anatomical landmarks," in IEEE Proc. Int. Conf. Pattern Recognition, VOL. 3, pp. 203–206, Sep. 2000.

[17] Philippe Thévenaz, and Michael Unser, "Optimization of Mutual Information for Multiresolution Image Registration," IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 9, NO. 12, DECEMBER 2000.

[18] Hong Shen, Charles V. Stewart, Badrinath Roysam, Gang Lin, and Howard L. Tanenbaum, "Frame-Rate Spatial Referencing Based on Invariant Indexing and Alignment with Application to On-Line Retinal Image Registration," IEEE Trans. on Pattern Analysis and Machine Intelligence, 2002.

[19] Ali Can, Charles V. Stewart, Badrinath Roysam, and Howard L. Tanenbaum, "A Feature-Based, Robust, Hierarichal Algorithm For Registering Pairs of Images of the Curved Human Retina," IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE, VOL. 24, NO. 3, MARCH 2002.

[20] France Laliberté, Langis Gagnon, and Yunlong Sheng , "Registration and Fusion of Retinal Images–An Evaluation Study," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 22, NO. 5, MAY 2003.

[21] Charles V. Stewart, Chia-Ling Tsai, and Badrinath Roys, "The Dual-Bootstrap Iterative Closest Point Algorithm With Application to Retinal Image Registration," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 22, NO. 11, NOVEMBER 2003.

[22] WILLIAM K. PRATT, "Correlation Techniques of Image Registration," IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS, VOL. AES-10, NO. 3, MAY 1974.

[23] A. Roche, G. Malandain, X. Pennec, N. Ayache, "The correlation ratio as a new similarity measure for multimodal image registration," Proceedings of the

First International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI'98), VOL. 1496, pp. 1115−1124, 1998.

[24] Paul A. Viola, "Alignment by Maximization of Mutual Information," Proceedings of the 5th International Conference on Computer Vision, pages 15−23, 1995.

[25] Frederik Maes, Andrt'e Collignon, Dirk Vandermeulen, Guy Marchal, and Paul Suetens, "Multimodality Image Registration by Maximization of Mutual Information," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 16, NO. 2, APRIL 1997.

[26] Nicola Ritter, Robyn Owens, James Cooper, Robert H. Eikelboom, and Paul P. van Saarloos, "Registration of Stereo and Temporal Images of the Retina," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 18, NO. 5, MAY 1999.

[27] A. Roche, G. Malandain, N. Ayache, "Unifying maximum likelihood approaches in medical image registration," International Journal of Imaging Systems and Technology VOL. 11, pp. 71−80, 2000.

[28] Daniel B. Russakoff, Torsten Rohlfing, and Calvin R. Maurer, Jr., "Fast Intensity-based 2D-3D Image Registration of Clinical Data Using Light Fields", Proceedings of the Ninth IEEE International Conference on Computer Vision (ICCV'03), 2003.

[29] Mark P. Wachowiak, Renata Smolikova, Yufeng Zheng, Jacek M. Zurada, and Adel S. Elmaghraby, "An Approach to Multimodal Biomedical Image Registration Utilizing Particle Swarm Optimization," IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION, VOL. 8, NO. 3, JUNE 2004.

[30] Jeongtae Kim and Jeffrey A. Fessler, "Intensity-Based Image Registration Using

Robust Correlation Coefficients," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 23, NO. 11, NOVEMBER 2004.%bibitemPhase3 Enrique Corona, Sunanda Mitra, and Mark Wilson, "A Fast Algorithm For Registration of Individual Frames and Information Recovery in Fluorescein Angiography Video Image Analysis," Fifth IEEE Southwest Symposium on Image Analysis and Interpretation," 2002.

[31] H. J. Johnson, and G. E. Christensen, "Consistent Landmark and Intensity-Based Image Registration," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 21, NO. 5, MAY 2002.

[32] Thitiporn Chanwimaluang, Guoliang Fan, and Stephen R. Fransen, "Hybrid Retinal Image Registration," IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE, VOL. 10, NO. 1, JANUARY 2006.

[33] Lyubomir Zagorchev & Ardeshir Goshtasby, "A Comparative Study of Transformation Functions for Nonrigid Image Registration," IEEE Trans. Image Processing, VOL. 15, NO. 3, pp. 529–538, 2006.

[34] Geir E. Oien, and Per Osnes, "Diabetic Retinopathy: Automatic Detection of early symptoms from retinal images," Proc. Norwegian Signal Processing Sym.

[35] Meindert Niemeijer, Bram van Ginneken, Joes Staal, Maria S.A. Suttorp-Schulten, and Michael D. Abràmoff, "Automatic Detection of Red Lesions in Digital Color Fundus Photographs," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 24, NO. 5, MAY 2005.

[36] C. I. O. Martins, F. N. S. Medeiros, R. M. S. Veras, F. N. Bezerra, and R. M. Cesar Jr., "EVALUATION OF RETINAL VESSEL SEGMENTATION METHODS FOR MICROANEURYSMS DETECTION," ICIP, 2009.

[37] Adam Hoover and Michael Goldbaum, "Locating the Optic Nerve in a Retinal Image Using the Fuzzy Convergence of the Blood Vessels," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 22, NO. 8, AUGUST 2003.

[38] Aliaa Abdel-Haleim Abdel-Razik Youssif, Atef Zaki Ghalwash, and Amr Ahmed Sabry Abdel-Rahman Ghoneim, "Optic Disc Detection From Normalized Digital Fundus Images by Means of a Vessels' Direction Matched Filter," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 27, NO. 1, JANUARY 2008.

[39] S. Chaudhuri, S. Chatterjee, N. Katz, M. Nelson, and M. Goldbaum, "Detection of blood vessels in retinal images using two-dimensional matched filters," IEEE Trans. Med. Imag., vol. 8, pp. 263−269, Sept. 1989.

[40] L. Gang, O. Chutatape, and S. M. Krishnan, "Detection and measurement of retinal vessels in fundus images using amplitude modified second-order Gaussian filter," IEEE Trans. Biomed. Eng., vol. 49, pp. 168−172, Feb. 2002.

[41] Bob Zhang, Lin Zhang, Lei Zhang, and Fakhri Karray, "Retinal vessel extraction by matched filter with first-order derivative of Gaussian," Journal of Computers in Biology and Medicine, VOL. 40, pp. 438−445, 2010.

[42] Adam Hoover, Valentina Kouznetsova, and Michael Goldbaum, "Locating Blood Vessels in Retinal Images by Piecewise Threshold Probing of a Matched Filter Response," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 19, NO. 3, MARCH 2000.

[43] Joes Staal, Michael D. Abràmoff, Meindert Niemeijer, Max A. Viergever, and Bram van Ginneken, "Ridge-Based Vessel Segmentation in Color Images of the Retina," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 23, NO. 4, APRIL 2004.

[44] A. Pinz, S. Berngger, P. Datlinger, and A. Kruger, "Mapping the human retina," IEEE Trans. Med. Imag.m VOL. 17, pp. 606−619, Aug. 1998.

[45] Yannis A. Tolias, and Stavros M. Panas, "A Fuzzy Vessel Tracking Algorithm for Retinal Images Based on Fuzzy Clustering", IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 17, NO. 2, APRIL 1998.

[46] O. Chutatape, L. Zheng, and S. M. Krishnan, "Retinal blood vessel detection and tracking by matched Gaussian and Kalman filters," in Proc. 20th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (EMBS'98), 1998, vol. 20, pp. 3144−3149.

[47] A. Can, H. Shen, J. N. Turner, H. L. Tanenbaum, and B. Roysam, "Rapid automated tracing and feature extraction from retinal fundus images using direct exploratory algorithms," IEEE Trans. Inf. Technol. Biomed., vol. 3, no. 2, pp. 125−138, Jun. 1999.

[48] M. Lalonde, L. Gagnon, and M.-C. Boucher, "Non-recursive paired tracking for vessel extraction from retinal images," Vision Interface, pp. 61−68, 2000.

[49] Enrico Grisan, Alessandro Pesce, Alfredo Giani, Marco Foracchia, and Alfredo Ruggeri, "A new tracking system for the robust extraction of retinal vessel structure," Proceedings of the 26th Annual International Conference of the IEEE EMBS, 2004.

[50] Di Wu, Ming Zhang, Jyh-Charn Liu, and Wendall Bauman, "On the Adaptive Detection of Blood Vessels in Retinal Images, IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING," VOL. 53, NO. 2, FEBRUARY 2006.

[51] Farsad Zamani Boroujeni, Rahmita Wirza, Norwati Mustapha,Lilly Suriani Affendey, Oteh Maskon and Majid Khalilian, "A New Tracing Algorithm for Automatic Boundary Extraction from Coronary Cineangiograms," Proceedings

of The International MultiConference of Engineers and Computer Scientists, VOL. II, 2010.

[52] Vijay Mahadevan, Harihar Narasimha-Iyer, Badrinath Roysam, and Howard L. Tanenbaum, "Robust model-based vasculature detection in noisy biomedical imagings," IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE, VOL. 8, NO. 3, SEPTEMBER 2004.

[53] Jao V. B. Soares, Jorge J. G. Leandro, Roberto M. Cesar Jr., Herbert F. Jelinek, and Michael J. Cree, Senior Member, IEEE, "Retinal Vessel Segmentation Using the 2-D Gabor Wavelet and Supervised Classification, IEEE TRANSACTIONS ON MEDICAL IMAGING," VOL. 25, NO. 9, SEPTEMBER 2006.

[54] Lili Xu, Shuqian Luo, "A novel method for blood vessel detection from retinal images," BioMedical Engineering OnLine, 2010.

[55] Frédéric Zana and Jean-Claude Klein, "Segmentation of Vessel-Like Patterns Using Mathematical Morphology and Curvature Evaluation," IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 10, NO.7, JULY 2001.

[56] Thomas Walter and Jean-Claude Klein, "Segmentation of Color Fundus Images of the Human Retina: Detection of the Optic Disc and the Vascular Tree Using Morphological Techniques," ISMDA 2001, LNCS 2199, pp. 282−287, 2001.

[57] YONG YANG, SHUYING HUANG, and NINI RAO, "AN AUTOMATIC HYBRID METHOD FOR RETINAL BLOOD VESSEL EXTRACTION," Int. J. Appl. Math. Comput. Sci., Vol. 18, No. 3, 399−407, 2008.

[58] Jian Chena, Jie Tiana, Zichun Tanga, Jian Xuea, Yakang Daia and Jian Zhenga, "Retinal vessel enhancement and extraction based on directional field," Journal of X-Ray Science and Technology, VOL. 16, pp. 189−201, 2008.

[59] A. Vasilevskiy and K. Siddiqi, "Flux maximizing geometric flows," IEEE Trans. Pattern Anal. Mach. Intell., vol. 24, no. 12, pp. 1565−1578, Dec. 2002.

[60] Hao Ju-tao, and Zhao Jing-jing, "Shape Constraint Incorporated Geometric Flows for Blood Vessels Segmentation," International Conference on Computational Intelligence and Security, 2008.

[61] Tim McInerney, and Demetri Terzopoulos, "T-snakes: Topology adaptive snakes," Medical Image Analysis, VOL. 4, pp. 73−91, 2000.

[62] Ricardo Toledo, Xavier Orriols, Xavier Binefa, Petia Radeva, Jordi Vitri'a, and J.J. Villanueva, "Tracking Elongated Structures using Statistical Snakes," IEEE Comput. Soc. Conf. Comput. Vision Pattern Recog. (CVPR), VOL. 1, 2000.

[63] Benson Shu Yan Lam and Hong Yan, "A Novel Vessel Segmentation Algorithm for Pathological Retina Images Based on the Divergence of Vector Fields," IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 27, NO. 2, FEBRUARY 2008.

[64] Changhua Wua and Gady Agamb, "Probabilistic Retinal Vessel Segmentation," SPIE Medical Imaging – Image Processing (MI05), 2007.

[65] Mouloud Adel, Monique Rasigni, Thierry Gaidon, Caroline Fossati, and Salah Bourennane, "STATISTICAL−BASED LINEAR VESSEL STRUCTURE DETECTION IN MEDICAL IMAGES," ICIP, 2009.

[66] M. Niemeijer, J. J. Staal, B. van Ginneken, M. Loog, and M. D. Abràmoff, "Comparative study of retinal vessel segmentation methods on a new publicly available database," in Proc. SPIE Med. Imag., J. M. Fitzpatrick and M. Sonka, Eds., vol. 5370, pp. 648−656, 2004.

[67] Richard O. Duda, Peter E. Hart and David G. Stork 2003. Pattern Classificationm, Second Edition. Wiley-Interscience, USA.

[68] Ethem Alpaydm. Introduction to Machine Learning. The MIT Press, Cambridge, England.

[69] Oleg Pomerantzeff, Robert H. Webb, and Francois C. Delori, "Image formation in fundus cameras," Assoc. for Res. in Vis. and Ophthal., Inc., Aug. 14, 1978.

[70] Patrick J. Saine, "Errors in Fundus Photography," Journal of Ophthalmic Photography, Vol. 7, No. 2, December 1984.

[71] Edward DeHoog and James Schwiegerling, "Fundus camera systems: a comparative analysis," Appl Opt., VOL. 48, NO. 2, pp. 221–228, January 2009.

[72] R. Theodore Smith, Jackie K. Chan, Takayuki Nagasaki, Umer F. Ahmad, Irene Barbazetto, Janet Sparrow, Marta Figueroa, and Joanna Merriam, "Automated Detection of Macular Drusen Using Geometric Background Leveling and Threshold Selection," ARCH OPHTHALMOL, vol. 123, 2005.

[73] R. Theodore Smith, Jan P. Koniarek, Jackie Chan, Takayuki Nagasaki, Janet R. Sparrow, and Kevin Langton, "Autofluorescence Characteristics of Normal Foveas and Reconstruction of Foveal Autofluorescence from Limited Data Subsets," Investigative Ophthalmology & Visual Science, Vol. 46, No. 8, 2005.

[74] A. P. Dempster, N. M. Laird, and D. B. Rubin, "Maximum likelihood from incomplete data via the EM algorithm," Journal Royal Statistics Society, vol. 39, no. 1, pp. 1-21, 1977. Taban M, Sharma S, Williams DR, Waheed N, and Kaiser PK, "Comparing retinal thickness measurements using automated fast macular thickness map versus six-radial line scans with manual measurements," Ophthalmology, vol. 116, no. 8, pp. 964-70, May 2009.

[75]

[76] Abdulrahman Almuhareb

APPENDICES

APPENDIX A

Phase Correlation Theory

Let $D_1(x,y)$ and $D_2(x,y)$ be the dilated images to be registered, the Fourier transform for both $F_1(u,v)$ and $F_2(u,v)$ is given by:

$$F_k(u,v) = \mathcal{F}\{D_k(x,y)\}$$

$$= \int_{y=-\infty}^{y=\infty}\int_{x=-\infty}^{x=\infty} D_k(x,y)\exp^{(-i2\pi\omega xy)}\,dxdy \tag{7.1}$$

where, $\mathcal{F}$ is the Fourier operator, K denotes image 1 or 2, ω is the frequency (in hertz), x and y are the spatial domain coordinates, u and v are the frequency domain coordinates of the two images.

Given two images of size $N \times M$ shifted against each other, according to the Fourier shift property, their Fourier becomes:

$$F_2(u,v) = F_1(u,v)\exp^{\left(-i2\pi\left(\frac{u\Delta x}{M}+\frac{v\Delta y}{N}\right)\right)} \tag{7.2}$$

The Normalized Cross Power Spectrum ($C(u,v)$) is defined as:

$$C(u,v) = \frac{F_1(u,v)\cdot F_2(u,v)^*}{|F_1(u,v)\cdot F_2(u,v)^*|} \tag{7.3}$$

where '.' denotes the element-wise product, '*' denotes the complex conjugate.

Using equation **??**:

$$C(u,v) = \frac{F_1(u,v)\cdot F_1(u,v)^*\exp^{\left(i2\pi\left(\frac{u\Delta x}{M}+\frac{v\Delta y}{N}\right)\right)}}{\left|F_1(u,v)\cdot F_1(u,v)^*\exp^{\left(i2\pi\left(\frac{u\Delta x}{M}+\frac{v\Delta y}{N}\right)\right)}\right|} \tag{7.4}$$

Since the phase term of $F_1(u,v)\cdot F_1(u,v)^*$ is zero, only the magnitude remains, i.e. $F_1(u,v)\cdot F_1(u,v)^* = |F_1(u,v)\cdot F_1(u,v)^*|$ and since the magnitude of any complex exponential is 1, the equation drops to:

$$\begin{aligned} C(u,v) &= \frac{|F_1(u,v)\cdot F_1(u,v)^*|\exp^{\left(i2\pi\left(\frac{u\Delta x}{M}+\frac{v\Delta y}{N}\right)\right)}}{|F_1(u,v)\cdot F_1(u,v)^*|} \\ &= \exp^{\left(i2\pi\left(\frac{u\Delta x}{M}+\frac{v\Delta y}{N}\right)\right)} \end{aligned} \tag{7.5}$$

the inverse Fourier transform of which is a delta function, i.e. a single peak.

The Normalized Cross Correlation (c) equals:

$$c = \mathcal{F}^{-1}\{C\} = \delta(x + \Delta x, y + \Delta y) \tag{7.6}$$

The shift in x and y between the two images $(\Delta x, \Delta y)$ takes the location of the maximum peak in c, such that:

$$(\Delta x, \Delta y) = \underset{x,y}{\operatorname{argmax}}\{c\} \tag{7.7}$$