Method for Registration of Multimodal Images of Human Retina

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Abstract. Analysis of the image data provided by confocal laser scanning ophthalmoscope (CSLO) and by color fundus-camera is a modern diagnostic tool for early glaucoma or arteriosclerosis detection. In both cases, the proper optical disc segmentation, currently performed by human operator introducing inaccuracy caused by his subjective point of view, is a necessary step for a good diagnosis. Hence, the automatic segmentation of the optic disc is fundamental to improve the diagnosis objectivity. Fusing information from both modalities into a vector-valued image is expected to improve the segmentation reliability. The paper describes a registration of these images using optimization based on mutual information criterion. Due to many local extremes of the criterion, the simulated annealing (SA) is used as the robust optimization routine. Finally, the multi-resolution algorithm for bimodal retinal image registration achieving the success-rate of 89% is proposed.

1 Introduction

To improve early glaucoma detection and progression monitoring, the Heidelberg Retina Tomograph (HRT) is used. The HRT is a confocal laser scanning system, which provides 3D image data of the human retina. The standard colour photographs provide different information; they are used for vessel segmentation and for computing arterio-venous diameter ratio, which is important for early detection of arteriosclerosis and diabetic retinopathy. In both cases it is important to detect the border of the optic nerve head (optic disc) correctly. We found, that rather than analysing each modality separately to produce a robust segmentation, fusing information from both modalities to a vector-valued image is helpful. This paper describes the method of transforming one image to fit the other so that they are in register forming a fused image.

2 Methods

The registration is defined as searching for the best geometric transform, which describes the relationship between the reference image and the registered image. The used affine transform T is supposed to depend on a vector parameter α, encompassing shift, rotation, scale and skew. The parameter is found by optimization,

$$\alpha_0 = \arg \left\{ \min_{\alpha} C\left(R, T_\alpha\left(F\right)\right) \right\},$$

where **R** is the reference image and **F** is the floating image to be registered, which is transformed by T (α) to coordinates of the reference image. The registration quality, corresponding to the transform T, is evaluated by the criterion function C. $T_{\alpha 0}$ is then the optimal registering transform with respect to the criterion.

Due to differences in properties of the used imaging modalities, commonly used similarity (or registration) criteria fail. Thus a measure has to be applied that can cope with substantially differing contrast mechanisms of corresponding features in both images. It has been shown, e.g. [**3**], that the mutual information (MI) is a suitable measure.

The process of computing mutual-information can be divided into three steps. First, floating image is transformed and superposed with the reference. Then the joint histogram (JH) is constructed from the overlap region of these two images and finally the match metric is determined from the joint histogram. Interpolation algorithms are needed to estimate the pixel intensities at intersample positions. We have tried several methods for constructing JH, beginning with the simplest nearest-neighbour (NN) interpolation, over bilinear (B) interpolation as an intermediate step to the partial volume (PV) interpolation. Unfortunately, the imperfect interpolation induces a pattern of local extremes in the registration function caused by the imperfect interpolation of grey levels from the neighbour grid points. NN interpolation produces stair-like artefacts. The bilinear interpolation produces arch artefacts, which are accentuated with increasing number of intensity bins. The partial volume interpolation induces inverted arches pattern of the MI cost-function. To overcome this problem, a combination of three approaches was proposed - nearest neighbour interpolation with jitter sampling, histogram blurring and decreasing of the number of intensity bins [4].

Because of many local extremes of the function of MI, simulated annealing (SA) optimization was chosen as the method of fully automated search for a proper set of parameters in the multidimensional parameter space. In each iteration, the SA algorithm generates coordinates of the new attempt in the parameter space and after that, the acceptance function decides, if the new parameter values become current values, or whether it would be discarded [3]. Steps leading to a lower function value are always accepted, but if the algorithm locks in a false local minimum, steps leading towards higher (worse) value are accepted with probability based on the sc. temperature and the degree of deterioration. During iterations, temperature decreases as given by the annealing schedule.

The rough detection of the optic disc in both to-be-registered images is used. It improves the algorithm accuracy and lessens computational demands. Then the SA algorithm, in combination with the multiresolution optimization approach, is applied. First, the optimal translational parameters are found using four-times subsampled images and the results of the rough detection of optic disc are determined. Then, all parameters of the affine transform are found using four-times subsampled images and the results of the previous step. Finally all parameters are refined using the full resolution image data.

3 Results

The proposed algorithm was tested on a set of 174 images of human retina acquired from the HRT and the Canon colour camera. First, the specificity of the rough optic discs detection was tested. The detection was considered successful if the detected point laid inside the optic disc. The success-rate of the detection of the optical disc in the Canon image was 97.1% and in the HRT image 99.4%.

There is no golden standard available, so that accuracy of all the algorithms was judged by a human observer. For this purpose, HRT image was combined with the edges from the Canon image (see Fig. 1). Five runs over the complete image set were done. All misregistered images in all runs were counted and then the rate of success was computed. The specificity of the registration was 89.1 %. When the very bad quality images were not considered, the specificity has increased to 93%.

5 Conclusions

The mutual information similarity criterion was found the only suitable for the multi-modal registration of ophtalmologic images. Unfortunately, the occurrence of local extremes of the function of mutual information makes using conventional optimization algorithms ineffective in a wider range. Therefore, the method based on the more robust simulated annealing was used. Specifically, mutual information was optimized for finding parameters of the affine transform. Jitter sampling, histogram blurring and particularly lowering the number of intensity bins were used to prevent interpolating artefacts. The simulated annealing optimisation algorithm was performed together with the pyramid sub-sampling to speed-up the convergence. The method has successfully registered 89% of accessible images in spite of very varying quality. It seems necessary to generalise the approach using elastic registration, at least for some images. This remains open for future research.

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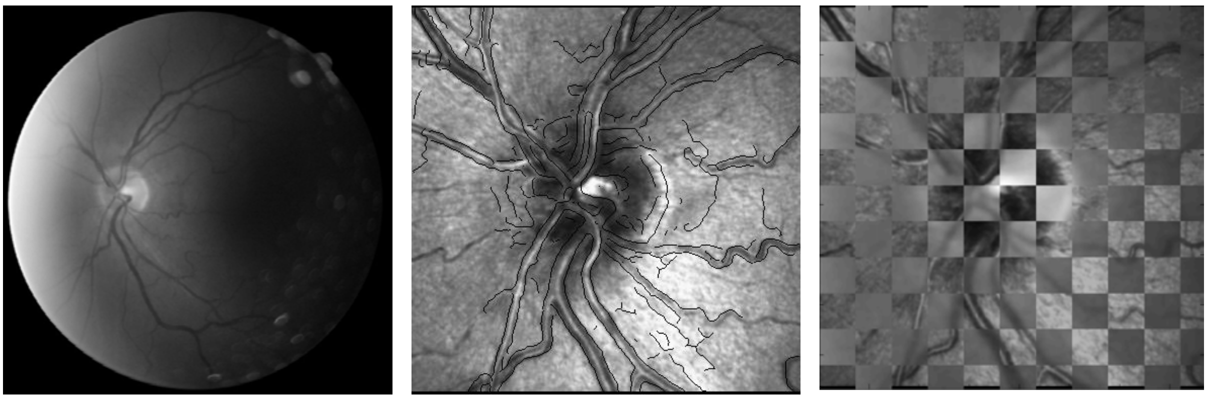

Fig.1: Left: Image from fundus camera (floating image). Middle: integral intensity image from the confocal laser tomograf (reference image) with superimposed edges obtained from registered fundus camera image using Canny edge detector - visual test of proper image registration. Right: Mosaic created from both registered images (alternating fields from the fundus camera and the laser tomography).