Computer Assisted Detection systems for lung Computed Tomography

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Introduction. Lung cancer has the highest mortality rate out of all forms of cancers all over the world. The 5-year survival rate is estimated to be between 10% and 15%, with an increase up to 50% if the cancer is detected at an early stage. It is easy to understand the importance of early diagnosis. The use of chest computed tomography (CT) greatly supports the radiologist in finding suspicious nodules. A recent work [1] demonstrates the real effectiveness of screening for lung cancer, showing a reduction of the 5-year mortality of more than 20% for subjects in the screening program with low-dose CT. This result has encouraged the development of CAD (Computer-Assisted Diagnosis) systems for the automated detection of lung nodules in CT scans. A CAD system can provide valuable assistance to the radiologist, giving a second opinion on a diagnostic image, which improves diagnosis reliability and time saving in the analysis. The CAD system for juxta-pleural nodules developed by the group of Lecce is a part of the project carried out by the MAGIC-5[1] Collaboration that aims to develop a fully adaptive CAD system for all type of lung nodule detection in chest CT scans. In this scenario, the juxta-pleural nodules, due to their position and their high density, are a *difficult* type of lung nodule to be detected by automatic systems. The purpose of implementing a CAD that deals exclusively with the nodules in contact with the pleura is therefore an attempt to develop a synergetic and parallel work to those of other generic lung CADs.

CAD system structure. The CAD system consists of 4 steps: (1) lung parenchyma segmentation, (2) localization of the regions of interest (ROIs), (3) statistical and morphological feature extraction from the ROIs and (4) classification of nodule candidates. Since the good performance of a CAD system depends on the quality of the example set used for training, it is important to have a reliable database of images you can trust, which is used as *gold standard*, that is as a true reference, according to which it is possible to train and then evaluate the CAD. In our system, this gold standard database is based on the consensus of several radiologists and comes from ITALUNG-CT program. The identification of the juxta-pleural nodules is performed automatically by the system, taking as input the binary mask obtained from the 3D segmentation step, and analyzing the border of the lung. Juxta-pleural nodules, due to their position and their high density, are not included in the binary mask in the process of segmentation, and form concavities along the edge of the lung (see fig. 1).

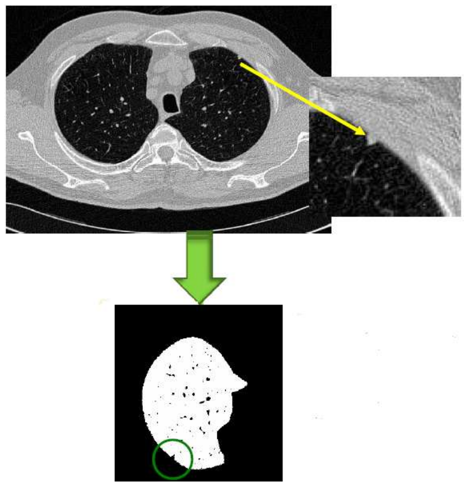

Figure 1. *Example of binary mask obtained from the segmentation of a CT. Due to its position and its high density, the juxta-pleural nodule is not included in the segmented volume.*

In order to include juxta-pleural nodules in the segmented volume we have to close the concavities by using a concavity-patching method that returns a smoothed lung border. The difference between the original border and the "closed" one gives a list of concavities which are nodule candi-

[1]Medical Applications on a Grid Infrastructure Connection, http://mag09xl.to.infn.it/site/, now M5I.

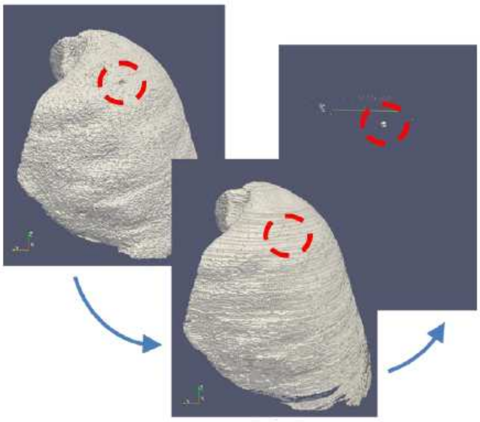

Figure 2. *Example of 3D analysis.*

dates.

3D analysis approach.

Among the concavity-patching methods, we tested the performance of two common used methods, *morphological closing* and *alpha-hull*, chosing the latter for its better efficiency in terms of both sensitivity and computation time saving with respect to the former [2].

The α-hull [3] is a convex hull generalization, able to detect concavities, whose shape depends on a curvature parameter α. The definition of α-hull is the following: given a set S of points in the plane, and a positive number α, the α-hull of S is the intersection of the closed complements of all the circles (balls) such that the intersection of these balls with S is empty. The α-hull applied to a segmentation mask of a lung CT performes the gradual closing of the concavities depending on the value of α. The difference between the alpha-hull and the original masks gives a list of concavities that can both be *natural* or due to *nodules*. In this work we aim to overpass the 2D analysis we performed in past year [2], by studying a possible 3D approach. A 3D analysis indeed gives us not only the possibility to significantly reduce the risk of counting several times the same concavity (as it can happen in the 2D case because of the slice-by-slice approach) and thus to reduce the number of FPs, but also to gain a more comprehensive, exhaustive and general view of the object under study, allowing to make a better matching with the values of the coordinates and radius, reported by radiologists, (which is necessary for nodule identification).

Currently, the calculation of the α-hull is performed in 2D (slice- by-slice) and is followed by the 3D reconstruction by stacking the single slices (smoothed) in the sequential order, and by appling the difference operation with the segmentated lung mask in order to obtain the subsequent identification of the nodules in 3D (fig. 2). Henceforth, all the calculations made in this work are performed with the optimum value of the parameter α ($\alpha = 0.010$) which led to a sensitivity, in the nodule hunting phase, equal to 100% with about 238 FPs/CT. However, after a proper preliminary quality cut on nodule candidates volume, we reduced the FPs to 52 FPs/CT, sensitivity being preserved. By using a single value of α, we also reduced significantly the number of FPs for the classification stage.

Feature extraction. In order to reduce the number of FPs (natural concavities) from the list of concavities obtained in the previous stage we introduce a set of parameters that characterize the objects (features). The study of the features lead us to discrimitate among concavities. The 3D features we chose are: the *geometrical coordinates of the centroid*, the *weighted coordinates of the centroid* (weighted with the gray-level values of each voxel), *mean radius*, *minimum radius*, *maximum radius*, *volume*, *roundness* and *inertia tensor*.

Classification. A supervised two-layer, 14-input, variable hidden neurons number, 1-output feed-forward neural network, trained with gradient descent learning rule with momentum, was chosen as the classifier system. The criterion to establish if a candidate is a nodule or not is the following: the Euclidean distance between the centroid of the concavity, and the centroid of a diagnosed nodule, is lower than 1.5_{r_R}, where r_R is the nodule radius according to the radiologists. The Artificial Neural Network output, calculated on the concavity list, is distributed in the range [0,1]. By varying a decision threshold, and assigning target t=1 to candidates above threshold (probably positive), and t=0 to candidates below threshold (probably negative), sensitivity and specificity referred to the known diagnosis and relative ROC curve can be calculated. The best result obtained from our studies led to a sensitivity of 90%, specificity of 87%, $AUC = 0.94$ with about 7 FPs/scan (at the same sensivity). The reported result refers to a network without hidden neurons.

REFERENCES

1. The National Lung Screening Trial Research Team: *Cancer Mortality with Low-Dose Computed Tomographic Screening*; New England Journal of Medicine, Vol. 365, No.5, 395-409 (2011)
2. G. De Nunzio et al., *Approaches to juxta-pleaural nodule detection in CT images within the MAGIC-5 Collaboration*, NIMA (2011)
3. W.F.Sensakovic et al., *A general method for the identification and repair of concavities in segmented medical images*, in: Proc. of Medical Image Conference Dresden (2008)