Toward Robust Myocardial Blush Grade Estimation in Contrast Angiography

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Abstract. The assessment of Myocardial Blush Grade after primary angioplasty is a precious diagnostic tool to understand if the patient needs further medication or the use of specifics drugs. Unfortunately, the assessment of MBG is difficult for non highly specialized staff. Experimental data show that there is poor correlation between MBG assessment of low and high specialized staff, thus reducing its applicability. This paper proposes a method able to achieve an objective measure of MBG, or a set of parameters that correlates with the MBG. The method tracks the blush area starting from just one single frame tagged by the physician. As a consequence, the blush area is kept isolated from contaminating phenomena such as diaphragm and arteries movements. We also present a method to extract four parameters that are expected to correlate with the MBG. Preliminary results show that the method is capable of extracting interesting information regarding the behavior of the myocardial perfusion.

Keywords: Medical Imaging, Tracking, Optical Flow, Myocardial perfusion, Myocardial Blush Grade, Primary Angioplasty.

1 Introduction

Primary angioplasty is the most effective way to re-establish a normal flow in an obstructed artery after an acute myocardial infarction. This medical intervention aims at recover a proper coronary flow into the obstructed artery. Physicians localize the artery by visual inspection of a contrast angiography. However, even in a successful primary angioplasty, it can happen that an adequate irrigation on the area subtended by the affected artery is not optimal. In this area, the microcirculation could be not sufficient even after a successful primary angioplasty, thus compromising in a serious way the long term patient survival [1].

The physicians are able to ascertain with enough precision if the normal flow in the unblocked artery has been really recovered by observing pre and post intervention angiographies. To do this, physicians inject a contrast liquid into the

H. Araujo et al. (Eds.): IbPRIA 2009, LNCS 5524, pp. 249–256, 2009.
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artery that is visible in the x-ray angiography. A major difficult arises when medical doctors try to determinate if the myocardial perfusion has been recovered in a sufficient way or not. The different levels of myocardial perfusion have been standardized using a subjective score called Myocardial Blush Grade (MBG) [1]. The evaluation of the MBG requires the visual assessment of the contrast liquid quantity in the area subtended by the infarcted artery. The assessment of myocardial blush grade is a very difficult task which requires medical doctors with high expertise and training. Only expert medical doctors achieve an observer agreement and a low variability between subjective judgments [2]. The MBG helps to diagnose critical situations that prompt the use of specific drugs and medications [3]. An adequate estimate of the myocardial blush grade can be useful to improve the prognosis of the coronary patients due to its impact on the long term morbidity and mortality [4,5]. Moreover it can be useful for researchers in testing innovative pharmacological approaches and study of new invasive procedures for the myocardial perfusion treatment. In this paper we present and discuss a computer vision methodology for Myocardial Blush Grade **objective** measurement with the aim of creating a tool able to assess the MBG in a semi-automatic way.

2 Previous Work

At the best of our knowledge, only one paper on MBG estimation by means of computer vision has been published. The work in [6] calculates objective descriptors of myocardium staining pattern in order to define an objective score of the myocardial perfusion. The method analyzes image local statistics and tries to discriminate among different phenomena observed in the angiography. The phenomena present in the contrast angiography (contaminating the myocardial perfusion signal) are: x-ray noise, breathing (diaphragm movement) and heartbeat (arteries movement). The method in [6] aims at separate these phenomena by sampling the average gray-scale value of 4 different squares in the angiography video. One square is placed on the blush area, another on a boundary of the diaphragm, the third on a artery and the last one on a noisy area where no other signals are present. In our opinion, the method has several flaws. Firstly, the average gray-scale level measurement is prone to mix different phenomena if the four squares are placed inaccurately; this requires that the user checks the squares positions along the whole video. This tedious procedure cannot be used in real clinic cases and it affects importantly the repeatability of the method. Secondly, the estimation of the MBG is based on spectral analysis on a predefined set of frequency ranges selected with the aim of separate each phenomenon. While this could be reasonable for the diaphragm movement, artery movement and noise, where the signal is expected to be periodic, it is somehow incorrect for the analysis of microcirculation opacity, that is expected to vary in a non periodic way.

3 Proposed Method

The proposed method requires that the physician selects the blush area. Then the method, using an optical flow technique, tracks the blush area during the whole video. On the other side, a simple technique is used to detect the contrast liquid into vessels. This detection is necessary to discard the image pixels that describe the macro-circulation into the arteries, while keeping the information regarding the microcirculation. Once the pixels representing the blush area (but without the vessels) are computed, the method measure the opacity variation by means of the gray level variation during the video. Finally, the method extracts relevant parameters that summarize the behavior of myocardial microcirculation.

3.1 Detection of the Blush Area

Selecting the right blush area into a contrast angiography sequence is a complex task. Physicians must look at the angiography several times to determine the blush area and select the best angiographic projection. For this reason, we do not propose any methodology aimed at automatically detect the blush area. The physician is asked to tag the blush area on only one frame of the angiography sequence (Figure 1 shows an example of tagged blush area).

Fig. 1. Frame of the angiography sequence with the blush area duly demarcated by a physician

3.2 Tracking by Optical Flow

To estimate the apparent motion of objects in the angiography video, we use the optical flow technique described in [7]. Using the optical flow technique, we can calculate the displacement field in the angiography (see Figure 2 for an example). Despite the x-ray noise in the angiography video we noticed that the optical flow estimates the diaphragm and heart movements in a consistent way. In this way, we can estimate the position of the blush area on all the frames in the angiography starting from the frame tagged by the physician. This tracking permits to avoid that the diaphragm and coronary artery can enter the blush

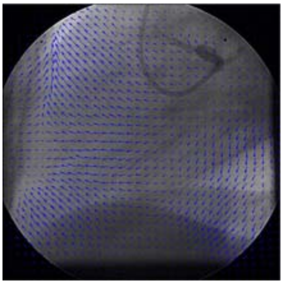

Fig. 2. An example of displacement field obtained using the optical flow technique

area thus corrupting the measurement of blush area opacity. As a consequence, our approach does not have to discriminate between different phenomena using a spectral analysis method on different signals. Moreover, performing the measurement from a wider area (with respect of a small fixed square) gives a more reliable signal that is also less prone to errors induced by the x-ray noise. However, up to now, one limitation of the proposed methods is that the tagged frame should present a blush area isolated from the diaphragm (see Fig. 1). In this unwanted case, the optical flow cannot detect the movement at the blush area boundary because it is located in the internal part of the diaphragm where the apparent movement is almost null.

3.3 Vessel Detection

The vessel detection has been devised using gray-scale morphology. We create a map $M_t(x, y)$ to highlight the vessels as following:

$$M_t(x, y) = (I_t \bullet SE)(x, y) - I_t(x, y) \tag{1}$$

where '$\bullet$' is the gray-scale closing operator and SE is a flat structuring element, more precisely a disk of 8 pixels radius. After this, we define the set $V(t)$ of pixels belonging to a vessel at frame t as following:

$$V(t) = \{(x, y) \mid M_t(x, y) > thr, (x, y) \in \mathcal{I}\} \tag{2}$$

where $\mathcal{I}$ is the spatial support of the image $I_t(x, y)$ and thr is a threshold parameter. The setting of the threshold thr has been done using the method in [8]. An example of this procedure is shown in Figure 3. This vessel detection method is sufficiently accurate. However, the results are not completely satisfactory, thus this point will be further investigated in future papers.

3.4 Measuring Opacity in the Blush Area

After obtaining a good estimation of the blush area on each frame of the video, we can estimate its opacity. The increase of the opacity in the blush area is

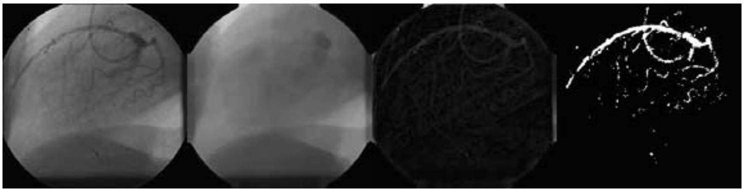

Fig. 3. From left to right: an input frame I_t, the closing of the input image with the structuring element SE, the map $M_t(x, y)$ and finally the map of detected pixels in the set $V(t)$

caused by the flooding of the contrast liquid in the microcirculation. Measuring this opacity is an indirect way to measure how much of the contrast liquid reached the microcirculation thus it is an indirect way to measure the blush grade. Intuitively, the lower the gray value in the angiography, the higher the opacity. We describe the gray-scale value of a frame at time t and at pixel position (x, y) as $I_t(x, y)$. Being $\Omega(t)$ the set of pixels inside the estimated blush area at the frame t, we compute the average gray-scale $g(t)$ during the whole angiography video as following:

$$g(t) = \frac{1}{|\Omega(t) \setminus V(t)|} \sum_{(x,y)\in\Omega(t)\setminus V(t)} I_t(x, y) \tag{3}$$

The average gray-scale value is computed using the set of pixels in the blush area ($\Omega(t)$) that not belongs to vessels ($V(t)$). This measurement can vary importantly if the settings of the x-ray machine are changed. As an example, if the contrast of the image is enhanced, the variation of $g(t)$ will be higher than in a case in which the x-ray image has a lower contrast. Moreover, the contrast can change during the angiography. We thus compute the standard deviation of the image gray-scale values during the whole video:

$$\sigma(t) = \sqrt{\frac{1}{N} \sum_{(x,y)\in\mathcal{I}} (I_t(x, y) - \overline{I_t})^2} \tag{4}$$

where N is the number of image pixels and $\overline{I_t}$ is the average gray-scale value of the frame at time t. Finally, we define the normalized gray-scale blush area signal as:

$$ng(t) = g(t)/\sigma(t) \tag{5}$$

3.5 Extraction of Blush Parameters

In an ideal case, if the medical doctor does not inject the contrast liquid, our measurement $ng(t)$ should be constant. When the medical doctor injects the contrast liquid, in cases in which the microcirculation is sufficiently good, we expect the opacity to increase temporarily and then return to its previous value (when the contrast liquid is not present anymore). This expectation translates to a temporal decrease of the average gray-scale value, followed by an increase to the initial value. Figure 4 (a) shows the ideal expected behavior. Then the question is: how to extract the useful information from $ng(t)$ to infer the MBG? To this aim we describe the expected ideal signal as following:

$$i(t) = k - a \cdot \exp\left(-\frac{(t-t_G)^2}{2\sigma_G^2}\right) \tag{6}$$

where k represents the constant gray-scale value if no contrast liquid is injected; a represents the peak amplitude of the Gaussian, thus the peak of the opacity during the video; t_G represents the center of the Gaussian, thus providing the instant in which the opacity is maximal; finally, σ_G represents the temporal extent of the Gaussian, thus providing information on the duration of the contrast liquid flooding in the microcirculation. Once we obtain the signal $ng(t)$ (as in Figure 4 (c)) we can estimate the parameters by minimizing the L^2 norm between $ng(t)$ and $i(t)$ as following:

$$\{k, a, t_G, \sigma_G\} = \arg \min_{k,a,t_G,\sigma_G} ||i(t) - ng(t)|| \tag{7}$$

Since this minimization requires a non-linear regression [9], the parameter initialization is important. A bad parameter initialization can lead the minimization algorithm to fall in a local minima. Thus we set the initial solution as following:

$$k \equiv \mu(ng(t)) \tag{8}$$

$$a \equiv \mu(ng(t)) - \min_t(ng(t)) \tag{9}$$

$$t_G \equiv \arg\min_t(ng(t)) \tag{10}$$

where $\mu(\cdot)$ is the average operator. Fortunately, once set the above defined three parameters, the standard deviation σ_G is not critical for the convergence of the minimization algorithm to the global minima in equation (7). Figure 4 (d) shows the fitting for the signal in Figure 4 (c); in this case the resulting fitting parameters are $k = 1.35$, $a = 0.13$, $t_G = 2.5s$ and $\sigma_G = 1.17s$.

4 Preliminary Results

To show the advantage of a tracking method for measuring the blush area opacity, in Figure 4(b) we plot the mean gray level temporal variation calculated on the blush area but without applying any optical flow technique. Figure 4(c) shows the measurement obtained for the same video, same blush area, but adapting the blush area during the video according the optical flow based tracking.It is clearly visible that, thanks to the tracking, the artifact induced by the diaphragm movement (which period is of $2.6s$ approximately) has been completely removed while small oscillations are still present, probably due to contrast liquid flow in a vessel inside the blush area that has not been properly detected.

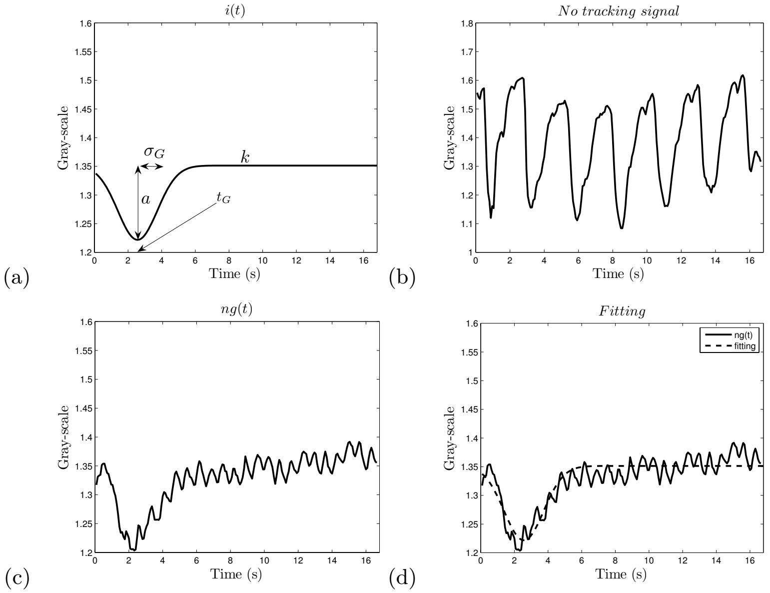

Fig. 4. Gray level variation curve as a descriptor of myocardial staining during an angiography: (a) ideal (b) static blush zone (c) adaptable blush zone using optical flow and (d) curve fitting

5 Conclusion and Future Works

In this paper we proposed a methodology to measure the blush area opacity. To this aim we track the blush area during the video by using an optical flow technique. The vessels are detected and removed not to influence the measurement of microcirculation. This detection has been performed using gray-scale morphology operators. The measured signal is then approximated using a predefined model which parameters summarize the behavior of the contrast liquid in the microcirculation. As above discussed, this paper shows very preliminary results of our research. Future works encompass: (1) the validation of the fitting model and, if necessary, its extension to a more powerful model; (2) the analysis of the correlation between the model parameters and the MBG on a large set of clinical cases; (3) the development of a method to detect and track the diaphragm with the aim of extending the level of automation of the method and, at the same time, increasing the robustness of the whole methodology; (4) refining the vessel detection using more performing algorithms and exploiting the temporal coherence using the displacement field to improve vessel detection.

Acknowledgments

This research is/was supported in part by the projects TIN2006-15308-C02, FIS PI061290, CONSOLIDER-INGENIO 2010 (CSD2007-00018), MI 1509/2005.

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