IDENTIFYING THE CARDIAC REGION IN IMAGES OF ELECTRICAL IMPEDANCE TOMOGRAPHY THROUGH WAVELET TRANSFORM

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Abstract: Electrical Impedance Tomography (EIT) is an imaging technique, still in development, in which an image of the conductivity of part of the body is inferred from surface electrical measurements. Despite the benefits, its resulting image still does not offer a good spatial resolution. In EIT images of the thorax the largest challenge is the treatment of the lung perfusion, especially in the identification of the cardiac region. The current EIT equipments, used in the treatment of ICU (Intensive care unit) patients with respiratory complications, have a need to better define the cardiac region in dynamic EIT images, in order to offer a better system of support to the medical decision. In an attempt to overcome this problem, Tanaka and collaborators proposed a methodology using the theory of fuzzy sets. Fuzzy logic approach allowed a more appropriated treatment of the uncertainty in identifying the pixel as belonging to a pulmonary or cardiac region. However, this fuzzy model presented some limitations when submitted to different clinical conditions, such as PEEP variation. In this work we present a methodology based on wavelet transform for analysis of the EIT signals of the pulmonary perfusion obtained in an animal experiment.

1 INTRODUCTION

Electrical Impedance Tomography (EIT) is an imaging technique, still in development, in which an image of the conductivity of a transversal section of an object is inferred from electrical measurements done in a series of electrodes placed on its surface. Despite the benefits presented by this technique, it has some limitations, amongst which we detach the low spatial resolution. Although the EIT method presents a high time resolution, the low spatial resolution hinders the characterization of the activity of regions according to their physiological origin in a dynamic image. One of the most important EIT studies concerns to the images of the thorax, aiming the monitoring the cardio-respiratory functions. In that sense, Tanaka et al. proposed the use of the theory of fuzzy sets to deal with the uncertainty of identification of the pixels, aiming a segmented image containing the cardiac and pulmonary regions (Tanaka et al, 2008). Despite the good results, this model presented some limitations in identifying the heart in more complex situations. Therefore, it is realized that a tool that could extract more information from EIT signal could be capable to separate with more clearness the pulmonary and cardiac regions. One of the tools capable to extract information of signals in the time and frequency domains, with possibilities to minimize this limitation, is the Wavelet Transform.

Wavelet transform emerged as a result of developments in this type of representation of signals. Basically, there are three classes of wavelet transforms: the Continuous Wavelet Transform (CWT), the Semi-Discrete Wavelet Transform (SWT) and the Discrete Wavelet Transform (DWT) (Polikar, 1999). The DWT is a multi-resolution representation of the original signal and is particularly useful for noise reduction and data compression, whereas the CWT is better for feature extraction purposes. The SWT is simply a discretization of the CWT in order that this can be processed by computers and digital equipments.

A typical EIT system has the following components: a set of current injection electrodes; a system of measure of electric potentials between the electrodes; and an algorithm of image reconstruction (Adler et al, 1997). Among the benefits offered by this technique, we detach: it is a noninvasive technique; it presents a high temporal resolution; the

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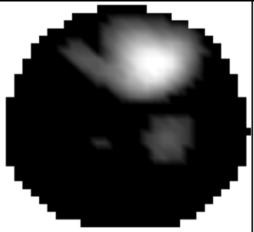
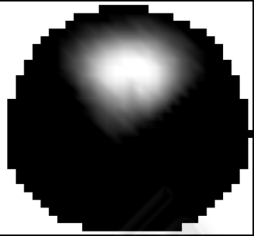
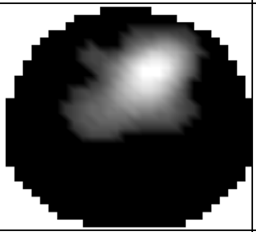
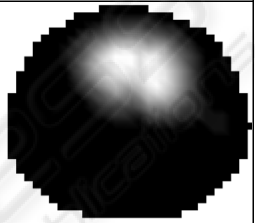
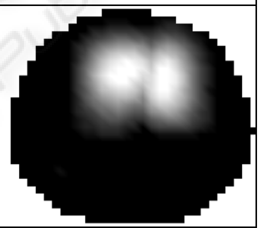
Table 1: Heart maps provided by the systems for each PEEP values: a) the wavelet analysis; b) the fuzzy approach; and c) the saline injection.

PEEP	WaveletAlgorithm 1	WaveletAlgorithm 2	Fuzzy	Saline
18 cm H2O				
12 cm H2O				
0 cm H2O (ZEEP)				

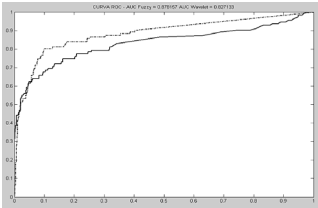
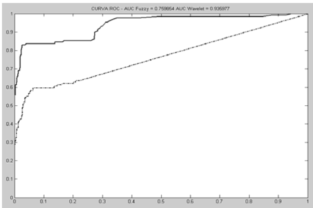
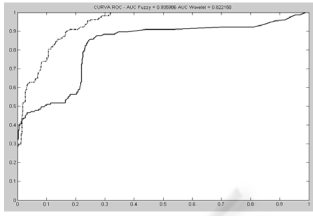
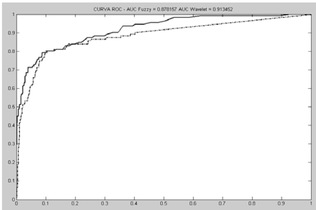
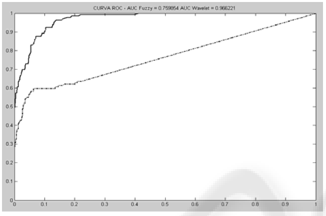
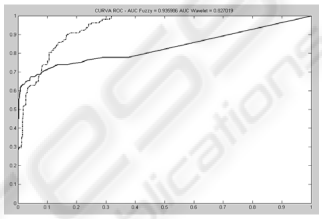
equipments are cheap, relatively small and can be installed at the bedside of the patient. As for its limitations, we can point the low spatial resolution and the relationship between the differences of electrical potential measures on the surface and the internal parameters of the object in analysis is not linear, which difficult the development of the image reconstruction algorithm (Tanaka et al, 2008; Brown, 2003; Noor, 2007).

2 MATERIALS AND METHODS

The image generated by the EIT system used is formed by 1024 pixels, where each pixel corresponds to a certain area of the body of the object under analysis. These pixels have variations in their impedances due to the flow of blood during the cardiac cycle. In order to develop a methodology able of identifying the heart region in EIT images of a thorax, it is necessary a qualitative analysis of the information contained in these signals. Firstly, this qualitative analysis was based on the wave patterns and after each pattern was discussed with a panel of experts, taking into account the physiological knowledge about the cardio-respiratory dynamic. This analysis was the fundamental importance in the model development, because it provided the standard behavior for each region of chest (lungs, ventricle, atrium, aorta, etc.).

EIT raw data were collected in an animal experiment (pig) by means of an electrical impedance tomography, based on the Enlight ® technology (DIXTAL, Brazil), which uses the image reconstruction algorithm developed by Lima and collaborators (Lima et al, 2005). EIT signal was synchronized with the peak of the wave "R" of the ECG signal. The pig was submitted to different values of Positive End-Expiratory Pressure (PEEP): 18cmH2O (PEEP18), 12cmH2O (PEEP12) and 0cmH2O (ZEEP). This is important to evaluate the robustness of the system developed in different clinical conditions. For each one of these PEEPs was done an experiment using a hypertonic solution (20% NaCl), which serves as contrast to EIT images, during apnea. The EIT images obtained by means of this contrast allows localizing the different structures for where the flow passed. The objective with the saline data is to establish a reference base, so it will be possible to compare the results of the

Table 2: ROC curves obtained for the wavelet and fuzzy approaches, compared with the heart region obtained through the saline injection, for each PEEP values, where AUC means Area under of Curve.

	THE ROC CURVES: __Wavelet ---Fuzzy		
	PEEP18	**PEEP12**	**ZEEP**
WAVELET ALG1			
	AUC_{Wav}=0.83; AUC_{Fuz} =0.88	**AUC_{Wav}=0.94; AUC_{Fuz} =0.86**	**AUC_{Wav}=0.82; AUC_{Fuz} =0.95**
WAVELET ALG2			
	AUC_{Wav}=0.91; AUC_{Fuz} =0.88	**AUC_{Wav}=0.97; AUC_{Fuz} =0.86**	**AUC_{Wav}=0.83; AUC_{Fuz} =0.95**

present model with this EIT contrast.

In order to identify the regions with similar pixels, we began our analysis by a qualitative evaluation from the patterns presented by EIT signals. Based on experts' experience of the respiratory ICU at the Clinics Hospital of São Paulo, Brazil, in a consensus method, we took off conclusions about on which organ (heart or lungs) each pixel belonged with larger possibility. This analysis requires that the beginning of each EIT signal must be synchronized with the peak of the wave "R" of the ECG signal, marking the beginning of the systolic phase. It allow us to identify the pixels with the standard behavior of heart or lung.

According to discussed above, we proposed the following method to analyze extracted signals of thorax by means of Electrical Impedance Tomography in order to identify the cardiac region:

a) We suppose that the pigs are healthy. Therefore, the cardio-respiratory functions are performed with certain normality and so we can consider the same standard behavior found by qualitative physiological analysis;

b) Two algorithms using the Wavelet Transform were developed based on finding the pixel that had the largest positive variation in its impedance during the first half of the cardiac cycle and decomposing the signal of the pixel above by means of the CWT using the wavelet *gaus4*.

3 RESULTS AND DISCUSSIONS

The analysis of EIT signals of the thorax of the pig with controlled pressure PEEP18 was used to identify the macro regions according to variations of blood flow during the cardiac cycle. After physiological analysis, we determined a typical variation of impedance of those found in ventricular region during the cardiac cycle, in which the different phases of the cardiac cycle are very well defined. In order to find the adequate wavelet for our analysis, several tests were performed. The wavelet that adjusted better to the EIT signals was the gaus4.

Table 1 shows the heart maps provided by wavelet and fuzzy approaches, and also the maps found with the saline contrast. We can note in these figures that the pixels, corresponding to the heart region, are located in a superior central position, independently of the PEEP values. It important to detach that in this region there is a crossover of the different cardio-breathing functional structures, such as ventricle, atrium, lung, aorta, and so on, which causes important alterations in the expected pattern for the dynamics of the cardiac cycle. We can also note in table 1 that the wavelet approach, mainly the wavelet algorithm 2, provides an almost crisp heart map. Thus, in this method the pixel identification uncertainties are practically vanished. The fuzzy model provides an image containing pixels of several magnitudes in the interval [0, 1], so varying a cutoff value, the area corresponding to the heart region may contracts or expands. On the other hand, varying the cutoff in the wavelet approach, the area correspondent to the heart region practically does not change. In this sense, the fuzzy model is dependent of the cutoff value, which clearly is not desirable in an automatic process. Other fact of great importance in an automatic process is that the fuzzy model is dependent of the PEEP settings, i.e., for each PEEP its parameters need to be changed. This limitation does not have in the wavelet model; its configuration is not dependent on PEEP value. Comparing the heart maps generated from wavelet and fuzzy models with the image of the cardiac region obtained by the saline method, we elaborated ROC curves for each PEEP value. Table 2 presents these results. We can note that both models presented excellent agreements with the saline injection. ROC curves of fuzzy and wavelet models were practically equivalent. In general, the best results were found with the wavelet algorithm 2.

Due to the movement of the heart in the longitudinal axis and to the fact that the lungs should be more closed in the ZEEP condition, it is expected that the identification of the pixels as belonging or not to each anatomical structure becomes more difficult in this situation. In this sense, we expected that the agreement would be larger for PEEP18, followed by smaller values of agreement for PEEP12 and ZEEP, respectively. However, this monotonic behavior was not observed. The possible hypothesis for this fact is that the ventricle was dislocated to a more central region due to the heart movement.

4 CONCLUSIONS

The wavelet methodology proposed was able to identify the heart region from EIT data of perfusion when compared with the saline method and fuzzy model. Both methodologies present limitations to be overcome. In the wavelet approach, we should have extended our analysis to other cardiac chambers beside the ventricular region. In the fuzzy model, the limitations consist in the cutoff and PEEP dependences in the generation of the heart maps. These limitations should be understood in a more deep work.

Finally, the results presented here were encouraging and indicate that the modeling of EIT images pos data acquisition, besides the reconstruction algorithm, is a good way that should be certainly explored

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