DETECTION AND CHARACTERIZATION OF LESIONS IN BREAST MR IMAGING

L. Bocchi*, P. De Giacomo**, B. Innocenti***, S. Lombardo*, F. Toccafondi**** and F. Veronesi*****

* Dip. Elettronica e Telecomunicazioni, Univ. di Firenze, Firenze, Italy
** Centro per la Ricerca Biomedica, IRPPS-CNR, Roma, Italy
*** Dip. Meccanica e Tecnologie Industriali, Univ. di Firenze, Firenze, Italy
**** Diagnostica Senologica, AOU Careggi, Firenze, Italy
***** Dip. Elettronica, Informatica e Sistemi, Univ. di Bologna, Bologna, Italy

leonardo.bocchi@unifi.it

Abstract: Magnetic resonance is a powerful tool which allows to improve detection and diagnosis of suspect breast lesions. Accordingly to clinical procedures, it is necessary to estimate several parameters in order to evaluate the likelyhood of a malignant pathology. In this work, it is described an authomatic procedure which allows to evaluate the degree of malignancy of suspect lesions, accordingly to the BIRAD criterium. The procedure is composed by a registration module, to reduce artefacts caused by the movement of patient, a segmentation module which identifies the lesion, and a bank of modules for paremeter estimation, to assess the dynamic, geometrical and intensity related properties of the lesion. Finally, a classifier is used to assess a score which indicates the degree of malignancy from the estimated properties. Performances of the system has been tested of a clinical dataset, and they exhibit a strong agreement with the manually assessed scores.

Introduction

Breast cancer is the most common tumoral disease in women, and is one of the major causes of death among women in industrialised countries. Indeed, statistics classify breast cancer as the second cause of death among women in the United States [1]. It has been estimated that in Europe, in the year 2000, there were about 350,000 new cases, which caused about 130,000 deaths [2].

On the other side, clinical evidence shows that an early diagnosis may help to increase the survial rate of affected patients. Therefore, in industrialized countries it is a common practice to perform periodical screenings of the population in order to detect subtle anomalities which may indicate the presence of early stages of a tumoral disease.

During the screening processes, the most diffuse diagnostic methods to achieve an early diagnosis of this pathology is trough X-Ray mammography or ultrasound imaging. Both methods are very effective, reasonably cheap and fast to execute. However, in the last years, great attention is being payed to Magnetic Resonance Imaging (MRI) to improve detection and classification of suspect breast lesions. MRI has proved to be an effective diagnostic method for detection and diagnosis of breast cancer, by overcoming limitations of X-Ray imaging (radiation exposure, and its reduced sensibility in presence of dense tissues or hormone therapy) and echographic imaging (low spatial resolution, and high dependency from the operator).

Unfortunately, MR imaging does not provide adequate discrimination of tumoral tissue without the utilization of a contrast agent, beacuse of the similarity of relaxing times beteween normal and pathological tissues. For this reason, the standard clinical procedure includes a injection of a contrast agent containing Gadolinium compounds which produces a high enhancement of tumoral tissue. It has been observed that the neoplastic tissue exhibits an higher enhancement with respect to normal tissue due to an increase in vascularity and in vascular permeability.

The enhancement is further increased by using a subtractive technique. A first image (called anatomical) is acquired before the injection of the contrast medium. Then, a variable number (usually 5) of acquisitions are performed after the injection, in order to follow the dynamic evolution of the image. The subtraction of the anatomical image from the post-contrast ones allows to greatly improve the contrast between normal and neoplastic regions.

Using this procedure, it is possible to diagnose the suspect lesions using both their morphological description and its dynamic behaviour after the iniection of the contrast medium [3]. The BIRAD criterium suggests a diagnosing procedure based of the attribution of a score, which is evaluated from a set of morphological and dynamical parameters:

Morphology: A lesion which presents an irregular boundary is assigned an higher score (1 point) than one with a circular or oval boundary (0).

Sharpness: A lesion which does not present a well-

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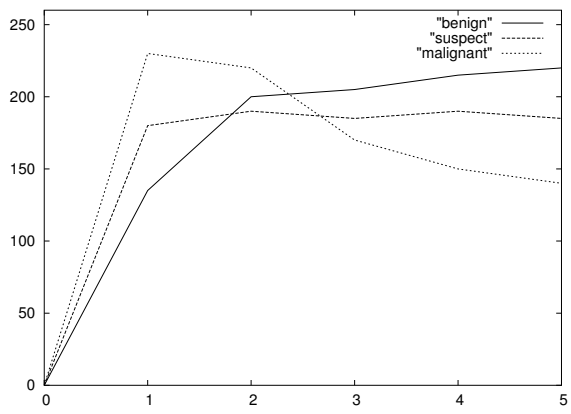

Figure 1: Typical enhancement curves: benign, suspect and malignant.

defined boundary is given a higher score (1) than a well-defined one (0).

Kinetics: A ring-shaped enhancement in the first few acquisitions has an higher score (2) than a non-homogenous enhancement (1) or an uniform enhancement (0)

Initial enhancement: A lesion which exhibits an high degree of enhancement in the first acquisition (above 100%) is assigned a score of 2 points. If the enhancement is low (below 50%) it is assigned 0 points. If the enhancement is between those values, it is assigned 1 point.

Continuity: When the enhancement is increasing during the whole exam, the lesion is assigned 0 points. If the curve stabilizes on a high level, the lesion is assigned 1 point, while a rapid wash out of the contrast medium is associated to a score of 2 points.

As indicated by this scoring system, the most important factor is the shape of the enhancement curve (Fig. 1) which has typical behaviours for benign, uncertain and malignant lesions.

Materials and Methods

The system has been developed using a modular approach, which is reported in Fig.2. The main goal of the design is to allow to develop, at first, the modules which perform the parameter extraction and evaluation of the overall score. Such modules will form the processing kernel for the development of a complete system aimed to support the diagnosing process from the initial detection of suspect lesions to the planning of a surgical treatment. The proposed system structure is composed of a first stage which acquires the images and allows the user to select the regions to be processed. The acquired images are then registered and preprocessed to improve the results of the segmentation stage. Then a set of modules act in parallel to describe the lesion using a set of quantitative features designed to emulate the descriptive features

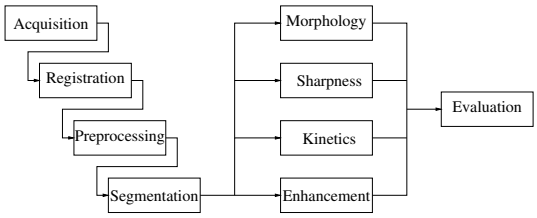

Figure 2: Overall architecture of the system

included in the BIRAD scoring system. Those features are the quantized and processed by an evaluation module which assesses the probability of malignancy of the lesion.

Acquisition

The images have been acquired using a Siemens MR console, and exported in DICOM format. The present version of the acquisition module is designed to read images from CDROM, using an offline acquisition. However, the module is designed to be easily extended in order to acquire the images directly from the MR console using a network connection. A simple user interface allows the user to select one or more regions of interest (ROI) containing suspect lesions.

Registration

The overall duration of the MR exam is several minutes. Therefore it is quite common that the patient is unable to remain completely still along the complete duration of the acquisition. This causes artifacts during the subtraction process between the anatomical and the post-contrast images. In order to reduce those artifacts, it is necessary to perform a registration of the post-contrast images with the anatomical one. As the breast is composed of soft tissue, an optimal registration of the whole image requires to take into account the deformation of the tissue. However, it can be observed that deformation can be discarded when the elaboration is limited to a ROI centered on the suspect lesion, which is usually of a very limited size. For this reason, in this phase, we performed a rigid registration of each ROI, which required a low computational cost, while giving a good registration accuracy.

The selected registration method is based on the maximization of the mutual information between each post-contrast image and the anatomical one [4, 5]. Mutual information between two images A and B is defined as:

$$I(A,B) = \sum_{a,b} p(a,b) \log \frac{p(a,b)}{p(a)p(b)} \qquad (1)$$

where $p(a)$ is the probabilty of having a gray level a in a given pixel of the image A, and $p(a,b)$ is the probability of having the gray levels a and b in a given pixel of the images A and B, respectively.

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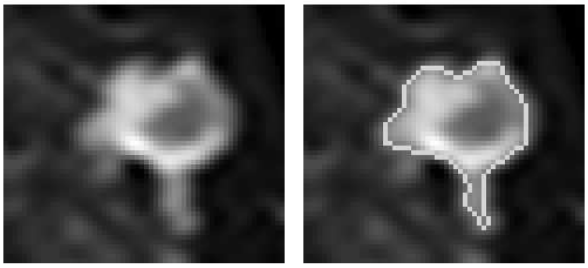

Figure 3: Sample lesion, on the subtracted image (left) and result of the segmentation stage (right)

To improve the registration accuracy, the registration has been performed by evaluating the mutual information between the gradient of the images. The gradient of the image enhances edges, which represent the boundary of the lesion, allowing the mutual information algorithm to better detect alignment of the lesion.

Segmentation

After a preprocessing stage, which performs an image subtraction between the post contrast ROI and the anatomical one, the segmentation stage identifies the lesion inside the ROI. The segmentation process consists of a modified watershed algorithm [6, 7], which can be described as follows. Starting from a seed pointm, selected as one of the brightest pixels in the ROI, the regions is grown to include all connected pixel having a gray level above a given threshod θ, and the contrast between the boundary and the surrounding region is evaluated. The value of θ is varied over all the possible values, and the value of θ which gives the maximum contrast is determined. This value is selected to perform the segmentation. An example of the results of the segmentation stage is reported on Fig. 3.

Parameters extraction

The stage for the extraction of the parameters is composed of four modules which evaluate an appoximation of the parameters of the BIRAD method. The first module extracts the parameters which describe the enhancement of the curve from the sequence of the six images. The image which presents the maximum average enhancement value is processed in order to detect the pixel which has the peak of the enhancement. A small 3×3 regions is centered on this pixel, and used to evaluate, for each image, the average enhancements M_i, $i = 1,..,6$, which can be used to visualize the shape of the curve. From these parameters we estimate the initial enhancement (IE) as:

$$IE = \frac{M_2 - M_1}{M_1} \times 100 \qquad (2)$$

and the continuity as:

$$C = \frac{M_6 - M_3}{M_6} \times 100 \qquad (3)$$

The first parameter gives an estimation of the speed of the absorption of the contrast medium by the lesion, while the second one is correlated to the long term behaviour: a rapid wash-out of the contrast medium gives a strong negative value of continuity, a plateau (the concentration remains approximately constant during time) corresponds to an almost null value, and a continuous increase of the concentration gives a positive value of continuity.

The kinetics and homogeneity of the lesion is estimated, by the second module, from the image where the lesion has the maximum enhancement. The estimation of the homogeneity is based on the variance of the gray level over the segmented area of the lesion. Sperimental results indicates that this parameter correlates well with the perceived inhomogeneity of the lesion. However, the BIRAD criterium requires to discriminate between the direction of the emhancement, giving higher scores when the center of the lesion has a slower enhancement speed than the border (ring-shaped enhacement, see Fig 3). The measure of the variance is unable to discriminate this kind of lesions, and it will therefore necessary to design a new method to measure the homogeneity of the lesion.

An estimate of the shape of the lesion is more difficult to obtain. The third module extracts a morphological parameter by evaluating the center of mass of the segmented lesion. The position of the center of mass is computed by assigning to each pixel belonging to the lesion a mass equal to its grey level. Afterward, the module evaluates the distance between of the center of mass and the boundary of the segmented lesion as a function $r(\phi)$ of the direction ϕ, with $0 \leq \phi < 2\pi$. The function $r(\phi)$ is filtered using a low-pass filter to remove noise, and the number of local minima is evaluated. Lesions having a circular or elliptical shape are characterized by a number of minima equal to one or two. Instead, lesions having an irregular, or spiculated, shape have a larger number of local minima, usually 4 or more. The plot of the function $r(\phi)$ computed from the lesion reported in Fig. 3 is shown in Fig. 4. The plot clearly shows a large number of local minima, corresponding to the irregular shape of the lesion.

The last module evaluates the sharpness of the lesion. In the clinical practice, a lesion is defined sharp when it has well-defined margins. Therefore it is possible to obtain an estimation of the sharpness of the lesion through the evaluation of the image gradient. A sharp lesion is expected to be associated with high values of the gradient module, while a lesion having not well-defined margins produces an image having low values of the gradient along its boundary. The image has been filtered using a Gradient of Gaussian kernel, with $\sigma = 3$, in order to remove high frequency noise. Following the filter stage, the magnitude of the gradient along the boundary of the lesion has been considered, and the percentage p_g of pixel exceeding a fixed threshod ($g_t = 20$) has been computed. The threshold t_g has been selected sperimentally.

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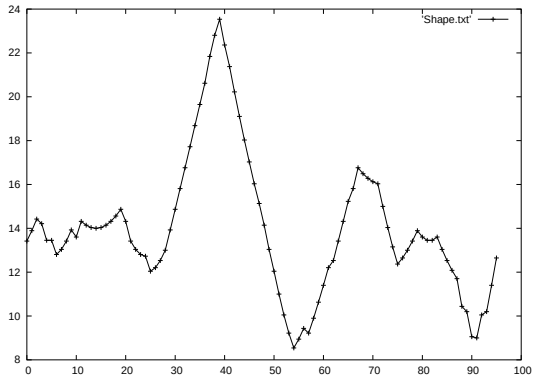

Figure 4: Plot of the shape descriptor $r(\phi)$ evaluated from the lesion in Fig. 3

Evaluation

The last stage performs the evaluations of the parameters and the assessment of the probability of malignancy of the lesion. The evaluation has been carried out accordingly to the BIRAD criterion, i.e. using a threshold on parameters value, althought it can be argued that a classification scheme which utilizes using fuzzy logic may improve the results.

The scoring criterion is summarized in table 1. While the thresholds used to assign the score to the initial enhancement and to the continuity are derived from the medical practice, the others have been determined sperimentally to correspond with the scoring of the lesion performed manually by the medical expert. However, the proposed values have been selected in order to privilege sensibility over specificity.

Table 1: Scoring criterium

Parameter	**Score**		
	0	1	2
Enhancement	$IE < 50$	$50 \leq IE < 100$	$IE \geq 100$
Continuity	$C \geq 10$	$-10 \leq C < 10$	$C < -10$
Homogeneity	$\sigma < 2000$	$\sigma \geq 2000$	
Morphology	$n_m \leq 2$	$n_m > 2$	
Sharpness	$p_g \geq 20\%$	$p_g < 20\%$	

The evaluation module computes the score which is assigned to each lesion and classifies it as a benign lesion if the totals score (the sum of the scores assigned to each parameter) is at most three, and classifies it as a suspect lesion if the total score is above three. This threshold value has been determined accordingly to the BIRAD criterium.

Results

The system has been tested on a dataset composed of twenty patients with different kinds of lesions, ranging from large benign nodules to small malignant ones. The image set includes also a few cases where a significative movement of the patient during the acquisition can be observed. The aquisition protocol, carried out on a 1.5T system, consists of six (an anatomical acquisition and 5 post contrast) acquisition using a T1-weighted gradient echo sequences, with gradient coils of 30mT/s. Each acquisition lasts for about 65s, with a total aquisition time is about 7 minutes. The spatial resolution of the images is 0.95mm/pixel on each slice, with a slice thickness ranging from 1.3 to 2.5 mm, depending on the patient.

All cases where diagnosed by a medical expert, using the standard clinical procedure. In suspect cases, diagnosis has been supported by a biopsy. Images have been exported from the console, anonymized and stored compact disks. Afterward, the images have been evaluated by the proposed system, in order to compare the scoring of each parameter and the overall score.

Results of the registration stage have been evaluated both visually and by comparison with the manual alignment performed by the medical expert. In both cases, it can be assumed that the evaluation is a qualitative assessment. Results indicate that a relative shift of one pixel in any direction is correctly identified by the registration module, althought it goes usually unnoticed during the clinical diagnosis. Larger shifts are correctly detect by the module, althought a relative error of one pixel between the manual registration and the automatic one can be present. In some cases, when the movement occurs during one of the acquisitions, a “ghost” image may appear. In such cases, the automatic registration cannot be performed successfully.

The automatic segmentation of the lesion has been evaluated using three aspects. The first test concerns the presence of regions which belongs to the nodule but are not included in the segmentation. This may happen when there are dark zones in the lesion. Results show that in about 20% of cases the segmented region does not include a significant part of the real nodule. In the same way it has been verified in all cases of the test database the segmented region does not include zones which are not part of the lesion. The last aspect which has been considered is the presence of openings in the nodular region. Openings are very important to detect because the presence of a ring-shaped nodule is a strong sign of a malignant lesion. In our dataset there were two lesions with openings, both of which have been correctly detected.

In order to evaluate the results of the evaluation module, the scores determined from each of the parameters have been compared with the scores manually assigned by the medical expert. In the present work, it has been assumed that the manual classification, performed by a working team of two radiologists, can be considered substantially correct. Therefore the result reported in Tab. ref-

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Table 2: Results: agreement between the automatic procedure and the manually assessed parameters

Parameter	Agreement ratio
Enhancement	100%
Continuity	90%
Homogeneity	70%
Morphology	90%
Sharpness	90%

fig:results report the percentace of agreement between the scores obtained using the manual and the automatic method. The comparison of the overall score has been considered redundant, as it is obtained as a sum of the single scores. Among the five scores, the homogeneity of the nodule has shown to be the one which gives the highest error ratio: the automatic estimate disagrees with the scoring obtained by visual inspection of about 30%. Results are significantly better for the other parameters: automatic assessment of sharpness, shape and continuity are in agreement with the manual assessment of the same parameter in about 90% of cases. The initial enhancement of the lesion is in complete agreement with the scoring by the medical expert in all cases belonging to the test dataset.

Discussion

The reported results, althought obtained on a small test set, indicate that an automated method is well suitable to perform an automated evaluation of the BIRAD score for suspect lesions in magnetic resonance imaging. The more quantitative parameters, as the ones which describe the dynamic behaviour of the enhancement, can be measured automatically with a very good accuracy. Results indicate that the evaluation of features which are more descriptive than quantitative is more complex. In particular, the 'homogenity' or kinetic parameter, which describes the distribution of contrast medium inside the lesion, is quite difficult to capture using a simple mathematical expression.

Conclusions

The proposed work is part of a larger project aimed to develop a system for computer assisted diagnosis of breast magnetic resonance. The performances of the system indicate that such a system may be very useful to improve the diagnosing process, as a throughtful examination of each image requires a large effort by the medical staff.

At present, the primary effort is aimed to collect a large clinical dataset which may represent the different clinical aspect of the lesions, in order to better assess the performances of the system and to identify the typology of lesions which may impact the performance.

The following steps will be toward the realization of a simple prototype which may be used routinely by the medical staff in order to better the evaluate the impact of a tool for computer-aided diagnosis on the daily practice. At the same time, we plan to start working of the automatic detection of suspect lesions and on a module for non-rigid registration which could allow to process the whole slice at the same time.

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