

PAPER

# Study of a breast tumor extraction algorithm for three-dimensional ultrasound images, using multiple space differentiation filters: Automated breast tumor extraction algorithm with improved accuracy

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**Abstract:** The system to be developed in the present study will enable us to extract the tumor region automatically from three-dimensional ultrasonic images of the breast, and differentiate benign from malignant tumors by using the characteristics of their surface form. In application of such a system, the accuracy of diagnosis greatly depends on its ability to extract tumor automatically. We developed an algorithm for determination of the tumor region using fuzzy reasoning, that is, we classified each voxel of three-dimensional images as “tumor,” “normal tissue” and “boundary,” and, using relaxation techniques to resolve regional contradictions, made final decisions as to the tumor region. It must be noted that, according to this algorithm, a three-dimensional the space differentiation filtering automatically generates a membership function for the fuzzy reasoning. Previous attempts of extracting tumor used a single LoG filter as the space differentiation filter. We recently developed a method which can cope with diverse ultrasound images more flexibly. With this new method, multiple DoG filters with varying characteristics are prepared in addition to the LoG filter, and the optimum one is selected from multiple extraction results. The introduction of this method improved the accuracy of extraction.

**Keywords:** Three-dimensional ultrasonic image, Contour extraction, Fuzzy reasoning, Log/Dog filter

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## 1. INTRODUCTION

We are developing a system for differentiating benign from malignant tumors from the three-dimensional ultrasonic images of the breasts [1–4]. The characteristics of mammary tumors are that, whereas the surface of malignant tumors is rough and relatively lumpy, benign tumors frequently have a smooth and flat surface.

This system enables us to differentiate between benign and malignant tumors by utilizing the geometric characteristics of the tumor form, which makes it crucial for the geometric form of tumors to be acquired accurately. The previous ‘tumor region extraction algorithm’ used a single space differentiation filter when creating membership functions for fuzzy reasoning to extract tumors. The new method uses multiple space differentiation filters for extraction of tumor regions. We propose a tumor region extraction algorithm using multiple space differentiation filters for precise determination of tumor shape. The use of this algorithm elevated the tumor-extracting capability, as reported below.

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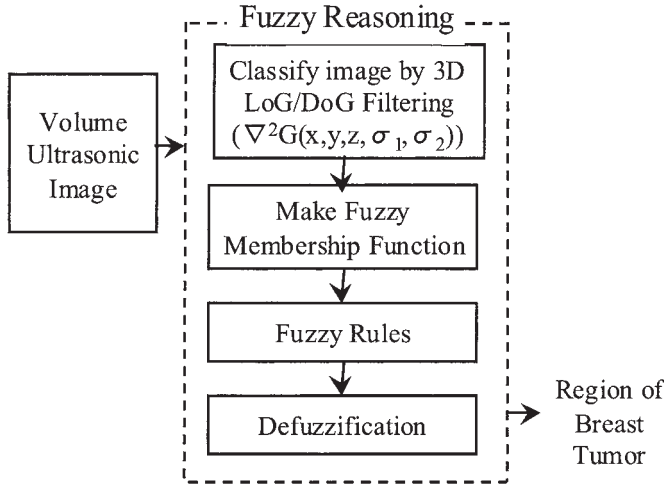


Fig. 1 Flow of the proposed method.

## 2. SYSTEM CHARACTERISTICS

Figure 1 shows the flow chart for the conventional ‘tumor region extraction algorithm.’ This system uses the ultrasonic tomograms of the breast converted to the voxel data as case data. The tumor region is automatically extracted from these case data, then the characteristics of the tumor surface form are quantified, and the tumor is determined as benign or malignant. For the automatic extraction of tumors by this system, fuzzy reasoning and defuzzification by the relaxation technique are used. In diagnostic ultrasonography, the breast tumors are generally visualized as low-brightness images. We therefore used the regional mean brightness, brightness dispersion and brightness centroid vector as parameters in fuzzy reasoning. Meanwhile, since the mean brightness of the whole image in ultrasonic tomography varies with such factors as the thickness of subcutaneous fat and the frequency of ultrasonic waves, a fixed membership function does not operate well in calculation. For this reason, membership function was calculated for each set of case data.

A three-dimensional space differentiation filter is used for creating membership functions, allowing automated creation of the functions reflecting the characteristics of individual cases.

The use of the space differentiation filter for fuzzy reasoning allowed stable extraction. Each process when using the conventional tumor region extraction algorithm is shown in the next section.

With the conventional tumor region extraction algorithm, only one kind of Log (Laplacian of Gaussian) filter was used for creation of membership functions. With the new method, Dog (Difference of Gaussian) filters are additionally used. Multiple membership function were created by changing the parameters for these filters, and the multiple extraction results were compared. With this new method, the examiner selects the optimum result from the

multiple extraction results. In this way, the accuracy of extraction was improved from the level achieved by the use of a single space differentiation filter.

## 3. TUMOR EXTRACTING ALGORITHM

Membership function for fuzzy processing was generated.

The 3-dimensional space differentiation filter was applied to the voxel data (case data), and zero crossing processed the output image. This put the voxel data into one of 3 classes, “low brightness region,” “high brightness region” and “contour region.”

For each class established in this way, the histogram of each fuzzy parameter was drawn up. Fuzzy parameters were the parameters used in subsequent fuzzy reasoning, and consisted of “mean brightness,” “dispersion of brightness” and “size of brightness centroid vector.”

The parameters “mean brightness  $u$ ,” “brightness dispersion  $v$ ” and “brightness centroid vector  $d$ ” were obtained from  $7 \times 7 \times 7$  voxels adjacent to the voxel of interest, and showed the regional characteristics of voxel data.

The histogram obtained in this way showed the tendency of values of fuzzy parameter in each class. Since the histogram of brightness of ultrasonic tomogram is known to follow Rayleigh distribution in general, Rayleigh distribution or, if it was not appropriate, Gaussian distribution was approximated to the histogram, which yielded membership function. Membership function varied with the characteristics of filter, so that the result of automated extraction depended on the characteristics of filter.

In the past, LoG filter was used as the space differentiation filter for generation of membership function. In the present study, DoG filter was introduced as a new technique for improvement of the extraction.

Equation (1) shows 3-dimensional LoG filter. In this equation,  $\gamma$  denotes the distance from the origin, and  $\sigma$  indicates the standard Gaussian deviation.

Equation (2) DoG filter. A single parameter ( $\sigma$ ) is set for the LoG filter. For the DoG filters, which determine the difference between two LoG filters, two LoG filter parameters ( $\sigma_1$  and  $\sigma_2$ ) can be set [5]. Varying these parameters may generate space differentiation filters with different characteristics. Figure 2 shows an example of changes in frequency characteristics resulting from changes in parameter values. More parameters can be set for the DoG filter than for the LoG filter, allowing more diverse filter setting.

Since it is thus possible to change the characteristics of the space differentiation filters, multiple membership functions with varying characteristics can be created for each individual case.

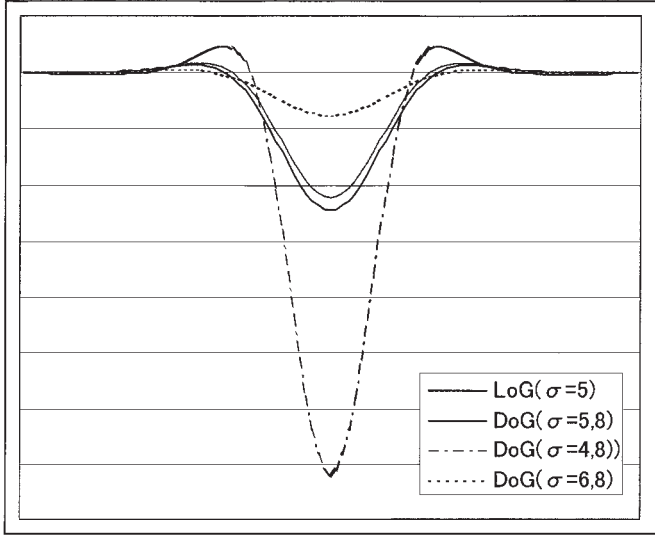


Fig. 2 Characteristics of LoG and DoG filter.

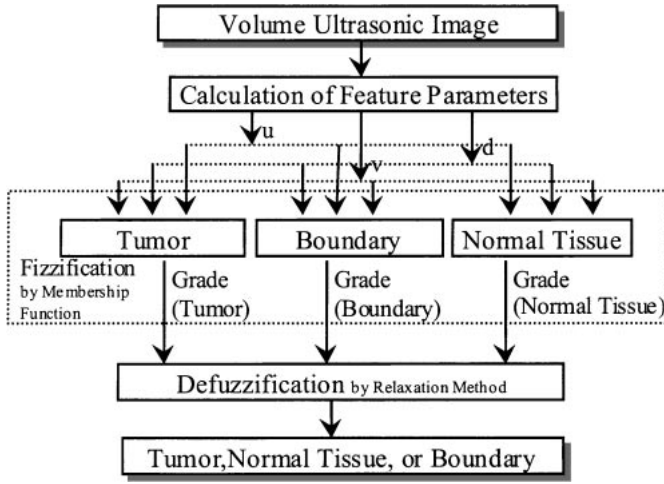


Fig. 3 The scheme of the breast tumor extraction algorithm employing fuzzy reasoning.

$$G(r, \sigma) = \frac{r^2 - 3\sigma^2}{\sqrt{2\pi^3\sigma^7}} e^{\left(\frac{-r^2}{2\sigma^2}\right)} \quad (1)$$

$$G(r, \sigma_1, \sigma_2) = G(r, \sigma_1) - G(r, \sigma_2) \quad (2)$$

In fuzzy reasoning, the grade of “tumor,” “boundary” and “normal tissue” for each voxel are calculated. “Membership function” obtained in the previous process is used to calculate these grades. The parameters “mean brightness  $u$ ,” “brightness dispersion  $v$ ” and “brightness centroid vector  $d$ ” of  $7 \times 7 \times 7$  voxels adjacent to the voxel of interest were input into membership function, and the grade of each parameter was calculated.

The grade information for “tumor,” “boundary” and “normal tissue” obtained by fuzzy reasoning are calculated on the basis of fuzzy parameter characteristics for each voxel of interest. In subsequent defuzzification, grade information is updated on the basis of regional restriction

rules for adjoining voxels by utilizing the relaxation technique.

The following three rules are defined as regional restriction rules:

- (1) If the voxel of interest is “tumor,” it does not adjoin “normal tissue.”
- (2) If the voxel of interest is “boundary,” it always adjoins “tumor” and “normal tissue.”
- (3) If the voxel of interest is “normal tissue,” it does not adjoin “tumor.”

The contradictions generated by the regional restrictive conditions are resolved by updating, and the voxel of interest is classified as “tumor,” “boundary” or “normal tissue.”

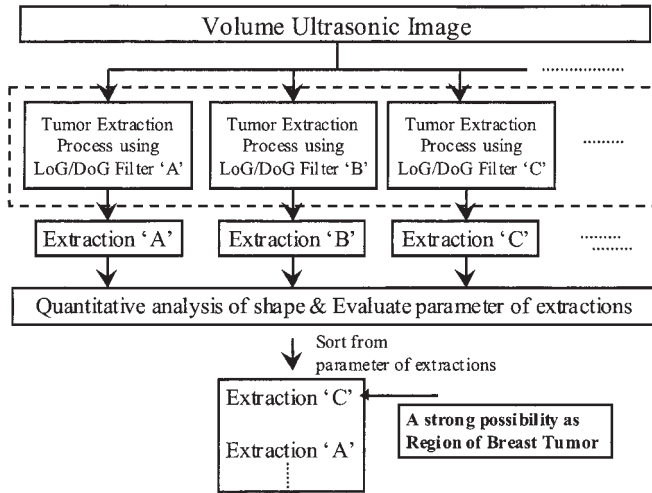
#### 4. IMPROVEMENT OF EXTRACTION RATE BY USE OF MULTIPLE SPACE DIFFERENTIATION FILTERS

The tumor region was extracted by the above algorithm. In the present study, the new technique “using multiple space differentiation filters to extract tumor region” was used. When the characteristics of space differentiation filters used in generating membership function are changed, the results of tumor region extraction change. Currently it is not clear what relationship exists between the characteristics of space differentiation filter and the results of tumor region extraction. This makes it difficult at present to determine in advance the space differentiation filter most suitable for extracting tumor regions from the ultrasonic image under study.

Accordingly, we devised the new approach “selecting the most suitable filter among multiple space differentiation filters in consideration of the results of extraction of tumor regions using these filters.” Currently, selection of the fittest data depends largely on the examiner’s experience, and the final judgment cannot be left to the system. For this reason, selection of the fittest data is entrusted to the examiner. Prior to the selection process by the examiner, several candidates for the “suitable extraction” are automatically selected from multiple different results of extractions obtained by the extraction process. Before the examiner selects the optimum result, the candidates of optimum extraction are selected. This algorithm was newly devised in the present study. In this “candidate selecting process,” several data sets are automatically selected from the results of extractions using multiple space differentiation filters. The examiner needs to select only the fittest one from these several data sets.

Figure 4 shows the flow of algorithm for tumor region extraction using multiple space differentiation filters.

For one set of case data for extraction, the tumor region was extracted using multiple space differentiation filters (written as LoG/DoG filter ‘A,’ LoG/DoG filter ‘B,’ ... in



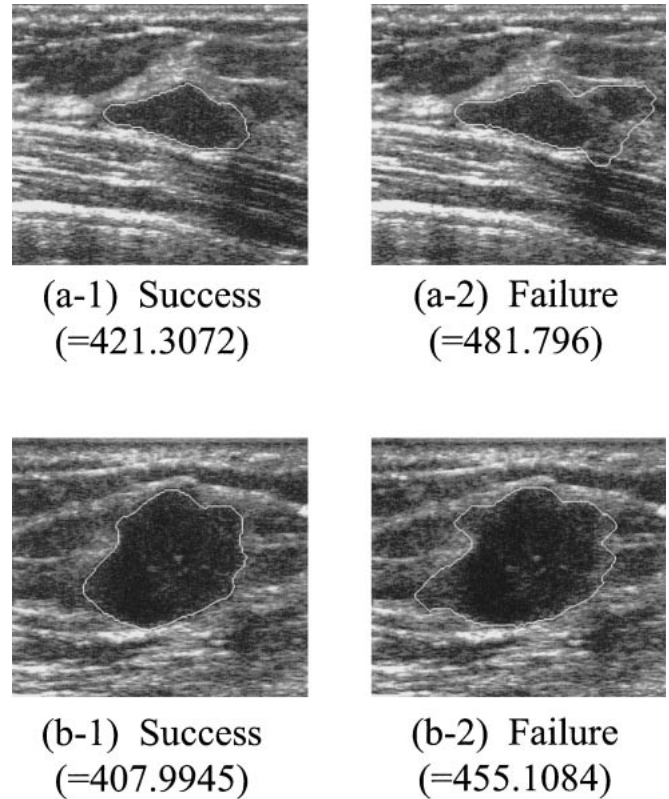
**Fig. 4** Flow of the proposed method using variety LoG and DoG filters.

Fig. 4). Here, extraction of tumor regions was performed using 11 space differentiation filters with varying characteristics. These include 3 LoG filters and 8 DoG filters determined through past studies. The same 11 filters were used for all of the subjects. The results of extractions of tumor regions (Extraction 'A,' Extraction 'B,' ...) are compared with each other by use of parameter showing "whether or not tumor region is correctly extracted," and the candidates for appropriate extraction are determined. The system selects 6 candidates from the 11 extraction results, using the algorithm mentioned below. The number of candidates for data selected by the system was placed at 6 in consideration of the convenience to the examiner and the environment of system operation, etc. The examiner confirms 6 sets of candidate data by visual observation, and selects the most appropriate data set.

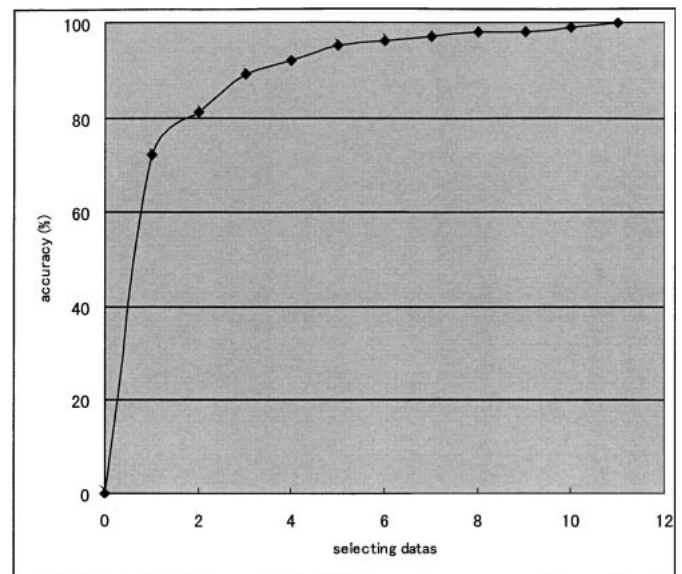
Parameters used were composed of quantitative information (surface area, volume ratio, etc.) about extraction results. They represented the degree of tumor surface irregularities numerically. With this algorithm, lower degrees of tumor surface irregularity are preferentially selected as candidates for optimum extraction.

Figure 5 shows examples of borderline depiction results obtained with different filters from a given case and examples of the parameters used for this case. Extraction appears to be smooth when the filter allowing accurate depiction of the borderline was used than when the other filter was used. Since failure in extraction is often reflected into inappropriate surface irregularities, it is possible to select candidates for 'optimum extraction' by comparing the degree of tumor surface irregularities among different extractions from the same case.

In practice, each parameter is calculated on the basis of the results of extraction with 11 space differentiation filters. Candidates for optimum extraction are selected from the extraction results with smaller values of the parameter.



**Fig. 5** Comparison scores of the parameter between success and failure to extract.

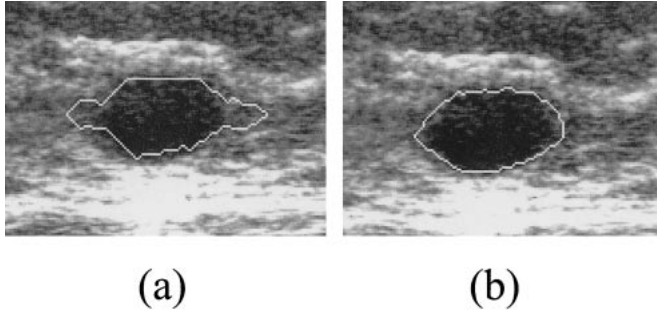


**Fig. 6** Accuracy of selecting process from some differently extractions.

Figure 6 graphically shows the number of data sets selected as candidates and the percentage of appropriate data included in candidate data.

Since 6 sets of candidate data were selected in this study, the percentage of appropriate data included in candidate data was 95% or over.





**Fig. 7** Comparison of the breast tumor regions extracted by the 3D LoG filtering (a) and 3D DoG filtering ( $\sigma_1 = 31$ ,  $\sigma_2 = 1$ ) (b).

## 5. EXPERIMENT

An algorithm for tumor region extraction, using multiple space differentiation filters, was applied to extraction of tumor regions on two-dimensional ultrasound images containing low-brightness breast cancer-affected areas, to evaluate its validity. The ultrasonic tomograms had been converted to 3-dimensional voxel data in advance. Figure 7 shows examples of the results of extraction using LoG or DoG filter. In these examples, the tumor region did not agree with the tumor in extraction using LoG filter [Fig. 7(a)], but agreement with the tumor was accomplished by appropriate setting of  $\sigma$  in DoG filter [Fig. 7(b)].

As in the above example, extraction of the tumor contour using several different space differentiation filters seemed to be an effective method for coping with the diversity of diagnostic ultrasonic images.

## 6. EVALUATION OF THE ACCURACY OF EXTRACTION

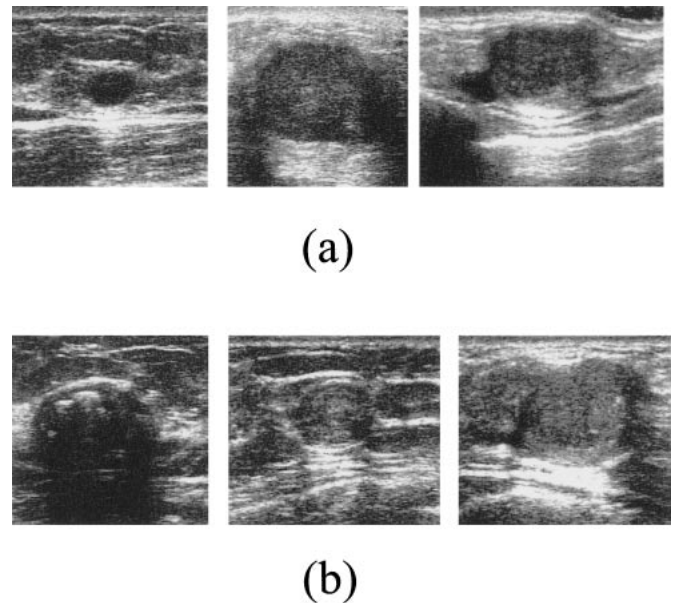
The accuracy of extraction by the present method was evaluated. In evaluation of the performance, 2 evaluation points were used, “accuracy of the extraction of tumor region” and “accuracy of the selection of the results of extraction.” “Accuracy of the extraction of tumor region” was evaluated with “whether or not the tumor region was accurately extracted” as the indicator. Evaluations of “whether or not the tumor region was accurately extracted” were qualitatively classified by comparing the tumor contour delineated by the present system with the contour delineated by the examiner’s visual observation, and classified as “success” or “failure” of extraction. The present system uses multiple space differentiation filters to extract the tumor region. In this study, total 11 space differentiation filters differing in the parameter  $\sigma$  were used. Multiple space differentiation filters were used to cope with the diversity of ultrasonic images. Accordingly, if 11 sets of extraction results contain even one set of appropriate extraction, extraction in that set of case data was evaluated as “success.”

With the present system, after extraction of tumor region using multiple space differentiation filters, several candidates for the appropriate tumor extraction data are selected. “Accuracy of the selection of the results of extraction” is evaluated with “whether or not the candidates were accurately selected” as the indicator.

In the present study, 6 sets of candidate data were selected from 11 sets of the results of extraction, and the selection was evaluated as “success” if the candidates contained appropriate results of extraction.

Data for evaluation were obtained from 209 cases (116 benign data, 93 malignant data) in “mammary data with low-brightness tumor region” acquired clinically at Jichi Medical School. Images satisfying the following requirements were subjected to analysis as mammary gland data depicting low-brightness tumor regions: (1) the tumor region contains no unhomogeneous high-brightness area and is approximately uniformly hypoechoic; and (2) a marked difference in brightness is seen between the tumor region and the area outside the tumor region. The presence or absence of shadow was not considered when selecting images for this analysis. Ultrasound images with shadow were also studied. Figure 8 shows examples of the images, where Group a images were subjected to analysis and Group B images were excluded from the analysis.

First, “accuracy of the extraction of tumor region” was evaluated. In extraction using 11 types of filters, extraction was successful in 176 of 209 cases (extraction rate 84%). Then, “accuracy of the selection of the results of extraction” was evaluated. In evaluation of 176 sets of case data with successful extraction, selection was evaluated as successful in 171 of 176 cases (selection accuracy



**Fig. 8** Image group (a) is target on this system. Image group (b) is not target on this system.

**Table 1** Comparing matrix with the current algorithm and the new algorithm.

	Accuracy of the extraction.	Accuracy of the selection	The accuracy
LoG (1 filter)	21%	—	21%
LoG+DoG (11 filters)	84%	97%	81%

97%). The overall performance of the system was evaluated. The accuracy with which correct tumor contour was extracted from random case data was “ $84\% \times 97\% = 81\%$ ” from the results of evaluation of “accuracy of the extraction of tumor region” and “accuracy of the selection of the results of extraction.”

For the sake of comparison, the performance of the system using a single filter was evaluated. In evaluation of “accuracy of the extraction of tumor region,” extraction was successful only in 43 of 209 cases with the use of LoG filter alone (extraction rate 21%). Since only a single filter was used, “accuracy of the selection of the results of extraction” was not indicated. From the above results, it was confirmed that extraction rate improved in the use of 11 types of space differentiation filters vs. the use of a single space differentiation filter.”

## 7. CONCLUSION

The algorithm for automatic extraction of tumor region in the computer-aided diagnostic system using three-dimensional ultrasonography for breast was reviewed. In this system, tumor region was extracted by fuzzy reasoning using membership function and defuzzification using the relaxation technique. Membership function was generated for each set of case data, to cope with the diversity of ultrasonic images under study. In the process of generating membership function, the images were classified by space differentiation filtering. This space differentiation filter

allowed the parameters to have various degrees of freedom, also to cope with the diversity of ultrasonic images. We devised a technique by which tumor region was extracted by using multiple space differentiating filters, and appropriate data were selected from among multiple sets of extraction results obtained thereby. The method was confirmed to improve markedly the accuracy of extraction as compared with the automatic extraction using a single filter. In the clinical evaluation of the effectiveness of the present technique in 209 cases of low-brightness breast tumors (79 benign cases, 36 malignant cases), the extraction rate was  $\geq 80\%$  with the use of 11 types of filters.

In the present study, the parameter  $\sigma$  was fixed at a certain level for each of the 11 space differentiation filters used for creation of membership functions. With this method, however, the tumor region extraction algorithm needs to be applied to all of the 11 parameters, possibly increasing the time needed for image processing. A possible measure to deal with this problem is selection of an appropriate value of the parameter  $\sigma$  for the space differentiation filters in individual cases. How to put this method into practice is an open issue for the future.

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