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Usefulness of digital images segmentation in pulmonary transplantation

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Usefulness of digital images segmentation in pulmonary transplantation

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Abstract. In the presence of pulmonary pathologies such as chronic obstructive pulmonary disease, diffuse pulmonary disease and cystic fibrosis, among others, it is common to require the removal or replacement of a portion of lungs. There are several requirements for both donors and organ receivers (recipients) established in the literature. May be the main one is the volume that the donor's lungs occupy in the thoracic cavity. This parameter is vital because if the volume of the lungs exceeds the thoracic cavity of the recipients the transplant, logically, is unfeasible for physical reasons such as the incompatibility between the receiver lung volume and the donor lung volume. In this sense, the present paper proposes the creation of a hybrid technique, based on digital image processing techniques application to raise the quality of the information related to lungs captured in three-dimensional sequences of computed tomography and for generating the morphology and the volumes of the lungs, belonging to a patient. During the filtering stage median, saturated and gradient magnitude filters are applied with the purpose of addressing the noise and artefacts images problems; whereas during the segmentation stage, methods based on clustering processes are used to extract the lungs from the images. The values obtained for the metric that assesses the quality of the hybrid computational technique reflect its good performance. Additionally, these results are very important in clinical processes where both the shapes and volumes of lungs are vital for monitoring some lung diseases that can affect the normal lung physiology.

1. Introduction

The procedure called lung transplantation (LT) was performed, for the first time, in 1963 and has become a life option for patients with irreversible lung diseases that can lead to respiratory failure [1]. Generally, the criteria for LT are based on the pulmonary diseases such as chronic obstructive pulmonary disease (COPD), diffuse pulmonary disease and cystic fibrosis, among others. Figure 1 shows a brief classification of pulmonary pathologies.

In this investigation, we chose multi-slice computed tomography (MSCT) modality to generate the lung morphology and to obtain the lungs volumes. The lung volume is a very important parameter in surgical routine called lung transplant [2-4].

Some researchers have addressed the issue of lung segmentation. In this sense, Wang *et al.* [5] developed a method based on texture analysis for accurate segmentation of the lungs with severe interstitial lung disease on MSCT images. The segmentation method reached an average overlap rate of 96.7%. Rebouças *et al.* [6] present an automatic computational scheme (ACS) for lung segmentation, considering MSCT images. The ACS uses a technique based on actives contours. They report an average F-measure of 99.22% and a 3D adequate representation of the morphology of lung.

Finally, Mingjie *et al.* [7], proposes a deep learning automatic algorithm for lung segmentation reporting an average Dice score (Ds) of 0.96. This result is highly precise due to the Ds is a metric with values among 0 and 1; being the best results values near to 1.

In our paper, we use MSCT images and propose a computational strategy, based on the application of a filter bank and segmentation techniques, for lungs semi-automatic segmentation. The importance of this kind of research is the possibility of generate automatic strategies for detecting and monitoring efficiently some pathologies linked to human lungs.

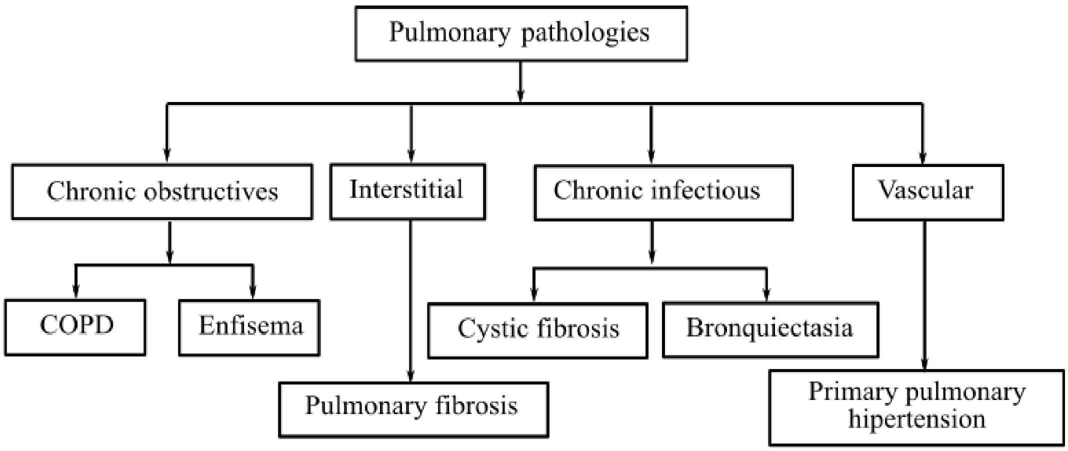

Figure 1. Pulmonary diseases brief classification.

2. Materials and methods

2.1. Dataset

One three-dimensional (3D) MSCT dataset was used and it was supplied by the Instituto de BioIngeniería y Diagnóstico S.A., Venezuela. Additionally, lungs manual segmentation (ground truths) generated by a neumologist, are available.

2.2. Computational strategy proposed

Figure 2 shows a block diagram of the automatic computational strategy (SACS), proposed in this paper, for segmenting the lungs.

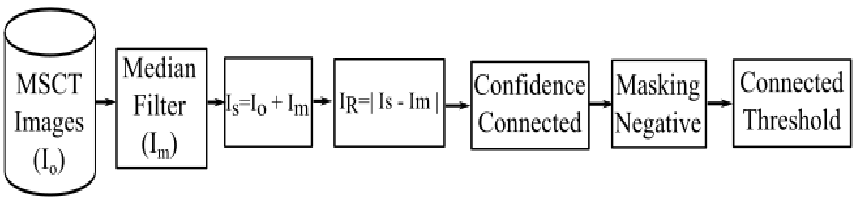

Figure 2. Block Diagram of the proposed strategy (SACS).

2.2.1. Pre-processing. In this paper, several preprocessing techniques are applied in order to diminish the effect of noise in the MSCT image quality. These filters are presented below.

Median filter. The main feature of this filter is its capacity of remove noise without affect the information contained into the images. For this, usually a median kernel is implemented considering unitary size step with for generating an image called median [8].

This filter computes a smoothed image (Im) of the original image (Io) using the median of an arbitrary neighborhood of each voxel present into Io. The median filter performance is controlled by two parameters: neighbourhood size (ns), normally between (1x1x1) and (11x11x11), and an arbitrary step size (sz), usually sz belong to the set of natural numbers. In this paper, using the values proposed in [8], an isotropic approach is considered for the ns which is a tuning parameter that varies between (1x1x1) and (7x7x7), with a step size equal to 1. The others ns were not considered because the computational cost, when this filter deal with the considered images, is prohibited [8].

Arithmetic images. A saturated image (Is) is obtained using the arithmetic addition of Io and Im; whereas an enhanced image (I_R) is calculated by the absolute value of the arithmetic subtraction of Is and Im [9].

2.2.2. Segmentation. Both the confidence connected and connected threshold segmentation algorithms are considered, in this research, to address the lung segmentation problem. Additionally, a masking negative algorithm is necessary as an intermediate step.

Confidence connected segmentation technique (CCS). The CCS technique applied in this work uses the confidence connected approach for lung segmentation. In the CCS, the coordinates of a seed voxel are necessary. They are provided, manually, by a neumologist and they are used as the initial position for start growing the initial neighbourhood, which has an arbitrary size (s). The criterion for including new voxels in the region is defined by an intensity range around the mean value 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 (m) [10].

Masking negative technique (MNT). In this paper, the MNT is used for removing trachea of the CCS image (Is1) segmentation by masking with trachea image (Is2). MN sets to zero all the voxels that are non-zero in Is2 in Is1. This technique is useful for removing regions of the Is1 when performing progressive segmentation [11].

Connected threshold segmentation (CTS). This technique applies a region growing algorithm for segmentation. The criterion for including new voxels in the region is defined by an intensity range whose bound are provided by the user. These bounds are described as the lower and the upper thresholds. The region is grown starting from a set of seed points that the user should provide in the form of three-dimensional markers [11].

During the tuning process, the lungs segmented are compared with the ground truths traced by pneumologist. The Ds is used in order to estimate the difference between these structures [12].

3. Results

A maximum Ds of 0.95 is obtained from the tuning, which generated the optimal parameters for CCS technique (m = 9.0 and s = 1). For this Ds the size of median neighbourhood was (3x3x3). This size represents the optimal value for ns parameter in this research which was obtained heuristically.

Figure 3 shows axials views of an original image and the images linked to digital processing developed with the SACS. Notice the excellent visual performance developed by the automatic strategy applied over the lung MSCT images.

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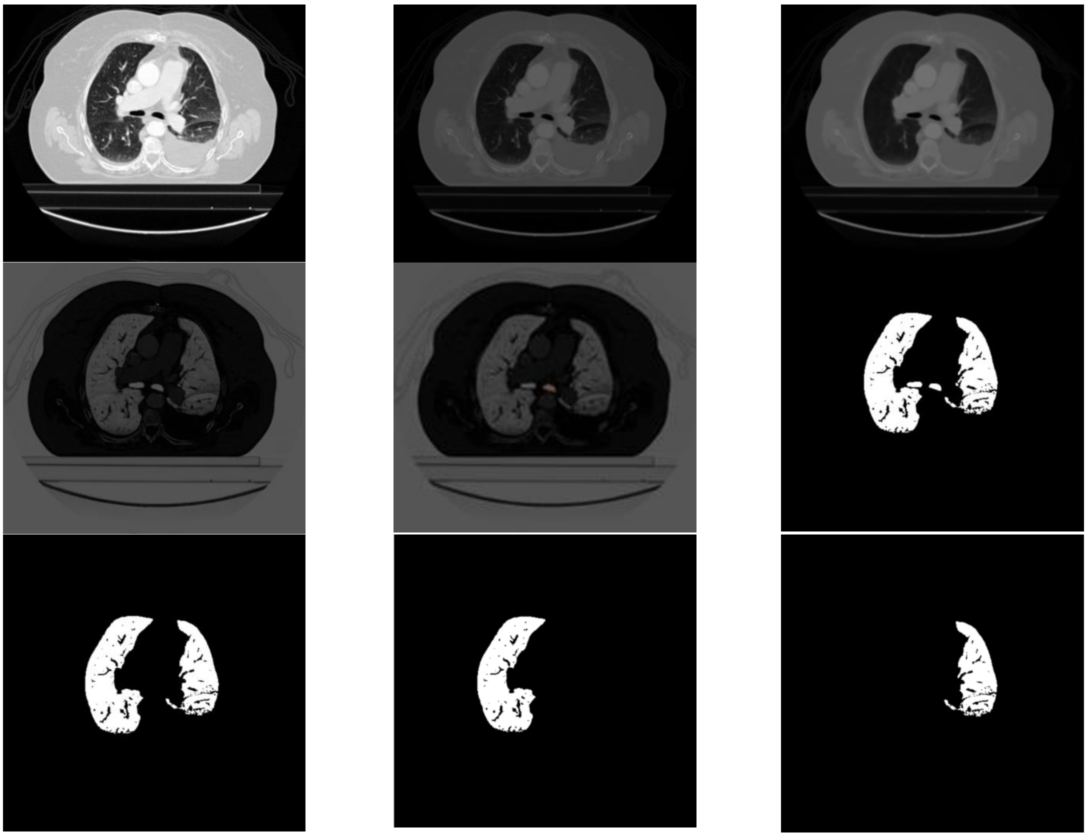

Figure 3. Axials views about effect of the SACS over lung MSCT dataset. Top row: Original image (Left), Median Filter (center) and Satured image (Right). Middle row: Enhanced image (Left), RG seed (center) and Trachea-Lungs set (Right). Bottom row: Both lungs (Left), Right lung (center) and Left lung (Right).

Figure 4 shows 3D view of trachea (Tc) and lungs morphology, using segmentation techniques: CCS + MNT + CTS. This kind of results is relevant because the automatic technique, proposed in this paper, is able to generate the 3D lung morphology, in a precise manner, which is necessary for liver quantification.

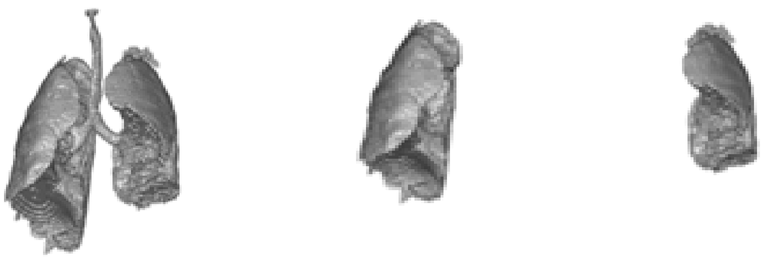

Figure 4. 3D view of the basic human respiratory apparatus. Left: Both lungs + Tc. Center: Only right lung. Right: Only left lung.

Finally, Table 1 shows the volume values (voxel size multiplied by the number of lung voxels) considering its automatic segmentation.

Table 1. Clinical parameters associated with segmented lungs.

	Left lung - Right lung
Volume (cm^3)	729.60 - 1603.00

Using the 3D lung representation is possible to realize the lung volume quantification. In this sense, the lung voxels number is multiplied by the voxels dimensions for calculating the lung volume. In the clinic context, this volume is an important parameter for performing the lung transplantation in humans.

In this section, it is necessary pointed that the Ds is a metric with values between 0 and 1. This metric is better when its value is closest to 1 [12]. In a medical image segmentation context, this means that the manual segmentation and the automatic one matching when the Ds is 1 and they no matching at all when the Ds is 0. In this sense, normally, values of Ds over 0.75 are good accepted, in the medical routine.

According to the results, the SACS had a good performance segmenting lungs because the maximum Ds value obtained for the lung segmentation was 0.95. This value is comparable with Ds = 0.96 obtained in [7].

4. Conclusions

In this paper, a novel automatic strategy for lung segmentation was developed using an adequate group of pre-processing techniques (filters bank) and a bank of segmentation techniques, based on RG and masking algorithms. The considered bank of filters (median, satured and gradient magnitude filters) let us address the noise and the artifacts problems, present in MSCT images; whereas the RG techniques had a good performance with the low contrast problem doing possible precise 3D lung segmentation.

In this research, manual and automatic liver segmentation were compared and as results the Ds value obtained suggests that the ACS developed has a good performance when the lung segmentation is performed. The lung segmentation is a crucial step in a surgical procedure called lung transplant because this kind of segmentation allows obtaining liver volume and considering this volume, and others parameters, the specialized personal in the medical context can decided which patients can receive this organ via transplantation.

It is planned, for the future, to use the ACS in the segmentation of an important number of datasets.

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