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(54) **Array system and method for locating an in vivo signal source**

Arrayanordnung und Verfahren zur Lokalisierung einer In-Vivo-Signalquelle

Système de quadrillage et procédé de localisation d'une source de signal in vivo

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(73) Proprietor: **Given Imaging Ltd.**
20692 Yoqneam (IL)

(72) Inventors:
- **Glukhovsky, Arkady**
  Nesher 36790 (IL)
- **Frisch, Mordechai**
  Moreshet 20186 (IL)
- **Meron, Gavriel**
  Petach Tikva 49556 (IL)

(74) Representative: **HOFFMANN EITLE**
Patent- und Rechtsanwälte
Arabellastrasse 4
81925 München (DE)

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EP-A- 0 667 115
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US-A- 5 211 165
US-A- 5 429 132
US-A- 5 913 820

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Description

[0001] The present invention as claimed relates to a method for estimating a location of an ingestible in-vivo capsule. Various in vivo measurement systems are known in the art. They typically include ingestible electronic capsules which collect data and which transmit the data to a receiver system. These capsules, which are moved through the digestive system by peristalsis, include "Heidelberg" capsules to measure pH, "CoreTemp" capsules to measure temperature and other capsules to measure pressure throughout the intestines. They have also been used to measure gastric residence time and intestinal passage time, which is the time it takes for food to pass through the stomach and intestines.

[0002] The intestinal capsules typically include a measuring system and a transmission system, where the transmission system transmits the measured data at radio frequencies to the receiver system. Alternate systems can store all the data within a storage device in the capsule. The data can then be read after the capsule exits the gastro-intestinal (GI) tract.

[0003] In vivo camera systems are known, such one known camera system which is carried by a swallowable capsule. The in vivo video camera system captures and transmits images of the GI tract while the capsule passes through the gastro-intestinal lumen. The system includes a capsule that can pass through the entire digestive tract and operate as an autonomous video endoscope.

[0004] Prior attempts at localizing an intra-gastric and intrauterine transmitting capsule includes spatially scanning a non-ambulatory patient with a receiver. The receiver and scanning system locates the points with the highest reception and plots a track of the capsule, the assumption being that the capsule is at the location where the strongest signal is received. These attempts use a laboratory device that is non-portable and non-commercial.

[0005] Other attempts at localizing an in vivo capsule analyze the statistics of signal variation during the passage of the capsule through the GI tract. Large signal level variations are observable during the passage of the capsule through specific significant locations in the lumen and these variations are associated with specific anatomical features. This method is inherently inaccurate since the anatomically significant locations of the GI tract are not rigidly attached to a fixed frame of reference.

[0006] EP-0 667 115 A1 describes an in vivo camera system. It shows an antenna array to be worn around a patient's body, which array comprises a multiplicity of antennas. The shown array has two rows of eight antennas each. The antennas serve to receive signals from a capsule in the patient's body. A data processor is disclosed for determining the capsule's location by comparing the output of certain ones of the antennas.

[0007] US 5,042,486 describes a catheter with a transmitting antenna. Receiving antennas are placed on a patient's skin.

[0008] The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with containers, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

Figs. 1A and 1B show a person wearing an antenna array;
Fig 2. shows a data recorder.
Fig 3. shows an in vivo signal source.
Fig 4. shows a torso wearing an antenna array and an estimated point of a signal source;
Fig 5. shows a three signal vectors in a two dimensional plane;
Fig 6. shows a three signal vectors in three dimensional space; and
Fig 7. shows a graph of a weighing function for signal vectors.

[0009] It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

[0010] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the present invention.

[0011] Unless specifically stated otherwise, as apparent from the following discussions, it is appreciated that throughout the specification discussions utilizing terms such as "processing", "computing", "calculating", "determining", or the like, refer to the action and/or processes of a computer or computing system, or similar electronic computing device, that manipulate and/or transform data represented as physical, such as electronic, quantities within the computing system's registers and/or memories into other data similarly represented as physical quantities within the computing system's memories, registers or other such information storage, transmission or display devices.

[0012] The processes and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct a more specialized apparatus to perform the desired method. The desired structure for a variety of these systems will appear from the description below. In addition, embodiments are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings as described herein.

[0013] Reference is now made to Figs. 1A and 1B. As part of the present invention, an in vivo signal source may be localized using a wearable antenna array or antenna array belt 10, as shown in Figs. 1A and 1B. The antenna array belt 10 is fitted such that it may be wrapped around a patient and attached to a signal recorder 20. Additional embodiments include antenna elements having adhesive, which may adhere the element to a point on a body. Each of the antennas elements 10a through 10z in the array may connect via coaxial cables to a connector, which connects to the recorder 20. Each antenna element 10a through 10z may be a loop antenna, or may be any other antenna configuration known in the art.

[0014] In one embodiment the antenna array belt includes eight antenna elements that are typically positioned on a subject's midsection. According to the invention as claimed, the antenna elements are positioned as follows. A first antenna element is positioned on the intersection of the right 7th intercostal space and right mid clavicular line; a second antenna element is positioned on the xiphoid process; a third antenna element is positioned on the intersection of the left 7th intercostal space and left mid clavicular line; a fourth antenna element is positioned on the right lumbar region at umbilical level; a fifth antenna element is positioned above the navel; a sixth antenna element is positioned on the left lumbar region at umbilical level; a seventh antenna element is positioned on the right mid-linguinal region; and an eighth antenna element is positioned on the left mid-linguinal region.

[0015] Aside from having a data storage unit 22, the data recorder 20 may also have a receiver 21, a signal strength measurement unit 24, a processing unit 26, and an antenna selector 25 as shown in Fig. 2. In alternate embodiments the data recorder 20 may include other combinations of components, and the components described may be divided among other units. The signal strength measurement unit 24 may measure the signal strength of signals received by the receiver 21 from each of the antenna elements 10a through 10z, and the processing unit 26 may perform calculations to correlate the received signal with an estimated location of the source of the signal. The antenna selector 25 may open a signal path to single antenna element from which the receiver 21 will receive a signal. The antenna selector 25 may be adjusted to scan through all or subset of antenna elements 10a through 10z. The scan rate and pattern may be adjusted to maximize signal to noise ratios for the received signals.

[0016] Turning now to Fig. 3, there is shown an example of an in vivo signal source 100. The source 100 is a capsule, which may be ingested. The capsule 100 may contain several sensors such as temperature 110a, PH 110b, and optical 110c. Other sensors or sets of sensors may be used. The sensors 110 may provide data, for example, to a data transmitter 120. A beacon 130 may send out an intermittent beacon signal, or the beacon 130 may be instructed to transmit at or about the same time the data transmitter 120 transmits a data signal. Typically, the data transmitter 120 will transmit at a higher frequency than the beacon 130, but need not. In one embodiment the data transmitter 120 may transmit a non-modulated signal as a beacon signal. In one embodiment the capsule is similar to or may comprise components similar to embodiments described in the art.

[0017] Turing now to Fig. 4, there is shown a close-up of a human torso wearing a belt 10 or adhesive antenna array. Also visible is an estimated location of an in vivo signal source 100. The location is shown as the intersection point of three circles having radius R1, R2 and R3. Each radius value being an estimated distance value of the source 100 from each of antenna elements 10k, 10f and 10g, receptively. The distance values may be calculated by the processing unit 26 based on signal strength measurements preformed by signal strength measurement unit 24. For example, the propagation assumption used in processing the localization signal data assumes that radiation attenuation is linear within the body. This is equivalent to

$$I_r = I_o \propto \alpha^{\bullet} r \qquad \textbf{(Eq. 1)}$$

where r is the distance (in cm) between the capsule and the antenna, I_O is the signal level (in dBm) at the capsule, I_r is the signal level (in dBm) at r, and alpha is the absorption coefficient (in dB/cm). The assumption of linear attenuation is valid at the working frequency range (200 - 500 MHz) and at intermediate distances between the transmitter and receiver, i.e. for distances of half a wavelength to 2 - 2.5 wavelengths. Knowing the signal level at the source and the measured signal level at each antenna, one can derive the distance between the source and the antenna.

[0018] General signal source triangulation techniques as shown in Fig. 4 are well known. For purposed of completeness, however, the following is yet another example of a method of estimating the location of an in vivo signal source according to the present invention.

[0019] Shown in Fig. 5 are three signal vectors relating to signals received at three antenna elements 10d, 10p, 10q. Beginning at the origin of a coordinate system centered at the navel, each signal vector points in the direction of its respective antenna element and has a magnitude relating to the strength of the received signal. Each signal vector may be calculated as the product of a pointing vector from the origin to the point where its respective antenna element is placed, multiplied by a normalized received signal value. A normalized signal strength value may be computed by dividing each measured signal strength value by the strongest measured value. This results in the strongest measured value being normalized to 1, and the rest to values smaller than one. Thus, the signal vector pointing to an antenna element receiving the strongest signal level will look identical to its pointing vector. The other signal vectors will be shorter than their pointing vectors.

[0020] The estimated point or location of the signal source 100 may be estimated as the vector sum of all the signal strength vectors, the location vector. Signal vectors may be calculated for two or more antenna elements 10a through 10z. Signal vectors can be calculated for only elements placed at the front of the torso, or as Fig. 6 shows, signal vectors may also be calculated for elements placed at the back of the body (Fig. 1B). The point estimated to be the location of the signal source 100 in Fig. 6 is within the body. Typically, the location vector starts at the origin of a three dimensional system and ends at a point within the body.

[0021] As part of the present invention, one may use an absolute coordinate set where points on the body are measured in terms of standard units such as centimeters or inches. Alternatively, one can assign values relative to anatomical points on the body and later normalize the results. For example, an antenna element placed at the navel may be given the coordinate set 0,0; an element placed at the right end of the torso at navel level may be given the coordinate set 5,0; and an element place at left end of the torso -5,0. Distance values or vector magnitudes can be calculated using these coordinate sets. And later the values may be proportionally adjusted to fit the body's actual dimensions. For example, if there was calculated a distance value of 2.5 inches based on the above stated coordinates, but it was later measured that the body was actually 7 unit from navel to the right end, the distance value of 2.5 could be adjusted in the same proportion, 7/5.

[0022] Only the two or three strongest signal sources may be used, rejecting the weaker signal strength values, to calculate signal vectors or distance values upon which a location estimate is based. Once the strongest group of signals is identified, a second signal strength measurement may be performed. The processing unit may be adapted to perform a conventional vector sum operation on a subset of the largest vectors, and to perform a weighted sum operation on the signal vectors which are relatively smaller. Other manipulations of the collected signals may be used, using other operations.

[0023] The antenna selector 25 may be adjusted to perform a scan of only the antenna elements from which the strongest signals were received, excluding all other antennas. Excluding or rejecting signal information from antennas providing weak signals generally increases signal to noise ratios.

[0024] However, in another embodiment, location vectors or distance values may be calculated relating to many antenna elements and signal vectors having relatively low magnitudes may be multiplied by a reducing/weighing factor as shown in Fig. 7.

[0025] An estimated location of an in vivo signal source may be continuously or semi-continuously tracked. An instantaneous velocity vector for the signal source may be computed using the position information. For example, the velocity vector would be the vector starting at the tip of a first location vector and ending at the tip of a consecutive location vector. Or, the signal source's speed may be computed as a derivative of its position, and its direction may be plotted on a display or a graph functionally associated with the data recorder 20.

[0026] In an embodiment of the invention a supplementary procedure for detecting defective antenna elements may be carried out. If an antenna element is determined to be defective the entire trajectory may be invalidated. In an example of such a procedure readings for all frames (if not discarded) are collected, for each antenna, into two bins, for example, Bin1=number of readings in the range 0 to 40 and Bin2= number of readings in the range 41 to 255 or Bin1=number of readings in the range 0 to 107 and Bin2=number of readings in the range 108 to 255. The result is 8 histograms of 2 bins each, one for each antenna. If Bin1/(Bin1+Bin2)>0.75 the antenna is defective. Else the antenna is OK. The trajectory is considered valid if all antennas are OK. Further, if thReception(n)<60 (for the first example) or if thReception(n)<117 (for the second example) the current sensor readings can be discarded.

[0027] While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes, and equivalents will now occur to those skilled in the art. It is, therefore, to be understood that the appended claims define the scope of protection.

Claims

1. A method for estimating a location of an ingestible in-vivo capsule signal source with a wearable antenna (10) array, said method comprising the steps of positioning

   - a first antenna element on the intersection of the right 7th intercostal space and right mid clavicular line,
   - a second antenna element on the xiphoid process,
   - a third antenna element on the intersection of the left 7th intercostal space and left mid clavicular line,
   - a fourth antenna element on the right lumbar region at umbilical level,
   - a fifth antenna element above the navel,
   - a sixth antenna element on the left lumbar region at umbilical level,
   - a seventh antenna element on the right midlinguinal region,

- an eighth antenna element on the left mid-linguinal region,

receiving a signal at two or more of said antenna elements (10a-10z) within the array (10);
measuring the received signal strength; and
estimating the location of the capsule signal source based on the signal strength measurements.

2. The method according to claim 1, wherein each of at least two antenna elements (10a-10z) is located near a point having a known coordinate set within a coordinate system centred in proximity of the body.

3. The method according to claim 1 or 2, further comprising the step of calculating a distance value associated with a received signal.

4. The method according to one of claims 1 to 3, further comprising the step of correlating the location of the signal source using the distance values associated with two or more antenna elements.

5. The method according to one of claims 1 to 4, further comprising the step of calculating a signal vector relating to each received signal.

6. The method according to claim 5, further comprising the step of performing a vector sum operation of the signal vectors.

7. The method according to claim 6, further comprising the step of applying a weighing factor to the signal vector.

8. The method according to claim 7, wherein the weighing factor is applied to signal vectors having a relatively small magnitude.

9. The method according to one of claims 1 to 8, further comprising the step of displaying the signal source's estimated location.

10. The method according to claim 9, wherein the signal sources estimated location is displayed graphically as a pointer with a figure of a body.

Patentansprüche

1. Ein Verfahren zum Abschätzen eines Orts einer einnehmbaren in vivo Kapselsignalquelle mit einem tragbaren Antennearray (10), wobei das Verfahren die folgenden Schritte umfasst:

Positionieren

- eines ersten Antennenelements auf dem Kreuzungspunkt des rechten 7-ten Zwischenraums und rechten mittleren Klavikulalinie,
- eines zweiten Antennenelements auf dem Schwertfortsatz,
- eines dritten Antennenelements auf dem Kreuzungspunkt des linken 7-ten Zwischenraums und linken mittleren Klavikulalinie,
- eines vierten Antennenelements auf dem rechten Lumbalbereich auf dem Nabelniveau,
- eines fünften Antennenelements oberhalb des Nabels,
- eines sechsten Antennenelements auf dem linken Lumbalbereich auf dem Nabelniveau,
- eines siebten Antennenelements auf dem rechten mittleren Linguinalbereich,
- eines achten Antennenelements auf dem linken mittleren Linguinalbereich,

Empfangen eines Signals an zwei oder mehr der Antennenelemente (10a - 10z) in dem Array (10);
Messen des empfangenen Signalstärke; und
Abschätzen des Orts der Kapselsignalquelle basierend auf den Signalstärkenmessungen.

2. Das Verfahren nach Anspruch 1, wobei jedes der mindestens zwei Antennenelemente (10a - 10z) in der Nähe eines Punktes positioniert ist, der eine bekannte Koordinate aufweist, die innerhalb eines Koordinatensystems eingestellt ist, das in der Nähe des Körpers zentriert ist.

3. Das Verfahren nach Anspruch 1 oder 2, ferner umfassend den Schritt des Berechnens eines Abstandswertes, der mit einem empfangenen Signal assoziiert ist.

4. Das Verfahren nach einem der Ansprüche 1 bis 3, ferner umfassend den Schritt des Korrelierens des Orts der Signalquelle unter Verwendung der Abstandswerte, die mit zwei oder mehr Antennenelementen assoziiert sind.

5. Das Verfahren nach einem der Ansprüche 1 bis 4, ferner umfassend den Schritt des Berechnens eines Signalvektors bezüglich jedes empfangenen Signals.

6. Das Verfahren nach Anspruch 5, ferner umfassend den Schritt des Durchführens einer Vektorsummenoperation der Signalvektoren.

7. Das Verfahren nach Anspruch 6, ferner umfassend den Schritt des Anwendens eines Gewichtungsfaktors für den Signalvektor.

8. Das Verfahren nach Anspruch 7, wobei der Gewichtungsfaktor auf Signalvektoren angewendet wird, die relativ kleine Größen aufweisen.

9. Das Verfahren nach einem der Ansprüche 1 bis 8, ferner umfassend den Schritt des Darstellens des abgeschätzten Orts der Signalquelle.

10. Das Verfahren nach Anspruch 9, wobei der abgeschätzte Ort der Signalquellen graphisch als ein Zeiger mit einer Figur eines Körpers dargestellt wird.

Revendications

1. Procédé pour estimer un emplacement d'une source de signaux d'une capsule in vivo ingérable avec un réseau d'antennes (10) que l'on peut porter, ledit procédé comprenant les étapes consistant à positionner

- un premier élément d'antenne sur l'intersection du 7ème espace intercostal droit et la ligne mi-claviculaire droite,
- un deuxième élément d'antenne sur l'appendice xiphoïde,
- un troisième élément d'antenne sur l'intersection du 7ème espace intercostal gauche et la ligne mi-claviculaire gauche,
- un quatrième élément d'antenne sur la région lombaire droite au niveau ombilical,
- un cinquième élément d'antenne au-dessus du nombril,
- un sixième élément d'antenne sur la région lombaire gauche au niveau ombilical,
- un septième élément d'antenne sur la région mi-linguinale droite,
- un huitième élément d'antenne sur la région mi-linguinale gauche,

recevoir un signal à deux ou une pluralité desdits éléments (10a, 10z) d'antennes dans le réseau (10);
mesurer l'intensité du signal reçu; et
estimer l'emplacement de la source de signaux de capsule sur la base des mesures de l'intensité de signaux.

2. Procédé selon la revendication 1, dans lequel chacun d'au moins deux éléments (10a, 10z) d'antennes est situé près d'un point ayant une coordonnée connue établie dans un système de coordonnées centré à proximité du corps.

3. Procédé selon la revendication 1 ou 2, comprenant en plus l'étape consistant à calculer une valeur de distance associée à un signal reçu.

4. Procédé selon l'une des revendications 1 à 3, comprenant en plus l'étape consistant à établir une corrélation de l'emplacement de la source de signaux en utilisant les valeurs de distance associées à deux ou à une pluralité d'éléments d'antennes.

5. Procédé selon l'une des revendications 1 à 4, comprenant en plus l'étape consistant à calculer un vecteur de signaux relatif à chaque signal reçu.

6. Procédé selon la revendication 5, comprenant en plus l'étape consistant à effectuer une opération de somme vectorielle des vecteurs de signaux.

7. Procédé selon la revendication 6, comprenant en plus l'étape consistant à appliquer un facteur de pondération au vecteur de signaux.

8. Procédé selon la revendication 7, dans lequel le facteur de pondération est appliqué à des vecteurs de signaux ayant une amplitude relativement faible.

9. Procédé selon l'une des revendications des revendications 1 à 8, comprenant en plus l'étape consistant à afficher l'emplacement estimé de la source de signaux.

10. Procédé selon la revendication 9, dans lequel l'emplacement estimé de la source de signaux est affiché graphiquement comme une aiguille avec une figure d'un corps.

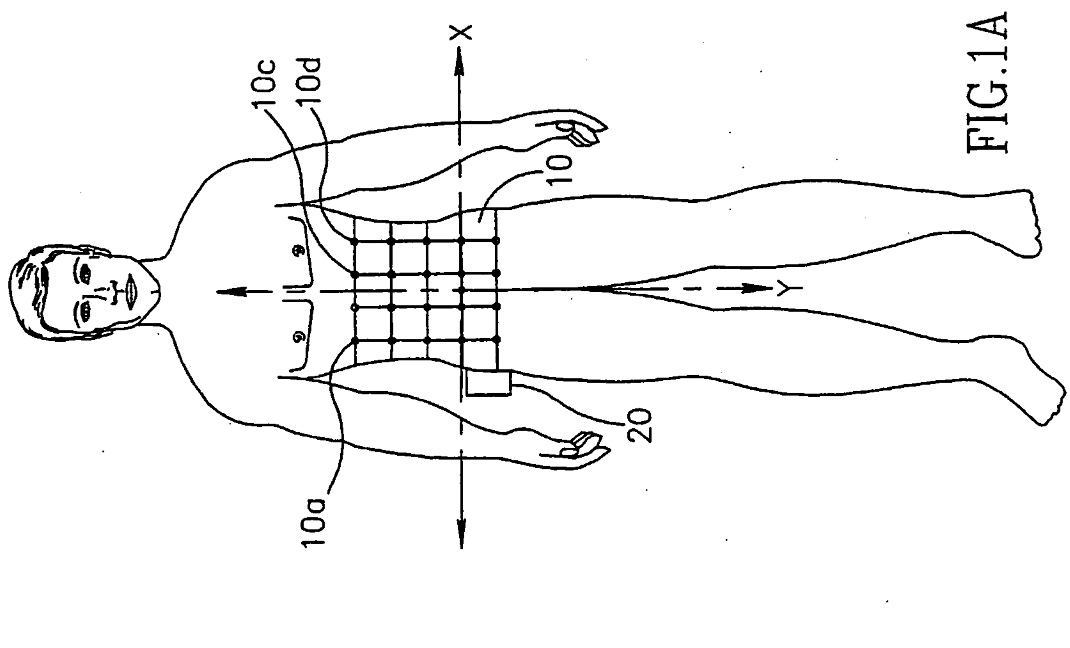

FIG.1A

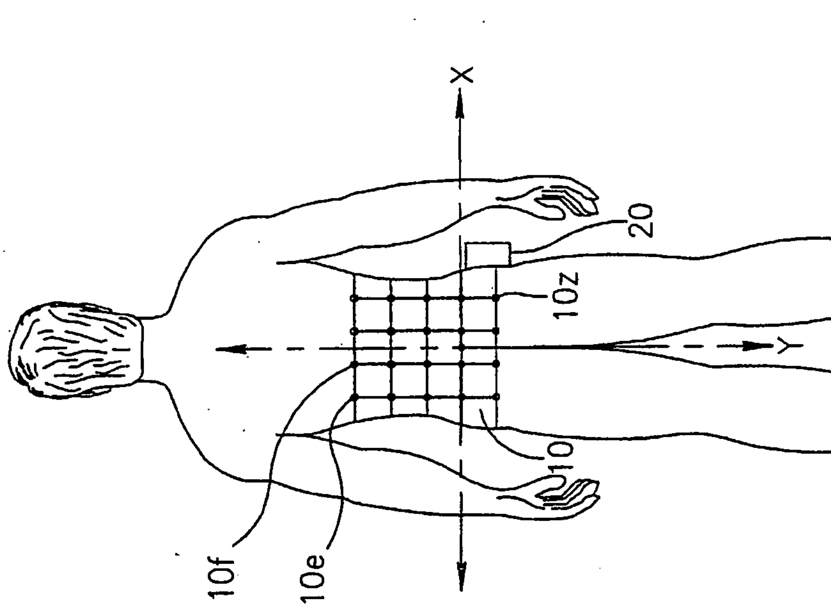

FIG.1B

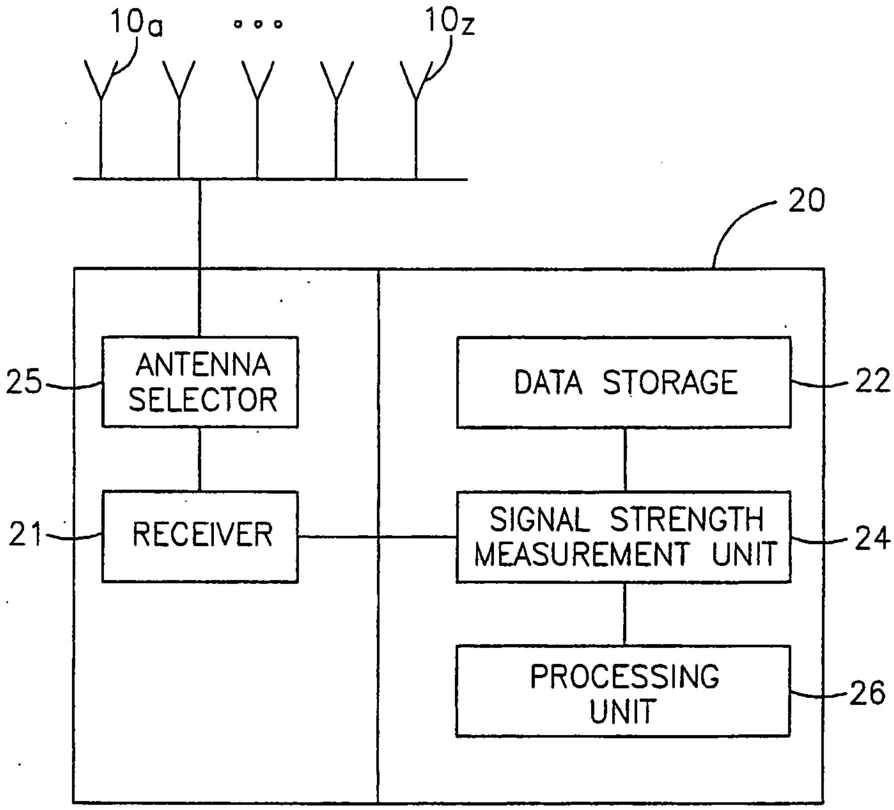
10a
10z
20
25
ANTENNA SELECTOR
21
RECEIVER
DATA STORAGE
22
SIGNAL STRENGTH MEASUREMENT UNIT
24
PROCESSING UNIT
26

FIG.2

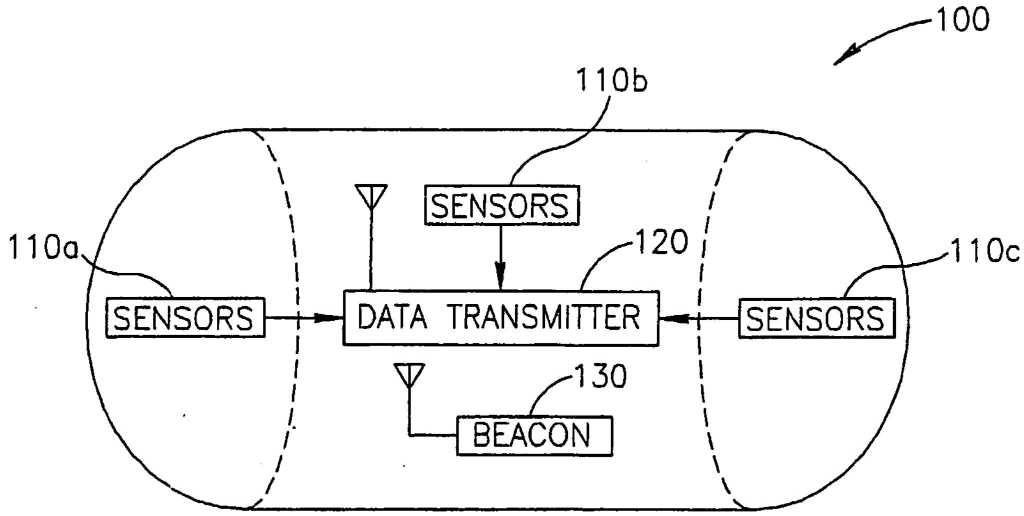
100
110b
SENSORS
110a
120
110c
SENSORS
DATA TRANSMITTER
SENSORS
130
BEACON

FIG.3

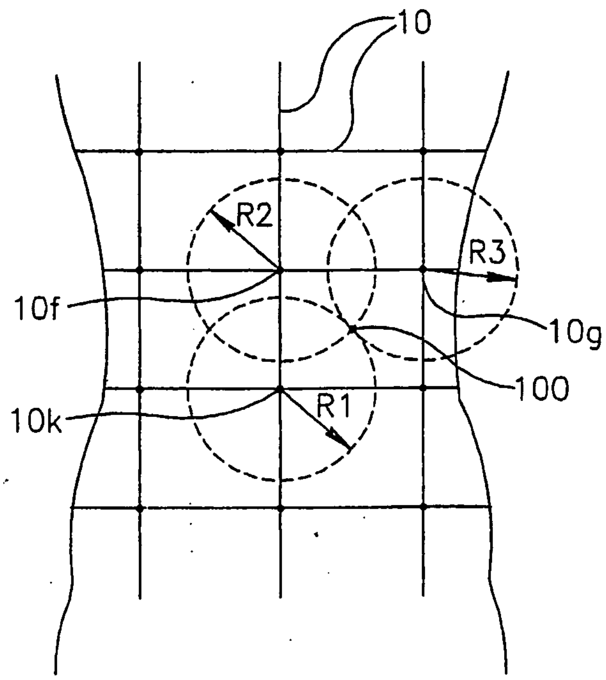
10
R2
R3
10f
10g
100
10k
R1

FIG.4

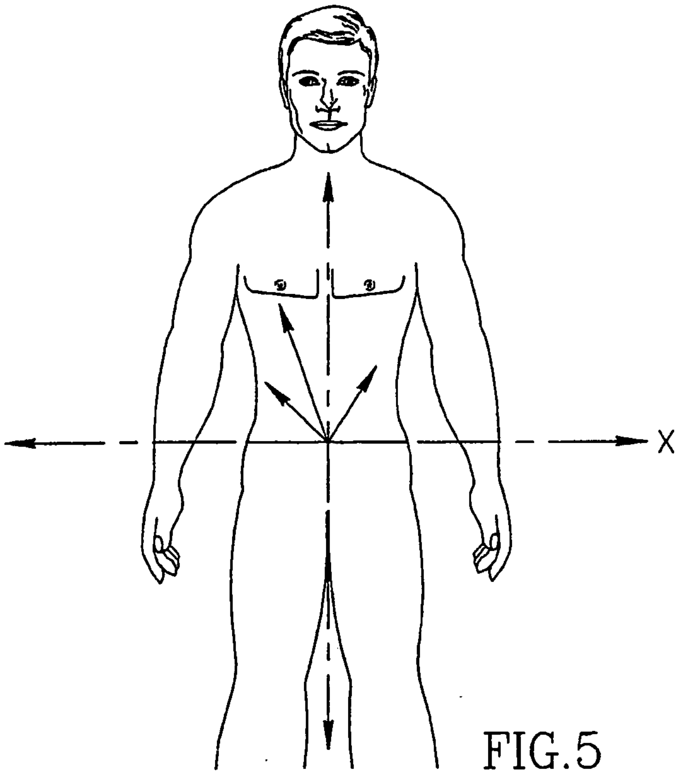

FIG.5

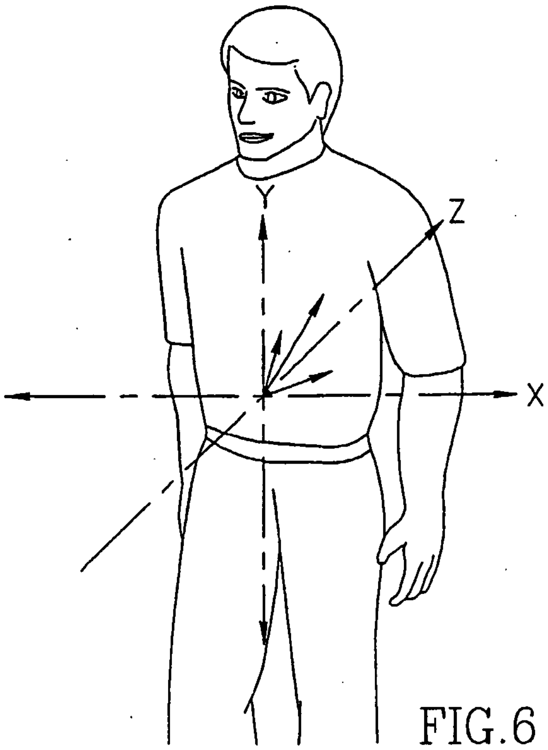

FIG.6

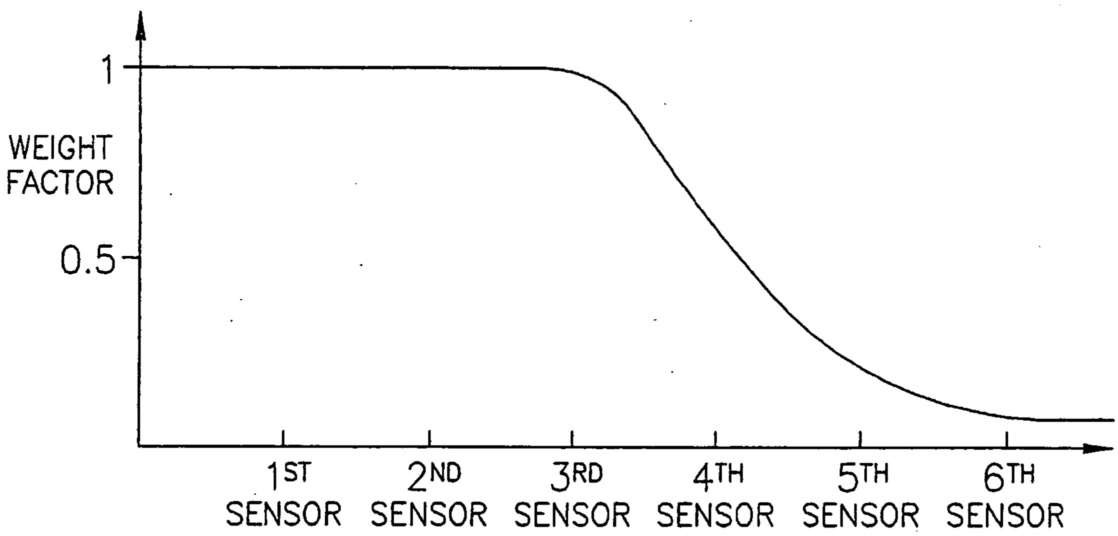
1
WEIGHT FACTOR
0.5
1ST SENSOR
2ND SENSOR
3RD SENSOR
4TH SENSOR
5TH SENSOR
6TH SENSOR

FIG.7

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 0667115 A1 **[0006]**
- US 5042486 A **[0007]**

patsnap

专利名称(译)	用于定位体内信号源的阵列系统和方法		
公开(公告)号	EP1260176B1	公开(公告)日	2009-12-09
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[标]申请(专利权)人(译)	基文影像公司		
申请(专利权)人(译)	基文影像有限公司.		
当前申请(专利权)人(译)	基文影像有限公司.		
[标]发明人	GLUKHOVSKY ARKADY FRISCH MORDECHAI MERON GAVRIEL		
发明人	GLUKHOVSKY, ARKADY FRISCH, MORDECHAI MERON, GAVRIEL		
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优先权	143260 2001-05-20 IL		
其他公开文献	EP1260176A2 EP1260176A3		
外部链接	Espacenet		

摘要(译)

一种使用具有至少两个天线元件的可佩戴天线阵列来定位体内信号源的系统和方法。接收信号并在两个或更多个天线元件处测量信号强度。从信号强度测量导出估计的坐标集。

$$I_r = I_0 \alpha a r \qquad \text{(Eq. 1)}$$