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(54) **APPARATUS FOR 3D ULTRASOUND IMAGING AND THERAPY**

GERÄT FÜR DIE 3D-ULTRASCHALLDARSTELLUNG UND -THERAPIE

APPAREIL D'IMAGERIE ET DE THERAPIE ULTRASONORES TRIDIMENSIONNELLES

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## Description

**[0001]** The invention relates to an apparatus containing two separate two-dimensional (2D) ultrasound array transducers, one for providing three-dimensional (3D) images, and the other for generating therapy beams that can be electronically steered in three dimensions; The use of the apparatus in delivering ultrasound mediated therapy such as localized gene delivery, drug delivery, sonothrombolysis, tissue ablation etc. is also disclosed.

**[0002]** Ultrasound has many therapeutic applications such as tissue ablation, drug delivery, hyperthermia, clot dissolution, etc. Single element therapy transducers are limited by a fixed focal length, and depend on mechanical translation to treat different regions of the body. In order to steer the therapy beam to different locations in the body, electronically phased array transducers may be employed. Simultaneous imaging of tissues during therapy makes it possible to plan and monitor the treatment.

**[0003]** One example of a combined therapy and imaging system is described by US patent Nock et al (US6,716,188). This patent describes a system for drug delivery enhancement and imaging comprising a transducer having only one linear array of elements.

**[0004]** US patent 5,558,092 (Unger et al) discloses one example of a combined ultrasound imaging and therapy system with separate transducers on the same substrate. Several transducer configurations are proposed including one that has a 2D matrix of elements for both the imaging and therapy that are operated in a multiplexed manner such that a sequential linear set of elements are activated.

**[0005]** US patent 6,428,477 (Mason) assigned to Philips, describes a fully steerable two-dimensional ultrasound array that delivers therapy by steering and selective focusing of beams. Same transducer is used for both therapy and imaging.

**[0006]** US patent 6,719,694 describes ultrasound transducers that perform both therapy and imaging. A quality factor circuit changes the bandwidth of the transducer such that high bandwidth operation is used in imaging.

**[0007]** US patent 6,500,121 describes an ultrasonic therapy system having a single transducer that performs imaging, therapy, and temperature monitoring, where the single transducer can be operated to provide imaging or therapy in a 3D manner.

**[0008]** Document US-B1-6425867 discloses an ultrasonic apparatus for imaging and therapy comprising a 2D ultrasound imaging array, a 2D ultrasound therapy array and a controller to provide images and simultaneously deliver therapy.

**[0009]** The method of Unger et al uses multiplexed linear elements (USS,558,092). The therapy array is not configured to perform 3D steering of the beam and only provides shallow operation near the skin surface. Moreover, the same substrate is used for both the imaging and therapy arrays. This leads to the possibility of cross talk between the two arrays especially since the therapy array commonly utilizes higher power levels. Also, imaging array is fixed and cannot be swapped with other imaging probes for the same therapy array. Using the same substrate for both the arrays leads to less optimal use of the piezo material, since therapy arrays might benefit from being made of piezocomposite materials where arbitrary elements size and shapes can be made.

**[0010]** The method of Mason (US6,428,477), Weng (US6,719,694) and Slayton et al (6,500,121) uses the same transducer for imaging and therapy. However, therapy and imaging have different requirements since the focusing capabilities and frequency requirements are different. It is often difficult to optimize the transducer for both the applications. For example, ultrasound imaging typically employs frequencies greater than 2 MHz, whereas therapy employs frequencies less than two MHz. For small animal studies, even higher frequencies such as 15 MHz are preferred for imaging. The small aperture sizes of imaging transducers are insufficient to achieve focusing gains needed for therapy that usually requires much larger transducers. Moreover the imaging array has regularly spaced elements and if used for therapy would require a large number of elements in order to accommodate the requirement to avoid grating lobes.

**[0011]** However, as discussed above, problems still persist with these systems and methodology in ultrasound imaging and therapy, particularly for biological tissue in a spatial volume which may be in motion, which are overcome by the apparatus and methodology disclosed herein.

**[0012]** According to this invention, herein disclosed is an apparatus containing two separate two-dimensional (2D) ultrasound array transducers, one for providing three-dimensional (3D) images, and the other for generating therapy beams that can be electronically steered in three dimensions.

**[0013]** Specifically, it is an object of the invention to provide an apparatus for application of three-dimensional ultrasound imaging and therapy as defined in claim 1.

**[0014]** Another object of the invention is to provide an apparatus further comprising each of the imaging and therapy transducer arrays having a plurality of ultrasound elements that are individually controllable in amplitude, phase and frequency of operation.

**[0015]** Another object of the invention is to provide an apparatus further comprising the controller correlating the imaged volume with the therapy transducer array so that the therapy is delivered to the volume.

**[0016]** Another object of the invention is provided in dependent claim 4.

**[0017]** These and other aspects of the invention are explained in more detail with reference to the following embodiments and with reference to the figures.

**[0018]** Figure 1 depicts an embodiment of the apparatus having a combined 2D therapy and 2D imaging array or probe. The imaging array in the shape of a square is placed at the center of the annular hole and the therapy

array having numerous elements shown as circles are in the annulus surrounding the imaging array.

**[0019]** In any non-invasive therapy application, planning, guidance, and monitoring are critical. This invention provides three important benefits to these goals: fast real-time three dimensional interrogation of the 3D spatial volume surrounding the target biological tissue, accurate and precise correlation or co-registration of the ultrasound therapy or treatment beam's) to the ultrasound 3D imaging information and near-real-time adjustment of both the size and shape of the 3D spatial volume target zone containing the biological tissue of interest and the path of the treatment beam's). For example, in the treatment of the heart, the movement of the target tissue may be complicated and irregular due to respiration motion and arrhythmia. The imaging array can image in real time this motion, then the therapy array can be programmed to deliver the therapeutic ultrasound with temporal gating and/or spatial steering so that the treatment zone coincides with the target volume.

**[0020]** According to the invention herein, the apparatus contains two separate 2D ultrasound array transducers, one for providing 3D images, and the other for providing therapy beam that is electronically steerable in three dimensions; the individual elements of both arrays are distributed along two dimensions, and are individually controllable in amplitude, phase, and frequency of operation. The elements of both the imaging and therapy arrays could be distributed in a random or irregular manner over the surface. The two arrays can use separate beam formers for steering and focusing. The two arrays allow the 3D images and therapy beams to be registered or correlated with respect to each other.

**[0021]** In one embodiment, the therapy array consists of a 2D spherical annulus. The hole in the annulus provides space for the imaging array. The elements of the therapy array are circular in shape and randomly distributed throughout the array. Figure 1 shows the therapeutic array with the imaging array at the center. This embodiment provides a simple implementation for the registration of the therapy probe in the space of the image provided by the imaging array. The imaging probe could be any matrix transducer such as the X3-1 transducers sold by Philips.

**[0022]** In another embodiment, the 2D imaging array is attached to the side of the therapy array and fixed with respect to it. The two arrays are rigidly fixed with respect to each other and hence the registration information is known a priori.

**[0023]** In another embodiment, an arrangement of several therapy arrays is used with one imaging transducer. The different 2D therapy arrays could be located around the imaging array in a circular fashion. Each array may provide treatment in different spatial regions or different treatment regiments such as frequencies and penetration depth. The imaging array would provide a wide field of view for planning purpose. One or more of the therapy arrays would be turned on to activate the therapy based on spatial location and depth of the treatment region, available acoustic window and other factors.

**[0024]** The controller that controls and co-registers the ultrasound therapy delivery with 3D images provided by the ultrasound image transmitter and receiver can include one or more computers or processors. The beam forming and steering electronics controlled by the controller are conventional and can be operated according to computer programs known to one skilled in the art. The therapy system consists of an array of piezo-electric, piezocomposite, crystal, or ceramic elements capable of generating either a high, low duty cycle or a lower, longer duty cycle pressure field. The transducer elements are excited by a voltage supplied by a high power amplifier and generated by either an arbitrary wave or a single frequency source. The timing of these signals is controlled by either programmable trigger circuitry or a therapeutic beam former. The commencement and cessation of therapy pressure field can be controlled through programmable triggers, controlled externally, or from a derived trigger event from the 2D imaging array (e.g. when the desired tissue volume is within a specific spatial location). The entire system consisting of both therapeutic and imaging arrays and corresponding electronic circuitry (amplifiers, power supplies, signals sources, beam formers, trigger circuitry) is controlled by a external controller, usually a personal computer. This external controller is the master controller of most timing events, user interaction, and integration of the imaging and therapy probe.

**[0025]** Ultrasound therapy is an emerging application and business opportunity. Currently ultrasound therapy is used routinely in cancer treatment in China; in the USA it is approved by the FDA for the treatment of uterine fibroid and in trials for prostate cancer and benign prostate hyperplasia; and in Europe clinical trials are on-going.

**[0026]** The invention can be used in many application areas for delivering ultrasound therapy, for example in treating hyperthermia, high intensity focused ultrasound (HIFU), and microbubble/nanoparticle-mediated therapy. The last application area exploits acoustically induced bioeffects to enhance and control localized gene and drug delivery, such as delivery of high intensity ultrasound beams to cause previously injected microspheres containing a drug substance to burst at the tissue site releasing the drug substance; and other applications in the field of ultrasound mediated molecular medicine. This area also includes the use of ultrasound to enhance the efficacy of thrombolytic agents used in an acute setting following an atherosclerotic event. The application can also be used where ultrasound is used for clot dissolution for stroke or DVT patients.

**[0027]** The invention can be used in any areas where focused ultrasound may provide therapeutic effects. Typical examples include brain lesions, uterine fibroids, liver tumor, breast tumor and other tumors of the mammalian body and blood clots. In the cardiac setting, novel appli-

cations are being developed to protect the heart prior to or subsequent to a myocardial infarction.

**[0028]** While the present invention has been described with respect to specific embodiments thereof, it will be recognized by those of ordinary skill in the art that many modifications, enhancements, and/or changes can be achieved without departing from the scope of the invention. Therefore, it is manifestly intended that the invention be limited only by the scope of the claims.

## Claims

1. An apparatus for application of three-dimensional ultrasound imaging and therapy comprising:

   a two-dimensional ultrasound imaging array of transducer elements having an image signal transmitter and receiver that is configured to form, steer and selectively focus ultrasound beams to a three-dimensional moving or stationary spatial volume;
   one or more two-dimensional ultrasound therapy arrays of transducer elements, each array having a therapy signal transmitter that is configured to form, steer and selectively focus and deliver ultrasound therapy to the volume; wherein the location of the array of imaging and therapy transducer elements are known relative to one another, further wherein the one or more two-dimensional ultrasound therapy arrays of transducer elements is located in a two-dimensional annular space between two concentric circles, wherein the elements of one or more of the two-dimensional ultrasound therapy arrays are circular in shape and randomly distributed throughout the respective therapy array, and the two-dimensional imaging array of transducer elements is located within a two-dimensional space of an inner circle of the two concentric circles; and
   a controller that is configured to control the image transmitter and receiver to provide three-dimensional images of the volume and simultaneously independently control each of the one or more therapy transmitters to deliver therapy to the volume.

2. The apparatus of claim 1 further comprising each of the imaging and therapy transducer arrays having a plurality of ultrasound elements that are individually controllable in amplitude, phase and frequency of operation.

3. The apparatus of claim 1 further comprising the controller being configured to co-register the imaged volume with the therapy transducer array so that the therapy can be delivered to the volume.

4. The apparatus of claim 1 further comprising a plurality of said therapy transducer arrays located in the two-dimensional annular space between the two concentric circles wherein each of the plurality of therapy arrays is capable of providing therapy in different spatial volumes, different therapy regimens including different ultrasound wave frequencies and different tissue penetration depths.

## Patentansprüche

1. Vorrichtung zur Anwendung von dreidimensionaler Ultraschallbildgebung und -therapie, die Folgendes umfasst:

   ein zweidimensionales Ultraschallbildgebungsarray aus Wandlerelementen mit einem Bildsignalsender und -empfänger, der konfiguriert ist, um Ultraschallstrahlenbündel zu bilden, zu lenken und selektiv auf ein dreidimensionales sich bewegendes oder stationäres Raumvolumen zu fokussieren;
   einen oder mehrere zweidimensionale Ultraschalltherapiearrays aus Wandlerelementen, wobei jedes Array einen Therapiesignalsender hat, der konfiguriert ist, um Ultraschalltherapie zu bilden, zu lenken und selektiv zu fokussieren und an das Volumen abzugeben, wobei die Position des Arrays aus Bildgebungs- und Therapiewandlerelementen in Bezug zueinander bekannt ist, wobei weiterhin das eine oder mehrere zweidimensionale Ultraschalltherapiearrays aus Wandlerelementen in einem zweidimensionalen ringförmigen Raum zwischen zwei konzentrischen Kreisen angeordnet ist bzw. sind, wobei die Elemente des einen oder der mehreren zweidimensionalen Ultraschalltherapiearrays kreisförmig sind und zufällig über das betreffende Therapiearray verteilt sind, und das zweidimensionale Bildgebungsarray aus Wandlerelementen innerhalb eines zweidimensionalen Raums von einem inneren Kreis der beiden konzentrischen Kreise angeordnet ist; und
   eine Steuereinheit, die konfiguriert ist, um den Bildsender und -empfänger zu steuern, um dreidimensionale Bilder des Volumens zu schaffen, und um gleichzeitig unabhängig jeden der einen oder mehreren Therapiesender zu steuern, um Therapie an das Volumen abzugeben.

2. Vorrichtung nach Anspruch 1, weiterhin umfassend, dass jedes der Bildgebungs- und Therapiewandlerarrays eine Vielzahl von Ultraschallelementen hat, die einzeln in Amplitude, Phase und Betriebsfrequenz steuerbar sind.

3. Vorrichtung nach Anspruch 1, weiterhin umfassend,

dass die Steuereinheit konfiguriert ist, um das abgebildete Volumen mit dem Therapiewandlerarray mitzuregistrieren, so dass die Therapie an das Volumen abgegeben werden kann.

**4.** Vorrichtung nach Anspruch 1, weiterhin mit einer Vielzahl von genannten Therapiewandlerarrays, die in dem zweidimensionalen ringförmigen Raum zwischen den zwei konzentrischen Kreisen angeordnet sind, wobei jedes der Vielzahl von Therapiearrays in der Lage ist, eine Therapie in verschiedenen Raumvolumina zu liefern, wobei unterschiedliche Therapiepläne unterschiedliche Ultraschallwellenfrequenzen und unterschiedliche Gewebeeindringtiefen umfassen.

**Revendications**

**1.** Appareil d'application d'imagerie et de thérapie par ultrasons à trois dimensions comprenant :

un réseau d'éléments transducteurs d'imagerie par ultrasons à deux dimensions comportant un émetteur-récepteur de signal d'image qui est configuré pour former, diriger et sélectivement focaliser des faisceaux d'ultrasons sur un volume spatial mobile ou immobile à trois dimensions ;
un ou plusieurs réseaux d'éléments transducteurs de thérapie par ultrasons à deux dimensions, chaque réseau comportant un émetteur de signal de thérapie qui est configuré pour former, diriger et sélectivement focaliser et apporter une thérapie par ultrasons au volume ; dans lequel l'emplacement du réseau d'éléments transducteurs d'imagerie et l'emplacement du réseau d'éléments transducteurs de thérapie sont connus l'un par rapport à l'autre ; dans lequel le ou les réseaux d'éléments transducteurs de thérapie par ultrasons à deux dimensions se trouvent dans un espace annulaire à deux dimensions entre deux cercles concentriques ; dans lequel les éléments du ou des réseaux de thérapie par ultrasons à deux dimensions sont de forme circulaire et sont distribués aléatoirement dans tout le réseau de thérapie respectif, et le réseau d'éléments transducteurs d'imagerie à deux dimensions se trouve dans un espace à deux dimensions d'un cercle intérieur des deux cercles concentriques ; et
un contrôleur qui est configuré pour commander à l'émetteur-récepteur d'images de fournir des images à trois dimensions du volume et pour commander simultanément et indépendamment à chacun du ou des émetteurs de thérapie d'apporter la thérapie au volume.

**2.** Appareil selon la revendication 1, comprenant en outre chacun des réseaux de transducteurs d'imagerie et de thérapie comportant une pluralité d'éléments d'ultrasons pouvant être individuellement commandés en amplitude, en phase et en fréquence de fonctionnement.

**3.** Appareil selon la revendication 1, comprenant en outre le contrôleur étant configuré pour co-enregistrer le volume imagé avec le réseau de transducteurs de thérapie afin que la thérapie puisse être apportée au volume.

**4.** Appareil selon la revendication 1, comprenant en outre une pluralité desdits réseaux de transducteurs de thérapie situés dans l'espace annulaire à deux dimensions entre les cercles concentriques, dans lequel chacun de la pluralité de réseaux de thérapie est capable d'apporter la thérapie dans différents volumes spatiaux, différents régimes de thérapie comprenant différentes fréquences d'ondes d'ultrasons et différentes profondeurs de pénétration de tissu.

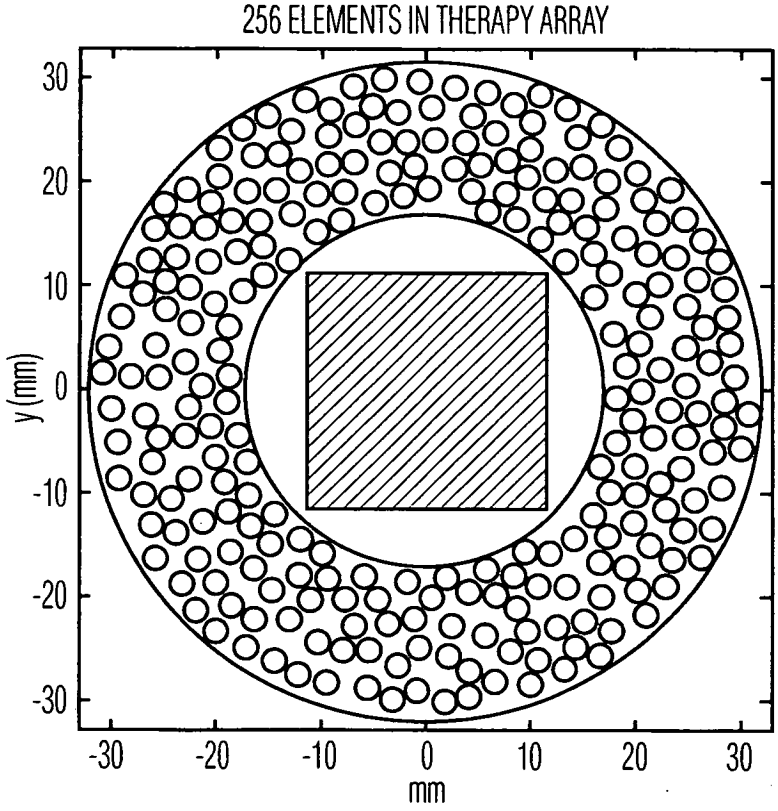
256 ELEMENTS IN THERAPY ARRAY
30
20
10
0
-10
-20
-30
y (mm)
-30
-20
-10
0
10
20
30
mm

FIG. 1

## REFERENCES CITED IN THE DESCRIPTION

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| | | | |
|---|---|---|---|
| 专利名称(译) | 用于3D超声成像和治疗的装置 | | |
| 公开(公告)号 | EP2091438B1 | 公开(公告)日 | 2012-01-11 |
| 申请号 | EP2007826995 | 申请日 | 2007-11-06 |
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| 优先权 | 60/887640 2007-02-01 US<br>60/867464 2006-11-28 US | | |
| 其他公开文献 | EP2091438A1 | | |
| 外部链接 | Espacenet | | |


摘要(译)

一种用于三维超声成像和治疗的应用的装置，包括具有图像信号发射器和接收器的换能器元件的二维超声成像阵列，所述图像信号发射器和接收器形成，操纵并选择性地将超声波束聚焦到三维移动或静止空间体积;换能器元件的一个或多个二维超声治疗阵列，每个阵列具有治疗信号发射器，其形成，操纵并选择性地聚焦并向该体积递送超声治疗;其中成像和治疗换能器元件阵列的位置相对于彼此是已知的;控制器控制图像发送器和接收器以提供体积的三维图像，并同时独立地控制一个或多个治疗发射器中的每一个以向该体积递送治疗。还公开了一种利用该装置将超声治疗传递到三维移动或静止空间体积中的生物组织的方法。


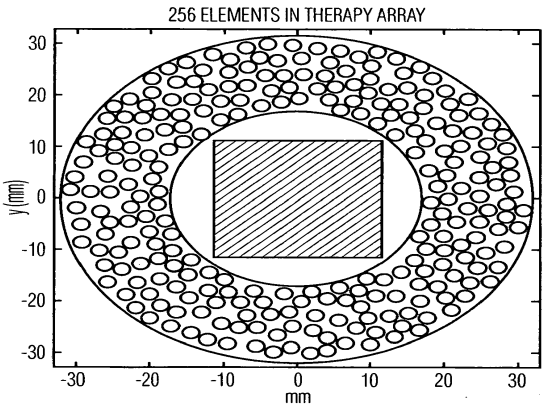


FIG. 1