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(54) **RECEIVED DATA PROCESSING APPARATUS OF PHOTOACOUSTIC TOMOGRAPHY**

PHOTOAKUSTISCHES TOMOGRAPHIEGERÄT ZUR AUFBEREITUNG VON EMPFANGENEN DATEN

APPAREIL DE TRAITEMENT DE DONNÉES REÇUES DE TOMOGRAPHIE PHOTOACOUSTIQUE

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(56) References cited:
EP-A1- 1 561 424

- **XIANG, L; XING, D.; YANG, D.; YANG S.; HUA, G.: "Listening to light by fast photoacoustic tomography based on a digital phased array system" SPIE, PO BOX 10 BELLINGHAM WA 98227-0010 USA, vol. 6826, 2007, pages 1-8, XP040431869**
- **FRENZ M ET AL: "Combined Ultrasound and Optoacoustic System for Real-Time High-Contrast Vascular Imaging in Vivo", IEEE TRANSACTIONS ON MEDICAL IMAGING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 24, no. 4, 1 April 2005 (2005-04-01), pages 436-440, XP011129441, ISSN: 0278-0062, DOI: 10.1109/TMI.2004.843199**

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Description

Technical Field

[0001] The present invention relates to a received data processing apparatus of photoacoustic tomography used for a photoacoustic tomography diagnostic apparatus, and more particularly, to a technique of generating image data based on an acoustic wave receiving signal.

Background Art

[0002] Conventionally, it has been known that, when an electromagnetic wave is irradiated to a living body, an acoustic wave is generated due to a temperature increase and thermal expansion of an organism of the living body caused from the electromagnetic wave absorption of the living body. A technique (referred to as a photoacoustic tomography (PAT)) for visualizing an inner portion of the living body in a non-invasive manner by using the phenomenon has been attracting attention and employed in clinical sites using photoacoustic tomography diagnostic apparatuses.

[0003] In the photoacoustic tomography diagnostic apparatus, light is irradiated to a specimen as a target, and an acoustic wave generated therefore is received by a one-dimensional or two-dimensional micro-transducer array in which a plurality of micro-transducers are arrayed. As the one-dimensional or two-dimensional micro-transducer array, probes used for an ultrasonic diagnostic apparatus generally are used.

[0004] For image reconstruction in the photoacoustic tomography, various algorithms are applied. In general, a delay-and-sum process used for the image reconstruction in the ultrasonic diagnostic apparatus may be adapted.

[0005] After the light irradiation to the specimen, although the acoustic wave generated from the target position is received during the time of receiving the acoustic wave, a distance from the target position to each of the micro-transducers are not equal to each other. For this reason, the acoustic wave signal generated from the target position reaches the micro-transducers at the different time points. Therefore, in general, in the photoacoustic tomography diagnostic apparatus, the time difference in the acoustic wave signals that reach at the different time points is adjusted by using the delay-and-sum process so as to generate the photoacoustic tomography image data corresponding to the target position. The generated data of the target position are minimum constitution units (called pixel or voxel) of the two-dimensional or three-dimensional photoacoustic tomography image. In the delay-and-sum process, the acoustic wave analog signals received by the micro-transducer array are amplified by an amplifier and converted to digital signals by A/D converters, and the acoustic wave receiving digital signals are stored in a storage device. Accordingly, signal values originated from the same target position are added for all required channels.

[0006] In addition, in the photoacoustic tomography diagnostic apparatus, a process called apodization is performed in order to improve directionality of the one-dimensional or two-dimensional micro-transducer array. This process is not to uniformly add the acoustic wave signals received from the micro-transducers in the micro-transducer array but to attenuate the acoustic wave signals that reach a region of the micro-transducer array. Therefore, this process is provided so as to improve the directionality of the micro-transducer array by suppressing the strengths of the acoustic wave signals originated in directions except for the target direction. In general, different weighting factors intend to be applied to the acoustic wave signals received by the micro-transducers so that the same effect as applying the window functions or functions depending on solid angles and distances to the acoustic wave signals can be obtained.

[0007] In the delay-and-sum process on the digital signals, a delay apparatus for adjusting the delay times for the receiving channels is used. As the delay apparatus, a storage device such as a first in first out (FIFO) memory or a RAM is mainly used.

[0008] Recently, a large scale of a field programmable gate array (FPGA) chip has been provided. Moreover, high-speed rewritable FIFO memories or RAM memories are mounted thereon. Therefore, the FPGA chip can be easily mounted on the received data processing apparatus of photoacoustic tomography. However, the high-speed logic memories mounted on the FPGA chip have a limitation in terms of memory capacity. In addition, since the large-scale FPGA chip is expensive, the received data processing apparatus of photoacoustic tomography needs to be configured with as small logic memory capacity as possible.

[0009] Japanese Patent Application Laid-Open (JP-A) No. 2005-21380 or Japanese Patent Application National Publication (Laid-Open) No. 2001-507952 discusses technologies of irradiating light to a specimen, receiving an acoustic wave generated from thermal expansion of the specimen caused from the light irradiation, and constructing an image based on electrical signals obtained from the acoustic wave.

[0010] M. Frenz, et al. in "Combined Ultrasound and Optoacoustic System for Real-Time High-Contrast Vascular Imaging in Vivo", IEEE Transactions on Medical Imaging, volume 24, no. 4, 1 April 2005, pages 436-440 discloses a received data processing apparatus of photoacoustic imaging for receiving an acoustic wave generated by irradiating a light to a specimen and constructing an image from an electrical signal obtained from the received acoustic wave, wherein the light is irradiated at a predetermined time and at a repetition frequency of 7.5 Hz and the irradiation is followed by a waiting time before the next irradiation starts, comprising acoustic wave detectors that receive the acoustic wave originated from a specimen region; image construction means that constructs an image of the region of the specimen based on minimum constitution unit data; wherein the generation of all the minimum constitution unit data in the said specimen region occurs at the said repetition frequency.

SUMMARY OF INVENTION

[0011] However, in the prior examples discussed in Japanese Patent Application Laid-Open No. 2005-21380 or Japanese Patent Application National Publication (Laid-Open) No. 2001-507952, there is a problem in that a configuration of photoacoustic tomography diagnostic apparatus having multiple channels is complicated and a size thereof is enlarged. In other words, the size of the receiving circuit is enlarged, so that the cost is increased. In addition, when a photoacoustic tomography image is reconstructed by using software, a long time is taken to acquire the photoacoustic tomography image.

[0012] The present invention has been made in view of the above problems. Since the same problems occur in the field of ultrasonic diagnostic apparatus, various solutions may be used. However, since the features of the imaging in the photoacoustic tomography diagnostic apparatus are different from the features of the imaging in the ultrasonic diagnostic apparatus, there exist other effective solutions using the features.

[0013] The first different feature of the imaging between the photoacoustic tomography diagnostic apparatus and the ultrasonic diagnostic apparatus is the time interval of the light irradiation interval and the time interval of the ultrasonic wave transmission. In the case of the photoacoustic tomography, because of limitation to the light source that generates a practical light energy (several mJ or more), light irradiation time needs to be set to a predetermined time (several tens ms) or more. In other words, a long waiting time needs to be taken after the light irradiation. On the other hand, there is not such a limitation to an ultrasonic diagnostic apparatus. In addition, when the reception of the signal corresponding to the observation depth is completed, the ultrasonic wave transmission needs to be immediately performed in order to improve the frame rate. The time interval of the ultrasonic wave transmission is at most several hundreds of μs.

[0014] The second different feature of the imaging between the photoacoustic tomography diagnostic apparatus and the ultrasonic diagnostic apparatus is the difference in the observation depth and the reception time associated with the observation depth. In the photoacoustic tomography diagnostic apparatus, since the light attenuation in a human body is very high, the observation depth is limited to several cm. On the other hand, in the ultrasonic diagnostic apparatus, the observation depth may be set to several tens of cm. Therefore, in the photoacoustic tomography, the time of acquiring the receiving data after the light irradiation may be several tens of μs. However, in the ultrasonic diagnostic apparatus, when the depth of several tens of cm is observed, the time of acquiring the receiving data may be several hundreds of μs. For example, when the depth of 20 cm is observed, the time of acquiring the receiving data is about 260 μs.

[0015] In the ultrasonic diagnostic apparatus, since the transmission is immediately performed at the elapse of the time of acquiring the receiving data, the generation of the image data needs to be performed by performing the delay-and-sum process during the reception in order to maintain the real-time characteristics. Inthiscase, since the data incoming into the receiving channels need to be processed simultaneously, if the number of receiving channels is increased, the size of the apparatus is enlarged. The cost of the apparatus is increased.

[0016] On the other hand, in the photoacoustic tomography diagnostic apparatus, the light irradiation interval is long, and the time of acquiring the receiving data is short. In other words, a long waiting time is taken. Therefore, once the receiving data is stored in a storage medium, the generation of the image data can be performed in a sufficient time. This means that the image data can be generated in a time division manner by a miniaturized receiving data processing circuit. Since the real-time characteristics of the photoacoustic tomography image is rate-controlled by the light irradiation time, if the image data can be generated in the waiting time, the real-time characteristics of the image is not deteriorated.

[0017] The purpose of the present invention is to provide a received data processing apparatus of photoacoustic tomography having a novel structure capable of performing photoacoustic tomography image reconstruction by a miniaturized configuration at a high speed by using the aforementioned features of the photoacoustic tomography.

[0018] The above mentioned purpose is accomplished by a photoacoustic tomography apparatus according to claim 1. Further advantageous features are defined in the dependent claims.

[0019] According to the present invention, photoacoustic tomography image reconstruction can be performed by a miniaturized configuration at a high speed.

[0020] Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0021]

Fig. 1 is a block diagram illustrating a received data processing apparatus of photoacoustic tomography according to a first embodiment of the present invention;

Fig. 2 is a view illustrating a configuration of a calculation circuit according to the first embodiment of the present invention;

Fig. 3 is a view illustrating a positional relationship between a target voxel and an acoustic wave detector array in a specimen region;

Fig. 4 is a block diagram illustrating a received data processing apparatus of photoacoustic tomography according to a second embodiment of the present invention;

Fig. 5 is a flowchart illustrating operations of the received data processing apparatus of photoacoustic tomography according to the second embodiment of the present invention;

Fig. 6 is a block diagram illustrating a received data processing apparatus of photoacoustic tomography according to a third embodiment of the present invention;

Fig. 7 is a block diagram illustrating a received data processing apparatus of photoacoustic tomography according to a fourth embodiment of the present invention;

Fig. 8 is a view illustrating a configuration of a calculation circuit according to the fourth embodiment of the present invention;

Fig. 9 is a flowchart illustrating operations of the received data processing apparatus of photoacoustic tomography according to the fourth embodiment of the present invention; and

Fig. 10 is a block diagram illustrating a received data processing apparatus of photoacoustic tomography according to a fifth example of the present disclosure.

DESCRIPTION OF EMBODIMENTS AND EXAMPLES OF THE DISCLOSURE

[0022] Hereinafter, embodiments of the present invention and examples of the disclosure (not forming part of the invention) will be described in detail with reference to the accompanying drawings.

[First Embodiment]

[0023] Fig. 1 is a view illustrating a received data processing apparatus of photoacoustic tomography according to a first embodiment of the present invention. In Fig. 1, the total number of channels of the received data processing apparatus of photoacoustic tomography is N.

[0024] The received data processing apparatus of photoacoustic tomography forms an image based an electrical signal obtained by irradiating a light on a specimen and receiving an acoustic wave generated from localized thermal expansion and contraction of the specimen as a result of the light irradiation.

[0025] The apparatus includes N A/D converters 1-1 to 1-N, N delay adjustment memories (DELAY M) 2-1 to 2-N, and a calculation circuit 3. In addition, the apparatus further includes a memory control circuit 4, a reconstruction memory 5, a window function weighting factor calculation circuit 6, a delay memory address calculation circuit 7, a signal processing block 8 (log compression process, filter process), an image construction unit 9, and an image display unit 10.

[0026] The A/D converters 1-1 to 1-N are electrical signal conversion units that digitize analog electrical signals received by acoustic wave detectors 54-1 to 54-N of an acoustic wave detector array 52. The acoustic wave detector array 52 constitutes a receiving unit that allows the N acoustic wave detectors 54-1 to 54-N to receive an acoustic wave originated from a specimen region as a to-be-processed target and converts the received acoustic wave to the analog electrical signal.

[0027] The delay adjustment memories 2-1 to 2-N are first storage units that store the receiving digital signal digitized by the A/D converters 1-1 to 1-N in a time sequence .

[0028] The calculation circuit 3 is a minimum constitution unit data composition unit that reads receiving digital signals originated from voxels that are minimum constitution units of partitioning the specimen region as a target from the plurality of delay adjustment memories 2-1 to 2-N to compose voxel data. The voxel data is the acoustic wave data of each minimum constitution unit. The receiving digital signals originated from the voxels_are read according to delay information on the acoustic wave from the voxels to reach the acoustic wave detectors 54-1 to 54-N, and a delay-and-sum process is performed on the read receiving digital signal.

[0029] As shown in Fig. 2, the calculation circuit 3 includes N multipliers 11-1 to 11-N and one addition circuit 12. In addition, a plurality of the addition circuits 12 may be included in the calculation circuit 3.

[0030] The reconstruction memory 5 is a second storage unit that can store voxel data of the entire region of the specimen.

[0031] The image construction unit 9 is a unit that constructs an image of the specimen region based on the voxel data stored in the reconstruction memory 5.

[0032] In addition, the memory control circuit 4 is a control unit that sequentially stores the voxel data calculated by the calculation circuit 3 in the reconstruction memory 5 that is a second storage unit and reads the stored voxel data of the entire region of the specimen to transmit the voxel data to the image construction unit 9.

[0033] The delay memory address calculation circuit 7 is an address calculation unit that calculates delay times that are taken for the acoustic wave from the voxels to reach the acoustic wave detectors 54-1 to 54-N based on the voxel coordinates that are the minimum constitution unit coordinates in the specimen region. In addition, addresses in which receiving digital signals originated from the voxels corresponding to the delay times are stored to the delay memories 2-1 to 2-N.

[0034] The window function weighting factor calculation circuit 6 is a window function weighting factor calculation unit that calculates the window function weighting factors of the receiving channels through which the receiving signals of the acoustic waves are transmitted based on the voxel coordinates in the specimen region as a target and applies the calculated window function weighting factor to the calculation circuit 3.

[0035] In the embodiment, the signal processing block 8 is a second signal processing unit that performs signal processes including filter processes such as low-pass filter and high-pass filter, a logarithm compression (log compression) process, a differentiation process, an envelope detection process, and a quadrature detection process. The signal processing block 8 shown in Fig. 1 performs a signal process on the composed minimum constitution unit data. In this case, log compression process and filter process are featured in particular.

[0036] Next, the operations according to the first embodiment are described in detail.

[0037] Light such as a laser beam is irradiated from a light source (not shown) on the specimen, and as a result, the specimen is locally thermally expanded and contracted, so that the acoustic wave is generated. The acoustic wave is received by the N acoustic wave detectors 54-1 to 54-N of the acoustic wave detector array 52 to be converted to analog electrical signals. The analog electrical signals are digitized by the N A/D converters 1-1 to 1-N, so that N digital signals are output to the N delay adjustment memories (DELAY M) 2-1 to 2-N.

[0038] The delay adjustment memories (DELAY M) 2-1 to 2-N store digital signals output from the A/D converters 1-1 to 1-N.

[0039] The delay memory address calculation circuit 7 calculates the delay times and the delay adjustment memory addresses corresponding to the target voxels based on the voxel coordinates in the specimen region as a target and designates the delay adjustment memory addresses to the delay adjustment memories 2-1 to 2-N. The receiving digital data originated from the minimum constitution units in the specimen region, namely, originated from the target voxels are read from the delay adjustment memories 2-1 to 2-N according to the delay adjustment memory addresses calculated by the delay memory address calculation circuit 7. Next, the receiving digital data are output to the multipliers 11-1 to 11-N of the calculation circuit 3.

[0040] Fig. 3 illustrates an example of a positional relationship among a target voxel 53 in a specimen region as a target, an acoustic wave detector array 52, and an acoustic wave detector 54 in the array. If the coordinate (X1, Y1, Z1) of the target voxel 53 and the coordinate (X2, Y2, Z2) of the acoustic wave detector 54 in the array are determined in a predetermined coordinate system, a distance D between the target voxel 53 and the acoustic wave detector 54 in the array is immediately obtained by the Pythagorean theorem.

[0041] In addition, an acoustic wave reaching time (delay time) from the target voxel 53 to the acoustic wave detector 54 in the array is calculated by dividing the distance D between the target voxel 53 and the acoustic wave detector 54 in the array by a velocity of sound.

[0042] In addition, while the acoustic wave is received from the specimen region as a target, the delay adjustment memories 2-1 to 2-N sequentially stores the digital data originated from the acoustic wave in the addresses in the delay adjustment memories 2-1 to 2-N in the time sequence according to a predetermined rule. In other words, from the time of the light irradiation, the receiving digital signals are read in the time sequence manner from the delay adjustment memories 2-1 to 2-N, and the acoustic wave signals that reach by the delay times according to the distances from the positions of the voxels in which the acoustic wave is generated are stored in the delay adjustment memories 2-1 to 2-N.

[0043] The delay adjustment memory address can be specified based on the acoustic wave reaching time (delay time) that is taken for the acoustic wave from the target voxel 53 to reach the acoustic wave detectors 54-1 to 54-N in the array and the rule of storing the digital data in the delay adjustment memories 2-1 to 2-N. The delay memory address is a memory address in which digital data originated from a target voxel exists.

[0044] In the present invention, the delay memory address calculation circuit 7 calculates the delay adjustment memory addresses of the target voxels and designates the calculated delay adjustment memory addresses to the delay adjustment memories 2-1 to 2-N. The delay adjustment memories 2-1 to 2-N output the digital data originated from the minimum constitution units, namely, originated from the target voxels to the calculation circuit 3 according to the delay adjustment memory addresses designated by the delay memory address calculation circuit 7.

[0045] The window function weighting factor calculation circuit 6 calculates the window function weighting factors corresponding to the target voxels based on the voxel coordinates in the specimen region as a target and applies the window function weighting factors to the calculation circuit 3. Since the receiving digital signals output from the delay adjustment memories 2-1 to 2-N are in the apodization, the channels are applied with the window function weighting factors calculated by the window function weighting factor calculation circuit 6, and the receiving digital signals are output to the addition circuit 12.

[0046] The addition circuit 12 adds the receiving digital signals of all channels applied with the window function weighting factors. As a result of the process, the receiving digital signals that are acoustic wave receiving signal information originated from the target voxels are delayed and summed.

[0047] The delayed-and-summed target voxel data are stored in the reconstruction memory 5 by the memory control circuit 4. The process is repetitively performed on all the voxels, so that all the voxel data in the specimen region as a target are sequentially delayed-and-summed and stored in the reconstruction memory 5.

[0048] Once all the voxel data in the specimen region as a target are delayed-and-summed and stored in the reconstruction memory 5, the memory control circuit 4 outputs the voxel data to the signal processing block 8 (log compression process, filter process) as a second signal processing unit. The signal processing block 8 (log compression process, filter process) performs signal processes such as a log compression process and a filter process on the input voxel data and output the result thereof to the image construction unit 9. The signal processes may include filter processes such as a low-pass filter process and a high-pass filter process, a log compression process, a differentiation process, an envelope detection process, and a quadrature detection process. In addition, although not shown, a second parameter calculation unit that calculates a parameter required for the signal process and applies the parameter to the signal processing block 8 may be included.

[0049] The image construction unit 9 constructs the photoacoustic tomography image based on the voxel data on which the signal process is performed and outputs the image to the image display unit 10. The image display unit 10 displays the constructed photoacoustic tomography image. These are a series of the operations according to the first embodiment.

[0050] In the case of the photoacoustic tomography, because of limitation to the light source that generates a practical light energy (several mJ or more), light irradiation time needs to be set to a predetermined time or more. In the embodiment, the photoacoustic tomography receiving data is formed using the light irradiation interval, that is, the waiting time. Therefore, if the generation of all the voxel data in the specimen region as a target is ended before the next light irradiation starts, the real-time characteristics of the photoacoustic tomography image cannot be lost by the operations of the embodiment.

[0051] In the photoacoustic tomography, when the S/N ratio of the acoustic wave generated from light irradiation to the specimen is low, there is a need to perform an addition averaging process on the receiving signals multiple times so as to improve the S/N ratio. In this case, an addition averaging process may be performed on the delayed-and-summed data of the target voxels, that is, the minimum constitution unit data obtained by multiple times of reception by using the memory control circuit 4 and the reconstruction memory 5. In this case, the memory control circuit 4 becomes the addition averaging unit.

[0052] According to the configuration, the addition averaging process is performed at the time when all the processes are ended, so that the target voxel data having improved S/N ratio can be stored in the reconstruction memory 5.

[0053] The type of memories used as the delay adjustment memories 2-1 to 2-N and the reconstruction memory 5 is not particularly limited. These memories may be configured by using FIFO (first-infirst-out) memories or RAMs (not shown) . If can be adapted, other storage units may be used.

[0054] In addition, the signal processing block 8 (log compression process, filter process) is not necessarily disposed just before the image construction unit 9 as shown in Fig. 1. If needed, the signal processing block 8 may be disposed at any position in the received data processing apparatus of photoacoustic tomography. In addition, the only one signal processing block 8 is not necessarily disposed. For example, the signal processing block 8 may be disposed in the calculation circuit 3 or for each channel of the acoustic wave detectors. In addition, one signal processing block 8 may be disposed at the output portion of each of the delay adjustment memories 2-1 to 2-N for each channel (not shown). When the signal processing block 8 is provided to each receiving channel, the signal processing block 8 corresponds to the first signal processing units according to the present invention. In this case, a first parameter calculation unit that calculates an independent parameter required for the signal process for each channel and applies the parameter may be included (not shown) . In addition, the second signal processing unit and the first signal processing unit may be provided simultaneously.

[0055] In addition, the calculation circuit 3 is not necessarily designed to perform only the multiplication process and the addition process as shown in Fig. 2. If needed, a calculation unit and a signal processing unit required for performing photoacoustic tomography image reconstruction may be further included (not shown). In addition, a unit that calculates an independent parameter required for performing the signal process for each channel and applies the parameter may be included (not shown) . In this case, a parameter calculation unit may be disposed in the calculation circuit 3. Otherwise, separate calculation blocks may be provided to apply the calculated parameter to the calculation circuit 3 (not shown).

[0056] In addition, a mounting unit for the received data processing apparatus of photoacoustic tomography is not necessarily limited to an FPGA. If needed, the apparatus can be configured by combining a digital signal processor (DSP), a general purpose CPU, various volatile memories, and various non-volatile memories (not shown).

[0057] In addition, the acoustic wave detector array 52 is not necessarily a 2D array as shown in Fig. 3. For example, a 1D or 1.5D array may be used (not shown). In addition, as a shape of a probe of a general ultrasonic diagnostic apparatus, there are various shapes such as a linear shape, a sector shape, and a convex shape. However, the present invention is not necessarily limited to the shape of the probe used in the acoustic wave reception (not shown).

[0058] In addition, the method of implementing the image construction unit 9 is not particularly limited. A general purpose CPU or GPU may be used. Otherwise, other suitable units may be used.

[0059] Next, the second embodiment and examples of the present disclosure will be described. In the description hereinafter, elements different from those of the first embodiment are mainly described. In addition, the similar elements are denoted by the same reference numerals, and the description thereof is will not be repeated.

[Second Embodiment]

[0060] Fig. 4 is a view illustrating a received data processing apparatus of photoacoustic tomography according to a second embodiment of the present invention. In Fig. 4, the number of acoustic wave detectors is L, and the total number of channels of the received data processing apparatus of photoacoustic tomography is N. In this case, L > N, that is, the number of acoustic wave detectors is larger than the total number of channels of the received data processing apparatus of photoacoustic tomography.

[0061] The received data processing apparatus of photoacoustic tomography includes N A/D converters 1-1 to 1-N, N delay adjustment memories (DELAY M) 2-1 to 2-N, and a calculation circuit 3. In addition, the apparatus further includes a memory control circuit 4, a reconstruction memory 5, a window function weighting factor calculation circuit 6, a delay memory address calculation circuit 7, a signal processing block 8 (log compression process, filter process) that performs a log compression process and a filter process, an image construction unit 9, and an image display unit 10. In addition, between the acoustic wave detectors 54-1 to 54-L and the A/D converters 1-1 to 1-N, a switching circuit 16 as a connection switching unit of switching connection states therebetween is disposed.

[0062] Next, the operations of the second embodiment are described.

[0063] The operations of the circuits following the N A/D converters 1-1 to 1-N are basically the same as those as the first embodiment. However, unlike the first embodiment, the connection states between the acoustic wave detectors 54-1 to 54-L and the A/D converters 1-1 to 1-N can be switched by the switching circuit 16.

[0064] Fig. 5 is a flowchart illustrating the operations according to the second embodiment.

[0065] Firstly, N acoustic wave detectors (a, a+1, a+2, ..., a+N-1) that are selected among the L acoustic wave detectors 54-1 to 54-L are connected to the N channels of the received data processing apparatus of photoacoustic tomography (refer to step S1).

[0066] Next, a light is irradiated to the target region of the specimen, and the acoustic wave generated therefrom is received and digitized by the A/D converters 1-1 to 1-N. The digitized receiving data are stored in the N delay adjustment memories 2-1 to 2-N (refer to step S2).

[0067] Next, the target voxel on which the delay-and-sum process is to be performed is determined (refer to step S3), and the delay memory address and the weighting factor required for the delay-and-sum process are calculated (refer to step S4). Next, the weighting factor is applied to the data read from the delay storage M according to the calculated delay memory address, the delay-and-sum process is performed, and the result thereof is stored in the reconstruction memory 5 (refer to step S5).

[0068] Once the delay-and-sum process on the selected target voxel is ended, it is determined whether the selection of all the voxels is completed. If the selection is not completed, the procedure returns to the step S3 to select the next target voxel, perform the delay-and-sum process, and the result thereof is accumulatively added in the reconstruction memory 5. This procedure is repeated until the delay-and-sum process on the all the voxels of the target region is ended. At this time, the delay-and-sum process on the target voxels is ended based on the acoustic wave received from the initially selected acoustic wave detector group (a, a+1, a+2, ..., a+N-1) .

[0069] Next, the N acoustic wave detectors to be selected are changed.

[0070] Fig. 5 illustrates an example where acoustic wave detectors (a+1, a+2, ..., a+N) are newly selected among the L acoustic wave detectors (refer to steps S8 and S1). Next, a light is irradiated to a target region of the specimen, and an acoustic wave generated therefrom is received by using the newly-selected N acoustic wave detectors (a+1, a+2, a+N). Next, the voxel data as the minimum constitution unit data that are sequentially obtained in a time division manner by performing the delay-and-sum process on all the voxels of the target region are accumulatively added in the same voxel data of the reconstruction memory 5 (refer to steps S2 to S 5).

[0071] The process is repeated until all the acoustic wave detectors 54-1 to 54-L in which the reception is to be performed are selected and the delay-and-sum process on all the target voxels are ended (S7). If reception scan of all the acoustic wave detectors 54-1 to 54-L is ended, the reception scan is ended (refer to step S9), and the voxel data stored in the reconstruction memory 5 are read to be transmitted to the image construction unit (refer to step S10) .

[0072] By using the aforementioned procedures, the reception can be performed in the configuration where the reception region is changed and divided in the array of the acoustic wave detectors 54-1 to 54-L. An advantage of the procedure is to reconstruct the photoacoustic tomography image by using the smaller number of channels of the received data processing apparatus of photoacoustic tomography than the number of the acoustic wave detectors in the acoustic wave detector array 52.

[0073] In addition, the same target voxel data may be received from different reception regions in the acoustic wave detectors 54-1 to 54-L. In this case, in the memory control circuit 4 and the reconstruction memory 5, an accumulative addition process or an addition averaging process is performed on the same target voxel data, so that target voxel data can be generated. When the reception regions in the array of the acoustic wave detectors 54-1 to 54-L are different, the weighting factors that the multipliers 11-1 to 11-N of the calculation circuit 3 designate to the receiving data may be changed.

[0074] In the embodiment, the memory control circuit 4 and the reconstruction memory 5 are provided in order to process and store the target voxel data, so that all the acoustic wave detectors need not to be simultaneously connected to the received data processing apparatus of photoacoustic tomography. In other words, the received data processing apparatus of photoacoustic tomography can be miniaturized.

[0075] Herein, the reception region selection scheme of the acoustic wave detectors 54-1 to 54-L is not necessarily the same as that shown in Fig. 5, but the selection scheme may be suitably determined as needed. In addition, a relationship between the number L of acoustic wave detectors and the number N of all the channels of the received data processing apparatus of photoacoustic tomography is not necessarily limited to L > N. Furthermore, it is not necessary that all the channels of the received data processing apparatus of photoacoustic tomography have to be used during reception.

[0076] In addition, a switching circuit as a connection switching unit of switching connection states between the A/D converters 1 and the delay adjustment memories 2 may be disposed, so that the acoustic wave can be received while the connection states between the A/D converters 1 and the delay adjustment memories 2 are sequentially switched (not shown) . For example, when the total number of A/D converters 1 is L and the total number of delay adjustment memories 2 is N (L > N), the connection states between the A/D converters 1 and the delay adjustment memories 2 are sequentially switched each reception. In addition, all the A/D converters 1 in which the reception is to be performed are selected, so that the processes are continuously performed until the delay-and-sum process for the target voxels is ended.

[0077] In this manner, the acoustic wave may be configured to be received while the connection states between the A/D converters 1 and the delay adjustment memories 2 and the connection states between the acoustic wave detector array 52 and the A/D converters 1 are sequentially switched.

[0078] In the case of the photoacoustic tomography, because of limitation to the light source, light irradiation time needs to be set to a predetermined time or more. In the embodiment, the photoacoustic tomography receiving data is formed using the light irradiation interval, that is, the waiting time. Therefore, if the generation of all the voxel data in the specimen region as a target is ended before the next light irradiation starts, the real-time characteristics of the photoacoustic tomography image cannot be lost by the operations of the embodiment.

[0079] Due to the switching circuit 16 disposed between the acoustic wave detector array 52 and the A/D converters 1, the apparatus can be configured with the smaller number of the A/D converters than the number of the acoustic wave detectors. In addition, due to the switching circuit disposed between the A/D converters 1 and the delay adjustment memories 2, the apparatus can be configured with the smaller number of the delay adjustment memories than the number of the A/D converters.

[0080] In addition, the signal processing block 8 (log compression process, filter process) that performs the log compression process and filter process is not necessarily disposed just before the image construction unit 9 as shown in Fig. 4. If needed, the signal processing block 8 may be disposed in the calculation circuit 3. In addition, the signal processing block 8 may be disposed for each N channel connected to the calculation circuit 3 from the switching circuit 16. In addition, the only one signal processing block 8 is not necessarily disposed. For example, the signal processing block 8 may be disposed in the calculation circuit 3 or at the output portions of each of the delay adjustment memories 2-1 to 2-N for each channel (not shown) . In this case, a parameter required for the signal process is calculated for each channel to be applied (not shown).

[Third example not forming part of the invention]

[0081] Fig. 6 is a view illustrating a received data processing apparatus of photoacoustic tomography according to a third example of the present invention. In Fig. 6, the total number of channels of the received data processing apparatus of photoacoustic tomography is N.

[0082] The received data processing apparatus of photoacoustic tomography includes N A/D converters 1-1 to 1-N, addition averaging circuits 15-1 to 15-N, N delay adjustment memories (DELAY M) 2-1 to 2-N, and a calculation circuit 3. In addition, the apparatus further includes a memory control circuit 4, a reconstruction memory 5, a window function weighting factor calculation circuit 6, a delay memory address calculation circuit 7, a signal processing block 8 (log compression process, filter process), an image construction unit 9, and an image display unit 10.

[0083] The third example is different from the first and second embodiments in that the addition averaging circuits 15-1 to 15-N as addition processing units are included. In addition, instead of the addition averaging process, an accumulative addition process may be performed.

[0084] Next, the operations according to the third embodiment are described. The operations of the N A/D converters 1-1 to 1-N and the operations of the circuits following the calculation circuit 3 are basically the same as those of the first and second embodiments. However, unlike the first and second embodiments, the delay adjustment memories 2-1 to 2-N cooperates with the addition averaging circuits 15-1 to 15-N to perform the addition averaging process or the accumulative addition process on the receiving digital signal.

[0085] In the photoacoustic tomography, when the S/N ratio of the acoustic wave generated from light irradiation to the specimen is low, there is a need to perform an addition averaging process or accumulative addition process on the receiving signal. In the third embodiment, the addition averaging circuits 15-1 to 15-N cooperates with the delay adjustment memories 2-1 to 2-N to store the addition-averaging-processed or accumulative-addition-processed receiving data in the delay adjustment memories 2-1 to 2-N. Moreover, the delay-and-sum process is performed on the target voxel data. According to the third embodiment, the target voxel data of which S/N ratio is improved can be obtained.

[0086] In the case of the photoacoustic tomography, because of limitation to the light source, light irradiation time needs to be set to a predetermined time or more. In the embodiment, the formation of the photoacoustic tomography receiving data is performed using the light irradiation interval, that is, the waiting time. Therefore, after the light irradiation is performed multiple times to perform the addition averaging process, if the generation of all the voxel data in the specimen region as a target is ended before the next light irradiation starts, the real-time characteristics of the photoacoustic tomography image cannot be lost.

[0087] In addition, in the third embodiment, a switching circuit may be disposed between the A/D converter 1 and the addition averaging circuit, and the acoustic wave may be received while the connection states between the A/D converter 1 and the addition averaging circuit are sequentially switched (not shown). For example, when the total number of A/D converters is L and the total number of addition averaging circuits is N (L > N), the connection states between the A/D converters and the addition averaging circuits are sequentially switched every reception. In addition, all the A/D converters in which the reception is to be performed are selected, so that the processes are continuously performed until the delay-and-sum process for all the target voxels is ended. In this manner, the switching circuit as a control unit that switched between the addition averaging circuits and the A/D converters is disposed, so that the apparatus can be configured with the smaller number of the addition averaging circuits and the delay adjustment memories than the number of the A/D converters.

[0088] In addition to the configuration, similarly to the second embodiment, as shown in Fig. 4, a switching circuit may be disposed between the acoustic wave detector array and the A/D converters (not shown). Due to the switching circuit disposed between the acoustic wave detector array and the A/D converters, the apparatus can be configured with the smaller number of the A/D converters than the number of the acoustic wave detectors in the array.

[0089] In this manner, the acoustic wave may be configured to be received while the connection states between the A/D converters and the addition averaging circuits and between the A/D converters and the delay adjustment memories and the connection states between the acoustic wave detector array and the A/D converters are sequentially switched.

[0090] In addition, in the configuration of the embodiment, as described in the first embodiment, the addition averaging process may also be configured to be performed on the delayed-and-summed data obtained by multiple times of reception by using the memory control circuit 4 and the reconstruction memory 5.

[Fourth Embodiment]

[0091] Fig. 7 is a view illustrating a received data processing apparatus of photoacoustic tomography according to a fourth embodiment of the present invention. In Fig. 7, the total number of channels of the received data processing apparatus of photoacoustic tomography is N.

[0092] The received data processing apparatus of photoacoustic tomography includes N A/D converters 1-1 to 1-N, N delay adjustment memories (DELAY M) 2-1 to 2-N, and a calculation circuit 28. In addition, the apparatus further includes a memory control circuit 4, a reconstruction memory 5, a window function weighting factor calculation circuit 6, a delay memory address calculation circuit 7, a signal processing block 8 (log compression process, filter process), an image construction unit 9, and an image display unit 10.

[0093] In the fourth embodiment, memory selecting switches 27-1 to 27-(N/M) are disposed between the delay adjustment memories 2-1 to 2-N and the calculation circuit 3. In addition, M delay adjustment memories that are grouped are connected to the memory selecting switches 27-1 to 27- (N/M), so that the memory selecting switches 27-1 to 27-(N/M) are configured to be selected by the channel selection circuit 32.

[0094] Fig. 8 is a view illustrating a configuration of the calculation circuit 28. The calculation circuit 28 includes (N/M) multipliers 50-1 to 50-(N/M) and an addition circuit 51. The outputs of the memory selecting switches 27-1 to 27-(N/M) are connected to the multipliers 50-1 to 50-(N/M).

[0095] Next, the operations according to the fourth embodiment are described.

[0096] The operations of the N A/D converters 1-1 to 1-N are basically the same as those of other embodiments. However, unlike the first and second embodiment and third example, the connection states between the delay adjustment memories 2-1 to 2-N and the calculation circuit 3 are sequentially switched by the memory selecting switches 27-1 to 27-(N/M).

[0097] Fig. 9 is a flowchart illustrating operations according to the fourth embodiment.

[0098] Firstly, a light is irradiated to the target region of the specimen, and the acoustic wave generated therefrom is received and digitized by the A/D converters 1-1 to 1-N. The digitized receiving data are stored in the N delay adjustment memories 2-1 to 2-N (refer to step S41). Next, (N/M) delay adjustment memories (a, a+M, a+2M, ..., a+N-M) that are selected among the N delay adjustment memories 2-1 to 2-N are connected to the multipliers of the calculation circuit 3 (refer to step S42).

[0099] Next, the target voxel on which the delay-and-sum process is performed is determined (refer to step S43), and the delay memory address and the weighting factor required for the delay-and-sum process are calculated (refer to step S44). Next, the delay-and-sum process is performed according to the calculated delay memory address and weighting factor, and the result thereof is stored in the reconstruction memory 5 (refer to step S45). Once the delay-and-sum process on the selected target voxel is ended, the next target voxel is selected, and the delay-and-sum process is performed (refer to steps S46 and S43). This procedure is repeated until the delay-and-sum process on the all the voxels of the target region is ended. At this time, the delay-and-sum process on all the voxels of the target region is ended based on the digital data stored in the (N/M) delay adjustment memories (a, a+M, a+2M, ..., a+N-M) initially selected among the delay adjustment memories 2-1 to 2-N (refer to step S46).

[0100] Next, (N/M) delay adjustment memories are newly selected (refer to steps S47 and S48). Fig. 9 illustrates an example where delay adjustment memories (a+1, a+M+1, a+2M+1, ..., a+N-M+1) are newly selected among the N delay adjustment memories 26-1 to 26-N. After the delay adjustment memories are selected, the delay-and-sum process is performed on all the voxels of the target region (refer to steps S43 to S 46).

[0101] The procedure is repeated until all the delay adjustment memories 2-1 to 2-N are selected (refer to step S47). If reading the group of all the delay adjustment memories is ended, the reading is ended (refer to step S49), and the voxel data stored in the reconstruction memory 5 are read to be transmitted to the image construction unit (refer to step S50).

[0102] In addition, in this case, although the same target voxel data may be read from different delay adjustment memories 2-1 to 2-N, the memory control circuit 4 and the reconstruction memory 5 perform the accumulative addition process or the addition averaging process on the same target voxel data.

[0103] As a result, all the voxel data in the target region are generated.

[0104] In this manner, the memory selecting switches 27-1 to 27- (N/M) are disposed between the delay adjustment memories 2-1 to 2-N and the calculation circuit 28, so that the calculation circuit 28 can be miniaturized.

[0105] In the procedure shown in Fig. 9, the delay-and-sum process is performed on the receiving data obtained from one-time reception by sequentially selecting a plurality of groups divided from the delay adjustment memories 2-1 to 2-N. Therefore, in comparison with, for example, the first embodiment, a long time is taken to generate all the voxel data in the target region. In the case of the photoacoustic tomography, because of limitation to the light source, light irradiation time needs to be set to a predetermined time or more. Therefore, even when the delay-and-sum process is performed in a time division manner like the embodiment, the generation of all the voxel data of the target region can be ended by the time of the next light irradiation. In other words, in the fourth embodiment, a bad influence to the frame rate does also not occur, and the real-time characteristics of the photoacoustic tomography image cannot be deteriorated.

[0106] In the fourth embodiment, the memory control circuit 4 and the reconstruction memory 5 are also provided in order to process and store the target voxel data, so that all the data in the delay adjustment memories 2-1 to 2-N need not to be simultaneously processed by the calculation circuit 28. Therefore, all the voxel data in the target region can be generated in a time division manner by a miniaturized received data processing apparatus of photoacoustic tomography.

[0107] Herein, the selection scheme of the delay adjustment memories 2-1 to 2-N is not necessarily the same as that shown in Fig. 7, but the selection scheme may be suitably determined as needed.

[0108] In addition to the configuration, a switching circuit may be disposed between the A/D converters and the delay adjustment memories, so that the acoustic wave may be configured to be received while the connection states between the A/D converters and the delay adjustment memories are sequentially switched (not shown). For example, when the total number of A/D converters is L and the total number of delay adjustment memories is N (L > N), the connection states between the A/D converters and the delay adjustment memories are sequentially switched each reception. In addition, all the A/D converters in which the reception is to be performed are selected, so that the processes are continuously performed until the delay-and-sum process for all the target voxels is ended. Due to the switching circuit disposed between the A/D converters and the delay adjustment memories, the apparatus can be configured with the smaller number of the delay adjustment memories than the number of the A/D converters.

[0109] In addition to the configuration, similarly to the second embodiment, as shown in Fig. 4, a switching circuit may be disposed between the acoustic wave detector array and the A/D converters (not shown). In this manner, due to the switching circuit disposed between the acoustic wave detector array and the A/D converters, the apparatus can be configured with the smaller number of the A/D converters than the number of the acoustic wave detectors.

[0110] Accordingly, the acoustic wave may be configured to be received while the connection states between the calculation circuit 28 and the delay adjustment memories, connection states between the A/D converters and the delay adjustment memories, and connection states between the acoustic wave detector array and the A/D converters are sequentially switched.

[0111] In addition, the calculation circuit 28 does not necessarily perform only the multiplication process and the addition process as shown in Fig. 8. If needed, a calculation unit and a signal processing unit required for performing photoacoustic tomography image reconstruction may be further included (not shown). In this case, an independent parameter required for the signal process is calculated for each channel to be applied.

[Fifth example not forming part of the invention]

[0112] Fig. 10 is a view illustrating a received data processing apparatus of photoacoustic tomography according to a fifth example of the present disclosure. In Fig. 10, the total number of channels of the received data processing apparatus of photoacoustic tomography is N.

[0113] The acoustic wave receiving data forming apparatus also includes N A/D converters 1-1 to 1-N, N delay adjustment memories (DELAY M) 2-1 to 2-N, and a calculation circuit 28. In addition, the apparatus further includes a memory control circuit 4, a reconstruction memory 5, a window function weighting factor calculation circuit 6, a delay memory address calculation circuit 7, a signal processing block 8 (log compression process, filter process), an image construction unit 9, and an image display unit 10.

[0114] In addition, similarly to the fourth embodiment, memory selecting switches 27-1 to 27-(N/M) are disposed between the delay adjustment memories 2-1 to 2-N and the calculation circuit 28. In addition, a group of M delay adjustment memories are connected to the memory selecting switches 27-1 to 27-(N/M) , so that the memory selecting switches 27-1 to 27-(N/M) can be configured to be selected by the channel selection circuit 32.

[0115] In addition, in the fifth example, similarly to the third example, the addition averaging circuit 38-1 to 38-N as addition processing units are disposed between the A/D converters 1-1 to 1-N and the delay adjustment memories (DELAY M) 2-1 to 2-N. This feature is the different point between the fifth example and fourth embodiments. Similarly to the third example, instead of the addition averaging process, an accumulative addition process may be performed.

[0116] Next, the operations according to the fifth example are described.

[0117] The operations of the A/D converters 1-1 to 1-N are basically the same as those of the fourth embodiment. However, unlike fourth embodiment, the delay adjustment memories 2-1 to 2-N cooperate with the addition averaging circuits 38-1 to 38-N to perform the addition averaging process of the receiving data.

[0118] In the photoacoustic tomography, when the S/N ratio of the acoustic wave generated from light irradiation to the specimen is low, there is a need to perform an addition averaging process on the receiving signal. In the fourth embodiment, the addition averaging circuits 38-1 to 38-N cooperate with the delay adjustment memories 2-1 to 2-N to store the addition-averaging-processed receiving data in the delay adjustment memories 2-1 to 2-N, and after that, the delay-and-sum process is performed on the target voxel data. According to the embodiment, the target voxel data of which S/N ratio is improved can be obtained.

[0119] In the case of the photoacoustic tomography, because of limitation to the light source, light irradiation time needs to be set to a predetermined time or more. In the embodiment, the formation of the photoacoustic tomography receiving data is performed using the light irradiation interval, that is, the waiting time. Therefore, after the light irradiation is performed multiple times to perform the addition averaging process, if the generation of all the voxel data in the specimen region as a target is ended before the next light irradiation starts, the real-time characteristics of the photoacoustic tomography image cannot be lost.

[0120] In the embodiment, the memory control circuit 4 and the reconstruction memory 5 are provided in order to process and store the target voxel data, so that all the data in the delay adjustment memories 2-1 to 2-N need not to be simultaneously processed by the calculation circuit 28. Therefore, all the voxel data in the target region can be generated in a time division manner by a miniaturized received data processing apparatus of photoacoustic tomography.

[0121] Herein, the selection scheme of the delay adjustment memories 2-1 to 2-N is not necessarily the same as that shown in Fig. 10, but the selection scheme may be suitably determined as needed.

[0122] In addition to the configuration, a switching circuit may be disposed between the A/D converters and the addition averaging circuits, so that the acoustic wave may be configured to be received while the connection states between the A/D converters and the addition averaging circuits are sequentially switched (not shown). For example, when the total number of A/D converters is L and the total number of addition averaging circuits is N (L > N), the connection states between the A/D converters and the addition averaging circuits are sequentially switched each reception. In addition, all the A/D converters in which the reception is to be performed are selected, so that the processes are continuously performed until the delay-and-sum process for the target voxels is ended. Due to the switching circuit disposed between the A/D converters and the addition averaging circuits, the apparatus can be configured with the smaller number of the addition averaging circuit and delay adjustment memories than the number of the A/D converters.

[0123] In addition to the configuration, similarly to the second embodiment, as shown in Fig. 4, a switching circuit may be additionally disposed between the acoustic wave detector array and the A/D converters (not shown) . In this manner, due to the switching circuit disposed between the acoustic wave detector array and the A/D converters, the apparatus can be configured with the smaller number of the A/D converters than the number of the acoustic wave detectors.

[0124] Accordingly, the acoustic wave may be configured to be received while the connection states between the calculation circuit 28 and the delay adjustment memories 2-1 to 2-N, the connection states between the A/D converters and the addition averaging circuits, and the connection states between the acoustic wave detector array and the A/D converters are sequentially switched.

[0125] In addition, according to the aforementioned embodiment and examples,

an operating frequency of a circuit that can change a processing speed of the voxel data composition can be improved by changing an operating frequency of the configuration subsequent to the A/D converters. In addition, a plurality of the circuits are disposed in parallel, so that the speed of generating the voxel data can be improved.

[0126] In addition, although the above description of the embodiments is made taking into consideration three-dimensional image reconstruction, in examples useful for understanding the invention pixel data may be used as the minimum constitution unit to perform two-dimensional image reconstruction.

[0127] While the present invention has been particularly shown and described with reference to embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the present disclosure.

[0128] While the present invention has been described with reference to an embodiment it is to be understood that the invention is not limited to the disclosed exemplary embodiments.

Claims

1. A photoacoustic tomography apparatus comprising a light source adapted to irradiate a specimen with light at a predetermined time followed by a waiting time before a next irradiation, and comprising a received data processing apparatus of photoacoustic tomography of receiving an acoustic wave generated by irradiating the light to the specimen and constructing an image from an electrical signal obtained from the received acoustic wave, comprising:

    a plurality of electrical signal conversion means (1-1, 1-2, ..., 1-N) that digitize received signals from a plurality of acoustic wave detectors (54-1, 54-2, ..., 54-N) that receive the acoustic wave originated from a three-dimensional specimen region in processing;
    a plurality of first storage means (2-1, 2-2, ..., 2-N) that store received digital signals digitized by the electrical signal conversion means;
    voxel data composition means (3) that sequentially reads the received digital signals, originated from voxels which partition the specimen region, from the plurality of the first storage means, based on delay information of the acoustic waves assuming that the acoustic waves reach the respective acoustic wave detectors from the respective voxels, and composes voxel data, which is acoustic wave data of the respective voxels, by performing a delay-and-sum process;
    second storage means (5) that stores the voxel data of the entire three-dimensional specimen region;
    image construction means (9) that constructs an image of the entire three-dimensional specimen region based on the voxel data stored in the second storage means; and
    control means (4) that sequentially stores the voxel data composed by the voxel data composition means in the second storage means, and reads the stored voxel data of the entire three-dimensional specimen region, and transmits the voxel data to the image construction means,
    wherein the photoacoustic tomography apparatus is adapted such that generation of the voxel data in said entire three-dimensional specimen region is ended before the next light irradiation starts.

2. The received data processing apparatus of photoacoustic tomography according claim 1, further comprising:

    address calculation means that calculates delay times that are taken for the acoustic wave from the voxels to reach the acoustic wave detectors based on coordinates of the voxels of the specimen region, and supplies addresses in which receiving digital signals originated from the voxels corresponding to the delay times are stored to the first storage means.

3. The received data processing apparatus of photoacoustic tomography according to any one of claims 1 to 2, further comprising:

    window function weighting factor calculation means that calculates window function weight factors on respective receiving channels which transmit received signals of the acoustic wave, based on coordinates of the voxels of the specimen region in processing, and applies the calculated window function weighting factors to the voxel data composition means.

4. The received data processing apparatus of photoacoustic tomography according to any one of claims 1 to 3, further comprising:

    first signal processing means that perform a signal process including at least one of a filter process, a logarithm compression process, a differentiation process, an envelope detection process, and a quadrature detection process on respective receiving channels which transmit received signal of the acoustic wave.

5. The received data processing apparatus of photoacoustic tomography according to claim 4, further comprising:

a first parameter calculation means that calculates an independent parameter of respective receiving channels, and applies the parameter to the first signal processing means.

6. The received data processing apparatus of photoacoustic tomography according to any one of claims 1 to 5,
wherein a processing speed of the voxel data composition means is changed by changing an operating frequency of the configuration subsequent to the electrical signal conversion means.

7. The received data processing apparatus of photoacoustic tomography according to any one of claims 1 to 6,
wherein a plurality of the configurations subsequent to the electrical signal conversion means are disposed in parallel.

8. The received data processing apparatus of photoacoustic tomography according to any one of claims 1 to 3, further comprising:

second signal processing means that can perform a signal process including at least one of a filter process, a logarithm compression process, a differentiation process, an envelope detection process, and a quadrature detection process, on composed voxel data.

9. The received data processing apparatus of photoacoustic tomography according to claim 6, further comprising:

a second parameter calculation means that calculates a parameter and applies the parameter to the second signal processing means.

Patentansprüche

1. Fotoakustische Tomographievorrichtung mit einer Lichtquelle, die angepasst ist, eine Probe mit Licht zu einer vorbestimmten Zeit, auf die eine Wartezeit vor einer nächsten Bestrahlung folgt, zu bestrahlen, und die aufweist:

eine Verarbeitungsvorrichtung empfangener Daten einer fotoakustischen Tomographie zum Empfangen einer akustischen Welle, die durch Bestrahlen der Probe mit dem Licht erzeugt wird, und zum Konstruieren eines Bildes aus einem elektrischen Signal, das aus der empfangenen akustischen Welle erhalten wird, mit:

einer Vielzahl von elektrischen Signalumwandlungseinrichtungen (1-1, 1-2, 1-N), die empfangene Signale von einer Vielzahl von akustischen Wellendetektoren (54-1, 54-2, ..., 54-N), die die akustische Welle, die von einem dreidimensionalen Probengebiet beim Verarbeiten ausgeht, empfangen, digitalisieren;
einer Vielzahl von ersten Speichereinrichtungen (2-1, 2-2, ..., 2-N), die die empfangenen digitalen Signale, die durch die elektrische Signalumwandlungseinrichtungen digitalisiert wurden, speichern;
einer Voxeldatenzusammensetzungseinrichtung (3), die nacheinander die empfangenen digitalen Signale, die aus den Voxeln hervorgehen, die das Probengebiet einteilen, aus der Vielzahl der ersten Speichereinrichtungen basierend auf einer Verzögerungsinformation der akustischen Wellen unter der Annahme, dass die akustischen Wellen die jeweiligen akustischen Wellendetektoren von den jeweiligen Voxeln erreichen, ausliest und die Voxeldaten, die akustische Wellendaten der jeweiligen Voxel sind, unter Durchführung eines Verzögerungs- und Summierungsprozesses zusammensetzt;
einer zweiten Speichereinrichtung (5), die die Voxeldaten des ganzen dreidimensionalen Probengebiets speichert;
eine Bildkonstruktionseinrichtung (9), die ein Bild des ganzen dreidimensionalen Probengebiets basierend auf den Voxeldaten, die in der zweiten Speichereinheit gespeichert sind, konstruiert; und
einer Steuerungseinrichtung (4), die sequenziell die Voxeldaten, die durch die Voxeldatenzusammensetzungseinrichtung zusammengesetzt sind, in der zweiten Speichereinrichtung speichert und die gespeicherten Voxeldaten des ganzen dreidimensionalen Probengebiets liest, und die Voxeldaten an die Bildkonstruktionseinrichtung überträgt,

wobei die fotoakustische Tomographievorrichtung angepasst ist, dass das Erzeugen aller Voxeldaten in dem ganzen dreidimensionalen Probengebiet endet, bevor die nächste Lichtbestrahlung startet.

2. Empfangsdatenverarbeitungsvorrichtung einer fotoakustischen Tomographie nach Anspruch 1, ferner mit:

einer Adressberechnungseinrichtung, die Verzögerungszeiten, die von der akustischen Welle von den Voxeln gebraucht werden, um die akustischen Wellendetektoren zu erreichen, basierend auf Koordinaten der Voxel des Probengebiets berechnet und Adressen zur Verfügung stellt, in denen empfangene digitale Signale, die von den Voxeln herrühren, entsprechend der Verzögerungszeit in der ersten Speichereinrichtung speichert.

3. Empfangsdatenverarbeitungsvorrichtung einer fotoakustischen Tomographie nach einem der Ansprüche 1 bis 2, ferner mit:

einer Fensterfunktionsgewichtsfaktorberechnungseinrichtung, die Fensterfunktionsgewichtsfaktoren auf jeweiligen Empfangskanälen, die empfangene Signale der akustischen Welle übertragen, basierend auf Koordinaten der Voxel des Probengebiets beim Verarbeiten berechnet und die berechneten Fensterfunktionsgewichtsfaktoren auf die Voxeldatenzusammensetzungseinrichtung anwendet.

4. Empfangsdatenverarbeitungsvorrichtung einer fotoakustischen Tomographie nach einem der Ansprüche 1 bis 3, ferner mit:

einer ersten Signalverarbeitungseinrichtung, die einen Signalprozess mit zumindest einem aus einem Filterprozess, einem logarithmischen Kompressionsprozess, einem Differenzierungsprozess, einem Einhüllendenerfassungsprozess, und einem Quadraturerfassungsprozess auf jeweiligen Empfangskanälen, die ein empfangenes Signal der akustischen Welle übertragen, durchführt.

5. Empfangsdatenverarbeitungsvorrichtung einer fotoakustischen Tomographie nach Anspruch 4, ferner mit:

einer ersten Parameterberechnungseinrichtung, die einen unabhängigen Parameter von jeweiligen Empfangskanälen berechnet und den Parameter auf die erste Signalverarbeitungseinrichtung anwendet.

6. Empfangsdatenverarbeitungsvorrichtung einer fotoakustischen Tomographie nach einem der Ansprüche 1 bis 5,
wobei eine Verarbeitungsgeschwindigkeit der Voxeldatenzusammensetzungseinrichtung durch Ändern einer Betriebsfrequenz der Konfiguration, die der elektrischen Signalumwandlungseinrichtung folgen, geändert wird.

7. Empfangsdatenverarbeitungsvorrichtung einer fotoakustischen Tomographie nach einem der Ansprüche 1 bis 6,
wobei eine Vielzahl der Konfigurationen, die der elektrischen Signalumwandlungseinrichtung folgen, parallel angeordnet sind.

8. Empfangsdatenverarbeitungsvorrichtung einer fotoakustischen Tomographie nach einem der Ansprüche 1 bis 3, ferner mit:

einer zweiten Signalverarbeitungseinrichtung, die einen Signalprozess mit zumindest einem aus einem Filterprozess, einem logarithmischen Kompressionsprozess, einem Differenzierungsprozess, einem Einhüllendenerfassungsprozess, und einem Quadraturerfassungsprozess auf zusammengesetzten Voxeldaten durchführen kann.

9. Empfangene Datenverarbeitungsvorrichtung einer fotoakustischen Tomographie nach Anspruch 6, ferner mit:

einer zweiten Parameterberechnungseinrichtung, die einen Parameter berechnet und den Parameter auf die zweite Signalverarbeitungseinrichtung anwendet.

Revendications

1. Appareil de tomographie photo-acoustique qui comprend une source de lumière adaptée pour irradier un spécimen avec une lumière à un moment prédéterminé suivi d'un temps d'attente avant l'irradiation suivante, et qui comprend un appareil de traitement des données reçues de tomographie photo-acoustique adapté pour recevoir une onde acoustique générée en irradiant la lumière vers le spécimen et pour créer une image à partir d'un signal électrique obtenu à partir de l'onde acoustique reçue, qui comprend :

une pluralité de moyens de conversion de signaux électriques (1-1, 1-2,..., 1-N) qui numérisent les signaux reçus de la part d'une pluralité de détecteurs d'ondes acoustiques (54-1, 54-2, ..., 54-N) qui reçoivent l'onde acoustique qui provient d'une zone de spécimen tridimensionnelle traitée ;
une pluralité de premiers moyens de stockage (2-1, 2-2, ..., 2-N) qui stockent les signaux numériques reçus et numérisés par les moyens de conversion de signaux électriques ;
un moyen de composition de données voxel (3) qui lit séquentiellement les signaux numériques reçus de la part de voxels qui partitionnent la zone de spécimen, de la pluralité de premiers moyens de stockage, sur la base d'informations de retard des ondes acoustiques en supposant que les ondes acoustiques atteignent les détecteurs d'ondes acoustiques respectifs depuis les

voxels respectifs, et compose des données voxel, qui sont les données d'onde acoustique des voxels respectifs, en effectuant un processus de retardement et de somme ;
un second moyen de stockage (5) qui stocke les données voxel de la totalité de la zone de spécimen tridimensionnelle ;
un moyen de création d'image (9) qui crée une image de la totalité de la zone de spécimen tridimensionnelle sur la base des données voxel stockées dans le second moyen de stockage ; et
un moyen de commande (4) qui stocke séquentiellement les données voxel composées par le moyen de composition de données voxel dans le second moyen de stockage, et lit les données voxel stockées de la totalité de la zone de spécimen tridimensionnelle, et transmet les données voxel au moyen de création d'image,
l'appareil de tomographie photo-acoustique étant adapté de sorte que la génération des données voxel dans ladite totalité de la zone de spécimen tridimensionnelle soit terminée avant le début de l'irradiation suivante.

2. Appareil de traitement de données de tomographie photo-acoustique reçues selon la revendication 1, qui comprend en outre :

un moyen de calcul d'adresse qui calcule des retards qui sont appliqués par l'onde acoustique qui provient des voxels pour atteindre les détecteurs d'ondes acoustiques sur la base des coordonnées des voxels de la zone de spécimen, et qui fournit les adresses auxquelles les signaux numériques de réception qui proviennent des voxels et qui correspondent aux retards sont stockés dans le premier moyen de stockage.

3. Appareil de traitement de données de tomographie photo-acoustique reçues selon l'une quelconque des revendications 1 et 2, qui comprend en outre :

un moyen de calcul de facteur de pondération de fonction de fenêtrage qui calcule des facteurs de pondération de fonction de fenêtrage sur des canaux de réception respectifs qui transmettent les signaux reçus de l'onde acoustique, sur la base des coordonnées des voxels de la zone de spécimen traitée, et applique les facteurs de pondération de fonction de fenêtrage calculés au moyen de composition de données voxel.

4. Appareil de traitement de données de tomographie photo-acoustique reçues selon l'une quelconque des revendications 1 à 3, qui comprend en outre :

un premier moyen de traitement de signal qui effectue un traitement de signal qui comprend au moins l'un d'un filtrage, d'une compression logarithmique, d'une différentiation, d'une détection d'enveloppe, et d'une détection en quadrature, sur les canaux de réception respectifs qui transmettent le signal reçu de l'onde acoustique.

5. Appareil de traitement de données de tomographie photo-acoustique reçues selon la revendication 4, qui comprend en outre :

un premier moyen de calcul de paramètre qui calcule un paramètre indépendant des canaux de réception respectifs, et applique le paramètre au premier moyen de traitement de signal.

6. Appareil de traitement de données de tomographie photo-acoustique reçues selon l'une quelconque des revendications 1 à 5,
dans lequel une vitesse de traitement du moyen de composition de données voxel est modifiée en changeant une fréquence de fonctionnement de la configuration située après le moyen de conversion de signal électrique.

7. Appareil de traitement de données de tomographie photo-acoustique reçues selon l'une quelconque des revendications 1 à 6,
dans lequel plusieurs configurations situées après le moyen de conversion de signal électrique sont disposées en parallèle.

8. Appareil de traitement de données de tomographie photo-acoustique reçues selon l'une quelconque des revendications 1 à 3, qui comprend en outre :

un second moyen de traitement de signal qui peut effectuer un traitement de signal qui comprend au moins l'un d'un filtrage, d'une compression logarithmique, d'une différentiation, d'une détection d'enveloppe, et d'une détection en quadrature, sur des données voxel composées.

9. Appareil de traitement de données de tomographie photo-acoustique reçues selon la revendication 6, qui comprend en outre :

un second moyen de calcul de paramètre qui calcule un paramètre et applique le paramètre au second moyen de traitement de signal.

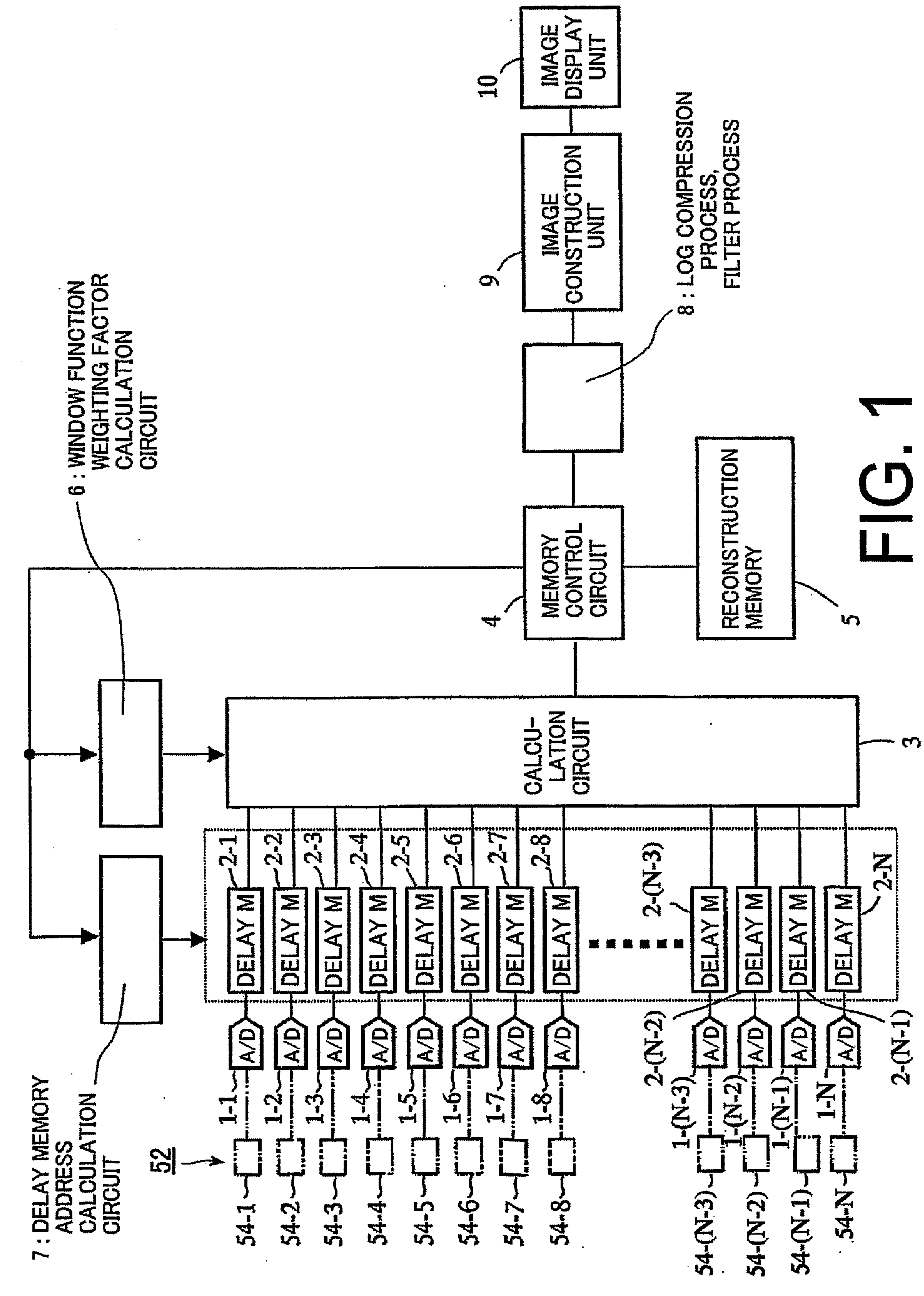
7 : DELAY MEMORY ADDRESS CALCULATION CIRCUIT
6 : WINDOW FUNCTION WEIGHTING FACTOR CALCULATION CIRCUIT
52
54-1
54-2
54-3
54-4
54-5
54-6
54-7
54-8
54-(N-3)
54-(N-2)
54-(N-1)
54-N
1-1
1-2
1-3
1-4
1-5
1-6
1-7
1-8
1-(N-3)
1-(N-2)
1-(N-1)
1-N
A/D
DELAY M
2-1
2-2
2-3
2-4
2-5
2-6
2-7
2-8
2-(N-3)
2-(N-2)
2-(N-1)
2-N
CALCU-LATION CIRCUIT
3
4
MEMORY CONTROL CIRCUIT
RECONSTRUCTION MEMORY
5
8 ; LOG COMPRESSION PROCESS, FILTER PROCESS
9
IMAGE CONSTRUCTION UNIT
10
IMAGE DISPLAY UNIT

FIG. 1

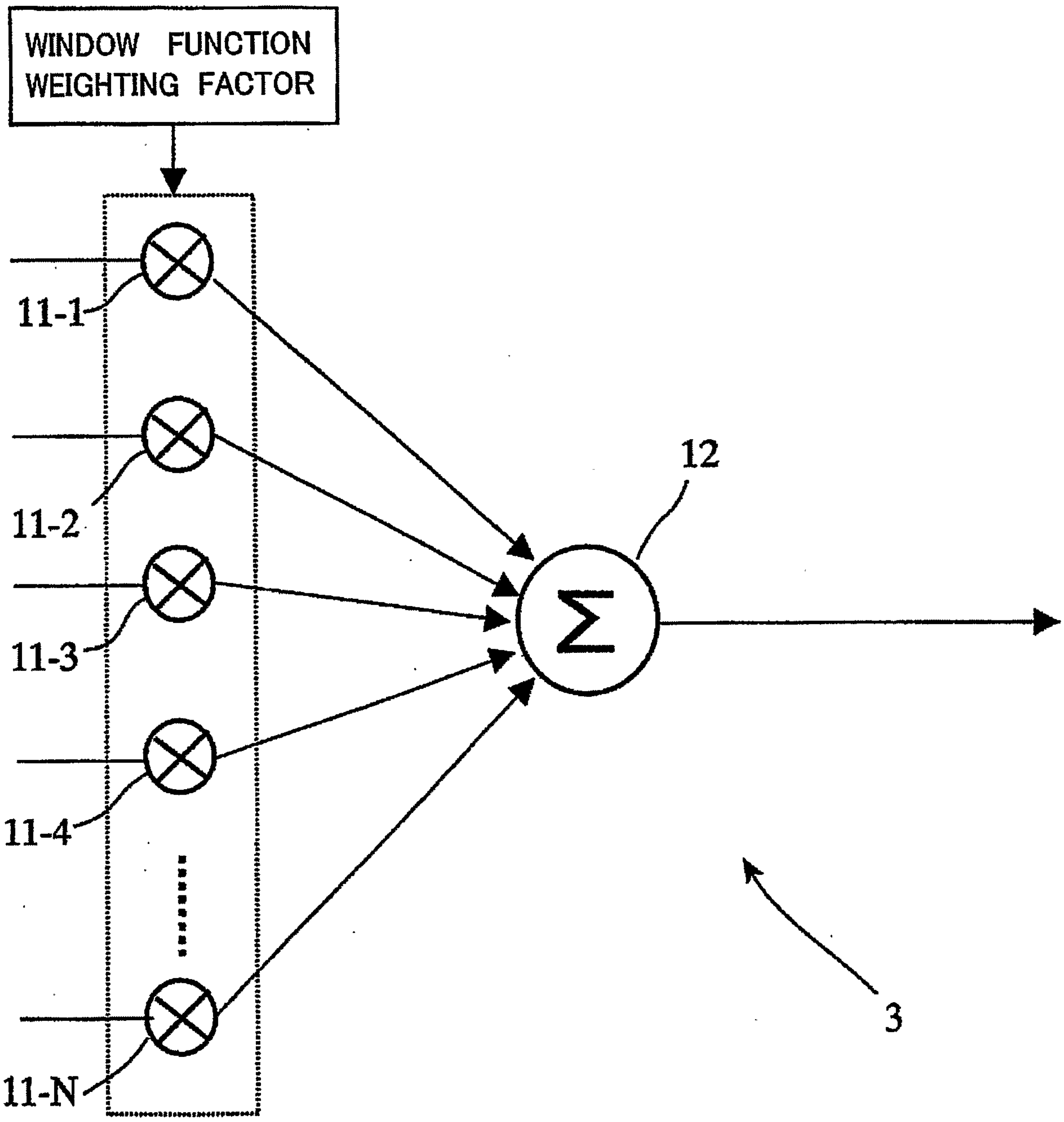

FIG. 2

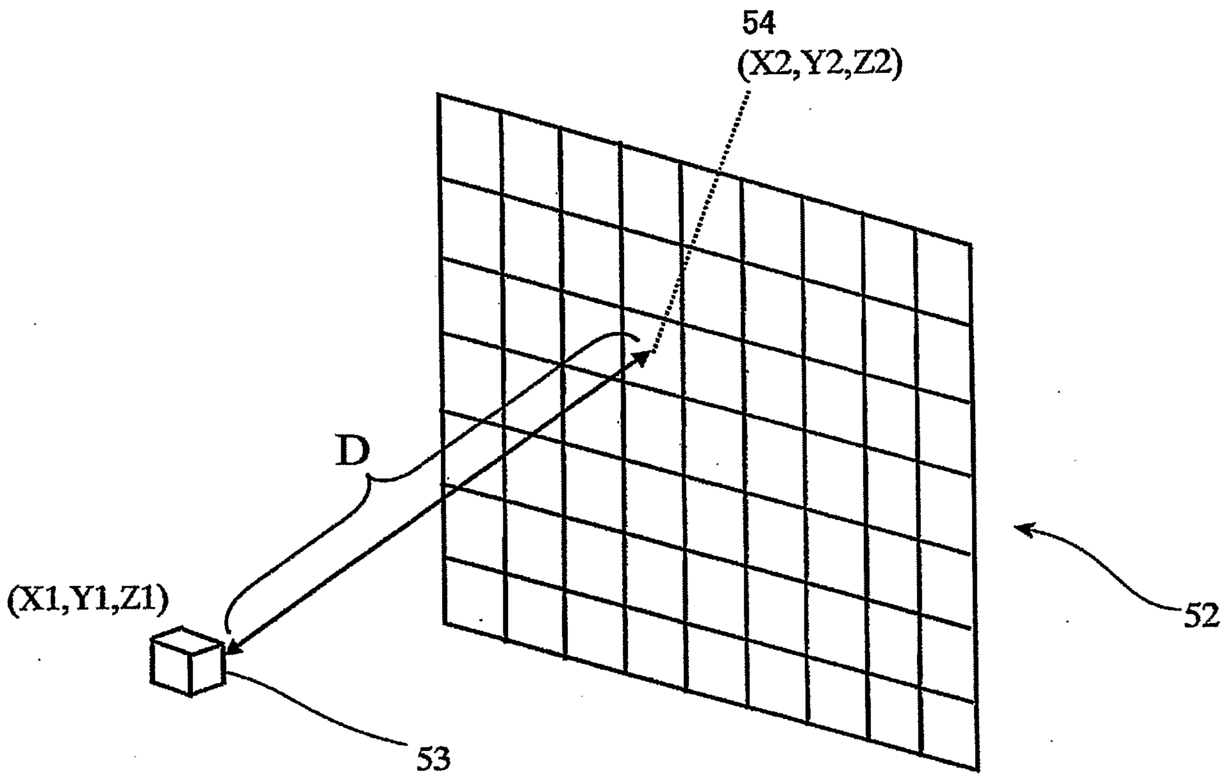

FIG. 3

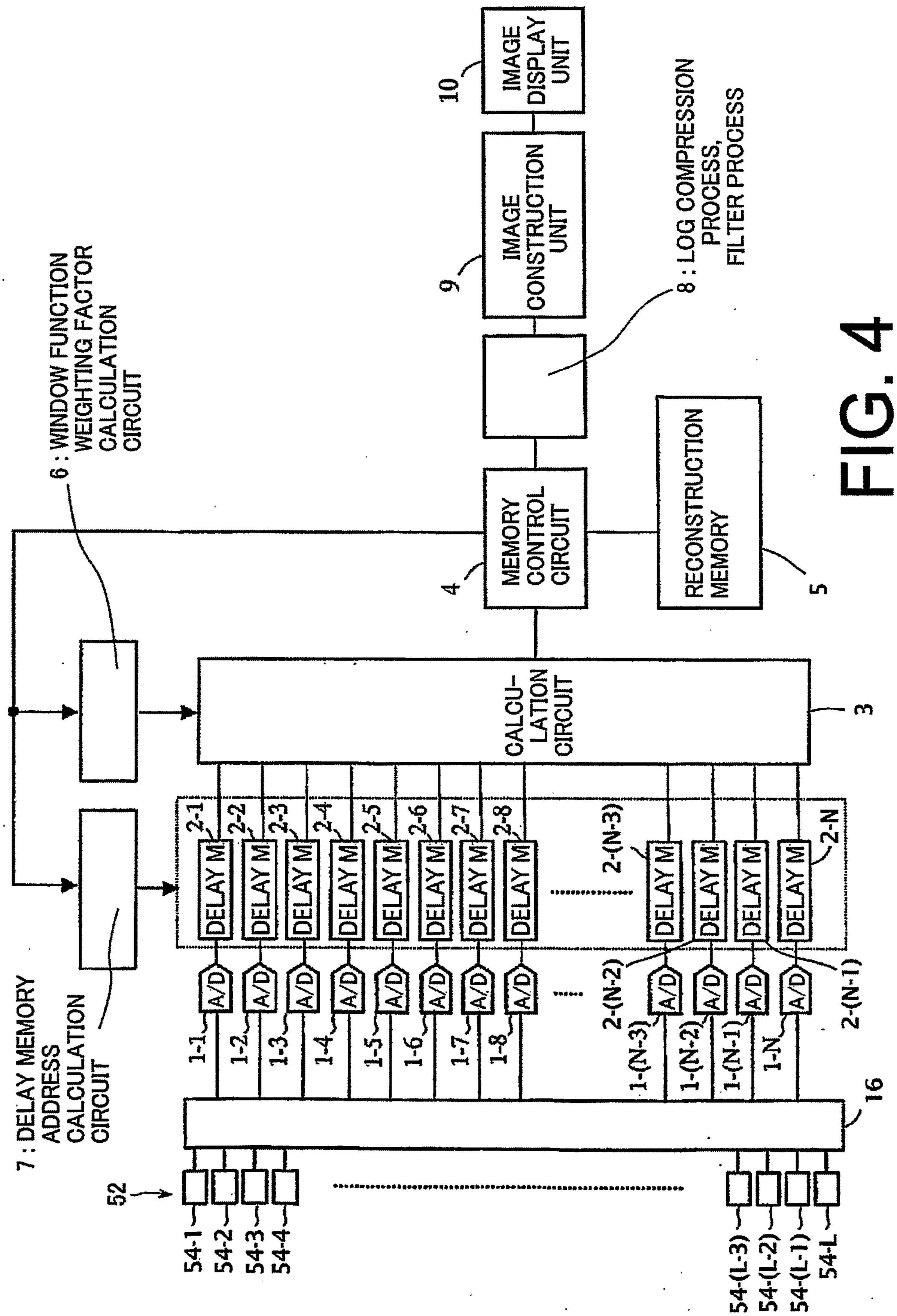
7 : DELAY MEMORY ADDRESS CALCULATION CIRCUIT
6 : WINDOW FUNCTION WEIGHTING FACTOR CALCULATION CIRCUIT
52
54-1
54-2
54-3
54-4
54-(L-3)
54-(L-2)
54-(L-1)
54-L
16
1-1
1-2
1-3
1-4
1-5
1-6
1-7
1-8
1-(N-3)
1-(N-2)
1-(N-1)
1-N
A/D
2-(N-2)
2-(N-1)
DELAY M
2-1
2-2
2-3
2-4
2-5
2-6
2-7
2-8
2-(N-3)
2-N
CALCU-LATION CIRCUIT
3
4
MEMORY CONTROL CIRCUIT
RECONSTRUCTION MEMORY
5
8 : LOG COMPRESSION PROCESS, FILTER PROCESS
9
IMAGE CONSTRUCTION UNIT
10
IMAGE DISPLAY UNIT

FIG. 4

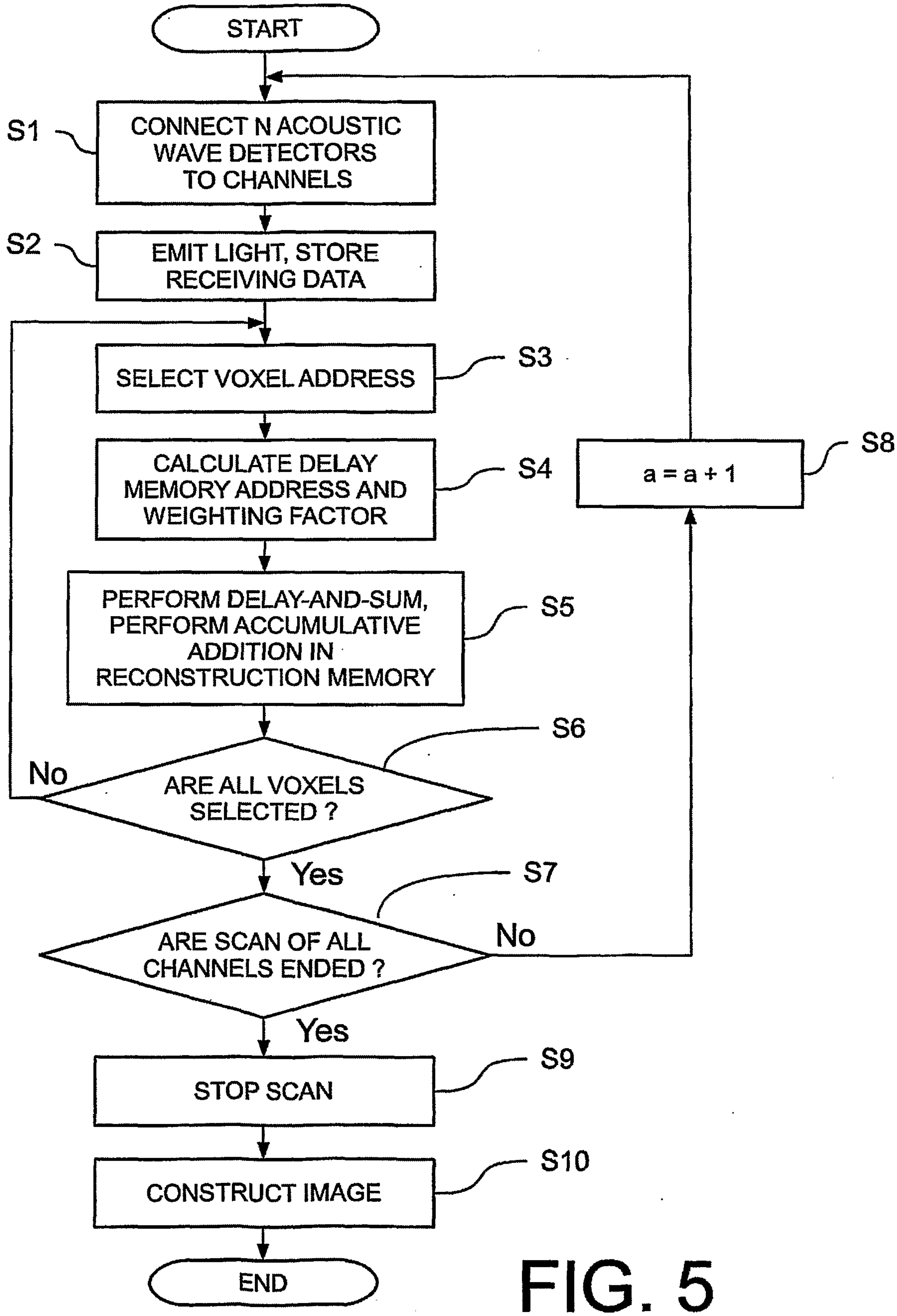
START
S1
CONNECT N ACOUSTIC WAVE DETECTORS TO CHANNELS
S2
EMIT LIGHT, STORE RECEIVING DATA
SELECT VOXEL ADDRESS
S3
CALCULATE DELAY MEMORY ADDRESS AND WEIGHTING FACTOR
S4
S8
a = a + 1
PERFORM DELAY-AND-SUM, PERFORM ACCUMULATIVE ADDITION IN RECONSTRUCTION MEMORY
S5
S6
No
ARE ALL VOXELS SELECTED ?
Yes
S7
ARE SCAN OF ALL CHANNELS ENDED ?
No
Yes
STOP SCAN
S9
CONSTRUCT IMAGE
S10
END

FIG. 5

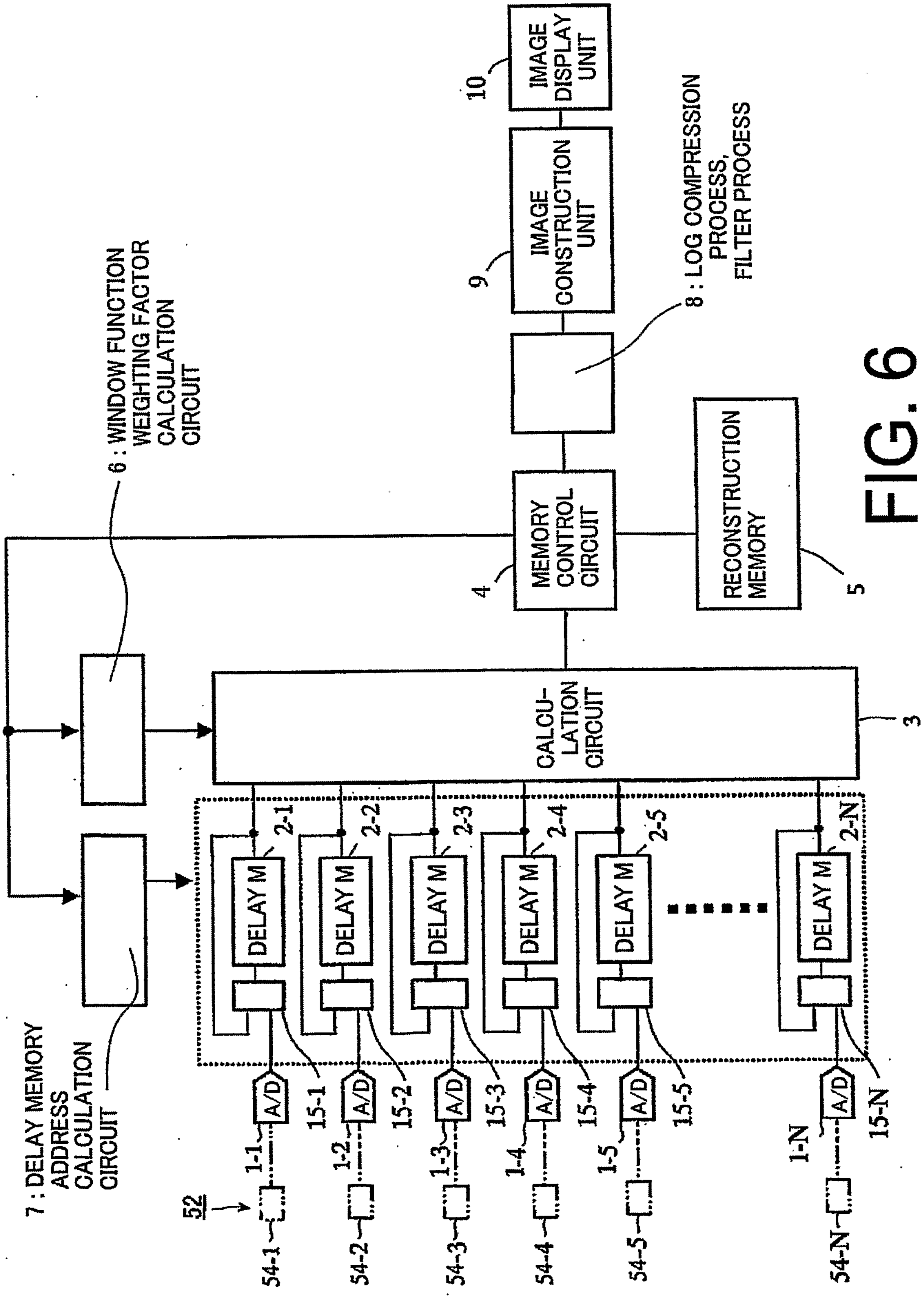
6 : WINDOW FUNCTION WEIGHTING FACTOR CALCULATION CIRCUIT
7 : DELAY MEMORY ADDRESS CALCULATION CIRCUIT
52
54-1
54-2
54-3
54-4
54-5
54-N
1-1
1-2
1-3
1-4
1-5
1-N
A/D
15-1
15-2
15-3
15-4
15-5
15-N
DELAY M
2-1
2-2
2-3
2-4
2-5
2-N
CALCU-LATION CIRCUIT
3
MEMORY CONTROL CIRCUIT
4
RECONSTRUCTION MEMORY
5
8 : LOG COMPRESSION PROCESS, FILTER PROCESS
IMAGE CONSTRUCTION UNIT
9
IMAGE DISPLAY UNIT
10

FIG. 6

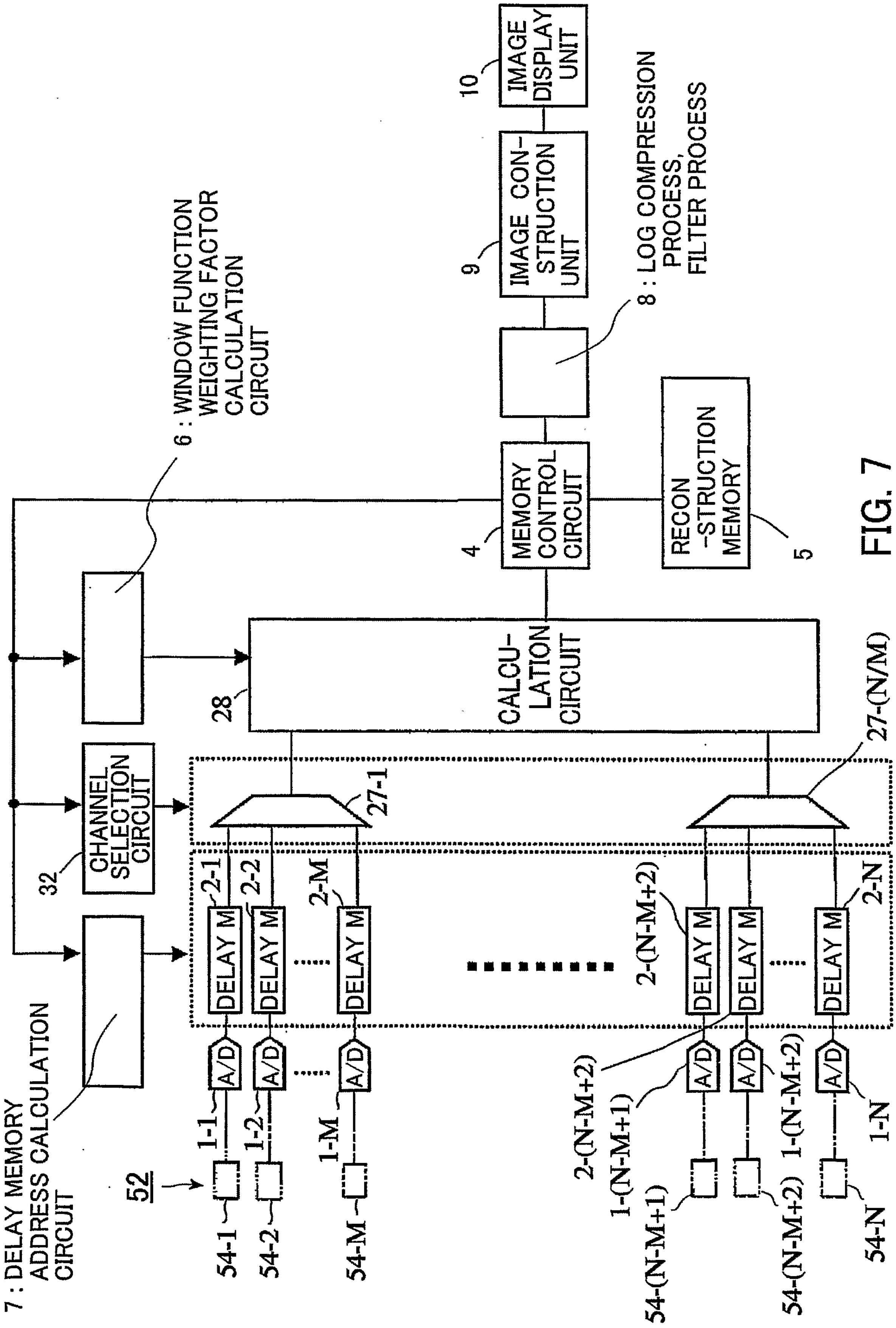
7 : DELAY MEMORY ADDRESS CALCULATION CIRCUIT
32
CHANNEL SELECTION CIRCUIT
6 : WINDOW FUNCTION WEIGHTING FACTOR CALCULATION CIRCUIT
28
CALCU-LATION CIRCUIT
4
MEMORY CONTROL CIRCUIT
RECON -STRUCTION MEMORY
5
8 : LOG COMPRESSION PROCESS, FILTER PROCESS
9
IMAGE CON-STRUCTION UNIT
10
IMAGE DISPLAY UNIT
52
54-1
54-2
54-M
54-(N-M+1)
54-(N-M+2)
54-N
1-1
1-2
1-M
1-(N-M+1)
1-(N-M+2)
1-N
A/D
DELAY M
2-1
2-2
2-M
2-(N-M+2)
2-N
27-1
27-(N/M)

FIG. 7

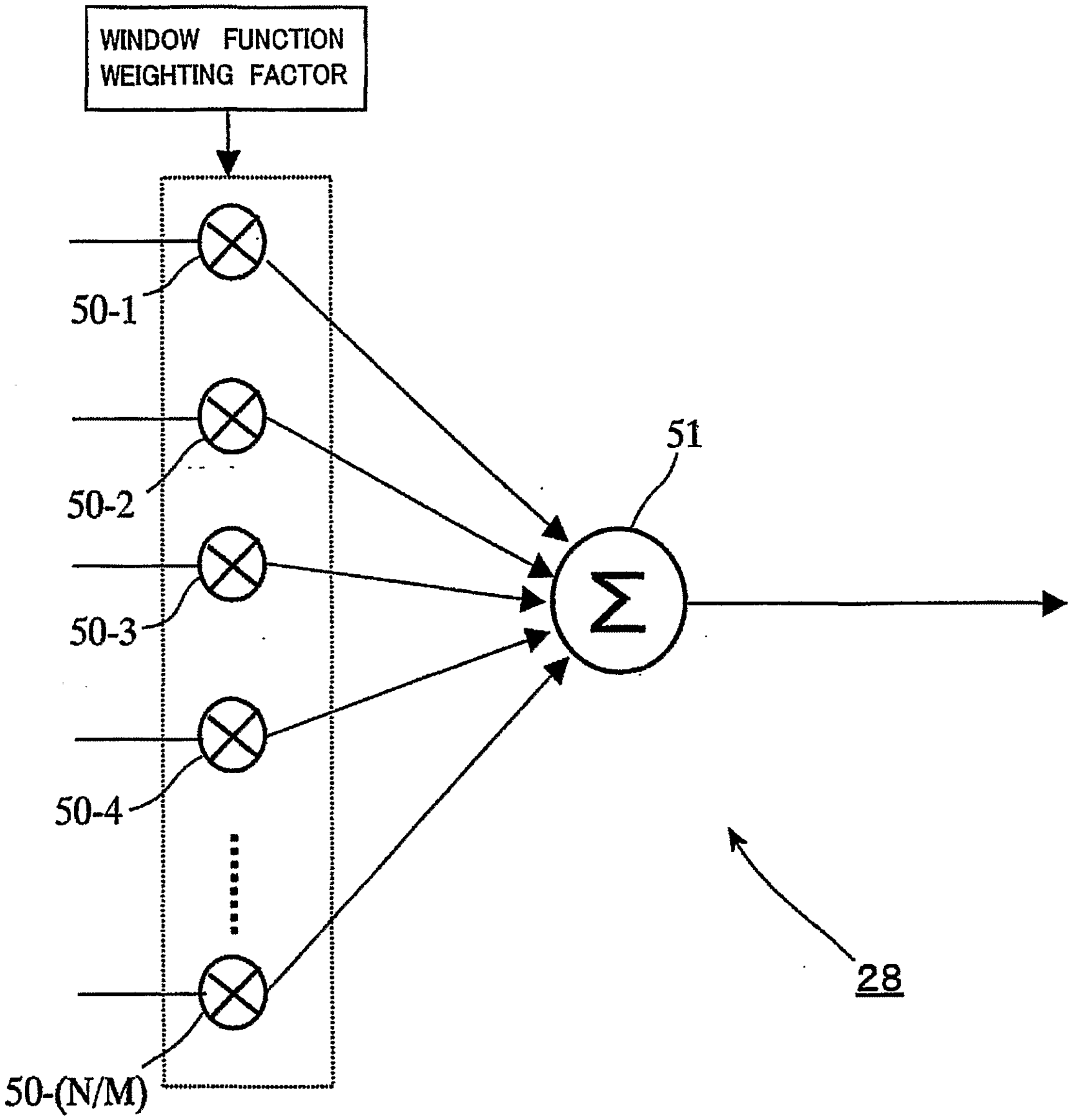
WINDOW FUNCTION WEIGHTING FACTOR
50-1
50-2
50-3
50-4
50-(N/M)
51
Σ
28

FIG. 8

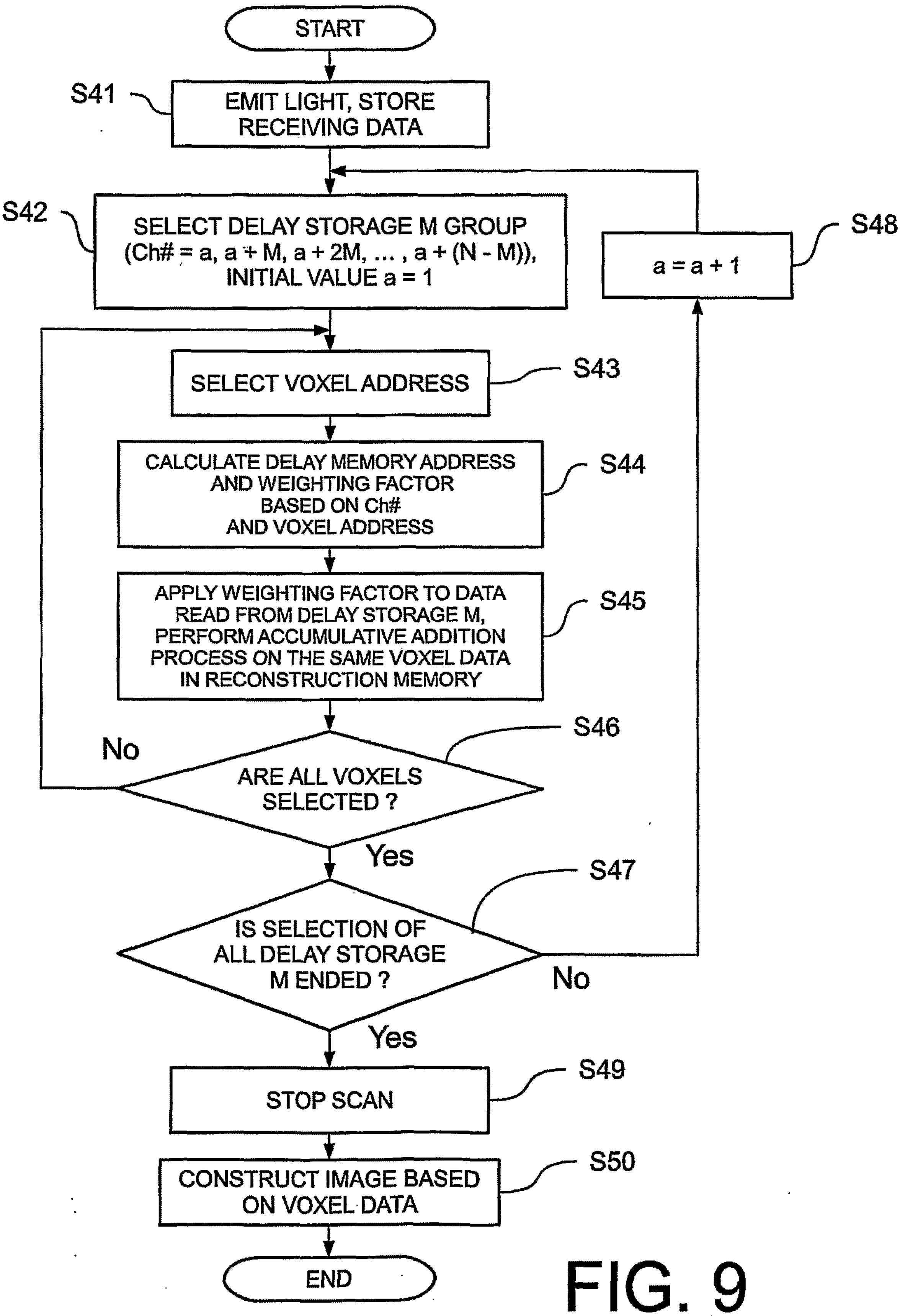
START
S41
EMIT LIGHT, STORE RECEIVING DATA
S42
SELECT DELAY STORAGE M GROUP (Ch# = a, a + M, a + 2M, ... , a + (N - M)), INITIAL VALUE a = 1
S48
a = a + 1
SELECT VOXEL ADDRESS
S43
CALCULATE DELAY MEMORY ADDRESS AND WEIGHTING FACTOR BASED ON Ch# AND VOXEL ADDRESS
S44
APPLY WEIGHTING FACTOR TO DATA READ FROM DELAY STORAGE M, PERFORM ACCUMULATIVE ADDITION PROCESS ON THE SAME VOXEL DATA IN RECONSTRUCTION MEMORY
S45
S46
No
ARE ALL VOXELS SELECTED ?
Yes
S47
IS SELECTION OF ALL DELAY STORAGE M ENDED ?
No
Yes
STOP SCAN
S49
CONSTRUCT IMAGE BASED ON VOXEL DATA
S50
END

FIG. 9

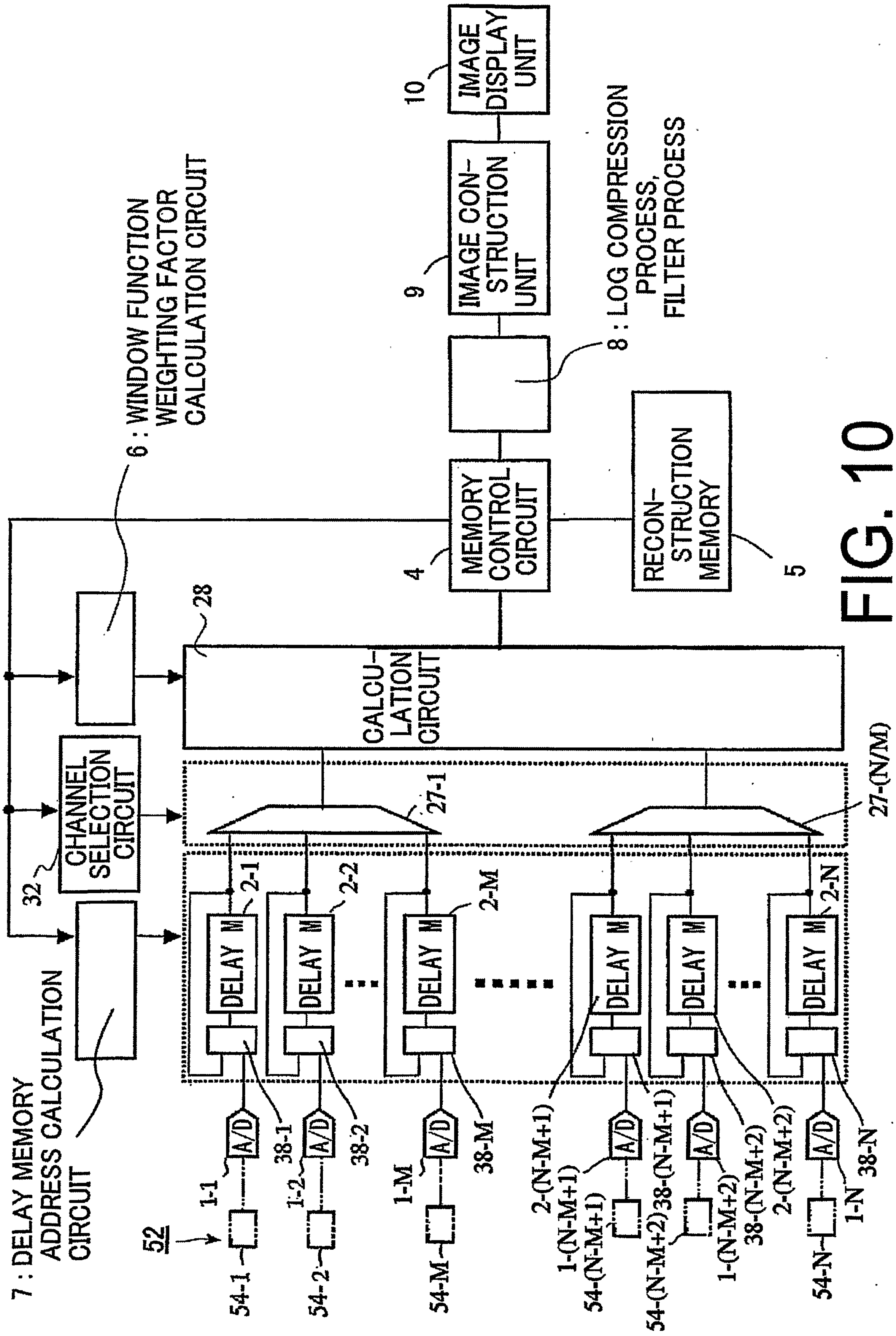
7 : DELAY MEMORY ADDRESS CALCULATION CIRCUIT
6 : WINDOW FUNCTION WEIGHTING FACTOR CALCULATION CIRCUIT
32
CHANNEL SELECTION CIRCUIT
28
CALCU-LATION CIRCUIT
4
MEMORY CONTROL CIRCUIT
RECON-STRUCTION MEMORY
5
8 : LOG COMPRESSION PROCESS, FILTER PROCESS
9
IMAGE CON-STRUCTION UNIT
10
IMAGE DISPLAY UNIT
27-1
27-(N/M)
DELAY M
2-1
2-2
2-M
2-N
A/D
52
54-1
54-2
54-M
54-(N-M+1)
54-(N-M+2)
54-N
1-1
1-2
1-M
1-(N-M+1)
1-(N-M+2)
1-N
38-1
38-2
38-M
38-(N-M+1)
38-(N-M+2)
38-N
2-(N-M+1)
2-(N-M+2)

FIG. 10

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2005021380 A **[0009] [0011]**
- JP 2001507952 A **[0009] [0011]**

Non-patent literature cited in the description

- **M. FRENZ et al.** Combined Ultrasound and Optoacoustic System for Real-Time High-Contrast Vascular Imaging in Vivo. *IEEE Transactions on Medical Imaging,* 01 April 2005, vol. 24 (4), 436-440 **[0010]**

专利名称(译)	接收光声层析成像的数据处理设备		
公开(公告)号	EP2334224B1	公开(公告)日	2017-11-29
申请号	EP2009788060	申请日	2009-09-03
[标]申请(专利权)人(译)	佳能株式会社		
申请(专利权)人(译)	佳能株式会社		
当前申请(专利权)人(译)	佳能株式会社		
[标]发明人	BABA YOSHITAKA YODA HARUO FUKUTANI KAZUHIKO		
发明人	BABA, YOSHITAKA YODA, HARUO FUKUTANI, KAZUHIKO		
IPC分类号	A61B5/00 A61B8/13		
CPC分类号	A61B5/0095 A61B5/0073 A61B5/7225 A61B5/7278 A61B8/13 A61B8/483		
代理机构(译)	TBK		
优先权	2008227091 2008-09-04 JP		
其他公开文献	EP2334224A1		
外部链接	Espacenet		

摘要(译)

提供一种光声层析成像的接收数据处理装置，包括最小构成单元数据合成单元，其顺序地从第一存储单元读取接收数字信号，并通过执行延迟来组成最小构成单元的声波的最小构成单元数据。 -sum过程;第二存储单元，存储样本的整个区域的最小构成单元数据;图像构建单元，其基于存储在第二存储单元中的最小构成单元数据构建样本的图像;控制单元，将由最小构成单元数据合成单元计算出的最小构成单元数据顺序存储在第二存储单元中，并读取所存储的样本的整个区域的最小构成单元数据，以将最小构成单元数据发送到图像构造单元。

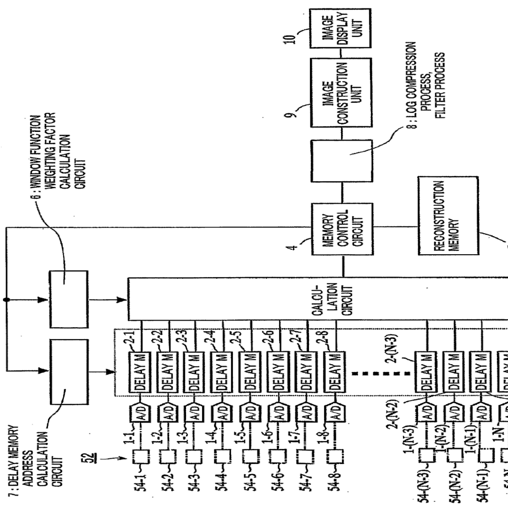

FIG. 1