Myocardium Segmentation Improvement with Anisotropic Anomalous Diffusion Filter Applied to Cardiac Magnetic Resonance Imaging

Antonio Carlos da S. Senra Filho[1], Gustavo C. Barizon[1], Luiz O. Murta Junior[1]

[1] University of São Paulo, Ribeirão Preto, Brazil

Abstract

Cardiologic magnetic resonance imaging (MRI) has recently been improved by faster acquisition and higher resolution hardware. Commercially available MRI equipment is able to capture contrast agents with the needed time and space definition to map myocardial viability. MRI myocardial imaging has an emerging role in cardiology studies, and it has experienced a crescent relevance in clinical investigations. Although MRI has potential for clinical investigation and application, an efficient digital filter is needed in order to allow robust myocardial segmentation. This paper proposes anisotropic anomalous diffusion (AAD) filtering to reduce noise levels while preserving myocardial traits. The proposed AAD filter follows the porous media equation consistent with inhomogenous complex media, and thus appropriate to model biological systems. In this study, the porous media equation together with gradient driven diffusion has been applied to digital image smoothing. Eleven MRI T1 weighted cardiology images were used hereby to evaluate both the AAD and classical Gaussian filter in a segmentation pipeline. in order to study the filtering application in a automatic segmentation algorithm (Geodesic Active Contour). The myocardial area, i.e. epicardic and endocardic border, was delineated with both the AAD and Gaussian filter. We calculated the root mean square error, when compared to the manual traces, to measure automatic segmentation quality. The AAD filter show a significant segmentation accuracy enhancement ($p < 0.001$), while no significant difference was found between the AAD filtered and manually segmented images. The findings suggest that AAD filtered image segmentations have similar reliability to manual segmentation.

1. Introduction

The advances in medical imaging hardware lead to increased spatial and temporal resolution. Following the advance in instrumentation , the image processing filtering is growing in many diagnostic image modalities and has a crucial importance in studies such as oncology [1], brain diseases [2] and cardiology applications [3]. Recently, cardiac MRI imaging protocol has been highly improved due to faster imaging acquisition and higher spatial resolution [4]. Therefore, there is a emergent necessity for efficient methods of image processing in this special type of image.

The anomalous diffusion theory, described by the generalized Fokker-Planck equations [5], are partial differential equation that have been applied in recent years to several applications in Physics, Economics and other areas of knowledge [5]. In particular, the porous media equation[5, 6] has been applied to digital images smoothing [7] with the formulation of anisotropic anomalous diffusion (AAD) filtering obtaining promising results especially with medical imaging denoising. Previous studies suggest that the anomalous distribution paradigm is more suitable for the study of diffusion behavior in media with high complexity features [5, 8].

There are several imaging techniques in MRI that could provide a crucial relevance to biomedical image diagnostic. A very powerful MRI application is in cardiology studies that has grown in recent years with faster image acquisition and better voxel resolution [4]. However, after the image acquisition, some diagnostic measurements are performed with manual tracing. One of those manual task is the miocardial segmentation, i.e. endocardium and epicardium, that is an important evaluation for tissue diagnostic. Some automatic approaches have been proposed for area calculations, but with limited success [4].

Our study intends to apply the AAD filter to the cardiology MRI protocol to improve automatic miocardic area measurement. We evaluated the use of AAD filter as a smoothing step previous to segmentation that could provide a better accuracy for this type of measurement. In this evaluation we verified the ability of AAD filter in reducing both the time necessary to perform the manual method and the human error intrinsic to the manual process.

1.1. The anomalous filtering method

The anomalous diffusion filters are defined from the porous media equation [5, 6], to which we can assign the anisotropic anomalous diffusion method (AAD). The AAD filler formulation is shown in Equation (1), where it is in the discrete forms.

.

$$I_{\phi,t+1} = I_{\phi,t} + \left[D_q(\overrightarrow{r},t).\nabla^2 I_{\phi,t}^{(2-q)}\right] \qquad (1)$$

Where $I(\overrightarrow{r},t)$ represents the image pixel intensity at position $\overrightarrow{r}$ and time t. The $D_q(\overrightarrow{r},t)$ parameter represents the generalized diffusion coefficient that is a fusion between the generalized diffusion coefficient, Equation (2), and the stop edge function [9], as seen in Equation (3).

$$D_q = \begin{cases} \frac{1}{2}.\alpha^{\frac{2}{3-q}}.\left(\sqrt{\frac{(1-q)}{\pi}}.\frac{\Gamma(1+\frac{1}{1-q})}{\Gamma(\frac{3}{2}+\frac{1}{1-q})}\right)^{\frac{2-2q}{3-q}} & q < 1 \\ \frac{1}{2}.\alpha & q = 1 \\ \frac{1}{2}.\alpha^{\frac{2}{3-q}}.\left(\sqrt{\frac{(q-1)}{\pi}}.\frac{\Gamma(\frac{1}{q-1})}{\Gamma(\frac{1}{q-1}-\frac{1}{2})}\right)^{\frac{2-2q}{3-q}} & 1 < q < 2 \end{cases} \qquad (2)$$

$$D_q(\overrightarrow{r},t) = D_q.exp(-|\nabla I(\overrightarrow{r},t)|^2/\kappa^2) \qquad (3)$$

Where $\alpha = (2-q)(3-q)$. For $q \neq 1$, Equation (2), the D_q parameter represents the generalized diffusion coefficient consistent with *q-Gaussian* probability distributions [5]. From the q parameter settings of the generalized diffusion coefficient, anomalous filters are defined and can be applied in digital image. For $q > 1$ we obtain a long range probability distribution, with infinite support, and for $q < 1$ we obtain a probability distributions of finite support, which are bounded by certain cutoffs [5]. Each distribution has its characteristic noise attenuation, and for $q > 1$ are reported in some studies as more efficient for some MRI medical imaging modalities [7, 10].

Two key parameters for adjusting the AAD filters are: the q parameter and the generalized diffusion coefficient (D_q) parameter. For the q parameter, we can use the values of $0 < q < 2$, due to algorithm stability problems when it is applied to digital images [10]. The q parameter is responsible for determining the probability distribution which is used throughout the filtering process. For $q = 1$ we return to the normal distribution, which returns to the classical filtering paradigm, and $q \neq 1$ uses the *q-Gaussian* distributions [5]. As for the generalized diffusion coefficient, D_q, we use the Equation (2) to define the local maximum intensity. Equation (2) informs the chosen probability distribution and it has the same definition as found for the Perona and Malik filter [9] when $q = 1$.

2. Materials and Methods

The time t and the generalized diffusion coefficient D_q parameters were fixed to $t = 5$ and $D_q = 1$, respectively. These values were chosen to generate a *q-Gaussian* probability distribution with standard deviation suitable for smoothing with minimal distortion in the images [10]. The anomalous parameter, called the q value, was set up to $q = 1.3$, which demonstrate a good filtering performance when it is applied in T1 weighted magnetic resonance imaging [10].

We used T1-weighted MRI images in this study in a 3 Tesla (3T) MRI tomograph, echo planar image (EPI) acquisition technique, TE/TR 1.64 ms/3.67 s, flip angle of 45^o, spatial resolution of 1.41×1.41 mm per pixel, and 10 mm spacing between slices. Only the slice that has the diastolic position was used for the endocardic and epicardic region. The image orientation was set to short axis planes. No contrast agents were used here. Eleven images, from different patients, were selected for this study.

The miocardial area, i.e. epicardial and endocardial tissue borders, was used as a quality measurement to infer the segmentation quality. The miocardial area was calculated after the image segmentation performed by the geodesic active contour algorithm [11].The myocardium segmentation was done with ITK and VTK image processing tools. The ITK (Insight Toolkit) is a multi platform that provides developers with a comprehensive set of software tools for analysis, segmentation and image registration. The VTK consists of a library that provides a set of tools for scientific visualization and has also been used for 2D and 3D image visualization. The Figure 1 shows the major components involved in the application of the Geodesic Active Contour to a segmentation task. The manual segmentations were made, with inter subjects, for statistical comparison with the automatic segmentation. All the manual segmentation measurements were calculated using the original image, i.e. no filter was used for the area manual estimation. The root mean square error (RMSE) was used to study the area measurement variation between the automatic segmentation and the manual segmentation.

3. Results and Discussion

Following the segmentation procedures, we obtain the myocardium area that are show in Table 1. It can be seen that the AAD spatial filter application promotes better accuracy in border location, both in internal and external region of the myocardium. When the area values were obtained by segmenting the original image (without filter application), we noted that there are some segmentation errors, as seen in Figure 2. The pixel intensity fluctuation representing the noise and the natural tissue contrast results in uncertainty about border location that implies in segmentation error. Even with the high spatial resolution and signal noise ratio provided by the T1 weighted image, the non use of a noise suavization process would bring error to the area measurement.

For comparison reasons, we performed manual area seg-

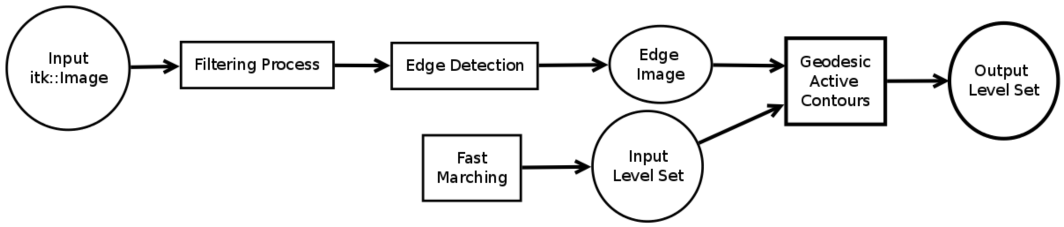

Figure 1. Diagram for the Geodesic Active Contour applied to a miocardial segmentation task. Input image for segmentation can be chosen as a filtered image, with AAD or Gaussian filters, or raw image. The image resulting from this process is the micardial segmented image as shown in Figure 2.

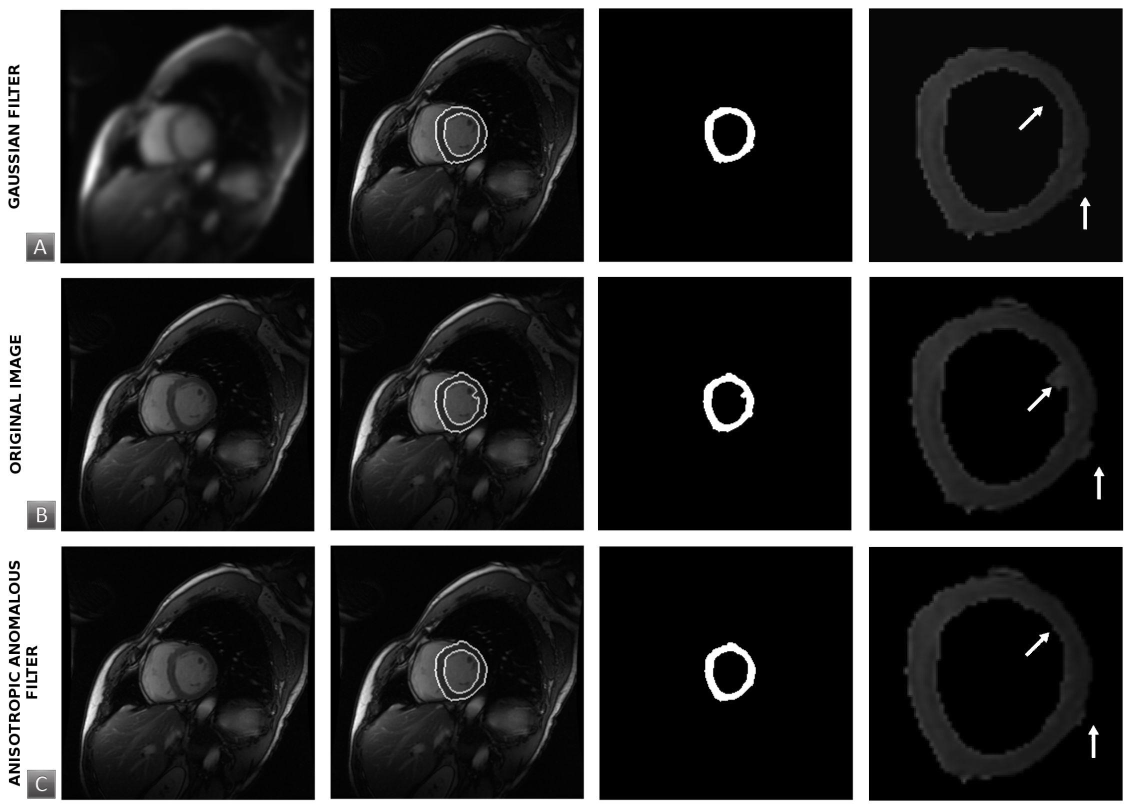

Figure 2. Miocardic segmentation in the short axis of an MRI image with the AAD filter, Gaussian filter and the original image. All the results are show in a row, where it has the same order: filtered image, miocardic segmentation, area segmented and a miocardic segmented amplification, respectively. A) Gaussian filtering, B) Original image without any filtering application, and C) Anisotropic anomalous diffusion filtering. See the white arrows that are pointing to a better local region segmentation.

mentation and measurements which obtained the value of $a_{manual} = 1172.42 \pm 146.64$. The RMSE values are shown in Table 1 and also the area values obtained with the application of spatial filters, which had better area estimation, in comparison with the manual approach. It is observed that the AAD filter is statistically equivalent to the manual approach ($p < 0.001$) that is not seen with the other two methods, with and without filter application.

The filtering performance obtained with the Gaussian filter got similar results in comparison with the real estimated value, obtained manually. However, the spatial filtering approach show less precision, given by the standard deviation, where it demonstrates low filtration efficiency due to the intense blurring on the entire image. The Figure 2 illustrates the case of the Gaussian filter, which strongly distorts the structures contained in the image. On the contrary, the AAD filter obtained a better edge preservation between the image structures and also decreased the noise level, conducting a more accurate segmentation process that are equivalent to what is obtained with manual segmentation ($p < 0.001$).

Table 1. Area measurements

Filter	Area (a.u.)	RMSE
Original	1470.89 ± 192.07	17.26 ± 4.70
AAD	1264.22 ± 164.44	9.58 ± 4.45
Gaussian	1346.55 ± 199.09	13.19 ± 4.76

The RMSE values found for the Gaussian filter show the lesser accuracy provided by this classic filtering. The edge deterioration and strong blurring provided by the Gaussian approach reflects in a higher RMSE value. As previously seen, the AAD filter show a better filtering performance, thus a better RMSE measurement. The local smoothing approach, with anomalous distribution, reveals robustness for cardiology MRI images and the area measure.

4. Conclusion

Manual segmentation of the myocardial region is a time consuming task with high inter and intra subject variability. Automatic segmentation algorithms are alternative approaches to decrease time necessary to segmented the miorcadial area. However, a low noise filtered image is necessary to guarantee robustness and reliability in segmentation. In this study, we observed that when the classical Gaussian filtering process is used we have lower accuracy and segmentation quality than seen with the anisotropic anomalous diffusion (AAD) filter. Its effect is mainly due the intense blurring and edge deterioration provided by the Gaussian blurring process. The segmentation results, with the AAD filter, show a significant area measure enhancement ($p = 0.001$), that could be compared with the manual segmentation. Therefore, our findings suggest that one can use automatic segmentation with reliability similar to manual tracing when using the AAD filter.

Our preliminary experiment has shown promising results for the use of AAD filter in the automatic myocardic area measurement. The research for computational tools that provide better accuracy, robust and achievable results has been in accelerate growth. The AAD filter is still a new technique and further studies will be performed in future research with cardiology MRI images in order to analyze this important imaging technique with more details.

Acknowledgements

The authors would like to thank CAPES for the financial support to this research project.

References

[1] Roy B, Gupta RK, Maudsley Aa, Awasthi R, Sheriff S, Gu M, Husain N, Mohakud S, Behari S, Pandey CM, Rathore RKS, Spielman DM, Alger JR. Utility of multiparametric 3-T MRI for glioma characterization. Neuroradiology May 2013;55(5):603–13. ISSN 1432-1920.

[2] Shiee N, Bazin PL, Ozturk A, Reich DS, Calabresi PA, Pham DL. A topology-preserving approach to the segmentation of brain images with multiple sclerosis lesions. NeuroImage 2010;49(2):1524–1535.

[3] Montillo A, Metaxas D, Axel L. Segmenting cardiac MRI tagging lines using Gabor filter banks. In Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No.03CH37439), volume 1. IEEE. ISBN 0-7803-7789-3. ISSN 1094-687X, 2003; 630–633.

[4] Petitjean C, Dacher JN. A review of segmentation methods in short axis cardiac MR images. Medical image analysis April 2011;15(2):169–84. ISSN 1361-8423.

[5] Tsallis C. Introduction to Nonextensive Statistical Mechanics: Approaching a Complex World. Springer, 2009. ISBN 0387853588.

[6] Schwämmle V, Nobre FD, Tsallis C. q-Gaussians in the porous-medium equation: stability and time evolution. The European Physical Journal B December 2008;66(4):537–546. ISSN 1434-6028.

[7] Senra Filho ACS, Murta Junior LO. Anisotropic anomalous filter as image enhancement method to nuclear magnetic resonance diffusion weighted imaging. Masters degree theses, University of São Paulo, 2013.

[8] S. De Santis MB, De Santis S, Gabrielli A, Bozzali M, Maraviglia B, Macaluso E, Capuani S. Anisotropic anomalous diffusion assessed in the human brain by scalar invariant indices. Magnetic resonance in medicine official journal of the Society of Magnetic Resonance in Medicine Society of Magnetic Resonance in Medicine April 2011;65(4):1043–52. ISSN 1522-2594.

[9] Perona P, Malik J. Scale-space and edge detection using anisotropic diffusion. IEEE Trans Pattern Anal Machine Intell 1990;12(7):629–639.

[10] Senra Filho ACdS, Duque JJ, Murta LO. Isotropic anomalous filtering in Diffusion-Weighted Magnetic Resonance Imaging. In Society IEiM, Biology (eds.), 2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). Osaka, Japan: IEEE. ISBN 978-1-4577-0216-7, July 2013; 4022–4025.

[11] Ranganath S. Contour extraction from cardiac MRI studies using snakes. IEEE transactions on medical imaging January 1995;14(2):328–38. ISSN 0278-0062.

Address for correspondence:

Antonio Carlos da S. Senra Filho
Av. Bandeirantes, 3900, 14040-901 - Ribeirão Preto, São Paulo, Brazil
acsenrafilho@usp.br