ORIGINAL RESEARCH

OPTICAL NERVE SEGMENTATION USING THE ACTIVE SHAPE METHOD

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Abstract

The paper deals with the segmentation procedure for optical nerve localization and the consequent determination of geometrical parameters such as optical nerve area, radius and diameter. An extraction of these geometrical parameters is especially important for clinical practice particularly in the case where retinal lesions are present. On the base of the optical nerve extraction, we are capable of comparing it with area of retinal lesions. Via this approach it is possible to track time evaluation of retinal lesions. The proposed algorithm for segmentation of optical nerve area is performed within two main steps. In the first step, the active contour method is used specially for the localization of the optical nerve. This part of the algorithm generates mathematical model of the optical nerve in binary form. Consequently, on the base of this mathematical model of the optical nerve respective geometrical parameters are worked out for future comparison with retinal lesions. Image preprocessing is an integral part of the segmentation procedure, improving the observability of the optical nerve to ensure as relevant detection of the optical nerve as possible.

Keywords

Optical nerve, retinopathy, retinal lesions, active contour, image segmentation, extraction of geometrical parameters

Introduction

The retinal area can be investigated by the system RetCam3. This device is able to capture retinal nerve, retinal blood vessels and retinal lesions. The extraction of the optical nerve geometrical features is closely related with the retinopathy disease. Within this disease it is especially important to track time evolution of retinal lesions in comparison with optical nerve which is denoted as a reference point to the respective retinal lesion. One possible clinical way for the evaluation retinal lesions is the ratio between respective area of retinal lesion to the optical nerve as a reference point.

Retinopathy of prematurity (ROP) is a vasoproliferative disease that affects especially prematurely-born infants with low birth weight. The ROP is the second most frequent cause of blindness of children in developed countries [1, 2]. In the Czech Republic, it represents the second most frequent cause of severe children vision impairment.

The aim of the ROP screening is an early detection of the first signs of the disease. That allows ophthalmologist to optimally schedule ophthalmological examinations, plan a possible treatment and hereby prevent a development of the severe vision impairment. For the purpose of the clinical rating of the size retinal lesions and for the purpose of measuring distances of retinal changes and the assessing their progression in time, we use the optic nerve disc diameter as a reference point. [1, 2, 3]

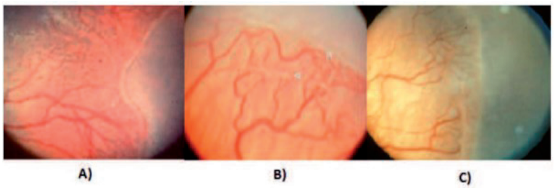

Fig. 1: The individual stages of Retinopathy, A) 1. Stage, B) 2. Stage, C) 3. Stage [4]

The System RetCam3

The RetCam3 is a digital imaging system that represents a modern alternative of screening and diagnostics of children retinal diseases. The main advantage of this system is the possibility of wide-angle view of the retina in comparison with a conventional method of the indirect ophthalmoscopy that is considered as a standard method for the screening of the ROP of prematurely-born infants. The possibility of acquiring image or video records during the examination allows ophthalmologists to assess the dynamics of the retinal changes or the efficacy of a therapy over time.

Examination by the system RetCam3 goes by similar way as the indirect ophthalmoscopy. A Retina is illuminated by very intensive light which is placed directly on the apex of the camera. Consequently, images or video records are captured and stored in the hard drive. Since, the device has smaller size it captures images relatively in lower resolution. Physician can browse individual images in programme menu, emphasize important artefacts and useless images can be deleted. [5]

Fig. 2: The System RetCam3 (left), retinal probe (right). [5]

Fig. 3: Ophthalmological examination of the prematurely-born infant with the RetCam3 digital imaging system. [5]

The Proposed Segmentation Algorithm

The structure of the segmentation algorithm for extraction of optical nerve area is adjusted to the features of retinal images which are acquired by system RetCam3. The device is intended for retina investigation of children patients which are not able to pay attention for longer time. Technical concept of this device is adjusted to this fact and for this reason the device captures images in lower resolution which corresponds with worse observation of the structures of interest. On the base of the mentioned reasons, one of the most important algorithm part is the image preprocessing. This part is intended for achieving as detailed optical nerve observation as possible. The whole structure of proposed algorithm can be summarized into following steps:

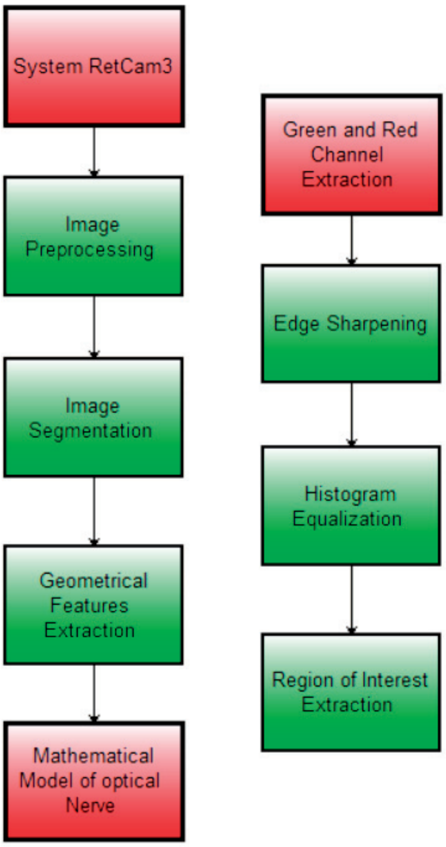

Fig. 4: The structure of proposed algorithm (left), the structure of image preprocessing (right).

The retinal records are generated in RGB spectrum. An Observation of the optical nerve is different in dependence on particular channel. By combination of R and G channel we acquire image with dominating optical nerve.

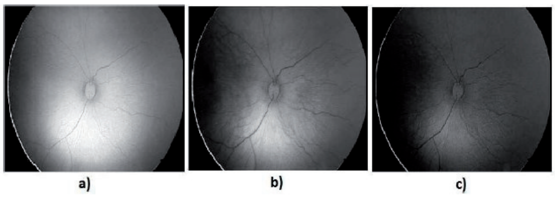

Fig. 5: a) red channel, b) green channel, c) blue channel

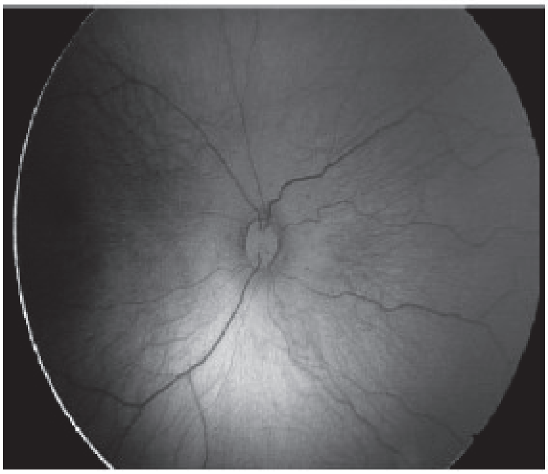

Fig. 6: The combination of red and green channel.

The further important part of the preprocessing is the sharpening procedure which allows better recognition of the optical nerve edges. The effect of this technique does not have to appear itself in the native data but it is beneficial for the segmentation accuracy. We can state that it is certain form of image filtering. The Filter permeable higher frequencies and in the same time lower frequencies are partially suppressed. In combination with the histogram equalization the filter creates the sufficiently effective procedure for the emphasizing of the optical nerve in native records.

Fig. 7: a) native retinal data, b) edge sharpening with histogram equalization

The last part of the preprocessing procedure is the Region of Interest selection. This concluding part is important for focusing area of optical nerve and for better investigation as well. Since the optical nerve takes really small area of analyzed image it is needed to supply the RoI by the linear interpolation technique. This functionality increases RoI resolution and the resulting preprocessed image appears itself smoother. The center of RoI is placed on the image center because it is supposed that it is spot of the optical nerve center.

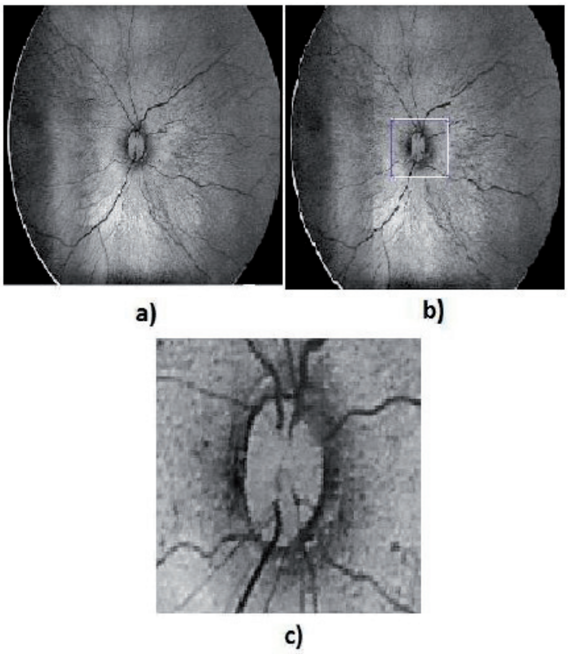

Fig. 8: a) native retinal data, b) RoI selection, c) RoI extraction with linear interpolation [6, 7, 8]

The Principle of The Active Shape Method

The main result of the complex proposed algorithm is the segmentation procedure which is able to fully automatically adjust itself to the shape of optical nerve. From the clinical point of view it is the only one appropriate way for reliable extraction features of the optical nerve. Optical nerve is approximated by the mathematical model which reflects the geometrical features of the optical nerve area and allows further clinical evaluation in the form of geometrical features such as area and nerve diameter which is commonly clinically called by the abbreviation PD (papilla diameter).

The active contour model is considered as an energy minimizing spline that is able to detect specified features in the image area. It is a flexible curve which represents surface which automatically adapts itself to the observed edges. By the numerical point of view, the active contour contains a set of control points connected by straight lines. The evolution of the active contour is performed by iterative process which controls the final contour shape.

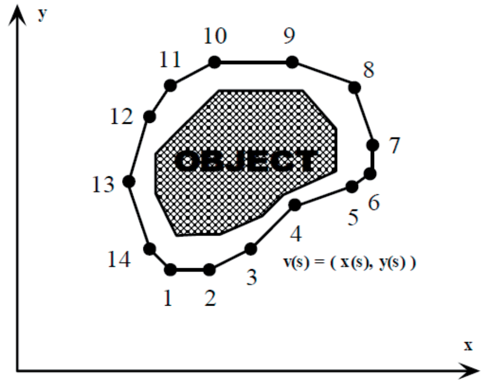

Fig. 9: Basic concept of the active contour model.

A set of control points on the contour is given by following parametric equation:

$$v(s) = (x(s), y(s)) \tag{1}$$

Where *x(s)* and *y(s)* represent coordinates *x* and *y* through contour and *s* signs normalized index of the control points.

The energy function that describes the active contour is composed from two main components, the internal energy and the external energy. The curve compactness is formed by the internal forces. The external forces tend the curve towards to the object's borders.

The internal energy is given by an elastic energy and so called bending energy. It is expressed by following equation:

$$E_{\text{int}} = E_{elastic} + E_{bend} \tag{2}$$

$$E_{\text{int}} = \alpha(s)\left|\frac{dv}{ds}\right|^2 + \beta(s)\left|\frac{d^2v}{ds^2}\right|^2 \tag{3}$$

Where α is an adjustable constant that specifies continuity and β is adjustable constant as well which specifies contour curving.

The elastic and bending energies are defined by following expressions:

$$E_{elastic} = \int \alpha(v(s) - v(s-1))^2\, ds \tag{4}$$

$$E_{bend} = \int \beta(v(s-1) - v(s) + v(s+1))^2 ds \qquad (5)$$

The functional energy which is minimized is expressed by following expression:

$$E^*_{snake} = \int_0^1 E_{snake}(v(s))ds \qquad (6)$$

$$E^*_{snake} = \int_0^1 \{E_{\text{int}}(v(s)) + E_{image}(v(s)) + E_{con}(v(s))\}ds \qquad (7)$$

Where E_{int} is the internal energy of the curve, E_{image} is the energy of the image and E_{con} determines the external limitations. [9, 10, 11, 12, 13, 14]

The Mathematical Modelling of Optical Nerve

The mathematical model of optical nerve should reflect the optical nerve geometrical features and locate area of optical nerve. The resulting model is created on the base of the active contour model in binary form. By binary representation, pixels are classified into two classes. The image background is represented by black color contrarily the area of optical nerve is indicated by white color.

The first step of segmentation procedure is the placing of the initial contour which roughly approximates shape of optical nerve. This fact is depicted on the Fig. 10.

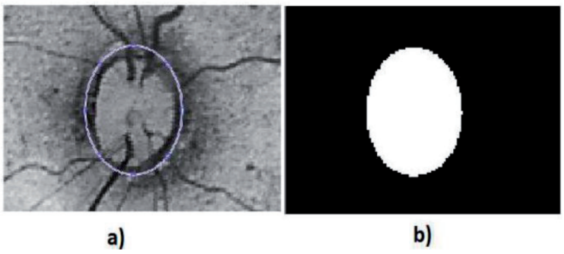

Fig. 10: a) the placing of the initial contour, b) the binary mask

The final model of optical nerve is formed by time evolution of initialization contour. Final shape is especially affected by number of iterations. On the base experiments using of 60 iterations appears itself as best compromise for reaching as relevant approximation of optical nerve as possible. Time evolution of optical nerve segmentation is depicted on the Fig. 11.

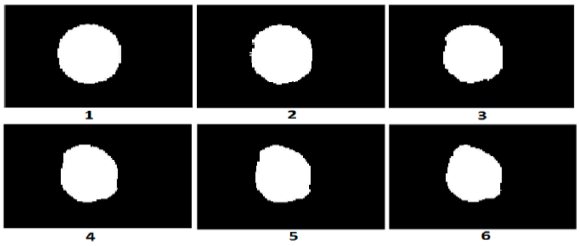

Fig. 11: The time evolution of the active contour from initialization contour (1) to the final model of optical nerve (6).

The key fact which influences the whole process of segmentation is the number of iterations. In the case of using lower number of iterations initialization contour should not reach the observed object, contrarily if we used higher number of iterations, contour would have tendency to spread itself out of the optical nerve. The comparison of individual iteration is depicted on the Fig. 12.

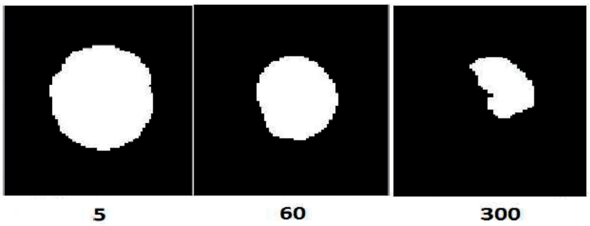

Fig. 12: The insufficient model of optical nerve, number of iterations = 5 (left), the relevant approximation of optical nerve, number of iterations = 60 (middle), the oversaturated model, number of iterations = 300 (right).

The Testing of Segmentation Algorithm

The proposed segmentation algorithm has been tested on the sample of 120 retinal records. For representative illustrating, the sample of 6 patient's records is presented. Records have been selected systematically to would be visible differences among higher and lower contrast retinal images. We are aware that the effect of the segmentation is partially depended on structure input data.

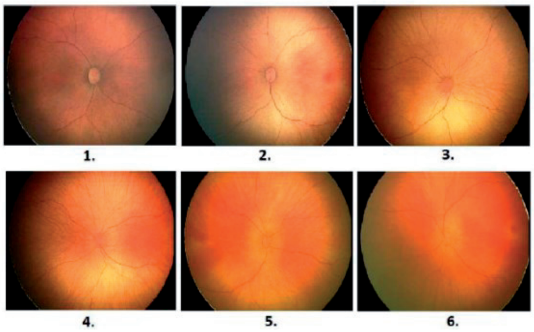

Fig. 13: The extract of retinal records, the images with optimal contrast (1–2), the images with average contrast (3–4) and the images with insufficient contrast (5–6).

The first step of analysis is the complex image preprocessing. After performing the edge sharpening with the histogram equalization we obtain adjusted images which are illustrated on the following Fig. 14.

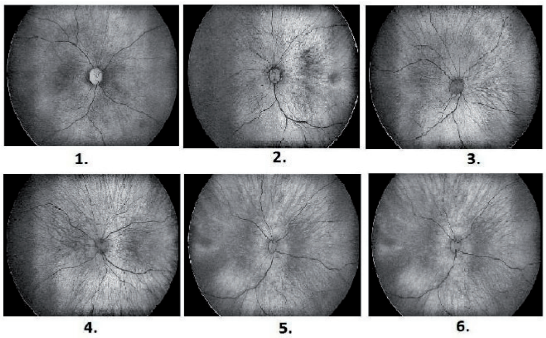

Fig. 14: The extract of the preprocessed images.

The following steps of the proposed algorithm comprise the extraction area of interest and consequently placing of the initial contour. The observed area is five times focused. This fact ensures better localization of the initial contour for final detection. This situation is depicted on the Fig. 15.

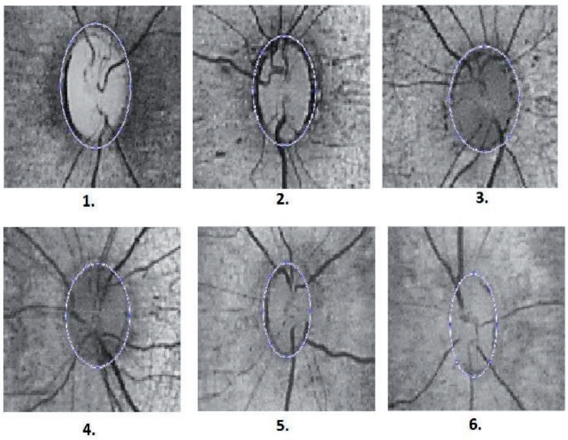

Fig. 15: The region of interest extraction with placing of the initial contour.

The last step deals with the detection of optical nerve. The final segmentation is done by using 60 iterations. The model of optical nerve is generated in the binary form. The binarized model is illustrated on the Fig. 16.

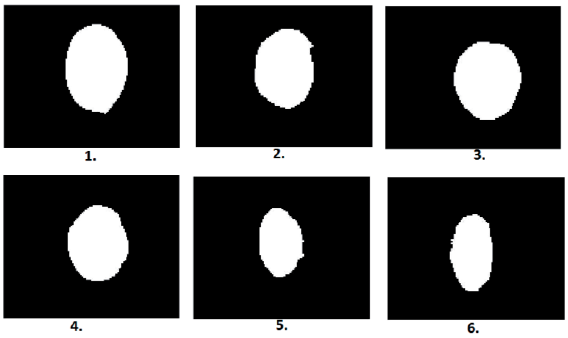

Fig. 16: The final mathematical model of the optical nerve area (60 iterations are used).

The important part of any segmentation algorithm is certain form of feedback which corresponds with the algorithm effectivity. The disadvantage of the optical nerve processing is absence of real measurable geometrical parameters of optical nerve from the native data so that there is no any reference level for the assessing objectivity of the proposed method. This fact can be at least partially compensated by the image fusion algorithm which serves for the overlaying of the native records and the segmentation model. On the base of the fusion algorithm we can state that the segmentation model reliably approximates area of optical nerve. The process of image fusion is depicted on the Fig. 17.

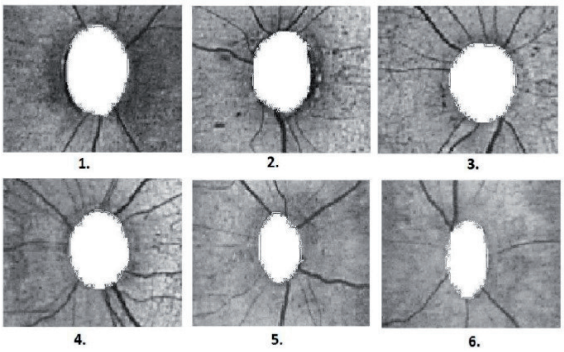

Fig. 17: The output of the image fusion algorithm.

Conclusion

Measuring and extraction of the optical nerve geometrical features is an important task in the field of clinical ophthalmology. This analysis is increasingly important in the context of the time evolution retinal lesions. It is supposed that the area of retinal lesion is not stable and exhibits certain dynamic progress. The optical nerve is commonly considered as a reference point for assessing the evolution of retinal lesions. The stage of respective retinal lesion is given as the ratio of lesion area to optical nerve area. We have proposed a suitable algorithm which is able to generate a mathematical model of the optical nerve which allows consequent extraction of geometrical features of this structure for comparison with retinal lesions. Native data was acquired from system RetCam3. A major problem is lower image contrast which is related to worse observation possibilities of the optical nerve. This unfavorable fact is partially eliminated by sophisticated data preprocessing which significantly improves the recognizability of optical nerve area. The segmentation algorithm is based on the active contour model which fully automatically adapts itself to the area of the optical nerve in iteration steps. For the segmentation of the optical nerve, 60 iterations were used. We faced with the difficulty of evaluating the algorithm effectivity because there is no feedback of the real optical nerve parameters. This fact is partially compensated by the image fusion technique. On the base of this procedure the algorithm exhibits identical geometrical features as the structure of the optical nerve from native data.

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