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Usefulness of cutting planes in the hierarchical segmentation of cardiac anatomical structures

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Abstract. A spatial geometric plane is defined by the three-dimensional coordinates of a pair of spatial points and the direction that the normal vector establishes, which is formed by joining those points by means of an oriented line segment. This type of planes, in three-dimensional images, is extremely useful as an alternative solution to the problem of low contrast that exhibit the anatomical structures present in cardiac computed tomography images. To do this, after using a predetermined filter bank and in order to define a region of interest, a smart operator based on least squares support vector machines is trained and validated in order to detect the aforementioned coordinates which enables the location of the plane, in the three-dimensional space that contains the considered images. Once the structure that is required to segment is identified, a discriminant function is used that cancels all information not linked to this structure. In this work, the segmentation of the left ventricle, based on region growing technique, is firstly considered and then the left atrium is segmented considering region growing technique and an inverse discriminant function. The results show an excellent correspondence relationship when the spatial union of both structures is made.

1. Introduction

In multi-layer computed tomography (MSCT) images, the presence of low contrast is a problem. In Figure 1, this problem is illustrated. The regions with the highest gray levels, in Figure 1, correspond to the left portion of the heart, which is located inside pericardium [1].

The left ventricle (LV) and the left atrium (LA) to belong to the left heart portion. Any filtering technique that is applied does not solve the problem of low contrast due to the very high similarity between those levels of gray [1].

The low contrast problem exhibited by computed tomography images cannot be addressed by filtering techniques. In this sense, a geometric element called spatial plane can be useful when it is necessary to define regions of interest (ROI) in the context of medical images [1]. For this, it is required:

- a) To identify, in the three-dimensional images, reference points that define the plane.
- b) A smart operator, for example, least square support vector machine (LSSVM) is used to identify the mentioned points.
- c) LSSVM can be used in the original domain or in a feature domain.



- d) In the feature domain it is required that the images be sufficiently filtered to guarantee the success of the smart operator.

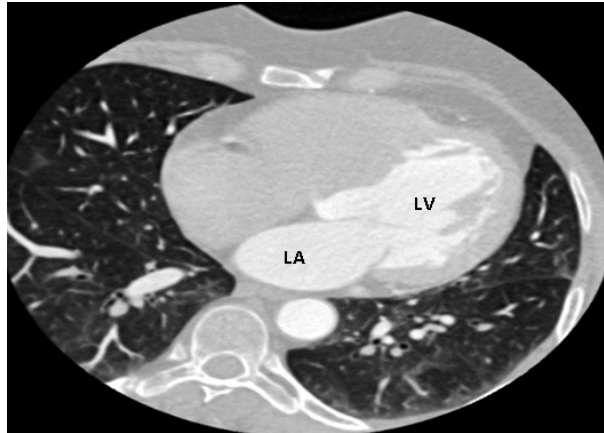


Figure 1. Left ventricle (LV) and Left atrium (LA) have the same gray levels (low contrast problem).

In specialized literature, some researchers have used spatial planes in order to address the low contrast problem. In this sense, Bravo, *et al.* [2], propose a discriminative function to isolate the LV. This action is necessary for left ventricle segmentation in multislice computerized tomography and for estimating the LV motion. Additionally, Zheng [3], present an automatic hybrid algorithm, to segment volumes of cardiac images obtained by MSCT. To do this, they consider an atlas, addressable filters and a technique called space learning marginal to address the low contrast problem and to detect, independently, each of the chambers of the heart in a significant number of images. Recently, Huérfano, *et al.* [4], use several spatial geometrics planes for extracting the three-dimensional (3D) morphology of more important anatomical structures that to belong to the right side of the human heart.

In our paper, we use MSCT images and propose a computational strategy, based on the application of a filter bank, smart operator, cutting geometric planes and region growing (RG) technique, for LV and LA automatic segmentation.

2. Materials and methods

2.1. Dataset

One three-dimensional MSCT dataset (DS) was used and it was supplied by the “Instituto de BioIngeniería y Diagnóstico S.A., Venezuela”. Additionally, LV and LA manual segmentation (ground truth) generated by a cardiologist, is available. Table 1 shows the dataset numerical features.

Table 1. Dataset numerical features.

Voxels number	Voxel dimensions (cm ³)	Sampling resolution (bits/pixel)
512x512x324	0.429x0.429x0.400	12

2.2. Proposed computational strategy

Figure 2 shows a block diagram of the automatic computational strategy (ACS), proposed in this paper, for segmenting the LV and LA.

2.2.1. Pre-processing. At this stage, initially, a filter bank is applied to the dataset described in 2.1 section. Then, a smart operator based on least square support vector machines is applied in order to define a region of interest. A brief explanation of these filters is found below.

- Median filter. This filter computes a smoothed image (I_m) of the original image (I_o) using the median of an arbitrary neighborhood of each voxel present into I_o . In this paper, an isotropic approach is considered for the size of this neighbourhood, which is a tuning parameter that varies between (1x1x1) and (7x7x7), with a step size equal to 1 [5].
- Arithmetic images. A saturated image (I_s) is obtained using the arithmetic addition of I_o and I_m ; whereas an enhanced image (I_R) is calculated by the absolute value of the arithmetic subtraction of $2I_s$ and I_m .
- Gradient Magnitude Filter (GMF). In this work, an approach based on finite differences centered was used for GMF computational implementation [6]. This filter generates a smoothed version, called I_{GM} , calculating the three-dimensional gradient magnitude of I_R , using the mathematical model given by Equation (1).

$$I_{GM} = \left(\left(\frac{\partial I_R}{\partial i} \right)^2 + \left(\frac{\partial I_R}{\partial j} \right)^2 + \left(\frac{\partial I_R}{\partial k} \right)^2 \right)^{1/2} \quad (1)$$

being: i, j, k the spatial directions in which the gradient is calculated and $\left(\frac{\partial I_R}{\partial i}, \frac{\partial I_R}{\partial j}, \frac{\partial I_R}{\partial k} \right)$ the partial derivatives of I_R .

- Gauss filter. This filter smooths an image by convolving it with a Gaussian kernel using as standard deviations, the standard deviation of I_{GM} [7]. In MSCT images, this filter is used for diminishing the images noise [8]. A discrete Gaussian distribution represented by the mentioned kernel, with arbitrary size, can be used. The kernel values are obtained according to Pascal's triangle. In this research, the size of its kernel is arbitrarily set to (3x3x3).
- Smart operators: LSSVM for volume of interest definition. Due to the high similarity about densitometric information into both LV and LA, it is necessary to establish a volume of interest (VOI) in order to address the low contrast problem. A detailed explanation of the how the LSSVM are used in VOI definition, can be found in [9].

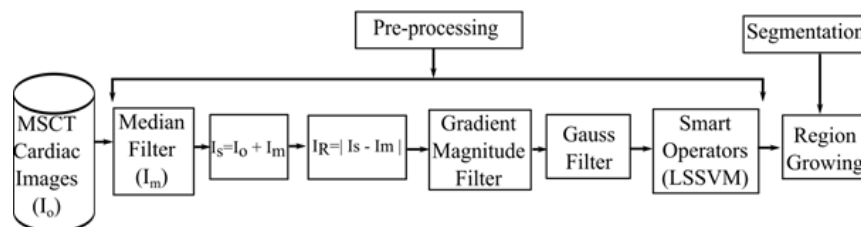


Figure 2. Block Diagram of the proposed strategy (ACS).

2.2.2. Segmentation. This stage involves two steps: seed point detection and RG segmentation technique. These steps are presented at next.

- Seed point detection. In the dataset, a LSSVM detect the seed voxel using the procedure explained in [10].
- Region growing technique. The RG technique applied in this work uses the confidence connected approach for LV and LA segmentation. In the RG, the coordinates of the seed voxel are necessary. These coordinates are detected using LSSVM and they are used as the initial position for starting the RG considering the initial neighborhood, which has an arbitrary size (s). The criterion for including new voxels in the region is defined by an intensity range, based on standard deviation (σ_{R_i}), around the mean value (μ_{R_i}) of the voxels existing in this region. The extent of the densitometric information interval is computed as the product of the variance image and an arbitrary multiplier (k) [10]. The RG splits an image (I) into regions (R_i) whose voxels (v_i) are connected according to certain predefined criterion (Pr_j) based on connectivity

and similarity of the image. Equation (2) shows a possible mathematical model for this kind of criterion [11].

$$|I - \mu_{R_i}| < k\sigma_{R_i} \quad (2)$$

In summary, the RG consists of Equation (3) to Equation (6):

$$I = \bigcup_{i=1}^n R_i \quad (3)$$

$$R_i \cap R_j = \emptyset; i \neq j \quad (4)$$

$$v_i \in R_j \leftrightarrow \text{Prj}(v_i) = 1 \quad (5)$$

$$v_i \notin R_j \leftrightarrow \text{Prj}(v_i) = 0 \quad (6)$$

During the tuning process, the LV and LA segmented are compared with the ground truths traced by cardiologists. The Dice coefficient (Dc) is used in order to estimate the difference between these structures [12].

3. Results

A maximum Dc of 0.89 is obtained from the tuning, which generated the optimal parameters for RG technique ($k = 8.30$ and $s = 20.00$). The LSSVM optimal parameters were 3.50 for penalty error parameter and 10.25 for the deviation parameter of radial base function; while the best size of median filter was (7x7x7).

Figure 3 shows an axial view of an original image and the images linked to digital processing developed with the ACS.

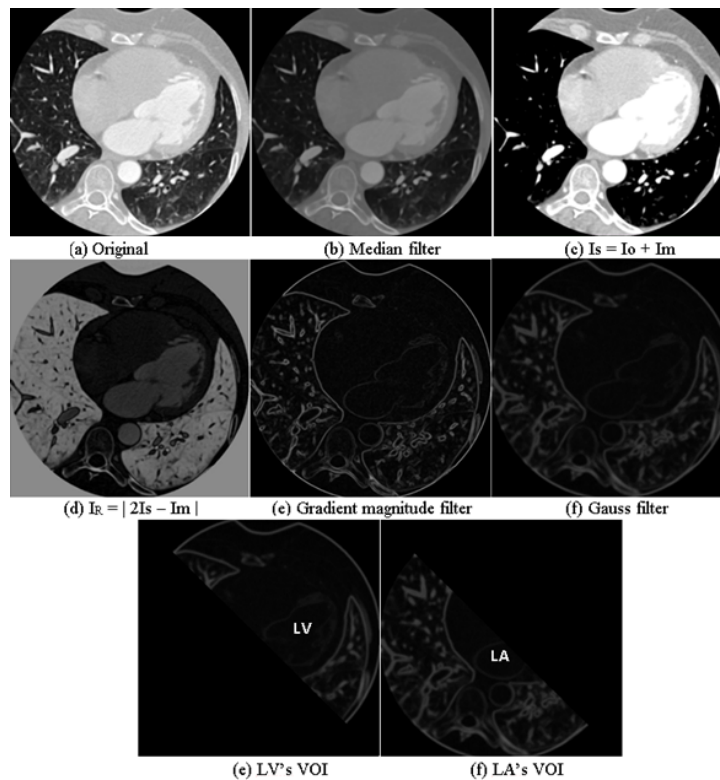


Figure 3. Effect of the ACS using a 2D view of LV and LA.

Additionally, the three-dimensional morphology of segmented LV and LA are shown in Figure 4; whereas the Figure 5 shows the merging representation the both LV and LA.

Figure 5 shows an excellent correlation between the segmented structures. The cutting plane that allowed approaching the problem of the low contrast between LV and LA is also observed.

In this point, it is necessary point that the interpretation of D_s values is: the manual segmentation and the automatic one matching when the D_s is 1 and they no matching at all when the D_s is zero. In this sense, normally, values of D_s over 0.75 are okay, in the medical routine. In this sense, according to the results, the ACS had a good performance segmenting LV and LA because the maximum D_s values obtained for the LV and LA segmentation were 0.89 and 0.87, respectively.

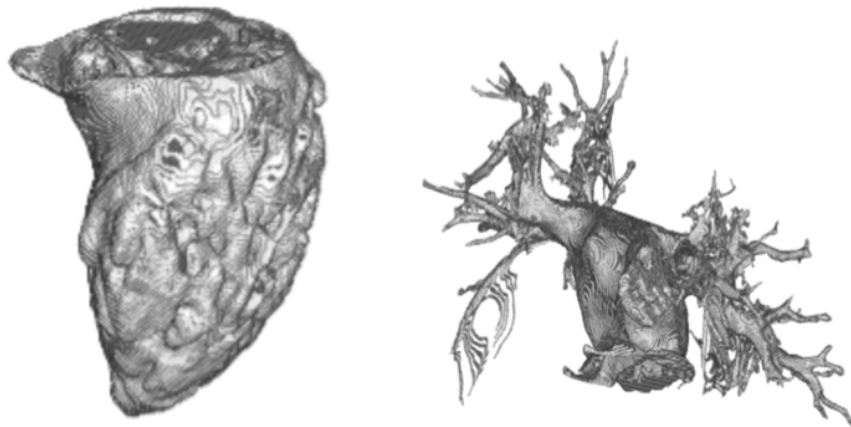


Figure 4. 3D representation of LV (left) and LA (right).

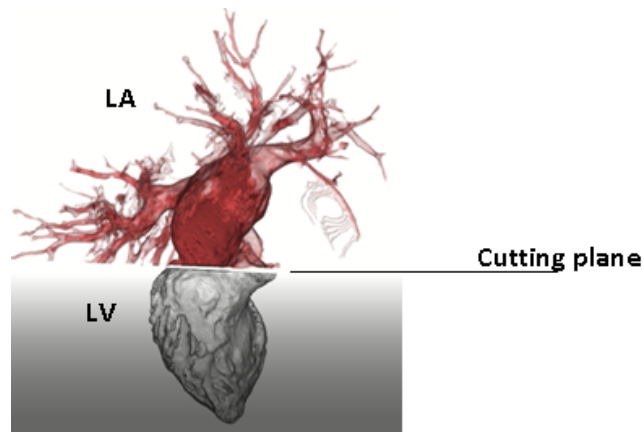


Figure 5. LV + LA using merge technique.

4. Conclusions

In this paper, a novel automatic strategy for LV and LA segmentation has been presented. This strategy is capable of addressing the problem of low contrast observed in computed tomography images using, for this, an adequate group of pre-processing techniques (filters and ROI definition technique) and a segmentation technique based on RG.

The considered filters let us address the noise and the artifacts problems; whereas the use of LSSVM, for VOI definition, let us address the low contrast problem, present in MSCT cardiac images.

The cutting plane was able to discriminate the database to generate, independently, the morphology of the cardiac chambers, on the left side of the heart, identified as left atrium and left ventricle.

The mentioned chambers are extremely useful to establish the cardiovascular function of patients suffering from cardiac pathologies.

Additionally, in this research, manual and automatic LV and LA segmentations were compared and as results, the Dc value obtained suggests that the automatic technique developed has a good performance when LV and LA segmentations are performed.

In the future, it is planned to validate the proposed technique with a significant number of databases in order to estimate the robustness of the aforementioned technique.

References

- [1] Vera M 2014 *Segmentación de estructuras cardiacas en imágenes de tomografía computarizada multi-corte* (Mérida: Universidad de Los Andes)
- [2] Bravo A, Mantilla J, Clemente J, Vera M, Medina R 2010 Left ventricle segmentation and motion analysis in multi-slice computerized tomography *Biomedical image analysis and machine learning technologies: applications and techniques* ed F Gonzalez (New York: Medical Information Science Reference) p 307
- [3] Zheng Y, Barbu A, Georgescu B, Scheuering M, Comaniciu D 2008 Four-chamber heart modeling and automatic segmentation for 3d cardiac ct volumes using marginal space learning and steerable features *IEEE Transactions on Medical Imaging* **27(11)** 1668
- [4] Huérfano Y, Vera M, Del Mar A, Bravo A 2019 Integrating a gradient-based difference operator with machine learning techniques in right heart segmentation *J. Phys. Conf. Ser.* **1160** 012003
- [5] González R, Woods R 2001 *Digital image processing* (New Jersey: Prentice Hall)
- [6] Pratt W 2007 *Digital image processing* (New York: John Wiley & Sons Inc)
- [7] Koenderink J 1984 The structure of images *Biological Cybernetics* **50** 363
- [8] Primak A, McCollough C, Bruesewitz M, Zhang J, Fletcher J 2006 Relationship between noise, dose, and pitch in cardiac multi-detector row ct *Radiographics* **26(6)** 1785
- [9] Vera M, Medina R, Del Mar A, Arellano J, Huérfano Y, Bravo A 2019 An automatic technique for left ventricle segmentation from msct cardiac volumes *J. Phys. Conf. Ser.* **1160** 012001
- [10] Bravo A, Vera M, Garreau M, Medina R 2011 Three-dimensional segmentation of ventricular heart chambers from multi-slice computerized tomography: An hybrid approach *Proc. Digital Information and Communication Technology and Its Applications* (France: Springer) **166** 287
- [11] Petrou M, Bosdogianni P 2003 *Image processing the fundamentals* (UK: Wiley)
- [12] Dice L 1945 Measures of the amount of ecologic association between species *Ecology* **26(3)** 29