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(54) **INTERACTIVE ULTRASOUND-BASED DEPTH MEASUREMENT FOR MEDICAL APPLICATIONS**

INTERAKTIVE TIEFENMESSUNG AUF ULTRASCHALLBASIS FÜR MEDIZINISCHE ANWENDUNGEN

MESURE INTERACTIVE DE LA PROFONDEUR UTILISANT DES ULTRASONS POUR APPLICATIONS MEDICALES

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US-B2- 6 817 862
US-B2- 6 899 680

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Description

Field of the invention

[0001] The present invention relates to a device for improved depth measurement during surgery.

Background of the invention

[0002] The present invention is hereinafter explained with reference to dental surgery. However the applications of the present invention are not limited to dental surgery only, and in fact include any surgery involving the use of a medical tool, which is intended to penetrate into tissue and bone such as in orthopedics, general surgery and other such fields.

[0003] For planning an implantation procedure, which is performed by an oral and maxillofacial surgeon, in the mandible or the maxilla, the patient undergoes an x-ray imaging, computer tomography (CT) and a panoramic imaging. From these images, the surgeon is able to plan the implantation procedure and also to take-out the data about the mandible, such as the depth of the canal that contains the nerve and the thickness of this bone. These imaging methods do not provide the surgeon with required information in real time, concerned with the distance between the bottom part of the drill and the top part of the canal that contains the nerve.

[0004] US transmission through a liquid jet was described as a confirmation sensor of a drill in its position in a drilling machine (US5850184), as a dental tool for removing plaque from teeth and for cleaning teeth (US5013241), a high velocity pulsating jet stream for the removal of the dental plaque (US4012842), A thermal imaging system for detecting cracks in tooth, by applying an US dental cleaning tool that transmits US energy through a jet of water to the tooth. This causes cracks in the tooth to heat up and a thermal camera is used to detect the thermal radiation emitted by the heated cracks (US6437334B1).

[0005] Another possibility is to sweep angularly with the jet of water that carries the US, and by this one is able to obtain an image of a section or of a volume.

[0006] US radiation is a proven technology used in many medical diagnostic applications and was also applied for bone diagnostics - density, structure and velocity of propagation (US6030221, US5006984, US5115813, US5402781 , US5518008, US5564423, US5651363). These parameters are important in order to investigate the correct value of the distance mentioned earlier. The radiation levels applied during the use of the present invention are in an accepted range for diagnosis and therefore pose no harm to the patient or the surgeon. Temperature gradients of the radiated area are negligible, especially when the US radiation is transmitted via a liquid jet as in the case of the present invention.

[0007] US 2002/0120197 disclosed an ultrasonic (US) transducer which is capable of emitting and receiving ultrasonic waves incorporated in the tool (demonstrated on a drill). The US transducer is coupled to the tip of a drill and placed in direct contact with the tissue and bone it drills. The drill rotates rapidly and so dues the US transducer, which is diagonally oriented (aligned with the diagonal surface of the drill).

[0008] US 5,755,571 (Companion et al.) discloses a periodontal structure mapping system employing a dental handpiece containing first and second acoustic sensors for locating the Cemento-Enamel Junction (CEJ) and measuring the differential depth between the CEJ and the bottom of the periodontal pocket. The tool described is placed in contact with the gum of a patient and water if filled into the gap between the gum and the tooth. The water filled area serves to effectively conduct US waves which traverse through the inute pool of water that forms within the gap.

[0009] EP 1110509 (Vercellotti et al.) describes a surgical device for bone surgery comprising a body able to be gripped by the user and a tip mounted at the head of the body and set in vibration at a modulated ultrasonic frequency to operate on bone tissue. The handpiece comprises a transducer, which can be piezoceramic, for example, and serves to generate sound waves that set the tip in vibration for inducing small cuts in the adjacent tissue and not for any type of imaging or mapping.

Object of the invention

[0010] The present invention to provide a probe for use in dental surgery for measuring distance from a bottom of a drill to surrounding bone.

Summary of the invention

[0011] In accordance with the present invention, there is provided a device for determining the internal structure of a bone along a path directed into the bone, the device comprising a nozzle fluidically connected to a liquid reservoir for providing a liquid jet directed at the bone in the direction of the path; an ultrasonic transducer for generating ultrasonic waves through the liquid jet and for detecting echoes traversing back through the jet of the ultrasonic waves caused by changes in the acoustical impedance in the bone characterizing changes in the structure of the bone along the path; and an analyzer for interpreting the echoes into meaningful information relating to the location of the structural changes along the path.

[0012] The device of the invention may suitably be incorporated in a surgery tool, such as a drill.

[0013] In one embodiment of the invention, the drill comprises a hollow drill bit, allowing the liquid jet to pass through the drill bit.

[0014] In an alternative embodiment, the liquid jet is outside the drill bit and directed to a tip of the drill bit.

[0015] The device of the preferred embodiment of the invention completes the information obtained by the CT and the panoramic imaging, by guiding the surgeon during the drilling process thus enhancing prevention of injuries during the surgery. The device measures the distance between the bottom part of a dental drill and vulnerable parts (such as the canal that contains the nerve in the lower mandible) in a patient's bone during an implantation surgery process. The device can be integrated into a dental drill to provide the dental surgeon with real time guiding location of the drill tip in the patient's bone during implantation surgery.

[0016] The present invention is particularly advantageous for surgery where depth measurements in the mandible and the maxilla are required, as for example, in mandible intra-osseous implantations.

[0017] An advantage of the invention for such surgery is that the US radiation is applied through an existing jet of liquid (usually distilled water) flowing from the dental tool. Therefore no additional medium is required, keeping the dimensions of the drill fitted with a dev ice of the invention small and well suited for work within restricted volumes, like the mouth.

[0018] A device of the preferred embodiment of the invention provides the surgeon with real-time information; is relatively inexpensive compared to other, less satisfactory imaging alternatives; and saves time for both the patient and the surgeon (since there is no need to move imaging equipment in and out or to interrupt the surgical procedure).

Brief description of the figures

[0019] The invention is described herein, by way of example only, with reference to the accompanying Figures, in which like components are designated by like reference numerals.

FIG. 1 illustrates how US waves are transmitted through, and reflected from, soft and hard layers of the body in accordance with a preferred embodiment of the present invention.

FIG. 2A illustrates a US transducer integrated into a liquid jet in an interactive ultrasound-based depth measurement device in accordance with a preferred embodiment of the present invention.

FIG. 2B illustrates front-end electronics located close to the US transducer in order to reduce signal loss in an interactive ultrasound-based depth measurement device in accordance with a preferred embodiment of the present invention.

FIG. 3A illustrates an interactive ultrasound-based depth measurement device integrated with a surgical dental drill in accordance with a preferred embodiment of the present invention.

FIG. 3B depicts a tip of a drill similar to the one shown in FIG. 3A. However in this example, the drill itself is hollow, allowing a liquid jet to pass through.

FIG. 4 illustrates how US waves propagate through the jet of liquid in a dental drill integrated with an interactive ultrasound-based depth measurement device in accordance with a preferred embodiment of the present invention.
FIG. 5 illustrates a detailed block diagram of analog and digital circuitry for a dental drill with an interactive ultrasound-based depth measurement device in accordance with a preferred embodiment of the present invention.

Detailed description of the invention

[0020] The present invention is based on transmitting ultrasonic (US) waves through a guided jet of liquid, such as distilled water, targeted to a bone or other tissue or a combination thereof (hereinafter - bone), in order to determine the internal structure along a path in the direction of the impinging jet. The echoes of the US waves are used to determine changes in the acoustical impedance of the bone characterizing changes in the internal structure, and determine their location along that path.

[0021] In one preferred embodiment, according to the present invention, the device is incorporated in a drill or other penetrating medical device, so as to provide the surgeon with information on the path along which the tool is penetrating the bone, and specifically distances to structural changes in the bone, thereby preventing or greatly reducing the risk of inflicting damage to vulnerable tissue.

[0022] However, the present invention is not limited to such incorporation, and a basic device, in accordance with some preferred embodiments of the present invention, would include only the provision of US transducer for provision of US waves carried by a liquid jet towards the surface of the bone, and for detecting echoes reflected from structural changes within the bone along a path in front of the impinging jet.

[0023] The measurement provided by the present invention is based on US wave propagation through a material. When there is a change in the velocity of propagation (i.e. a change in the acoustic impedance), reflections are obtained. These echoes are detected and provide finally electronic signals, which are finally interpreted as distances (given the velocity of propagation through the examined medium is known from these US measurements) where the reflections appeared.

[0024] It is known that the velocity of propagation of US waves through the bone varies. It is different for the upper and lower jaws. It is also different between males and females. It may vary with age. It also varies in different locations within the bone. In order to overcome this and take it into consideration in the measurement several methods may be incorporated. These include, for example, measuring the time intervals between the transmitted pulses and the received echoes, and at the same time measuring the velocity of propagation in the bone.

[0025] Accordingly, in order to properly conduct a distance measurement, it is important to measure simultaneously both the time between the transmitted and received waves as well as the velocity of propagation at the desired depth.

[0026] The US waves are transmitted through the jet of liquid, which is directed toward the bottom part of the bore produced by the drill, and into the bone under the bottom of the bore. Abrupt changes in the acoustic properties of the matter traversed by the US waves produce US echoes (reflections).

[0027] Fig.1 illustrates in principle how this property of US waves is put to use in the present invention. Power signals 32 are sent from power 33 circuits to US transducer 68. The control electronics 31 controls the power circuits 33. In the following case, US transducer 68 transmits US waves 34 through soft layers 26 and through a bone 22. US waves 34 encounter nerve canal 20 (containing nerve 24), which generates a distinct (mirror like) reflection 36. When reflection 36 returns from canal 20 via bone 22 and soft layers 26, a similar (attenuated) reflection is obtained, but with an opposite polarity. Reflection 36 is received by US transducer 68, which passes data signals 38 back to signal processing unit 37, which calculates (by means of a software) the distance to the cause of the reflection and presents the results to the surgeon, typically as text or graphic output 39.

[0028] In a preferred embodiment of the present invention it is possible to preprogram the US examination of the patient with a typical US wave duration of 1 [mu]sec or less, comprising sinusoidal waveforms that are typically in a frequency range of 10 to 20 MHz and with every wave lasting a fraction of a period to several periods. These are sample specifications and they can vary according to the application. They are presented here for illustrative purposes and do not limit the scope of the present invention.

[0029] Fig. 2a illustrates a US transducer integrated into a liquid jet in a interactive ultrasound-based depth measurement device 81 in accordance with a preferred embodiment of the present invention. US transducer 68 is located in vessel 67 through which liquid 52 (usually distilled water) flows. Liquid 52 starts in main reservoir 50 and is pumped by pump 54, when tap 56 is open, through pipe 58 to front reservoir 62. Liquid output from front reservoir 62 passes out of funnel and tube 72 (typically with a diameter in the range of 1 mm to 2.5 mm) and flows against the adjacent tissue or directly on the bone. The pump is preferably a pump that delivers constant mass flow rate, due to medical considerations, but this is not a requirement of the ultrasonic measuring system, hence the present invention is not limited to such pump. An example of such pump is OsseoCare(TM) Drilling Equipment from Nobel BioCare AB, Sweden and which also includes a torque limiter in order to avoid the mechanical overloading of the bone tissue.US transducer 68 is connected electrically 64 to electronic circuitry, such as a control unit, a power unit, a signal processing unit, an output unit, and sub-units of the transducer. US transmit and receive signals 70 from/to US transducer 68 follow the path 74 of liquid 52.

[0030] It should be noted that what is germane to the present invention is that the US transducer be located such that the wave that it transmits and reflection that it receives pass through the liquid jet, such that the jet provides the medium between the transducer and adjacent tissue or bone. Several mechanisms for providing a liquid jet are known. Which specific mechanism is used to generate the liquid jet for the present invention can vary and is not essential to the invention as long as the transducer of the present invention is situated such that it transmits and receives via the jet to the adjacent tissue or bone. In a preferred embodiment of the present invention, the liquid jet is adapted to serve both for the regular operation of a dental drill (cooling the bone and the drill and cleaning the bore from the drilled materials) and for operation of the interactive ultrasound- based depth measurement of the present invention.

[0031] Fig. 2b illustrates an interactive ultrasound-based depth r[eta]easurement device 81 in accordance with another preferred embodiment of the present invention, wherein front-end electronics 76 are located close to US transducer 68 in order to reduce signal loss and therefore increase the signal-to-noise ratio (S/N). Front-end electronics 76 contains parts of the electronic circuitry, such as a pre-amplifier and parts of the signal processing unit. Fig. 3a illustrates an interactive ultrasound-based depth measurement device 81 integrated with a surgical dental drill 86 in accordance with a preferred embodiment of the present invention. Drill 86 is a standard dental drill, typically comprising power cable 80, which supplies voltage to the electrical motor 82, which turns shaft 84, which is geared to turn drill bit 88 (which is locked in place with drill lock 90). The jet from nozzle 87 is directed along side the drill bit 88, aimed at the tip of the drill, or a target just in front of the tip, having a certain angle defined between the jet and the drill.

[0032] Fig. 3b depicts a tip of a dental drill similar to the one shown in Fig. 3a, but the liquid jet in this tip passes through the drill, via a duct provided along the drill. The actual distance measurement using the device of the present invention may be carried out while the drill is in use (such as in the case of the embodiment shown in Fig. 3b, where the jet passes through the drill), or when the drill is inactivated, or even retracted from the bore that was drilled, while at the same time directing the jet into that bore. When the jet is along side the drill, and defining a small angle with the drill, it may be practical to withdraw the drill from the drilled bore and direct the jet substantially perpendicular to the bottom of the bore for best results.

[0033] Interactive ultrasound-based depth measurement device comprises the components described earlier in this specification with several components adapted for integration with drill 86. These include: additional section of flexible pipe 53 running from funnel and tube 72 to metal tube 55, which exits drill 84 at a point next to drill bit 88, thereby creating egress next to drill bit 88 for liquid carrying transmitted US waves. The liquid serves both its normal function of cleaning and cooling the bore of the drill and its new function (as provided by the present invention) of acting as a medium for transmission of the US waves.

[0034] (In the embodiment shown in Fig. 3a or the one shown in Fig. 3b, front- end electronics 76 are installed to reduce signal loss (and therefore increases the S/N), as in Fig. 2B. Alternatively, all depth measurement device 81 electronics can be implemented at the back end, connected to US transducer via electrical connection 64.)

[0035] With reference to Fig. 1 and to Figs. 3a and 3b, during the drilling process, control unit 31 triggers (automatically or manually) transmission of US waves 34 by transducer 68. US wave reflections received back from different density tissues by transducer 68 are passed via link 64 to processing unit 37, which calculates the distance from the bottom of the drilled bore in the mandible to the upper part of the canal 20 (that has a mirror-like reflection) and which contains the nerve and outputs the results to output unit 39 where the surgeon can view them. Typically this output is provided to the surgeon displayed on an alphanumeric or graphical display.

[0036] Fig. 4 illustrates how US waves propagate through the jet of liquid in a dental drill integrated with an interactive ultrasound-based depth measurement device in accordance with a preferred embodiment of the present invention. Jet of liquid 52 flowing into bore 94 in bone 22 serves as medium for transmission 34 of US waves into bone 22 and reception of US reflections 36 from nerve canal 20.

[0037] In the case of the mandible, the depth is measured in real time between the bottom of bore 94 and the upper part of nerve canal 20. The depth measurement results are preferably displayed as alphanumeric information, providing the surgeon with an accurate indication of the distance (depth) between the lower part of drilled bore 94 and the upper edge of the sensitive tissue, such as nerve canal 20, that must be avoided with the drill. Alternative displays are also possible (for example graphic representation of the distance).

[0038] Fig. 5 illustrates a detailed block diagram of a circuitry for a dental drill with an interactive ultrasound-based depth measurement device in accordance with a preferred embodiment of the present invention. This block diagram operates in an analog 200 mode, and others - which operate in a digital 300 mode. These circuits provide improved noise filtering and signal amplification of transmission of US waves and reception of US wave reflections. The timing of the amplified signals is measured, and assuming known propagation velocity of the ultrasound pulses through bone, the distance from the bottom of the drill bore to the nerve canal is measured and displayed, as described above.

[0039] Power is supplied from power supply 100 to transmitter 104, which receives signal from signal generator 102. Transmitter 104 transmits US wave and activates the electronic switch 106, which activates receiver preamplifier and amplifier 110, which receives reflection of wave from different density tissue and time-gain compensation 108. Analog signal is converted 112 to digital and after time-gain compensation 114 is filtered 116, compressed 118, and stitched and offset 120. Calculated time of reflection return is converted to depth measurement 122 and the result is output to display 124.

[0040] In a preferred embodiment of the present invention, depth measurement using the present invention can be performed in real time while the drilling is in process or in steps: drilling for a short distance (depth), typically 1 mm to 2 mm and then measuring the distance between the bottom of the drilled bore and the upper edge of the nerve canal before proceeding.

[0041] In another preferred embodiment of the present invention, the measurement method can be applied for side measurements (for example, through the gums). One use of this application is identifying the three- dimensional location of the nerve canal (rather than just the linear direction to it).

[0042] In another preferred embodiment of the present invention, depth measurement can be applied for other medical applications involving drilling, such as bone implantation, to avoid drilling injury to nerves or blood vessels beneath the drill. In another preferred embodiment of the present invention, depth measurement can be applied for veterinary medical applications.

[0043] In another preferred embodiment of the present invention, it is possible to store the above-mentioned depth measurement on magnetic or other media - for further analysis, comparison, and documentation.

[0044] In another preferred embodiment of the present invention, it is possible to incorporate software to control the data transmission to the signal-processing unit and to enable configuring parameters of the invention, for example, to customize the device for pediatric patients.

Claims

1. A device (81) for determining the internal structure of a bone along a path directed into the bone, the device comprising:

a nozzle (87) fluidically connected to a liquid reservoir (50) for providing a liquid jet directed at the bone in the direction of the path;

an ultrasonic transducer (68) for generating ultrasonic waves through the liquid jet and for detecting echoes traversing back through the jet of the ultrasonic waves caused by changes in the acoustical impedance in the bone characterizing changes in the structure of the bone along the path; and

an analyzer (37) for interpreting the echoes into meaningful information relating to the location of the structural changes along the path.

2. The device of claim 1, incorporated in a surgery tool (86).

3. The device of claim 2, wherein the surgery tool is a drill (86).

4. The device of claim 3, wherein the drill comprises a drill bit (87) which is hollow, allowing the liquid jet to pass through the drill bit (87).

5. The device of claim 3, wherein the liquid jet is outside the drill bit (87), directed to a tip of the drill bit.

Patentansprüche

1. Ein Gerät (81) zur Bestimmung der internen Struktur eines Knochens entlang eines in den Knochen gerichteten Pfads, wobei das Gerät aus Folgenden besteht

   einer Düse (87), die strömungstechnisch an ein Flüssigkeitsreservoir (50) angeschlossen ist, um einen auf den Knochen in Richtung des Pfads gerichteten Flüssigkeitsstrahl zu liefem;
   einem Ultraschallwandler (68) zur Erzeugung von Ultraschallwellen durch den Flüssigkeitsstrahl und zur Feststellung von Echos, die durch den Strahl der Ultraschallwellen zurückkommen, die durch Änderungen in der akustischen Impedanz im Knochen verursacht werden und Änderungen in der Knochenstruktur entlang des Pfads anzeigen; sowie
   einem Analysegerät (37) zur Interpretation der Echos in aussagekräftige Angaben die sich auf die Stelle der strukturellen Veränderungen entlang des Pfads beziehen.

2. Das Gerät von Anspruch 1 in einem chirurgischen Instrument (86) inkorporiert.

3. Das Gerät von Anspruch 2, wobei es sich beim chirurgischen Instrument um einen Bohrer (86) handelt

4. Das Gerät von Anspruch 3, wobei der Bohrer einen Bohreinsatz (87) aufweist, der hohl ist, damit der Flüssigkeitsstrahl durch den Bohreinsatz (87) passieren kann.

5. Das Gerät von Anspruch 3, wobei der Flüssigkeitsstrahl außerhalb des Bohreinsatzes (87) und auf die Spitze des Bohreinsatzes gerichtet ist.

Revendications

1. Dispositif (81) destiné à la détermination de la structure interne d'un os le long d'un chemin dirigé dans l'os, le dispositif comprenant:

   une canule (87) connectée de manière fluidique à un réservoir de liquide (50) de manière à envoyer un jet de liquide sur l'os dans la direction du chemin ;
   un transducteur ultrasonique (68) pour la génération d'ondes ultrasoniques à travers le jet de liquide et pour la détection d'échos décrivant un mouvement de retour à travers le jet d'ondes ultrasoniques causé par les changements de l'impédance acoustique dans les modifications caractérisant l'os au sein de la structure de l'os le long du chemin ; et
   un analyseur (37) pour l'interprétation des échos en une information signifiante portant sur l'emplacement de changements structurels le long du chemin.

2. Dispositif de la revendication 1 incorporant un outil chirurgical (86).

3. Dispositif de la revendication 2, dans lequel l'outil chirurgical est un foret (86).

4. Dispositif de la revendication 3, dans lequel le foret comprend une fraise (87) qui est creuse, permettant au jet de liquide de passer à travers la fraise (87).

5. Dispositif de la revendication 3, dans lequel le jet de liquide se trouve en-dehors de la fraise (87), dirigé vers une extrémité de la fraise

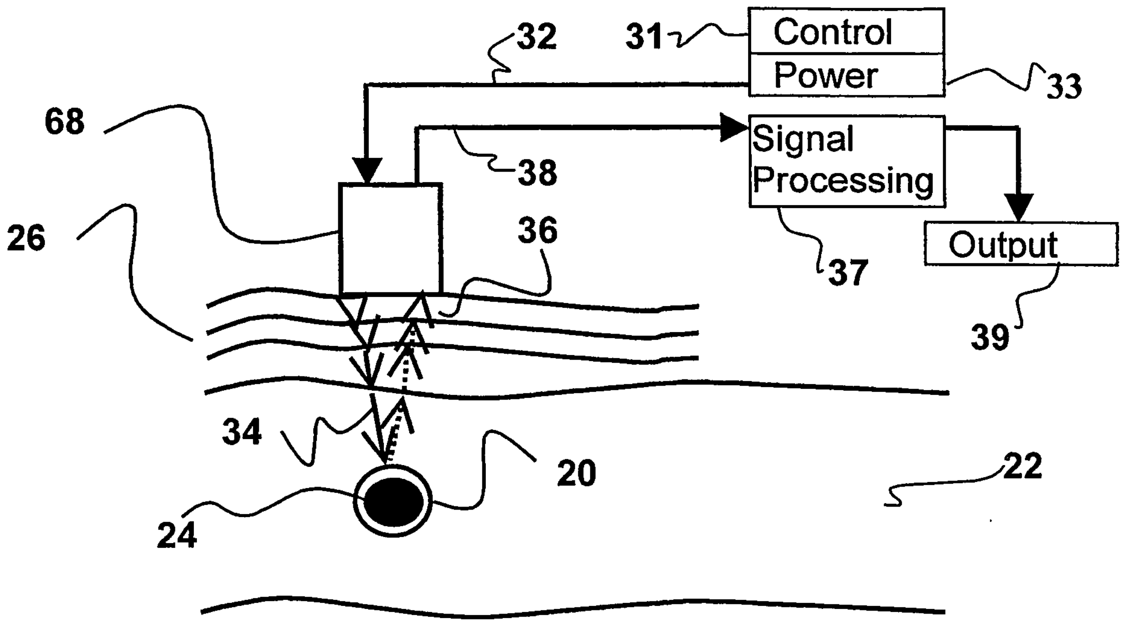
32
31
Control
Power
33
68
38
Signal
Processing
26
36
Output
37
39
34
20
22
24

FIG. 1

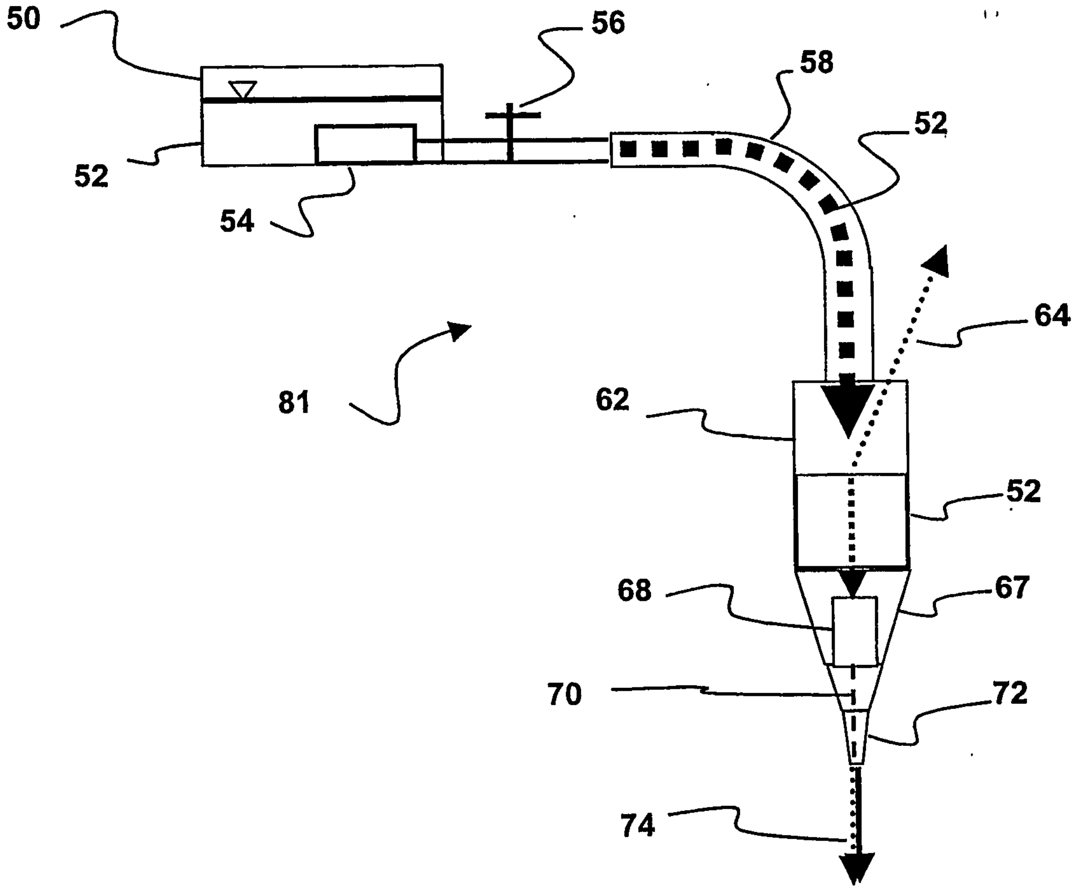

FIG. 2A

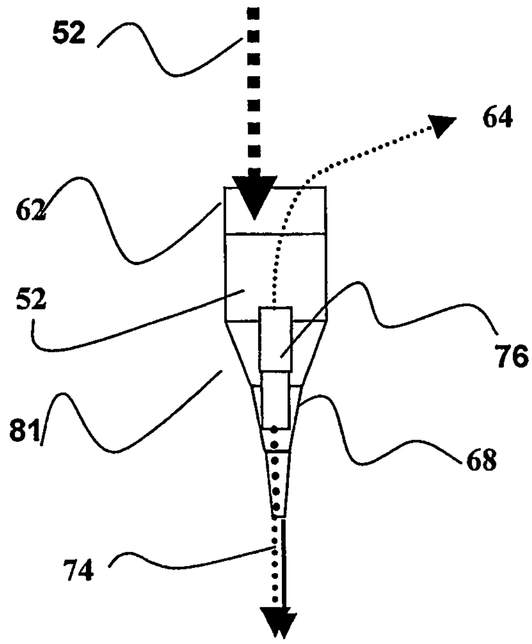

FIG. 2B

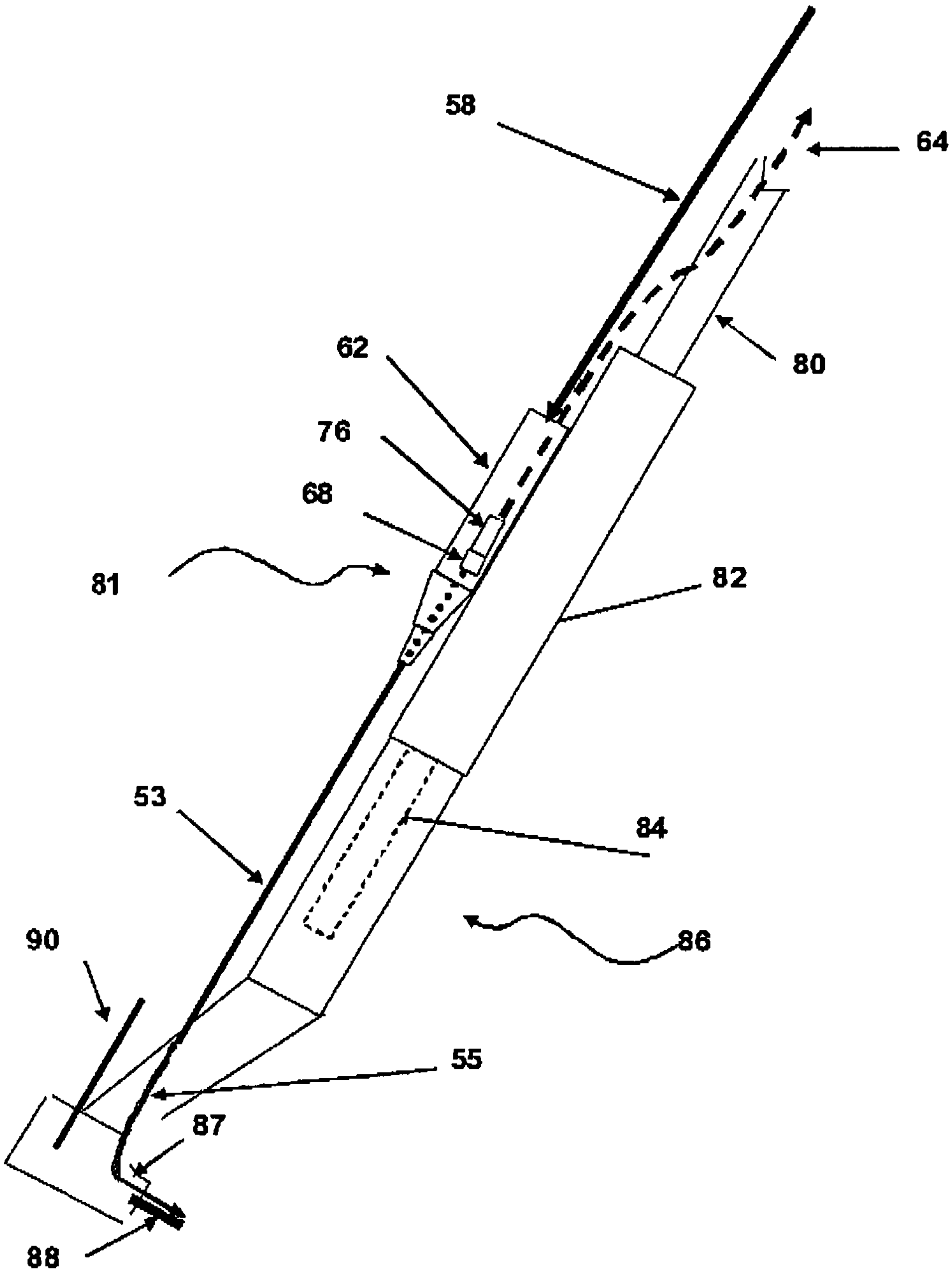

FIG. 3A

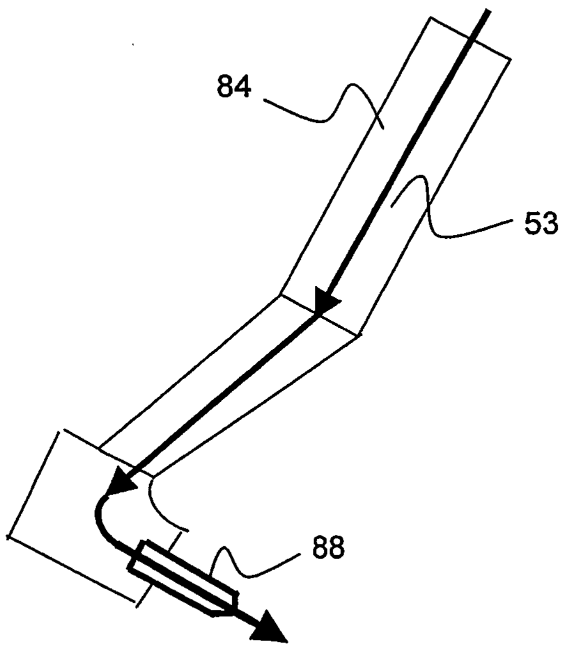

FIG. 3B

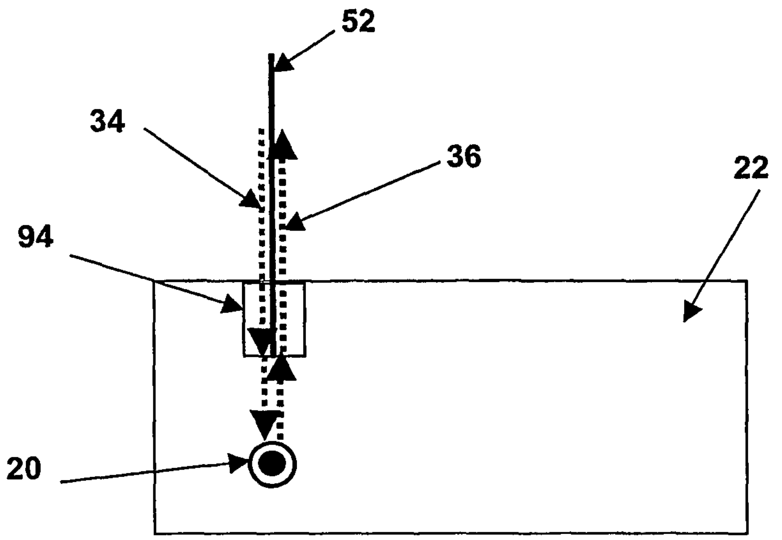

FIG. 4

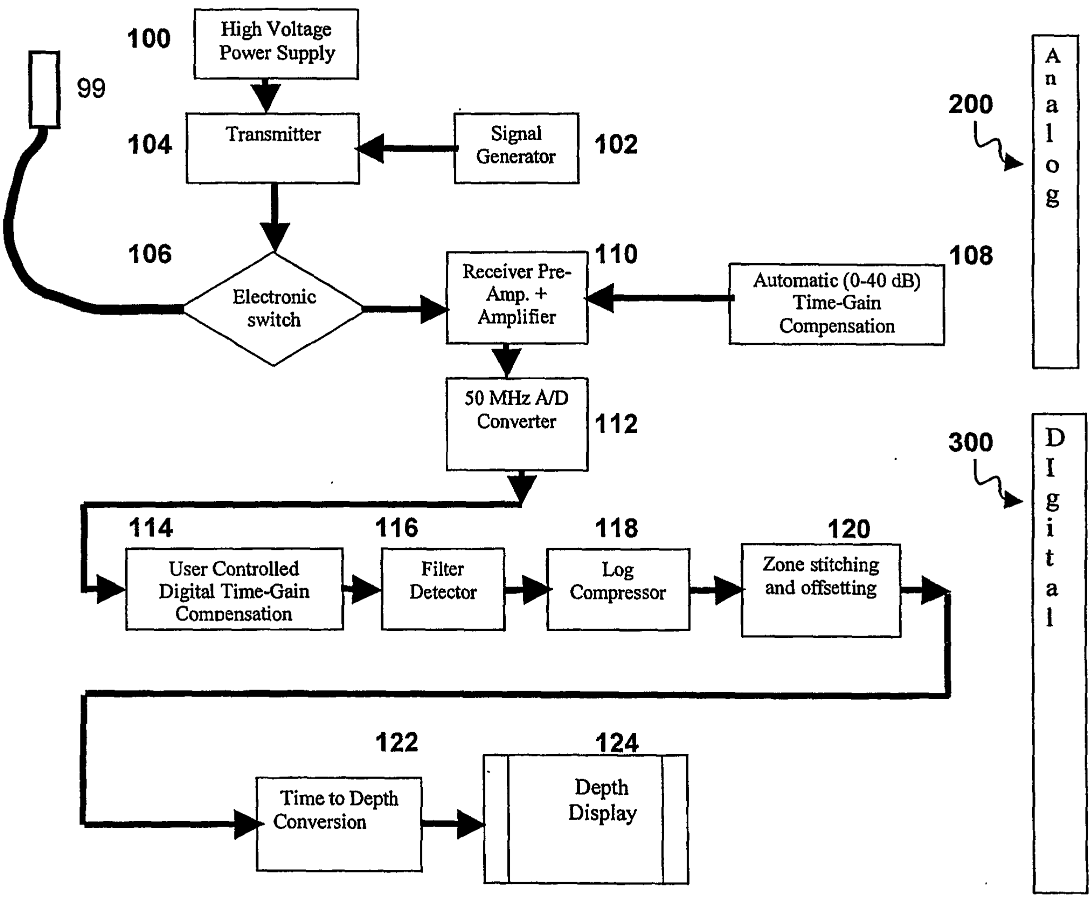
100
High Voltage Power Supply
99
104
Transmitter
Signal Generator
102
200
Analog
106
Electronic switch
Receiver Pre-Amp. + Amplifier
110
Automatic (0-40 dB) Time-Gain Compensation
108
50 MHz A/D Converter
112
300
DIgital
114
User Controlled Digital Time-Gain Compensation
116
Filter Detector
118
Log Compressor
120
Zone stitching and offsetting
122
Time to Depth Conversion
124
Depth Display

FIG. 5

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

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- US 5651363 A **[0006]**
- US 20020120197 A **[0007]**
- US 5755571 A, Companion **[0008]**
- EP 1110509 A, Vercellotti **[0009]**

patsnap

专利名称(译)	基于交互式超声波的医疗应用深度测量
公开(公告)号	EP1836487B1	公开(公告)日	2011-03-23
申请号	EP2005803704	申请日	2005-11-16
[标]申请(专利权)人(译)	JETGUIDE
申请(专利权)人(译)	jetguide公司
当前申请(专利权)人(译)	jetguide公司
[标]发明人	HALEVI - POLITCH JACOB KRAFT ANDRE
发明人	HALEVI - POLITCH, JACOB KRAFT, ANDRE
IPC分类号	G01N29/00 G01N29/07 A61B17/32 A61B5/00 A61B8/08
CPC分类号	A61B8/0875
代理机构(译)	MESSULAM , ALEC MOSES
优先权	166115 2005-01-03 IL
其他公开文献	EP1836487A2 EP1836487A4
外部链接	Espacenet

摘要(译)

公开了一种用于沿着指向骨(或其他组织)的路径确定骨的内部结构的装置。该装置包括与液体贮存器流体连通的喷嘴，用于提供在路径方向上指向骨骼的液体射流;超声波换能器，用于通过液体射流产生超声波，并用于检测由骨骼中声学阻抗的变化引起的超声波的回波，表征沿着路径的骨骼结构的变化;和分析器，用于将回波解释为与沿路径的结构变化的位置有关的有意义的信息。

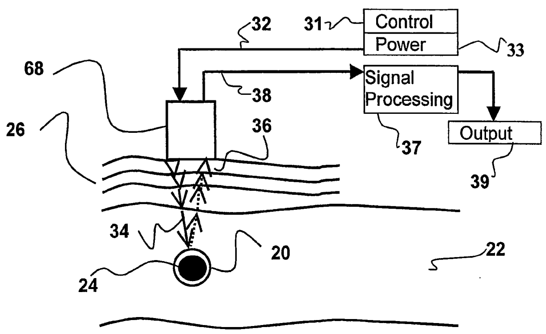

FIG. 1