

Motion control device of an ultrasonic treatment head focusing on a large-scale target area

Technical field

The invention relates to the technical field of medical instrument, in particular to a motion control device of an ultrasonic treatment head focusing on a large-scale target area.

Background

Focused ultrasonic is a technology where ultrasonic waves with a certain intensity are focused, similar to using a concave lens for focusing sunlight. The high sound intensity at the focal point can cause irreversible degeneration, which is known as ablation, of the tissue at that position quickly. This technology has been widely used in clinical treatment because of its non-invasive characteristics.

The core hardware of the focused ultrasonic system mainly comprises a mechanical moving part, a power amplifying part and a treatment head. The cooperation of different parts is required during the actual treatment process.

The development of focused ultrasonic tumor treatment equipment is more and more focused on lightness and intelligence. The treatment head of the external focused ultrasonic system can be divided into two types according to the focusing mode: self-focusing and phase-controlled focusing. The phase-controlled focusing technology has the advantages of deflecting the focus electronically and generating multiple focuses at the same time. With the reduction of its cost and complexity, the phase-controlled focusing ultrasonic system has been used more and more widely in clinical treatment.

Based on the different treatment methods, the treatment head of the external focused ultrasonic system can be divided into two types: upper type and lower type. The traditional lower type system is provided with the treatment head and the mechanical moving part fixed in the water tank of the bed, and the patient lies in

the prone position on the treatment bed during treatment.

Compared to the prone position, the supine position is more comfortable, so the upper type system has been used more and more widely. At present, the upper type system is mainly divided into two types, the treatment head of one type of the upper type system is similar to that of the lower type system, where the motion of the transducer during treatment is controlled by the motion of the multi-dimensional machinery in the water tank built by mechanical parts, and the bottom of the water tank is provided with the acoustic membrane for ultrasonic transmission. This type of system is bulky, heavy and inconvenient for use.

In addition, different treatment methods are used in different systems, and the electronic deflection range of the external phase-controlled focused ultrasonic equipment so far is mostly insufficient to cover the diseased tissue. Therefore, the combination of machinery and phase control has become a common solution, and the treatment method and the mechanical moving part should be considered at the same time in the system design.

Summary of the invention

(i) Technical problems to be solved

Aiming at the shortcomings in the prior art, the present invention provides a motion control device of an ultrasonic treatment head focusing on a large-scale target area, which has the advantages of simple structure, easy manufacture, or cost reduction, and solves the problems of the focused ultrasonic tumor treatment device being bulky, heavy or inconvenient for use.

(ii) Technical solution

The present invention provides the following technical solution: the motion control device of an ultrasonic treatment head focusing on a large-scale target area, which comprises a swing control module and an ultrasonic imaging probe control module, the swing control module comprises a vertical motion module, a left-right motion module and an axial motion module, the three motion modules control the

probe control module to swing in two degrees of freedom of front-back and left-right and rotate axially respectively, and perform ultrasonic imaging on a target area;

the vertical motion module comprises a lifting cross arm, an end of the lifting cross arm is provided with a first rotating disk, and a power input end of the first rotating disk is connected to a first swing motor in a driving manner;

the left-right motion module comprises a metal connecting part that is rotatably connected to a disk portion of the first rotating disk, one side of the metal connecting part is provided with a second swing motor, and an output end of the second swing motor is connected to a power input end of a second rotating disk in a driving manner;

the axial motion module comprises a frame-shaped metal base mounted on a disk portion of the second rotating disk, a third rotating disk is mounted on a top opening of the metal base, a power input end of the third rotating disk is connected to an rotation control motor for the ultrasonic imaging probe in a driving manner, one side of a disk portion of the third rotating disk is connected rotatably to a fixing clamp for the ultrasonic imaging probe, a bottom of the fixing clamp for the ultrasonic imaging probe passes through a bottom plate of the metal base and is provided with a treatment head, and a bottom of the treatment head is covered with a water bladder with good sound permeability;

the treatment head comprises a multi-array phase-controlled focused ultrasonic transducer and an ultrasonic imaging probe, and the ultrasonic imaging probe is provided in the fixing clamp for the ultrasonic imaging probe.

Preferably, each channel of the multi-array phase-controlled focused ultrasonic transducer can be controlled independently, and a position of a focus of the ultrasonic imaging probe can be changed within a certain space range by controlling its excitation voltage and phase signal, and a rotating axis of the ultrasonic imaging probe, a central axis of the ultrasonic imaging probe and the multi-array focused ultrasonic transducer are all arranged coaxially.

Preferably, the left-right motion module of the swing control module and the

rotating disk of the left-right motion module are perpendicular to each other, and the centers of which are located on the same horizontal plane; and an intersection point of the rotating axis of the two rotating disks is located on a straight line where an acoustic beam axis of the multi-array focused ultrasonic transducer is located.

Preferably, the rotating disk of the swing control module and the rotating disk connected to the ultrasonic imaging probe are both provided with corresponding limiting sensors that limit their rotation range.

Preferably, after the ultrasonic imaging probe has been driven by swinging the swing control module, a distance between the position of the geometric focus and the acoustic beam axis of the multi-array phase-controlled focused ultrasonic transducer satisfies the following formula:

$$d = \sqrt{x_1^2 + y_1^2} \quad (1)$$

x_1 : x coordinate of the position of the geometric focus after swinging;

y_1 : y coordinate of the position of the geometric focus after swinging;

d : the distance between the position of the geometric focus and the acoustic beam axis of the multi-array phase-controlled focused ultrasonic transducer after swinging.

Preferably, after the ultrasonic imaging probe has been driven by swinging the swing control module, the coordinate of the position of the geometric focus after swinging satisfies the following formula:

$$z_1 = R - \sqrt{R^2 - (x_1^2 + y_1^2)} \quad (2)$$

R : the swinging radius of the treatment head (10);

z_1 : z coordinate of the position of the geometric focus after swinging.

Preferably, after the ultrasonic imaging probe has been driven by swinging the swing control module, swinging angles in the left-right and front-back directions satisfy the following formula:

$$\begin{aligned} \alpha &= \arcsin(y_1 / \sqrt{R^2 - x_1^2}) \\ \beta &= \arcsin(x_1 / \sqrt{R^2 - y_1^2}) \end{aligned} \quad (3)$$

α : the swinging angle of the treatment head 10 in the left-right direction;

β : the swinging angle of the treatment head 10 in the front-back direction

Preferably, the first rotating disk, the second rotating disk and the third rotating disk are all electric indexing rotating disks.

(iii) Beneficial effects

Compared to the prior art, the present invention provides a motion control device of a ultrasonic treatment head focusing on a large-scale target area, which has the following beneficial effects:

(1) Compared to the prior art, the motion control device of the ultrasonic treatment head focusing on the large-scale target area provided by the present invention has the effects of simple structure, easy manufacture and cost reduction.

(2) The treatment method provided by the present invention, where the irradiation treatment of different treatment units is achieved by swinging the treatment head, is novel and creative.

(3) The treatment method provided by the present invention, where both the treatment head and the target area remain stable, is beneficial to improve the safety of treatment.

Description of drawings

Fig. 1 is a schematic structural diagram of the motion control device of the ultrasonic treatment head focusing on the large-scale target area provided by the present invention;

Fig. 2 is a schematic diagram of the motion of the treatment head provided by the present invention.

Fig. 3 is a schematic diagram of the treatment plane reconstructed from the imaging plane of the ultrasonic imaging probe provided by the present invention;

Fig. 4 is a projection diagram of the ultrasonic imaging plane on the focal plane provided by the present invention;

Fig. 5 is a flow diagram of irradiation and real-time monitoring of the

treatment plane provided by the present invention.

In the Figures: 1. lifting cross arm; 2. first swing motor; 3. first rotating disk; 4. second swing motor; 5. second rotating disk; 6. rotation control motor for a ultrasonic imaging probe; 7. third rotating disk; 8. fixing clamp for ultrasonic imaging probe; 9. metal base; 10. treatment head; 11. water bladder; 12. metal connecting part.

Embodiments of the invention

The technical solutions in the embodiments of the present invention will be described clearly and completely below with reference to the drawings of the embodiments of the invention. Obviously, the embodiments described are only part of the embodiments of the present invention, but not all of them. Based on the embodiments of the present invention, all other embodiments obtained by those skilled in the art without creative labor are within the scope of protection of the present invention.

Referring to Figure 1-5, a motion control device of an ultrasonic treatment head focusing on a large-scale target area comprises a swing control module and an ultrasonic imaging probe control module. The swing control module comprises a vertical motion module, a left-right motion module and an axial motion module, the three motion modules control the probe control module 10 to swing in two degrees of freedom of front-back and left-right and rotate axially respectively, and perform ultrasonic imaging on a target area.

The vertical motion module comprises a lifting cross arm 1, an end of the lifting cross arm 1 is provided with a first rotating disk 3, and a power input end of the first rotating disk 3 is connected to and driven by a first swing motor 2;

The left-right motion module comprises a metal connecting part 12 that is rotatably connected to a disk portion of the first rotating disk 3, one side of the metal connecting part 12 is provided with a second swing motor 4, and an output end of the second swing motor 4 is connected to and driven by a power input end

of a second rotating disk 5;

The axial motion module comprises a frame-shaped metal base 9 mounted on a disk portion of the second rotating disk 5, a third rotating disk 7 is mounted on a top opening of the metal base 9, a power input end of the third rotating disk 7 is connected to and driven by a rotation control motor 6 for an ultrasonic imaging probe, one side of a disk portion of the third rotating disk 7 is connected rotatably to a fixing clamp 8 for an ultrasonic imaging probe, a bottom of the fixing clamp 8 for an ultrasonic imaging probe passes through a bottom plate of the metal base 9 and is provided with a treatment head 10, and a bottom of the treatment head 10 is covered with a water bladder 11 with good sound permeability.

The treatment head 10 comprises a multi-array phase-controlled focused ultrasonic transducer and an ultrasonic imaging probe, and the ultrasonic imaging probe is provided in the fixing clamp 8 for an ultrasonic imaging probe.

Specifically, as shown in Figure 1, the first rotating disk 3 is driven to rotate by the first swing motor 2, thereby the treatment head 10 can be driven to swing vertically by the rotation of the first rotating disk 3. The second rotating disk 5 is driven to rotate by the second swing motor 4, thereby the treatment head 10 can be driven to swing leftwards and rightwards by the rotation of the second rotating disk 5. The third rotating disk 7 is driven to rotate by the rotation control motor 6 for an ultrasonic imaging probe, thereby the fixing clamp 8 for an ultrasonic imaging probe and the treatment head 10 are driven to rotate by 180° around the central axis thereof, realizing the multi-dimensional swinging of the treatment head 10 and the miniaturization of the whole device with a low manufacturing cost.

In this embodiment, each channel of the multi-array phase-controlled focused ultrasonic transducer can be controlled independently, and a position of a focus of the ultrasonic imaging probe can be changed within a certain space range by controlling its excitation voltage and phase signal. A rotating axis of the ultrasonic imaging probe, a central axis of the ultrasonic imaging probe and

the multi-array focused ultrasonic transducer are all arranged coaxially.

Specifically, it should be ensured that the ultrasonic imaging probe and the multi-array focused ultrasonic transducer rotate coaxially when swinging.

In this embodiment, the left-right motion module of the swing control module and the rotating disk of the left-right motion module are perpendicular to each other, and the centers of which are located on the same horizontal plane; and an intersection point of the rotating axis of the two rotating disks is located on a straight line where an acoustic beam axis of the multi-array focused ultrasonic transducer is locate.

Specifically, as shown in Figure 2(a), the multi-array phase-controlled focused ultrasonic transducers are distributed on a concave spherical surface (but not limited to this type). The treatment head 10 can be similar to a single pendulum in Figure 2(b) that takes an intersection point of the normal of the first rotating disk 3 and the second rotating disk 5 as a center, takes a distance from the center to a geometric center of the treatment head 10 as a swinging radius, and can focus on the position of different focuses by electronic deflection.

In this embodiment, the rotating disk of the swing control module and the rotating disk connected to the ultrasonic imaging probe are both provided with corresponding limiting sensors that limit their rotation range.

Specifically, the limiting sensor provided can identify the rotation angle of the rotating disk, so that the rotating disk is driven to rotate within a certain range by the motor controlled by a control mechanism.

In this embodiment, after the ultrasonic imaging probe has been driven by swinging the swing control module, a distance between the position of the geometric focus and the acoustic beam axis of the multi-array phase-controlled focused ultrasonic transducer satisfies the following formula:

$$d = \sqrt{x_1^2 + y_1^2} \quad (1)$$

x_1 : x coordinate of the position of the geometric focus after swinging;

y_1 : y coordinate of the position of the geometric focus after swinging;

d: the distance between the position of the geometric focus and the acoustic beam axis of the multi-array phase-controlled focused ultrasonic transducer after swinging.

Specifically, formula (1) can be used to calculate the distance between the position of the geometric focus and the acoustic beam axis of the multi-array phase-controlled focused ultrasonic transducer.

In this embodiment, after the ultrasonic imaging probe has been driven by swinging the swing control module, the coordinate of the position of the geometric focus after swinging satisfies the following formula:

$$z_1 = R - \sqrt{R^2 - (x_1^2 + y_1^2)} \quad (2)$$

R: the swinging radius of the treatment head 10;

z1: z coordinate of the position of the geometric focus after swinging.

Specifically, the diagram of the treatment plane is reconstructed from an imaging plane of the ultrasonic imaging probe as shown in Figure 3, where the centers of different treatment units can be obtained from the coordinates on the plane. In fact, the position of the geometric center of the treatment head in the vertical direction also changes after swinging with different precision;

The swinging radius R is the distance between the intersection point of the normal of the two rotating disks controlling the swinging of the treatment head and the geometric center of the treatment head. When the swing radius is much larger than d, z1 is close to R, which can be approximated that the position of the focus in the vertical direction has not been changed during swinging, so the whole treatment unit is distributed on the set plane. However, it is not necessary to make such an approximation, different embodiments may have different implementations.

In this embodiment, after the ultrasonic imaging probe has been driven by swinging the swing control module, swinging angles in the left-right and front-back directions satisfy the following formula:

$$\alpha = \arcsin(y_1 / \sqrt{R^2 - x_1^2})$$

$$\beta = \arcsin(x_1 / \sqrt{R^2 - y_1^2}) \quad (3)$$

α : the swinging angle of the treatment head 10 in the left-right direction;

β : the swinging angle of the treatment head 10 in the front-back direction.

The first rotating disk 3, the second rotating disk 5 and the third rotating disk 7 are all electric indexing rotating disks.

Specifically, R is determined by the treatment head and the motion device, and the swinging angles α and β of the treatment head in the left-right and front-back directions can be calculated automatically based on the coordinates of the center of the treatment unit. When irradiating different focal points in the treatment unit, the ultrasonic imaging probe rotates within $-90^\circ \sim 90^\circ$ to monitor the irradiation situation of the current treatment position in real time.

Specifically, the size of the treatment unit is smaller than the electronic deflection range of the multi-array phase-controlled focused ultrasonic transducer with multi-array elements, and the swinging angles and the rotation angle of the ultrasonic imaging probe are calculated based on the geometric center of the treatment unit and a current position of an irradiation focal point in the treatment unit.

Specifically, θ_1 and θ_2 in Figure 4(a) indicate that the ultrasonic imaging probe 10 rotates to specific angles around its rotation axis respectively, so that when the HIFU focus deviates from a geometric center O of the transducer by electronic deflection, it still remains on the ultrasonic imaging plane obtained when the ultrasonic probe rotates to a certain angle.

Based on the angle of the ultrasonic imaging probe 10 and the position of a target point in the imaging plane, coordinates of a corresponding HIFU phased array can be obtained. Since the rotation axis coincides with the imaging central axis, the ultrasonic probe can produce an image of a whole 3D space by rotating 180° . Figure 4(b) shows the projection of the ultrasonic imaging plane on a focal plane. According to the relationship between the angle of the ultrasonic probe and a coordinate axis of the HIFU phased array, the

coordinates of the HIFU phased array for a point A located in a shaded area of a certain focal plane shown in Figure 4(b) can be expressed by formula (4).

$$\begin{cases} x = r \cos(-90^\circ - \theta) \\ y = r \sin(-90^\circ - \theta) \end{cases}, \quad -90^\circ \leq \theta \leq 90^\circ \quad (4)$$

r : a distance AO from the point A to the rotation axis of the ultrasonic probe;

θ : an angle at which the imaging plane of the ultrasonic probe passes through the point A;

x : the coordinate of the point A in the x direction;

y : the coordinate of the point A in the y direction.

Since a point B is 180° different from the point A about the rotation axis, the coordinates of the HIFU phased array of the point B that is located on the other side of the central axis in the ultrasonic image on the imaging plane can be expressed by the following formula (5):

$$\begin{cases} x' = r' \cos(-270^\circ - \theta) \\ y' = r' \sin(-270^\circ - \theta) \end{cases}, \quad -90^\circ \leq \theta \leq 90^\circ \quad (5)$$

r' : a distance BO from the point B to the rotation axis of the ultrasonic probe;

x' : the coordinate of the point B in the x direction;

y' : the coordinate of the point B in the y direction.

The point A and the point B are always located on the left and right sides of the ultrasonic image respectively at different angles θ of the ultrasonic probe. The HIFU phased array takes its geometric center O as the origin of the coordinate axis, and the point O is located on the central axis of the ultrasonic image at the same time, and the position of which can be marked according to the scale on the ultrasonic image. Therefore, the values of the HIFU coordinates of the target point on the Z axis can be determined based on the vertical distance between the target point on the image and the marked HIFU origin, thereby the coordinates of the HIFU focus can be determined based on the rotation angle θ

of the ultrasonic probe and the position of the target point on the ultrasonic image.

Referring to fig. 5, the treatment of each treatment unit is performed independently, and the focal point arrangement and setting the irradiation parameters are performed according to different treatment units, at the same time, the ultrasonic imaging probe is selected during irradiation to monitor the current irradiation position in real time.

It should be noted that in this disclosure, relational terms such as first and second are only used to distinguish one entity or operation from another entity or operation, and do not necessarily require or imply any such actual relationship or sequence between these entities or operations. Moreover, the term ‘comprise’, ‘include’ or any other variation thereof is intended to cover non-exclusive inclusion, so that a process, method, product or equipment that includes a series of characteristics not only includes those characteristics, but also includes other characteristics that are not listed explicitly, or also includes characteristics inherent to such process, method, product or equipment. Without further restrictions, an characteristic defined by the statement ‘comprise a’ does not exclude the existence of another identical characteristic in the process, method, product or equipment that includes the said characteristic.

Although the embodiments of the present invention have been shown and described, it should be understood that various changes, modifications, substitutions and variations can be made to these embodiments by those skilled in the art without departing from the principle and spirit of the present invention, and the scope of protection of the present invention is defined by the appended claims and their equivalents.

Claims

1. A motion control device of an ultrasonic treatment head focusing on a large-scale target area, wherein comprises a swing control module and an ultrasonic imaging probe control module, the swing control module comprises a vertical motion module, a left-right motion module and an axial motion module, the three motion modules control the probe control module (10) to swing in two degrees of freedom of front-back and left-right and rotate axially respectively, and perform ultrasonic imaging on a target area;

the vertical motion module comprises a lifting cross arm (1), an end of the lifting cross arm (1) is provided with a first rotating disk (3), and a power input end of the first rotating disk (3) is connected to and driven by a first swing motor (2);

the left-right motion module comprises a metal connecting part (12) that is rotatably connected to a disk portion of the first rotating disk (3), one side of the metal connecting part (12) is provided with a second swing motor (4), and an output end of the second swing motor (4) is connected to and driven by a power input end of a second rotating disk (5);

the axial motion module comprises a frame-shaped metal base (9) mounted on a disk portion of the second rotating disk (5), a third rotating disk (7) is mounted on a top opening of the metal base (9), a power input end of the third rotating disk (7) is connected to and driven by an rotation control motor (6) for the ultrasonic imaging probe, one side of a disk portion of the third rotating disk (7) is connected rotatably to an fixing clamp (8) for the ultrasonic imaging probe, a bottom of the fixing clamp (8) for the ultrasonic imaging probe passes through a bottom plate of the metal base (9) and is provided with a treatment head (10), and a bottom of the treatment head (10) is covered with a water bladder (11) with good sound permeability;

the treatment head (10) comprises a multi-array phase-controlled focused ultrasonic transducer and an ultrasonic imaging probe, and the ultrasonic imaging probe is provided in the fixing clamp (8) for the ultrasonic imaging probe;

each channel of the multi-array phase-controlled focused ultrasonic transducer can be controlled independently, and a position of a focus of the ultrasonic imaging probe can be changed within a certain space range by controlling its excitation voltage and phase signal, and a rotating axis of the ultrasonic imaging probe, a central axis of the ultrasonic imaging probe and the multi-array focused ultrasonic transducer are all arranged coaxially;

the left-right motion module of the swing control module and the rotating disk of the left-right motion module are perpendicular to each other, and the centers of which are located on the same horizontal plane; and an intersection point of the rotating axis of the two rotating disks is located on a straight line where an acoustic beam axis of the multi-array focused ultrasonic transducer is located;

after the ultrasonic imaging probe has been driven by swinging the swing control module, a distance between the position of the geometric focus and the acoustic beam axis of the multi-array phase-controlled focused ultrasonic transducer satisfies the following formula:

$$d = \sqrt{x_1^2 + y_1^2} \quad (1)$$

x_1 : x coordinate of the position of the geometric focus after swinging;

y_1 : y coordinate of the position of the geometric focus after swinging;

d : the distance between the position of the geometric focus and the acoustic beam axis of the multi-array phase-controlled focused ultrasonic transducer after swinging;

after the ultrasonic imaging probe has been driven by swinging the swing control module, the coordinate of the position of the geometric focus after swinging satisfies the following formula:

$$z_1 = R - \sqrt{R^2 - (x_1^2 + y_1^2)} \quad (2)$$

R : the swinging radius of the treatment head (10);

z_1 : z coordinate of the position of the geometric focus after swinging;

after the ultrasonic imaging probe has been driven by swinging the swing

control module, swinging angles in the left-right and front-back directions satisfy the following formula:

$$\begin{aligned}\alpha &= \arcsin(y_1 / \sqrt{R^2 - x_1^2}) \\ \beta &= \arcsin(x_1 / \sqrt{R^2 - y_1^2}) \quad (3)\end{aligned}$$

α : the swinging angle of the treatment head (10) in the left-right direction;

β : the swinging angle of the treatment head (10) in the front-back direction.

2. The motion control device of the ultrasonic treatment head focusing on the large-scale target area according to claim 1, wherein the rotating disk of the swing control module and the rotating disk connected to the ultrasonic imaging probe are both provided with corresponding limiting sensors that limit their rotation range.

3. The motion control device of the ultrasonic treatment head focusing on the large-scale target area according to claim 1, wherein the first rotating disk (3), the second rotating disk (5) and the third rotating disk (7) are all electric indexing rotating disks.