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Bi - Domain Intraoperative Registration of Vessels

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Abstract: The segmentation and registration of structures are gaining importance due to the increasing demand of automated image enhancement and understanding. Especially in medicine and life science, assistance systems could have a large impact on diagnosis, treatment and quality control. Dye driven procedures, such as fluorescence imaging with Indocyanine green (ICG), are nowadays indispensable because they enhance contrast, reveal structures and deliver the operator with important information. The contact free ICG angiography is providing the surgeon spatial and temporal information on blood flow within a vessel. The processing of those information is done manually or semi automated but is very helpful for the surgeon. Extending the degree of automatism, the amount of information processed and even augment or transfer it into another domain could deliver the operator useful support and improve surgical work flow. Using, analyzing and transferring those information from ICG-IR domain into the RGB domain is the focus of this project. We are introducing a vessel registration method in the RGB domain driven by the spatial fluorescence behavior of the vessel in the ICG-IR domain. The method includes Superpixel based segmentation of the vessel in the ICG-IR domain, the spatial gradient based transfer and registration in the RGB domain and the continuous segmentation of the vessel in a RGB video. This paper show a proof of concept of the method. The results show an successful inter domain information transfer and registration of the vessel. Further tracking of the vessel over all frames is possible. Nevertheless limitations are revealed and discussed.

Keywords: Intraoperative, Segmentation, Registration, Vessel, ICG

1 Introduction

The increasing digitization in medicine and life science enables new possibilities in assisting the operator. The intraoperative optical registration of vessels in surgical scenes could provide the surgeon useful information on the vessels location and automatically determine its geometry and function. In neuro vascular surgeries often Indocyanine green (ICG) is used as a dye and an Infra Red (IR) camera is used to visualize it. ICG binds to the proteins in the blood plasma, emits in the IR spectral band and therefore can be used to visualize blood within a vessel without any contact [1] [2]. This procedure is for example used in aneurysm clipping to detect vessel compromise by the clip or continues aneurysm filling due to incomplete clipping. The provided information is crucial to ensure correct clipping and patient safety. But this procedure is providing much more, it is virtually a segmentation of the vessel since the ICG is only dissolved in the blood plasma. This chemical and physical property and the accompanied possibilities are not exploit so far. Our approach is to use this information in the ICG-IR domain, transfer it into the RGB domain to register the vessel and track it over time. Once a vessel is correctly recognized other parameters such as its geometry can be calculated and it can be detected and tagged within the surgery.

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2 Methods

The proposed method is split into three parts. The segmentation of the vessel in the ICG-IR domain, the initial registration of this segmentation in the RGB domain and the continous detection of the structure in the RGB domain. Figure 1 shows a flowchart illustrating the algorithm. In the following it is applied to a frame of an publicly available video showing an cerebral aneurysm. The video has an resolution of 560*470 pixels, consists of 85 frames recorded with a frame rate of 25 fps. The aneurysm and the recording system do move slieghtly in the video. [3]

2.1 Segmentation in the ICG-IR domain

First of all, a frame is taken from the video containing the ICG-IR records of the aneurysm, this frame is shown in figure 2. Superpixel analysis is applied to the frame to form areas of homogeneous intensity [4]. As shown in figure 3 the mean of each area is calculated and set for all pixels of the area. An intensity threshold is applied to segment the areas containing a high fluorescence signal. In the same figure the border of the segmented area is shown in the color cyan.

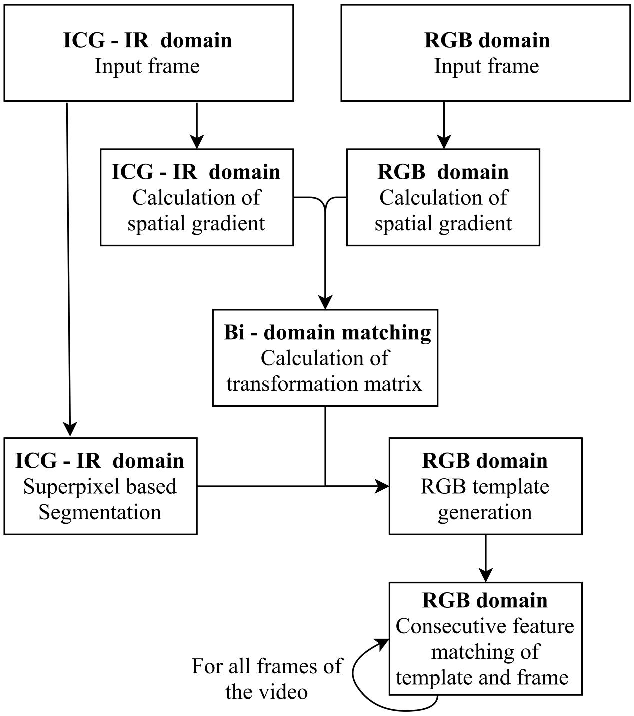

Fig. 1: Flowchart illustrating the algorithm

2.2 Registration of ICG-IR segmentation in the RGB domain

After segmenting the vessel in the ICG-IR domain the translation of the segmentation from ICG-IR to the RGB domain is needed.

This is done using some assumptions. First of all the tissue needs to be homogeneously illuminated, in the ICG-IR and in the RGB domain. IR radiation can penetrate tissue of several mm of thickness, it is possible to register vessels in the ICG-IR domain which are concealed in the RGB domain. We assume that the vessels are visible and in focus in the RGB domain. Distortions or different viewing angles can disturb the translation of information. We assume the recordings are done with the same viewing angle with little tolerance.

To prepare the translation of information first the spatial gradient of the frames in both domains are calculated using the Prewitt operator. The resulting gradient image of the into grayscale transformed RGB frame needs to be cleaned from gradients resulting from reflexes. Therefore all pixels of black and white areas in the RGB frame are set to zero in the gradient image. Now we have comparable measures in both domains and the registration and computation of the transformation matrix of the ICG-IR domain and RGB domain are done by maximizing the mutual information [5]. Knowing the rigid transformation from ICG-IR to RGB domain, the segmentation obtained in the previous chapter (2.1) can be translated into the RGB domain and a new template is created (see figure 6).

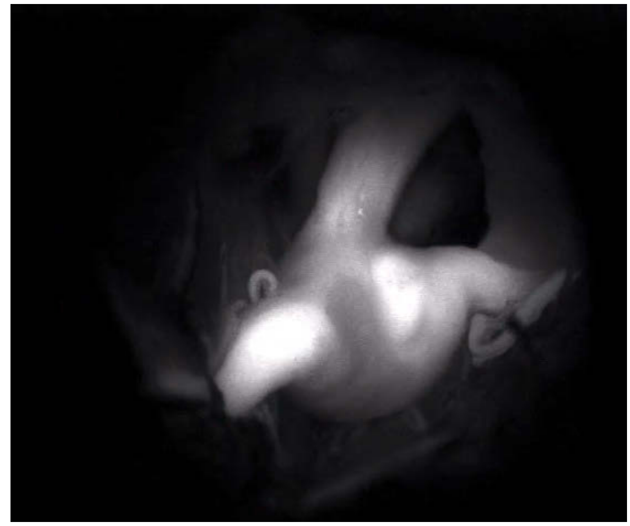

Fig. 2: ICG input frame

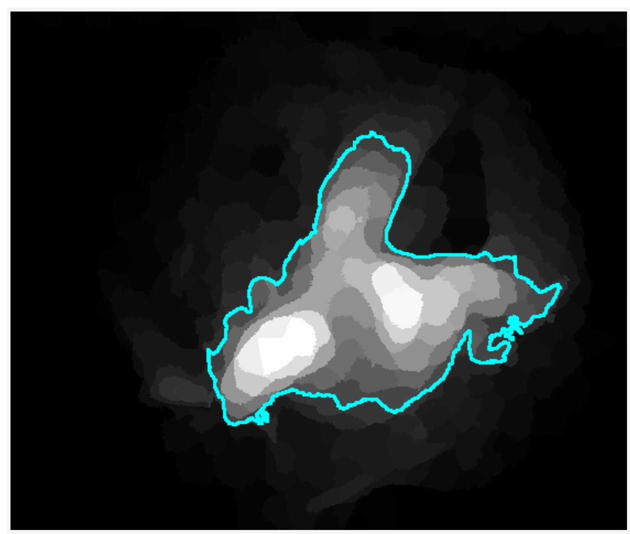

Fig. 3: Mean of Superpixels in ICG domain

2.3 Continuous detection of the vessel in the RGB domain

Since we have accomplished the translation of the location of the vessel from ICG-IR to RGB the successive registration of the vessel template in each RGB frame is needed. This is done by feature matching of the template and the frame. In this case the KAZE feature is used [6]. Other features or a combination can be used to adapt to different typologies of vessels. The feature matching results in an individual transformation matrix for each frame. The boarder of the template can be visualized as seen in figure 5. This matching is running in a loop for each frame of the recorded RGB Video.

2.4 Evaluation method

The evaluation is done by calculating the Sørensen - Dice coefficient (see equation 1) of the automated segmentation and a manual segmentation. Since manual segmentation of all frames is not practicable every 20 frames a evaluation is done.

$$DSC(A,B) = \frac{|\, A \cap B \,|}{|\, A \cup B \,|} \tag{1}$$

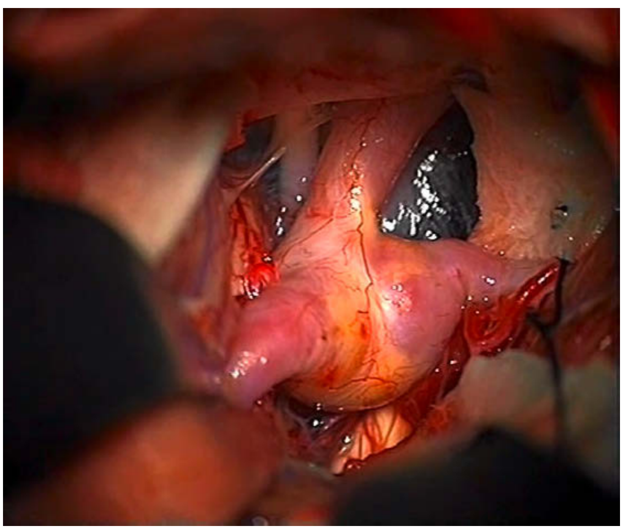

Fig. 4: RGB input frame

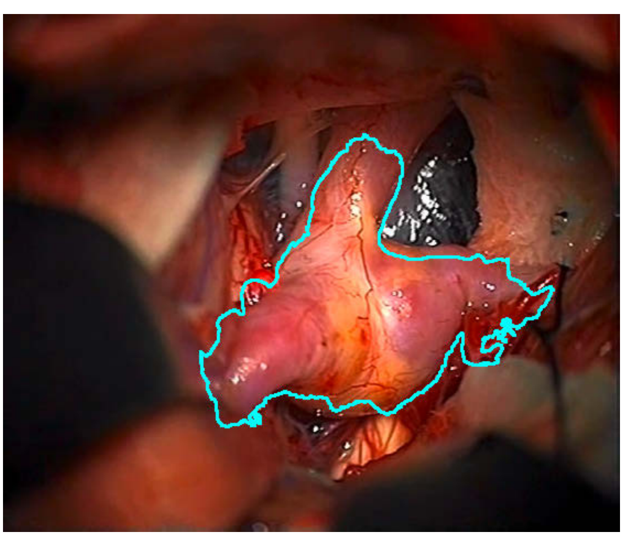

Fig. 5: RGB segmentation result

3 Results

The proposed algorithm is applied to a video but a single frame is taken to demonstrate the results in the following figures. In figures 2 and 4 we see the initial ICG-IR and RGB domain frames. Figure 5 shows the result after going though the method of section 2.1. The cyan line is the border of the segmentation and the mask is set to logical one within that area. After the registration of the gradient images of both domains the resulting transformation matrix is applied to the template in the ICG-IR domain and a new template in the RGB domain is computed, the new template is shown in figure 6. We would be finished in the case of a single image registration. In the case of a video the proposed feature matching in section 2.3 is done to localize the template robustly in each frame.

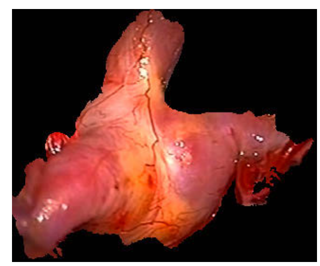

Fig. 6: Computed RGB Template after bi - domain matching

4 Evaluation

The evaluation method is described in section 2.4 and used on 4 frames (1st, 20th, 40th and 60th). The resulting Sørensen - Dice coefficient of the four mentions frames and their mean are shown in the table 1. In figure 7 the overlay of the manual and automatic segmentation are demonstrated for the 20th frame. White colored are the matching pixels, in pink the pixels segmented in the manual but not in the automatic segmentation and in green the pixels segmented in the automatic but not in the manual segmentation.

Tab. 1: Sørensen - Dice coefficient for the segmentation results

Frame	Sørensen - Dice coefficient
1	0.8313
20	0.8342
40	0.8177
60	0.8169
Mean	0.8252

Fig. 7: Comparison of manual and automatic segmentation

5 Discussion

The translation of information from the ICG-IR to RGB domain is done. The evaluation shows with a Sørensen - Dice coefficient of 0.8252 similarity of the ground truth (manual) and the automatic segmentation. A perfect match would result in a coefficient of 1. The data we are working on violates our assumptions of section 2.2. We do have different viewing angle in both domains. Further the ICG - IR video is not homogeneously illuminated and therefore the three vessels have different gray values which results in a cropped segmentation. Lastly there are fluorescent structures in the ICG - IR image which are not included in the manual segmentation. This exposes, that the factor of human manual segmentation leads to a more accurate segmentation in the case of not well illuminated areas and to a under segmentation in the case of the tiny blood supplied branches on the aneurysm. All the mentioned factors reduce the Sørensen - Dice coefficient in the case of not fulfilling the mentioned assumptions.
Nevertheless, this approach combines two domains to enhance image information content and assists the user in recognizing objects.

6 Conclusion

The segmentation of intraoperative images and videos supports the approach towards including assistance systems to medical devices such as surgical microscopes. We propose a method to translate spatial information from the ICG-IR to the RGB domain and tracking the structure of interest continuously in the RGB domain. This transformation of information reveals new possibilities in processing video data of two recording domains. The algorithm further tracks the transformed information in the new domain and can, on demand, provide constantly the user with useful information.
Evaluation was done with one set of data, further statistical investigations require a larger set of data. New data sets should fulfill our assumptions of section 2.2 as good as possible. Moreover the presented algorithm will be developed to enhance the robustness. It will be extended by an adaptive RGB domain template once the information is transferred. This will result in a more reliable registration. Detecting multiple structures separately in the RGB domain is as well an useful extension.

Author Statement

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