Candidate: Mikuláš Krupička

Title of dissertation thesis: Iris Analysis

Reviewer: Maria De Marsico

1. Up-to-datedness of the dissertation: good
2. Formal structure and organization of the dissertation: good
3. Completion of the dissertation objectives: many objectives have been reached
4. Assessment of the methods used in the dissertation: some points need clarification
5. Evaluation of the results and contributions of the dissertation: reported results need some extension; the contribution to state of the art for iris segmentation is quite significant.
6. Remarks, objections, notes, and questions for the defense: see details below
7. The overall evaluation of the dissertation: sufficient for defense
8. Statement whether you DO or DO NOT recommend the dissertation for the defense: I DO recommend the dissertation for the defense

The author of the dissertation proved the ability to conduct research and achieve scientific results. In accordance with par. 47, letter (4) of the Law Nr. 111/1998 (The Higher Education Act) I do recommend the thesis for the presentation and defense with the aim of receiving the Ph.D. degree.

Rome, January 27, 2018

Signature of the reviewer

Maria De Marsico

General evaluation

Structure of the thesis. The thesis is sufficiently well structured. Topics are well introduced and related to each other. All relevant problems are discussed in more or less detail.

State of the art. The competitor proposals in MICHE I should have been included in the state of the art. One of the proposed methods won the competition, therefore it would have been interesting to compare the approaches. Some recent publications are missing.

Presentation of the methods. The general approach can be understood, but some points are not completely clear either for lack of details, or for some notation misuse, or for language problems.

The term "training" is at present mostly referred to machine learning approaches, that focus on learning to recognize the single class/individual, and are much less often used for iris. In most iris, and biometric in general, recognition systems the training phase does rather refer to determine the best values for some operational parameters, such as the acceptance threshold providing the best results. Considering the cited reference Du06, the mention seems to be rather to the number of training samples used in the sense underlined above. It can also be intended as the number of samples in the biometric system gallery, i.e., the images captured during the subject enrollment and used for recognition by matching them with the incoming probe. In fact, it is widely accepted that having a multiple-sample gallery improves performance. The mentioned number of samples (1 to three) fits both latter conditions. It would be worth having a clarification of this point.

It is incorrect to say that no multispectral (NIR + RGB) iris dataset exists. A small one is introduced in: Boyce, C., Ross, A., Monaco, M., Hornak, L., & Li, X. (2006, June). Multispectral iris analysis: A preliminary study51. In *Computer Vision and Pattern Recognition Workshop, 2006. CVPRW'06. Conference on* (pp. 51-51). IEEE. Another one is UTIRIS (http://www.dsp.utoronto.ca/~mhosseini/UTIRIS%20V.1.zip) introduced in Mahdi S. Hosseini, Babak N. Araabi and H. Soltanian-Zadeh,"Pigment Melanin: Pattern for Iris Recognition," IEEE Transactions on Instrumentation and Measurement, vol.59, no.4, pp.792-804, April 2010. Having the possibility of using a multispectral dataset, it would be interesting to know if the candidate would have modified some steps in the presented approach.

The description of Multispectral Iris Texture Model should be refined by a better description of the parameters and their relations. In particular, the role and definition of the model support deserve some more explanation.

It seems that the occlusion mask still takes into account regions with reflections in their original form. However it seemed that these regions should have already been filled by inpainting. This point is not clear. Overall, the relation between reflection detection and occlusion detection is not completely clear, since from one side it seems that the former precedes the latter, and iris localization stays between these two steps; on the other side they seem to be carried out in strict sequence, or better, reflections are considered as parts of occlusions. In fact, in Figure 4.4 Reflection detection appears twice. Given this, which is the role of inpainting? Is it to transform reflections into better detectable occlusions? Why reflection detection is repeated after normalization? Once the involved pixels have been identified in the circular iris image, they could be just mapped onto the rectangular representation using the usual formulae.

Viola-Jones algorithm trained for eyes is quite effective and ready-to-use for the task of eye localization. Why was it decided to use a different method?

It would be interesting to have an idea of the final size of the extracted feature vectors, given that it is written: "Each iris is represented as the matrix of feature vectors where each vector corresponds to each pixel in normalized iris."

The use of KNN is not clear at all. What does it mean "each pixel is searched in opposite region"? What does it mean to use "one KNN classifier" and "another KNN classifier"? What is the goal of this step? This part is quite hard to read ... in my understanding, "opposite" refers to the other iris in the matched pair, and matching is performed by KNN in both directions (is this to guarantee symmetry to the distance?) so that two masks are produced. However, this part should be clarified.

Results in Table 7.1 are reported for 40 images only (the only ones for those the ground truth was created), and moreover they do not seem the same presented in Figure 7.1. This can create some perplexities.

The reason for choosing TK12 for a further comparison should be mentioned.

Since recognition results were compared for the simple ruling out strategies, it would be worth showing the comparison for the more complex approach. Most of all, it would be worth seeing the results both without and with the ruling out. No performance evaluation is provided for recognition.

Some critical discussion of the presented results is missing. Future work should be discussed and explored.

Quality of results. Segmentation results seem quite aligned with state of the art, even if only comparison with NICE and MICHE participants is presented. Recognition results are not reported at all.

Language.

Overall English language would have needed a thorough revision

Review of the Ph.D. Thesis of *Mikuláš Krupička* Entitled "*Iris Analysis*"

The thesis is devoted to image analysis tasks related to biometric identification based on 2D images of irises. The main contribution appears in the proposal and implementation of original approaches to (1) iris occlusion in Section 4 and also (2) iris recognition in Section 5.

A reliable detection of iris occlusions and a subsequent iris recognition require a complicated process of individual steps, which have to sophistically proposed especially if analyzing realistic (non-standardized) databases of irises. The author exploits a multispectral texture model, which is a causal autoregressive random field model of Haindl (2012). The robustness of the classification task with respect to occlusion is performed by means of a so-called occlusion mask, i.e. pixels corresponding to occluded parts of the iris do not contribute to the classification. Clearly implementing all the steps and combining them to robust algorithms together with tuning all parameters required very intensive programming.

The experimental part presented in Section 7 illustrates the performance of novel methods on individual iris images and overviews results over the whole databases of images. In my opinion, the presentation of results deserves more space and discussion. Table 7.2 can be described as the main result concerning the novel iris occlusion methods of Sections 4.2 and 4.3; there however the error measures E_1 and E_2 remain undefined and unexplained. Also the approach exploits various tuning constants; it is not clear why exactly these choices of constants are made.

On the whole, the results of the proposed methods seem to be promising, because the author compared them within two iris recognition tasks: the best of the methods works better compared to any method participating at the NICE.I contest (organized in 2008) and also served as the ground truth in the MICHE.II contest in 2016.

The major deficiency of the thesis is the lack of clarity in presentation. There appear some undefined notation or ambiguities especially in some of the mathematical formulas. Formulas are placed in the text somehow loosely without being incorporated to the text and without being explained sufficiently.

- Page 10, "*$G_\sigma(\rho)$ is convolution of sequence of differentiated radii ...*" I think that $G_\sigma(\rho)$ should denote only the kernel and not the whole convolution.
- Page 11, m and n (presumably the size of a given image) was not defined.
- Page 12, "*And $J(r_1, r_2)$ is pixel from output mask of the edge detector.*" Such notation does not make sense for the definition of $g(r_1, r_2, s_1, s_2, \rho)$. The meaning should be that $g(r_1, r_2, s_1, s_2, \rho)$ is evaluated for a pixel (r_1, r_2) like in Wildes (1997).
- Page 15, the notation $\circ$ is not defined.
- Page 43-44, understanding the notation fully is not possible without finding some missing definitions in Haindl (2012), for example $V_{z(r)}$ is not defined or including the definition $I_r^c = \{s; 1 \leq s_1 \leq r_1, 1 \leq s_2 \leq r_2, s \neq r\}$ would be very useful.

- Page 60. What is $I(r_1, r_2)$ and index k here?
- Page 73. A clear error in the definition of σ_I and σ_E, because using the author's notation we obtain

$$\sigma_I = \frac{1}{k-1}\sum_i (d_i^I - \mu_I) = \frac{1}{k-1}\sum_i (d_i^I - \frac{1}{k}\sum d_i^I) = 0.$$

From the formal point of view, the thesis is well structured and organized with a well described motivation (Section 1) and state of the art (Section 2). However, the English language requires improvements namely concerning the incorrect using of definite and indefinite articles. Moreover, some abbreviations seem to be undefined, e.g. ATM (page 1), HSV (page 11), or CAR and 3D-CAR defined by Haindl (2012).

Questions for the defense.

- Each of the methods was tested on a particular database and seems to be tailor-made to work reliably exactly for this database. What should be modified in order for the methods to be applicable to a different database of irises? And is it really needed that the distance of eyes from the camera is long (as stated on page 3)?
- Each individual has two irises. Are the two irises from the same individual taken as independent?
- What can you say about the computational time of the three methods of Section 4?

Conclusion. The author of the dissertation proved the ability to conduct research and achieve scientific results. In accordance with § 47, letter (4) of the Law Nr. 111/1998 (The Higher Education Act) I do recommend the thesis for the presentation and defense with the aim of receiving the Ph.D. degree.

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FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
department of biomedical engineering

Review of dissertation
titled "Iris Analysis"
authored by Mikuláš Krupička

Reviewer: Doc. Ing. Radim Kolář, Ph.D.

General description

Author of submitted thesis describes processing and analysis of iris images for biometric recognition using a publicly available datasets. Although, a lot of work has been done in this area in the past, there are still many challenging problems.

The thesis consists of nine chapters, including Introduction and Conclusion. The thesis is written on 93 pages plus list of references (>100). The structure of thesis conforms to principles and requests to the structure of scientific thesis.

The word processing of the thesis is adequate. The English grammar is not always good (e.g. page 41: "This methods works...", page 46: "It's image are...").

Up-to-dateness

The iris based identification and recognition is still a hot research topic. There are still some challenges – long distance acquisition, elimination of different acquisition artefacts, eyelid artefacts etc. This thesis solve an occlusion problem for different acquisition setups. Methods described in thesis also deal with low quality images. Hence, the topic is relevant and up-to-date.

Completion of the dissertation objectives

The goals as specified in chapter 1.3 are fulfilled. These goals are relevant with respect to *state-of-the-art*. Nevertheless, I would expect to be more ambitious in iris recognition part.

Assessment of the methods

Author used almost standard and well known methods in his work. He put these methods into a chain in order to create a "working pipeline" for iris-based recognition. For occlusion detection a multispectral iris texture model has been applied. This model is described in 4.1.4 and it is the application of previously described method. The description is not complete, because definition of some parameters is missing (beta, gamma, V). However, this and two other methods for occlusion detection are interesting and add some novelty. The second part dealing with iris recognition contains only minor contribution.

Evaluation of the results and contribution of the dissertation

The results are evaluated in Chapter 6 and 7. The standard metrics are used for segmented irises and the results are compared with published papers. Author achieved good results, outperforming current method in few cases. In iris recognition I would expect more detailed evaluation (at least ROC curve, AUC) and discussion on achieved results. Another weak point is that author ignored work published during last four years in this comparison.

Concluding remarks

The amount of work presented in this thesis should correspond to standard time spent in PhD studies. From this point of view the presented work looks rather weak (mainly in evaluation part and iris recognition part). The list of author's publication is also very weak. There is only one publication presented on local workshop, where the author is the first author. There is one journal paper, but some main journal publication authored by PhD applicant is missing. Other papers has been presented mostly on international conferences. Based on this simple fact, I have a doubt about ability of applicant to create some scientific results and conduct research. On the other hand, the presented work is relatively compact research work fulfilling the requirements on dissertation.

In accordance with par. 47, letter (4) of the Law Nr. 111/1998, I do recommend the thesis for presentation and defence with the aim of receiving the Ph.D. degree.

Questions:

1. The method Robust Iris Occlusion Detection in Challenging Images applies some correction for imprecisely detected iris region. This correction is described only by one sentence. Could you describe it more clearly or with some math notation?

2. Are your approaches (occlusion detection, iris recognition) applicable on images acquired from standard smartphones as used in current smartphone models with iris recognition? Did you performed any test?

3. You mentioned (Introduction and Conclusion) that iris images can be used for medical diagnosis. Although this would be interesting, there is still no reliable and desirable application in clinic, to my knowledge. If yes, some references should be added to support your idea.

4. The method for determining eye position is probably not robust enough (particularly for women with artificial or trimmed eyelashes). Did you perform some test/evaluation?

Brno, March 1st, 2018

Doc. Ing. Radim Kolář, Ph.D.