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On the potential use of anatomical and epidemiological information to enhance microwave and ultrasound breast imaging

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Abstract

This paper proposes the use of available anatomical and epidemiological (statistical) information regarding breast cancer in conjunction with microwave and ultrasound breast imaging. This information, which can be extracted from the broader medical research effort, can be used in conjunction with image reconstruction algorithms to further guide those algorithms towards a more accurate solution. In particular, we propose to consider the following anatomical and statistical information into the image reconstruction process via the tissue-type framework. Anatomical information is utilized in assigning a tissue-type and its corresponding probability to a given pixel by considering the neighbouring reconstructed pixels (epidemiological information related to the anatomical surroundings of the pixel is used to modify the prior probabilities in the Bayes prediction model). Two types of epidemiological information are used in reconstructing the tissue-type image to improve the discrimination between tumor and cyst: the quadrant of the breast within which a pixel is located provides statistical information regrading whether of being cancerous, and the age of the patient can provide similar information.

1 Introduction

Microwave and ultrasound imaging (MWI and UI respectively) can create quantitative images corresponding to the electromagnetic (*i.e.,* real and imaginary parts of complex permittivity) and ultrasonic (*i.e.,* sound speed, attenuation, compressibility and density) properties of the object of interest (OI) [1, 2, 3, 4, 5]. Integrating all these quantitative images into one image that incorporates the most important information of each individual image can be very useful; for example, in biomedical imaging applications, it is more practical and efficient for medical doctors to diagnose based on one single comprehensive image rather than checking several quantitative images with different range of colorbars. Furthermore, this concept (*i.e.,* integrating different images into one image) avoids the necessity for medical doctors to know the expected ranges of quantitative values for different tissue types of each quantitative image and also avoids the necessity for doctors to know which (part of the) quantitative image to trust more as compared to other images.

To this end, we introduced the concept of composite tissue-type image (cTTI) along with the probability image which can integrate all the quantitative images obtained from different modalities into one image; see [1]. Each pixel of this composite image corresponds to the special tissue type (e.g., breast tumor) as opposed to having quantitative values. In other words, reconstructed quantitative values of various images (e.g., conductivity image and sound speed image) can be combined to infer the tissue type. In addition, in this approach, the probability of choosing the special tissue type for each pixel is also provided in another image to help medical doctors determine the level of confidence for each pixel within the composite tissue type image. The reconstruction of cTTI along with its associated probability image based on the numerically generated data for ultrasound tomography and microwave tomography as well as their combination are presented in [1], in which, an inverse scattering approach (the Born iterative method or the Gauss-Newton inversion algorithm) is utilized to create the quantitative images. The experimental evaluation of this technique using ultrasound data for a tissue mimicking phantom based on ray-type methods is also described in [6].

In this approach, the prior probability of each tissue-type occupying each pixel is required to create a cTTI image based on Bayes' formula [1, 6]. When we do not have any prior information about the OI, we choose the prior probability of all the tissue types for each pixel to be the same. For example, in the case of breast imaging, we can consider five different tissue types: skin, fat, fibroglandular, tumor and cyst. Assuming that we do not have any prior information about where these tissue types are located within a breast, each pixel within the imaging domain will have a probability of 0.2 that it is occupied by one of these five tissue types. In this paper, we propose to take advantage of some anatomical information about the breast to provide a better prior probability for some of the pixels in the imaging domain, instead of naively assuming the same prior probability for each tissue-type. As will be shown in the presentation, this information can enhance the reconstruction of the cTTI.

A simple example of the use of anatomical information is the taking into account of the position of the skin tissue-type which is in the outer regions of the breast. Thus, the

chance of having a skin tissue in the central parts of the reconstructed breast volume is zero. Therefore, we can assign a zero prior probability for skin tissue-type to the pixels residing in the central parts of the breast. Furthermore, the tissue-types of the neighbouring pixels can also help to provide a better prior probability for that pixel. For example, if we know that the chance of a tumor occurring inside the fibroglandular tissue is high [7], then we can always check the neighbouring pixels of that pixel that has been reconstructed as tumor. That is, the prior probability of a pixel reconstructed as tumor might be reduced if its neighbouring pixels are skin and fat. Similarly, we can apply the same procedure for any cyst regions.

The statistical information about relevant to breast cancer can also take into account the case in which we have an ambiguity of choosing a pixel as being tumor or cyst. For example, this might happen when the associated probabilities of a pixel for being tumor or cyst are close to each other. In this case, in addition to creating a cTTI along with the probability image, we also provide another cTTI to provide further insight and guidance regarding such pixels based on the statistical information to help medical doctors. For example, this statistical information can be based on the location of the pixel in the breast and also the age of the patient, or any other statistical information available from the medical research community.

The structure of this paper is as follows. In the next section, we briefly explain the formation of a cTTI. Then, in Section 3, we discuss how to use anatomical and statistical information (available from epidemiological research) to enhance breast cancer diagnosis. Finally, our methodology will be described. More discussion and examples will be presented at the time of conference.

2 Composite Tissue Type Image (cTTI)

Two different methods are proposed in [1] to create a cTTI along with the probability image. In the first method, a single property tissue type along with the probability image is created for each property. Then, all these single property TTIs and probability images are utilized to create a cTTI. In the second method, all the properties are simultaneously used to create a cTTI. In both methods, Bayes' formula is utilized to calculate the probability of tissue-type T_k occupying the pixel of interest [1, 6]

$$P(T_k|x) = \frac{p(x|T_k)P(T_k)}{\sum_{i=1}^{N_t} p(x|T_i)P(T_i)} \qquad (1)$$

where N_t and x correspond to the total number of tissue types and the quantitative value of that pixel in the corresponding property image. Also, $p(x|T_k)$ is the value of the conditional probability density function (PDF) for property value x assuming the tissue type is T_k. As noted earlier, the prior probability of assigning tissue type T_k for that pixel is denoted by $P(T_k)$. Without any prior information it is usual to choose the same prior probability for all the tissue-types.

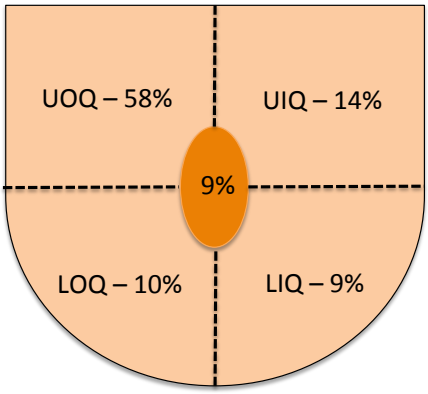

Figure 1. The chance of tumor arising in four different breast quadrants (dented by Q) based on the studies in [10]. This figure corresponds to the right breast with U indicating the upper, L indicting the lower, O indicating the outer and I indicating the inner; e.g., UOQ denotes the upper outer quadrant. The orange ellipse represent the nipple area.

3 Anatomical and Statistical Information

In this section, previously published reports related to breast cancer are discussed as an example of how one might extract prior information to improve our cTTI reconstructions. The specific information in these studies relates to the anatomical structure, the chances of a tumor being found in different breast quadrants, and the age of patients. We propose that taking into account this information can be very useful in the detection and identification of tumors via breast imaging. (This framework is general enough so that information obtained from other studies can easily be used to further enhance the reconstruction process.)

3.1 Anatomical Structure

Mammographic density (MD) which corresponds to the amount of fibroglandular tissue in the breast is one of the most important markers for breast cancer [7, 8]. The chance of breast cancer is four to six times for patients having dense breast tissue (occupying more than 75% of the breast) as compared to those having a low density (occupying less than 5% of the breast) [7, 8]. The study in [7] also shows that breast tumors emerge mainly within the radiodense tissue, specifically radiodense fibroglandular tissue. Furthermore, the fluid accumulation inside the glands leads to developing cysts in the breast [9]. Therefore, if a pixel is firstly identified to be tumor or cyst in the cTTI (using the equal prior probability assumption), we can subsequently check the neighbouring pixels of a pixel that has been identified to be tumor or cyst. Based on these studies, it is clear that the prior probability of a particular pixel being tumor or cyst can be reduced if the neighbouring pixels are skin and fat. The same procedure can also be considered for the skin tissue-type which should be in the outer region of the breast.

Table 1. The average age of cancer and non-cancer cases based on 300 cancer cases and 200 non-cancer cases based on the study in [13].

Decade	Cancer Cases [%]	Non-cancer Cases [%]
10-20	0	0.02
20-30	0.01	0.15
30-40	0.18	0.34
40-50	0.346	0.39
50-60	0.22	0.08
60-70	0.2	0.015
70+	0.043	0.005

3.2 Epidemiological Information

A study conducted from 1990 to 2005 found that among 13,984 women having tumors that these breast cancer tumors occurred 58% of the time in the upper-outer quadrant (UOQ), 14% in the upper-inner quadrant (UIQ), 9% in the lower-inner quadrant (LIQ), 10% in the lower-outer quadrant (LOQ), and 9% in the nipple complex [10] (these anatomical regions are shown in Fig 1). The same observation was also reported in [11]. Furthermore, an annual increase of breast cancer in UOQ was reported in [12]. Also, breast cancer in the UOQ is the highest among the youngest age group in this study (Age $\leq$ 49) [11, 12].

The chance of having tumor and cyst varies among different ages. For example, 300 cancer cases and 200 non-cancer cases were used in [13]. The average age of people having cancer and non-cancer based on these samples is tabulated in Table 1 [13]. Many more cancer cases (*i.e.,* 2,248) were considered in [14]. The percentage of cancer for three different age ranges using 2,248 cancer cases is tabulated in Table 2 [14]. As can be seen in Table 1, the percentage of cancer and non-cancer cases for the age below 30 is 0.01 and 0.17 respectively. Therefore, if after improving the cTTI using the previously discussed prior-modification methods we are still not sure whether to identify a pixel as being cancer or non-cancer (i.e., there is till an ambiguity), we can guess that the chance of being non-cancer is higher compared to cancer for a person in this age range. If in addition, the position of this pixel is not in the UOQ region (the quadrant having the highest chance of there arising a tumor), then the chance of being non-cancer may also be increased. For women of age greater than 60, the percentage of cancer and non-cancer cases is 0.243 and 0.02 respectively based on Table 1. Therefore, if there is ambiguity that a pixel has a tissue-type of cancer or non-cancer, for a patient in this age range, the chance of being cancer would be reported as being higher, especially for pixels in the UOQ region.

Table 2. The average age of cancer based on 2248 cases reported in [14].

Age	Number	Percentage
≤ 35	104	4.6
36-59	1503	66.9
≥ 60	641	28.5

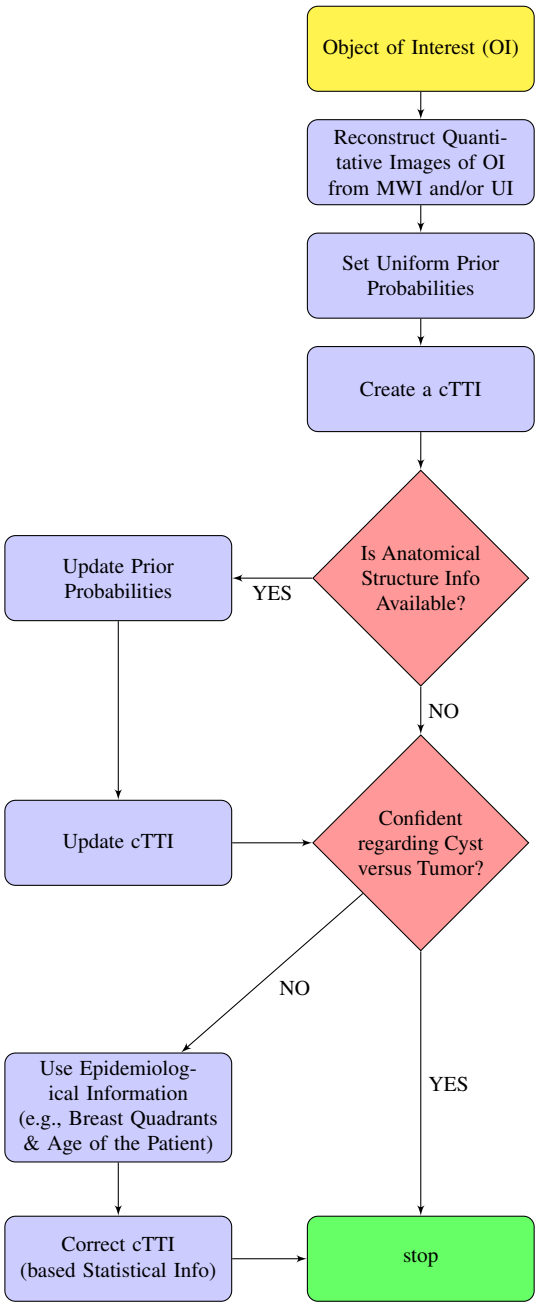

Figure 2. Flowchart of the proposed method for using anatomical and epidemiological information to enhance the cTTI reconstruction for breast imaging.

4 Framework

The flowchart of the framework for using anatomical structure and statistical information to improve the reconstruction of the cTTI for the breast is shown in Fig 2. In this method, we first create quantitative images of the breast. These quantitative images can be of the electromagnetic (*i.e.,* complex permittivity) and/or the ultrasonic properties (*i.e.,* sound speed, attenuation, density, and compressibility) of the breast. Different methods such as full-wave nonlinear inverse scattering algorithms, and ray based methods can be used to create these images [1, 2, 3, 4, 5, 6]. In the next step, the prior probabilities of all the tissue-types occupying each pixel are set to be the same. The cTTI along with the probability image is then reconstructed based on the two methods explained in [1]. After creating a cTTI based on the equal prior probability, we can check the neighbouring tissue-types of each pixel to provide a better prior probability based on the anatomical structure of the breast as discussed in Section 3.1. The new prior probability which is now modified based on the neighbouring tissue-types is used to enhance the reconstruction of the cTTI. Finally, if the cyst and tumor cannot be properly distinguished from each other (*i.e.,* the probability of being tumor or cyst is close to each other in a composite probability image), then the statistical information such as the chance of cancer in different breast quadrants, the age of patient (discussed in Section 3.2) or any other statistical information can be used to better determine the tissue type. Finally, another cTTI image based on all the statistical information is created. This final cTTI could be provided to medical doctors who would make the final diagnosis.

5 Conclusion

We have proposed a framework wherein one can incorporate available anatomical and epidemiological information about a breast being imaged into microwave and ultrasound imaging algorithms. Herein, we discussed some of forms of useful information which can be utilized to provide enhanced imaging or increased certainty about the reconstructed breast tissue type. A particular framework on how to incorporate this information into the cTTI reconstruction algorithm has been described using a flowchart. Examples demonstrating this approach will be presented at the conference.

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