

METHOD AND SYSTEM FOR TISSUE DIFFERENTIATION

FIELD OF THE INVENTION

This invention relates to methods for classifying tissues.

BACKGROUND OF THE INVENTION

It is known to apply a plurality of microphones onto a body surface in order to record body sounds simultaneously at a plurality of locations on the body surface. U.S. Patent No. 6,139,505, for example, discloses a system in which microphones are placed around a patient's chest and recordings of the microphones are displayed on a screen or printed on paper. Kompis *et al.* (*Chest* 120(4):2001) discloses a system in which microphones are placed on a patient's chest to record lung sounds that are analyzed to determine the location in the lungs of the source of a sound detected in the recording.

Applicant's copending Application No. 10/338,742 filed on January 9, 2003 and having the publication number US 2003-0139679 discloses a method and system for analyzing body sounds. A plurality of microphones are affixed to an individual's chest or back. The recorded sound signals are analyzed to determine an average acoustic energy at a plurality of locations over the chest. The determined acoustic energies are then used to form an image of the respiratory tract.

A learning neural network is an algorithm used to classify elements based upon previously input information on the nature of the elements. US Patent No 6,109,270 to Mah et al discloses use of a learning neural network to classify brain tissue as being either normal or abnormal. US Patent No. 6,463,438 to

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Veltri et al. discloses use of a neural network to distinguish between normal and cancer cells.

SUMMARY OF THE INVENTION

The present invention provides a method and system for tissue
5 differentiation. M acoustic signals are obtained during a time interval by placing
M microphones on a body surface such as an individuals back or chest. The M
acoustic signals are each subjected to frequency band filtering by means of N
frequency band filters. For each filter, the M outputs from the filter are input to a
first image processor. The first image processor generates an image using the M
10 outputs of the filter. The images may be obtained by any method for generating
an image from acoustic signals. For example, the images maybe obtained by the
method of Kompis et al. (supra). In a preferred embodiment of the invention, an
image is generated by the method disclosed in applicant's WO 03/057037. In the
method of WO 03/057037, an image is obtained from M signals $P(x_i, t)$ for $i=1$ to
15 M, (where the signal $P(x_i, t)$ is indicative of pressure waves at the location x_i ; on
the body surface) by determining an average acoustic energy $\tilde{P}(x, t_1, t_2)$ at at least
one position x over a time interval from a first time t_1 to a second time t_2 .

The N images are preferably, but not necessarily, transformed by an SVD
(singular value decomposition) processor, as explained in detail below. The
20 output of the SVD processor is input to a self-organizing map neural network and
to a classifier. A self-organizing map neural network is different from a learning
neural network in that it does not need the learning phase which includes an
external vector with the identification of a teacher and does not require the input
of previously acquired information on the nature of the elements. The output of
25 the neural network consists of L N-dimensional vectors where L is a
predetermined number of categories of interest. The output from the neural
network is input to the classifier.

For each pixel $p(x, y)$, the classifier is configured to calculate a probability
of assigning the pixel to each of the L categories. One or more images may then

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be generated by a second image processor based upon the output from the classifier.

Thus, in its first aspect, the invention provides a method for tissue differentiation comprising:

- 5 (a) obtaining M acoustic signals $s_i(t)$, $i=1$ to M , from M locations on a body surface;
- (b) for each of N frequency bands, and for each of the signals $s_i(t)$, i from 1 to M , subjecting the signal $s_i(t)$ to band pass filtering using N band-pass filters, so as to generate NXM signals $s_{ij}(t)$, $i=1$ to M , $j=1$ to N ;
- 10 (c) generating K images I_1 to I_K , where $K \leq N$, using the signals $s_{ij}(t)$, $i=1$ to M , $j=1$ to N ;
- (d) dividing pixels into a predetermined number L of categories C_ℓ , ℓ from 1 to L , using the images I_1 to I_K ; and
- (e) for each category C_ℓ , ℓ from 1 to L , and for each pixel $p(x,y)$, calculating a probability p_ℓ of assigning the pixel $p(x,y)$ to the category C_ℓ .

In its second aspect, the invention provides a system for tissue differentiation comprising:

- a. M sound transducers configured to obtain M acoustic signals $s_i(t)$, $i=1$ to M , from M locations on a body surface;
- 20 b. N band pass filters, each band pass filter being configured to receive each of the signals $s_i(t)$, i from 1 to M , so as to generate NXM signals $s_{ij}(t)$, $i=1$ to M , $j=1$ to N ;
- c. A first image generator configured to generate K images I_1 to I_K , where $K \leq N$, using the signals $s_{ij}(t)$, $i=1$ to M , $j=1$ to N ;
- 25 d. a neural network configured to divide pixels into a predetermined number L of categories C_ℓ , ℓ from 1 to L , using the images I_1 to I_K ; and
- e. a classifier configured, for each category C_ℓ , ℓ from 1 to L , and for each pixel $p(x,y)$, calculating a probability p_ℓ of assigning the pixel $p(x,y)$ to the category C_ℓ .

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BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

5 **Fig. 1** is a schematic diagram of a system for carrying out the method of the invention, in accordance with one embodiment of the invention;

Fig. 2 is shows 5 images of a heart obtained in accordance with one embodiment of the invention; and

Fig. 3 shows an image of an individual's lungs obtained in accordance
10 with one embodiment of the invention (Fig. 3a) and an image of the same lungs obtained without band pass filtering (Fig. 3b).

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a schematic diagram of a system for carrying out one embodiment of the method of the invention. M acoustic signals $S_1(t)$ to $S_M(t)$ are
15 obtained during a time interval by placing M microphones on a body surface (not shown) such as an individuals back or chest. The M acoustic signals are each subjected to frequency band filtering by means of N frequency band filters F_1 to F_N . For each filter F_j , j from 1 to N, the M outputs from the filter F_j , $S_{ij}(t)$, i from 1 to M, are input to a first image processor. The first image processor generates
20 N images I_j , j from 1 to N, where each image I_j is obtained using the M outputs of the filter F_j . The images I_j may be obtained by any method for generating an image from acoustic signals. For example, the images maybe obtained by the method of Kompis et al. (supra). In a preferred embodiment of the invention, an image is generated by the method disclosed in applicant's WO 03/057037. In the
25 method of WO 03/057037, an image is obtained from M signals $P(x_i, t)$ for $i=1$ to M, (where the signal $P(x_i, t)$ is indicative of pressure waves at the location x_i ; on the body surface) by determining an average acoustic energy $\tilde{P}(x, t_1, t_2)$ at at least one position x over a time interval from a first time t_1 to a second time t_2 .

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The N images I_j , j from 1 to N, are preferably, but not necessarily, transformed by an SVD (singular value decomposition) processor. The SVD processor calculates N eigen-images EI_j and N corresponding eigen-values λ_j , for j from 1 to N, (not shown) where the N eigen-values λ_j are ordered so that

5 $\lambda_1 \leq \lambda_2 \leq \dots \leq \lambda_j \leq \dots \leq \lambda_N$. The SVD processor then determines an integer $K \leq N$

where K is the smallest integer for which $\frac{\sum_{j=1}^K \lambda_j}{\sum_{j=1}^N \lambda_j} \leq a$, where a is a predetermined

threshold. The output of the SVD processor is the K eigen-images EI_1 To EI_K . The learning phase of the process is thus completed.

The output of the SVD processor is input to a self-organizing map neural

10 network. The output of the neural network consists of L N-dimensional vectors $C_1, \dots, C_L$, where L is a predetermined number of categories of interest. The classification phase is carried out by inputting. The output from the neural network is input to the classifier together with the output of the SVD. The classifier thus receives as input the K eigen-images EI_1 to EI_K from the SVD (or

15 the N images I_1 to I_N , if a SVD processor is not used) and the L vectors $C_1, \dots, C_L$ from the neural network.

For each pixel $p(x,y)$, the classifier is configured to calculate a probability p_j of assigning the pixel $p(x,y)$ to the category C_j . One or more images may then be generated by a second image processor based upon the output from the

20 classifier. For example, for each category C_j , an image may be generated in which the pixel (x,y) has a gray level proportional to the probability that the pixel belongs to the category j . As another example, each category may be assigned a different color, and an image is generated in which each pixel is colored with the color of the category having a maximum probability for that pixel. As yet another

25 example of an image, an image may be generated by selecting, say three categories, and displaying the image on an RGB (red green blue) color display screen. In this example, for each pixel, the red, green, and blue intensity is

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proportional to the probability that the pixel belongs to the first, second, or third category, respectively. The generated image may be used by a practitioner to identify different tissue types in the image. Generated images may be used to form a data base for automatic learning by the practitioner or by the neural
5 network to analyze the images and identify tissue types in the images.

EXAMPLES

Example 1: Cardiac imaging

40 acoustic signals $S_i(t)$ arising from an individual's heart were obtained
10 during 0.04 seconds by placing 40 microphones on the individual's back in the cardiac region. The 40 acoustic signals were each subjected to frequency band filtering by means of 3 frequency band filters. For each filter, the 40 outputs from the filter were processed into an image as disclosed in applicant's US provisional Patent Application No. 60/474,595. The 3 images were input to a self-organizing
15 map neural network. The output of the neural network consisted of 5 3-dimensional vectors $C_1, \dots, C_5$, where 5 was the predetermined number of categories of interest. The output from the neural network was input to a classifier.

For each pixel, the classifier calculated a probability p_j of assigning the
20 pixel to the category C_j , for j from 1 to 5. An image was then generated for each of the three categories in which the pixel (x_i, y_i) has a gray level proportional to the probability that the pixel belongs to that category. The 5 images are shown in Fig. 2.

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Example 2: pulmonary imaging

40 acoustic signals $S_i(t)$ arising from an individual's lungs were obtained during 0.1 second by placing 40 microphones on the individual's back over the lungs. The 40 acoustic signals were each subjected to frequency band filtering by
30 means of 3 frequency band filters. For each filter, the 40 outputs from the filter

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were processed into an image as disclosed in applicant's US Patent Application 10/338,742 having the publication number 2003 01 3967. The 3 images were input to a self-organizing map neural network. The output of the neural network consisted of 3 3-dimensional vectors $C_1, \dots, C_3$, where 3 was the predetermined
5 number of categories of interest. The output from the neural network was input to the classifier.

For each pixel, the classifier calculated a probability p_j of assigning the pixel to the category C_j , for j from 1 to 3. A color image was then generated as follows. A different color (red green and blue) was used to indicate each of the
10 three categories. In the color image, each pixel $p(x,y)$ has a red, green, and blue level that is proportional to the probability that the pixel belongs to the first, second and third category respectively. A black and white rendition of the color image is shown in Fig. 3a. Fig. 3b shows an image of the individual's lungs obtained from the original sound signals (without frequency filtering) as
15 disclosed in applicant's US Patent Application 10/338,742 having the publication number 2003 01 3967.

CLAIMS:

1. A method for tissue differentiation comprising:
 - (a) obtaining M acoustic signals $s_i(t)$, $i=1$ to M, from M locations on a body surface;
 - 5 (b) for each of N frequency bands, and for each of the signals $s_i(t)$, i from 1 to M, subjecting the signal $s_i(t)$ to band pass filtering using N band-pass filters, so as to generate NXM signals $s_{ij}(t)$, $i=1$ to M, $j=1$ to N;
 - (c) generating K images I_1 to I_K , where $K \leq N$, using the signals $s_{ij}(t)$, $i=1$ to M, $j=1$ to N;
 - 10 (d) dividing pixels into a predetermined number L of categories C_ℓ , ℓ from 1 to L, using the images I_1 to I_K ; and
 - (e) for each category C_ℓ , ℓ from 1 to L, and for each pixel $p(x,y)$, calculating a probability p_ℓ of assigning the pixel $p(x,y)$ to the category C_ℓ .
2. The method according to Claim 1 comprising
 - 15 (a) generating N images I'_1 to I'_N , wherein the image I'_j is obtained using the signals $s_{ij}(t)$, i from 1 to M, and
 - (b) generating K eigenimages and K eigenvalues using the N images I'_1 to I'_N .
3. The method according to Claim 1 or Claim 2 wherein the body surface is a chest or a back.
- 20 4. The method according to Claim 1 or w wherein the acoustic signals are indicative of cardiac sounds or respiratory tract sounds.
5. The method according to Claim 1 wherein an image is obtained from M signals $P(x_i, t)$ for $i=1$ to M, the signal $P(x_i, t)$ being indicative of pressure waves at the location x_i on the body surface by determining an average acoustic energy
 - 25 $\tilde{P}(x, t_1, t_2)$ at at least one position x over a time interval from a first time t_1 to a second time t_2 , using the signals $P(x_i, t)$ for $i=1$ to M.
6. The method according to Claim 1 further comprising generating one or more images using the probabilities p_ℓ .
7. A system for tissue differentiation comprising:

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- (a) M sound transducers configured to obtain M acoustic signals $s_i(t)$, $i=1$ to M, from M locations on a body surface;
 - (b) N band pass filters, each band pass filter being configured to receive each of the signals $s_i(t)$, i from 1 to M, so as to generate NXM signals $s_{ij}(t)$, $i=1$ to M,
5 $j=1$ to N;
 - (c) A first image generator configured to generate K images I_1 to I_K , where $K \leq N$, using the signals $s_{ij}(t)$, $i=1$ to M, $j=1$ to N;
 - (d) a neural network configured to divide pixels into a predetermined number L of categories C_ℓ , ℓ from 1 to L, using the images I_1 to I_K ; and
 - 10 (e) a classifier configured, for each category C_ℓ , ℓ from 1 to L, and for each pixel $p(x,y)$, calculating a probability p_ℓ of assigning the pixel $p(x,y)$ to the category C_ℓ .
8. The system according to Claim 7 further comprising a single value decomposition processor, configured to:
- 15 (a) receive N images I'_1 to I'_N , generated by the first image generator, wherein the image I'_j is obtained using the signals $s_{ij}(t)$, i from 1 to M, and
 - (b) generate K eigenimages and K eigenvalues using the N images I'_1 to I'_N .
9. The system according to Claim 67 or Claim 8 wherein the body surface is a chest or a back.
- 20 10. The system according to Claim 7 or 8 wherein the acoustic signals are indicative of cardiac sounds or respiratory tract sounds.
11. The system according to Claim 7 wherein the first image generator is configured to generate an image from M signals $P(x_i, t)$ for $i=1$ to M, the signal $P(x_i, t)$ being indicative of pressure waves at the location x_i on the body
- 25 surface by determining an average acoustic energy $\tilde{P}(x, t_1, t_2)$ at at least one position x over a time interval from a first time t_1 to a second time t_2 , using the signals $P(x_i, t)$ for $i=1$ to M.
12. The system according to Claim 7 further comprising a second image generator configured to generate one or more images using the probabilities p_ℓ .