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Positioning Methods and Systems for UWB Devices

Field of the invention

The present invention relates to methods and systems for finding the position of a UWB transceiver device relative to one or more UWB reference devices.

5 Background of Invention

The use of ultrawide band (UWB) radio signals for communication and positioning is of interest to many organizations. UWB has the potential to provide very high data rate communication within a short distance. It can be
10 used in a room environment for wireless connections among multiple CE devices such as a TV, a video camera, a DVD player, a PC etc. Furthermore, known impulse mode UWB devices have the potential to be used to accurately find the locations of the objects. Due to the short pulse width of the UWB signals, it may be possible to achieve high resolution, and thus highly
15 accurate positioning accuracy. This factor, together with the free spectrum usage and low cost of UWB devices, has given rise to much interest in using UWB devices to perform positioning. In fact, it is believed that the combination of the communication and positioning abilities of UWB devices will greatly enhance the convenience of human life.

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US patent 5,510,800 [1] describes an UWB positioning system based on measuring the respective times-of-flight of pulses transmitted from one transmitter to multiple receivers. The positions of the receivers have to be known a priori. The transmitter and multiple receivers must be synchronized
25 by same clock source through cable connections. US patent 5,589,838 [2] extends this system by using the relative time-of-flight of UWB pulses in multiple synchronized receivers. The main limitation of these systems is the need for accurate distribution of a clock signal among the multiple receivers.

US patent 6,054,950 [3] describes another kind of UWB positioning system which uses several (at least 3) fixed reference transceivers to locate a mobile receiver. This is illustrated schematically in Fig. 1, in which reference radio transceivers 1 transmit signal to a mobile receiver 3. The positions of the reference transceivers 1 must be known a priori. The differences between the times at which the pulses from multiple transceivers 1 arrive at the receiver 3 are used by a processor associated with the receiver 3, to determine the location of the receiver 3. A self synchronization among the transceivers 1 or a global clock is needed.

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US patent 6,483,461 [4] also uses at least 3 UWB units that can communicate with each other to locate a mobile unit. US patent 6,300,903 [5] provides a positioning method similar to [4].

15 In U. S. patent appln. US2004/0108954 [6], a positioning method uses at least 3 fixed receivers and a reference transmitter to locate a tag transmitter with ID information. The clocks of the multiple receivers are locked with a central clock and their phase differences relative reference transmitter can be determined. The invention can be used to rapid acquisition of the tag transmissions.

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Note that all of the above proposals require multiple UWB units at known positions to obtain the position of a mobile object. There are a lot of problems in deploying such systems since many measurements and much pre-setting are needed. With the current tendency to continue reducing hardware cost, the deploying cost may become the main obstacle for many applications.

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Summary of the Invention

The present invention aims to provide a new and useful UWB positioning system, and a positioning method used by that system.

5 In general terms the present invention proposes a positioning system incorporating a UWB transceiver and a UWB reference device. The UWB reference device generates UWB response pulses in response to UWB pulses received from the transceiver. The transceiver includes multiple antennas, splayed out around an angular range (typically such that the beam
10 profiles of the array of antennas span all directions within a two-dimensional 360° angular range around a predefined axis) , and circuitry for determining the amplitudes of respective signals received by the antennas from the UWB reference in response to UWB pulse(s) transmitted from the transceiver. In this way, the UWB transceiver is able to obtain the range of the reference
15 device, and the angular position of the reference device within the range.

A positioning method making use of this system for obtaining the relative position of the transceiver and reference device may include the steps of the transceiver transmitting a UWB pulse which generates a response pulse from
20 the reference device. The transceiver receives the response pulse through its multiple directional antennas and by comparing the signal amplitudes from different antennas, the direction of arrival (DOA) of the response pulse can be decided. By measuring the time delay of the response pulse relative to the transmitted pulse, the distance between the transceiver and reference device
25 can also be determined.

The proposed system is able to obtain useful positioning information even if there is only a single reference (although, the invention is not limited in this respect). Thus, one form of the proposed positioning method and system is

very simple in that it only uses a single UWB transceiver and a single reference device. Thus, in contrast to many previously known UWB positioning systems, the proposed configuration may be simple and easy to deploy.

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The multiple antennas with splayed angles make it possible to make the transceiver relatively simple and easy to use. The multiple antenna feature means that a transceiver as proposed is more fit for use in a portable device than either a mechanically rotating directional antenna, or an array of distance-separated multiple antennas.

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The reference device used here can be passive (one which merely instantaneously reflects a signal it receives from the transceiver) or active (one which is capable of generating a response signal after a delay and/or with a different time profile from the signal received from the transceiver). By using an active reference as a responder, the receiver is able to produce response signals which can be more easily distinguished from other echo signals. This makes it possible for the positioning method to be more robust and far-reaching, particularly in a multi-path environment, such as indoors.

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The proposed system is particularly useful in two kinds of positioning scenarios: (1) determining the position of a mobile (and typically moving) UWB transceiver relative to the reference device; (2) determining the position of the reference device relative to the UWB transceiver.

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In certain applications of the system (particularly in the first scenario) the transceiver may rotate (relative to an absolute reference system), and accordingly in some such applications the transceiver may be equipped with a device for measuring its rotation. This device may be a compass device or a gyroscope for example. In other applications, such a device is unnecessary.

For example, in typical applications of scenario (2), the compass or gyroscope is not necessary since either the transceiver does not self-rotate, or if it does it is the reference's position relative to the current orientation of the transceiver which is of interest. The scenario is analogous to typical applications of the
5 different field of radar positioning, and some of what is proposed here can be regarded from one point of view as an innovative implementation of UWB radar.

While the method is capable of providing useful results with only a single reference device, the method is not limited in this respect. Specifically, the
10 positioning system may include two (or more) reference devices, each able to generate UWB response pulses in response to UWB pulses from the transceiver. This option is particularly useful in the scenario of tracking the transceiver, and furthermore makes it possible to track the transceiver in three dimensions. Alternatively or additionally, it means that the rotation of the
15 transceiver relative to an absolute reference direction can be obtained without use of a rotation measurement device mounted on the transceiver.

Due to the simple configuration, the proposed scheme has many possible commercial applications. For example, it can be used to implement a "pasting-and-positioning" process in which by simply pasting the reference device to a
20 fixed location, the positioning process can begin. A possible application is in a home robot. For example, if the reference device is attached to the power-recharge site of the robot, then the recharge site may be put anywhere, and the robot will always automatically find the position of the recharge site.

A second, independent inventive concept disclosed herein is that a
25 transceiver and reference device of a UWB positioning system may use UWB pulses not only for positioning but also for data communication between them. The devices may simultaneously implement communication and positioning function. The communication can be conveyed by modulating the pulses. This

may be by BPSK modulation. By using the BPSK modulation of UWB pulses, one or more information bits can be embedded into the each pulses, while the same pulses can still be used for range and direction measurements. By combining the simple positioning configuration and the communication
5 function, a new kind of radio frequency identification (RFID) can be implemented. In contrast to the conventional RFID, which is basically a communication system, this UWB RFID has additional positioning ability.

Brief Description of The Figures

Preferred features of the invention will now be described, for the sake of
10 illustration only, with reference to the following figures in which:

Fig. 1 illustrates schematically a known UWB positioning system using multiple references;

15 Fig. 2 illustrates a first embodiment of the invention using a single UWB transceiver and a single reference to measure the relative position of the transceiver and reference;

Fig. 3 is composed of Figs. 3(a) and 3(b) which illustrate respectively
20 the signal profiles transmitted and received by the transceiver of Fig. 2 in the case that the reference is a passive reference (Fig 3(a)), and the signal profiles transmitted and received by the transceiver and an active responder (Fig. 3(b));

25 Fig. 4, which is composed of Figs. 4(a) to 4(c), illustrates a method for direction measurement in the embodiment of Fig. 2 which uses several directional antennas in the transceiver;

Fig. 5 illustrates use of the embodiment of Fig. 2 to track the changing position a transceiver with self rotation;

Fig. 6, which is composed of Figs. 6(a) and 6(b), illustrates use of the embodiment of Fig. 2 to track the position of the reference and show its position relative to the transceiver in a display device of the transceiver;

Fig. 7 is a scheme used by the embodiment of Fig. 2 to simultaneously implement positioning and communication functions by BPSK modulation; and

Fig. 8 shows a second embodiment of the invention which is capable of performing three-dimensional position finding.

Detailed Description of the embodiments

Referring to Fig. 2, a positioning system is shown which is an embodiment of the present invention and consists of two parts. One is an UWB transceiver 101 which transmits and receives UWB pulses. The other is a reference device 102 (in this section called simply a "reference"), which may be a passive reflector, or an active responder which can receive and re-transmit UWB pulses. The transceiver 101 includes a processor for determining its own position, or that of the reference 102. In either case, the target of the measurement is the relative position of the units 101, 102. As in a radar system, the position measurement is solely implemented at the transceiver 101 in that both the range and direction of the reference 102 is detected. Therefore the reference 102 can be very simple.

Fig. 2 is a perspective view, in which the transceiver 101 is shown at the origin of a two-dimensional plane defined by two orthogonal axes x, y. This plane is referred to in the following text as the "horizontal" plane. The

reference 102 may be within this 2-D plane, and if so this configuration is very suitable for 2-D positioning. Alternatively (in the case actually shown in Fig. 2), the reference 102 may not be within the 2-D horizontal plane of the transceiver 101, but is instead raised above the plane by a height Δh .

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Suppose firstly, that the reference 102 is within the x-y plane. In this case, the distance from the transceiver 101 to the reference 102 is denoted by R .

Alternatively, if the reference 102 is at a height Δh above the x-y plane, R is used to denote the actual distance ("slant distance") from the reference 102 to the transceiver 101, and the component of this distance within the 2-D plane (the "2-D plane range") is denoted by r .

In either case, the angle, from the x-axis, of the vertical plane containing the transceiver 101 and reference 102 is referred to as the azimuth angle θ .

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If Δh is known, r can be determined from the measured slant range R as:

$$r = \sqrt{R^2 - (\Delta h)^2} \quad (1)$$

Even if the Δh is unknown, if it is small and the slant range R is big, the slant range R will be very close to the plane range r , and using R in place of r in the following calculation will not cause a big error.

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Using the plane range r and the azimuth angle θ , the 2-D relative position of the transceiver 101 and reference 102 can be fully determined.

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In the following text, exemplary ways for range and direction measurement are illustrated in detail. Later we will discuss how to continuously monitor the position change of the mobile transceiver 101.

1. Range Measurement

The range measurement performed by transceiver 101 is based on the measurement of the time-of-arrival (TOA) of a UWB pulse transmitted by the transceiver 101 and echoed back by the reference 102.

Suppose firstly that the reference 102 is a passive reference. In this case the transmitted pulse from transceiver 101 will be directly reflected back after it hits the reference 102. Then it is received by transceiver 101. The process is described in Figure 3(a), showing the time profile of the signals sent/received at the transceiver 101. After transmitting a UWB pulse, the transceiver 101 will switch to a receiving mode and wait to receive the echoed pulse from the reference 102. The transmission of the pulse is at the left of the Fig. 3(a), and the profile of the received pulse is at a time τ later. Then the slant range R of the reference can be estimated as:

$$R = \frac{c\tau}{2} , \quad (2)$$

where c is the speed of light.

If the transceiver 201 is in an environment (such as a room) including multiple objects which reflect UWB pulses, then the transceiver will receive multiple echoes, possibly including multipath echoes in which the pulse has been reflected from multiple reflectors before reaching the transceiver. To differentiate the reference's echo from that of the other objects surrounding the transceiver 101, it is necessary to recognize the echo from the reference 102 (neglecting other echoes) using the features of the echo from the reference 102.

One possible feature is the amplitude of the echo from the reference 102. If the reference can generate a bigger echo than the other surrounding objects, it can be identified. One way to ensure this is true is to use a strong corner reflector as the passive reference 102. Of course, the amplitude of the echoes is strongly dependent on the range. To remove this range-dependent factor, time-sensitivity control can be used, i.e. increasing the gain of the transceiver for increasing ranges. Other possible features which can be used to identify the echo from the reference 102 include the polarization of the echo's electric-magnetic wave, or the range waveform profile since UWB has high resolution in range.

Suppose now, alternatively, that the reference 102 is an active reference. In contrast to a passive reference, the active reference 102 can receive and re-transmit the UWB pulses from the transceiver 101 after a delay and/or with a modification. An active reference is called a responder. The timing process of this scenario is illustrated in Fig. 3(b), where the upper part of the figure indicates the signals transmitted and received by the transceiver 101, and the lower part of the figure indicates the signals received and transmitted by the responder 102. After transmitting a UWB pulse, the transceiver 101 will switch to receiving mode and wait to receive the echoed pulse from the responder 102. Preferably, after the responder 102 receives the pulse from transceiver 101, the responder 102 initiates a delay-and-trigger gate which outputs a signal with an edge (e.g. a falling edge) after a non-zero time delay of τ_0 . The falling edge of the gate triggers the responder to generate a UWB pulse similar (or identical to) the received UWB pulse, and transmit it back to transceiver 101. Then the transceiver 101 will measure the time-of-arrival of this pulse. Since the delay τ_0 is pre-determined and known to the transceiver 101, the range of the responder can be estimated as:

$$R = \frac{c(\tau - \tau_0)}{2}. \quad (3)$$

The time delay τ_0 should be selected to be long enough to let all the multipath echoes for pulse 301 from the surrounding objects die out. In this case the transceiver 101 can easily identify the first echo it receives after the elapse time τ_0 as the re-transmitted pulse from the responder 102. Thus the range
 5 can be determined using (3).

In certain situations it is possible that the processes described above may not be able to perform the range measurement accurately using a single pulse. In this case, it may be preferable to transmit many repeated pulses to achieve
 10 more reliable range measurement.

Either or both of the responder 102 (if the reference 102 is active) and the transceiver 101 may include a correlator to the increase SNR. Either or both of the responder 102 (if the reference 102 is active) and the transceiver 101
 15 may be arranged to scan many range bins to find time at which it receives a pulse. This process usually requires that multiple pulses are transmitted by the transceiver 101 because a conventional correlator only outputs a signal indicating one of several range bins within one pulse-repeat-interval (PRI). In this case, multiple PRIs may be used to make the output of the correlator
 20 cover the whole possible range.

Note that, as an alternative to delay, the responder could modify the UWB pulse before transmitting it back, so that the transmitter can distinguish it from other echoes. However, this possibility is not as simple as a delay based
 25 method.

2. Direction Measurement

The direction of the reference 102 relative to transceiver 101 could in principle be measured in several ways. The simplest way to do this would be as in
 30 conventional radar in which a mechanically rotating directional antenna is

scanned through a range of angles. At each of a number of angular positions a directional antenna mounted on the transceiver 101 could transmit a UWB pulse and measure the amplitude of the response from the reference 102. The angular position of with the maximum amplitude may be taken as the
5 direction of the reference 102, or amplitude values from multiple ones of the angular positions may be used to estimate the correct direction of the reference 102. Another approach to estimating direction which could in principle be employed in the present invention is as shown in [5]: two or more antennas are placed in spaced apart locations (e.g. on the transceiver 101)
10 and the difference between the TOAs of a pulse (the time-difference-of-arriving, "TDOA") at the two antennas is measured. Due to the high resolution of UWB pulses, very short time differences can be measured and thus the direction can be estimated using the TDOA and the antenna geometry. Yet another possible way of measuring direction would be used a phase array to
15 steer the beam.

However, all of the above mentioned methods are either troublesome, large in size or too high cost for future low-power and low cost UWB devices, especially for portable UWB device. Accordingly, the embodiment of the
20 invention uses a method similar to the mono-pulse principle known in radar. It is illustrated in Fig. 4(a), which is a view looking towards the x-y plane of Fig. 2. In the transceiver 101 are provided multiple directional antennas 103, having respective "beam patterns" referred to as "beam 1", "beam 2", "beam 3" and "beam 4", each centred on a respective maximum sensitivity directions.
25 The antennas are arranged with their maximum sensitivity directions lying in the x-y plane, in a circular structure with their beam patterns (each of which has an angular beam width) partly overlapping. For example, assuming that (as shown in Fig. 4(a)) there are 4 directional antennas 103, each may have a 90° beamwidth (-3dB). The antennas 103 are arranged in such a regular
30 configuration that these antennas' maximum gain directions are 90° separated

from each other. Thus the 4 antennas are enough to cover the whole 360° circumference as shown in Fig. 4(a).

Fig. 4(b) shows for the full 360° range of angles the respective gain functions of each of the four antennas 103. If an echo signal comes from direction θ as shown in Fig. 4(b), the antenna associated with “beam 1” will receive it with antenna gain $g_1(\theta)$. At the same time, the antenna associated with “beam 2” will receive the echo with antenna gain $g_2(\theta)$. Normally $g_1(\theta) + g_2(\theta)$ will be the biggest among all the pairs of neighbour antennas combinations. For example, it is bigger than $g_2(\theta) + g_3(\theta)$. Thus it can be judged that the echo’s DOA falls within the direction between antenna 1 and 2. To obtain the accurate direction, the gain difference $g_1(\theta) - g_2(\theta)$ is used. The gain difference changes monotonously as the angle θ shifts from the maximum sensitivity direction antenna 1 to the maximum sensitivity direction of antenna 2.

In fact, by preference, the embodiment uses a normalised gain difference

$$f(\theta) = \frac{g_1(\theta) - g_2(\theta)}{g_1(\theta) + g_2(\theta)}, \quad (4)$$

shown in Fig. 4(c) for a range of possible values for θ . The normalization factor $g_1(\theta) + g_2(\theta)$ is used to remove the echo strength dependence of $g_1(\theta) - g_2(\theta)$. For example, if the absolute signal amplitudes from beam 1 and beam 2 are changed due to the change in the reference’s range, both $g_1(\theta)$ and $g_2(\theta)$ will be scaled by the same factor (say A), and the normalization process in (4) will remove this scale factor. In practice, the curve $f(\theta)$ can be pre-measured and stored for use in a calibration process. Specifically, during operation $g_1(\theta)$ and $g_2(\theta)$ are measured, and the signal’s DOA is estimated by a look-up-table from the pre-measured curve.

- The proposed mono-pulse DOA estimating method is different from conventional mono-pulse radar process, since in a conventional mono-pulse radar process normally only two antenna horns are used and they cover only a small range of direction (e.g. $2\sim 5^\circ$). Within this direction range, a highly accurate DOA can be determined. By contrast in the embodiment, the whole 360° circumference is covered. Considering the complexity and the cost, the number of antennas that we suggest using in this case is in the range of 3 to 10.
- 10 In some embodiments of the invention the complexity of the transceiver is reduced by providing only one receiving channel. In this case, the multiple antennas can be electrically switched on one-by-one. Multiple pulses are required, with one or more pulses for each antenna.
- 15 Note that the text above has not discussed how the transceiver 101 generates the pulse which it transmits. In principle would possibility would be for the transceiver 101 to include an omni-directional antenna used for the transmission, but this solution is not preferred. Rather, if each of the antennas 103 is used to simultaneously transmit an identical UWB signal, the result will
- 20 be a substantially omni-directional transmitted signal (within the plane spanned by the antennas 103). Further variations are possible in which the antennas 103 transmit UWB pulses at different times (such that the transmitted signal is not omni-directional, but rather a pulse (or a series of multiple pulses) transmitted by the specific antenna which is intended to
- 25 receive the echo(es) - such as the antenna which is connected at that time to the receive channel.

3 Positioning the Transceiver 101:

There are two positioning scenarios that can be implemented using the above transceiver-reference scheme.

One is to assume that the position of the reference 102 is fixed, and the position of the transceiver 101 is to be determined. The transceiver may for example be attached to a person. In this case, in addition to the transceiver configuration described above, the transceiver preferably includes a device for measuring rotation (such as a compass or a gyroscope) for measuring the self rotation of the transceiver in the horizontal plane (relative to an absolute horizontal direction, such as north). This scenario is illustrated in Fig. 5.

At the beginning of the measurement, a fixed coordinate system is established. The reference 102 can be assumed to be at the coordinate system's origin $(0, 0)$. During an initialisation phase, when the transceiver 101 first finds its position relative to the reference 102, it automatically sets up the coordinate system. For example, it can define the line which connects the reference 102 and transceiver 101 as the x-axis, and the direction of left 90° rotation as the y-axis. Thus the first position of the transceiver 101 is assumed to be $(r, 0)$ where r is the measured range. The actual measured angle θ can be normalized to 0° . After that, if the transceiver 101 is moved to another location with a self-rotation θ_r , the self rotation angle θ_r is measured by the compass or gyroscope. Let us assume that in the new position the measured results are r_1 and θ_1 respectively. Then the new position can be determined as $(r_1 \cos(\theta_1 - \theta_r), r_1 \sin(\theta_1 - \theta_r))$.

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In practice, to measure the self rotation angle θ_r of the transceiver 101, it is typically better to use a compass than a gyroscope. This is because that the compass will measure the absolute angle relative to the earth's north while the gyroscope will only measure the relative angle change, so the

measurement error of the gyroscope will accumulate, and may become very large if no calibration is done.

4. Positioning the Reference 102:

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In another positioning scenario, what needs to be determined is the position of the reference 102 position relative to transceiver 101. This scenario is the case, for example, in a situation in which somebody holds the transceiver 101, and wants to find the position of the reference 102 relative to his current
10 position. The transceiver 101 may include a display device which is used to show the position of reference 102. The y-axis of the display device may be set to be aligned with transceiver antenna's 0° direction. The x-axis may be defined as the 90° right rotation from the y-axis. The situation is illustrated in Fig. 6(a). The measurement result (r, θ) can be directly shown in the display
15 device, like in a radar's plane-position-indication (PPI), as shown in Fig. 6(b).

Note that in this scenario the transceiver 101 does not require a compass or gyroscope since the self rotation of transceiver 101 will be automatically reflected in the display device. For example, if the person's face is always
20 aligned with the y-axis of the display device, when the person rotates 90° to right, then the y-axis of the display device and the antennas of the transceiver 101 are also rotated 90° to the right. The new measured result will have a 90° direction change to left and will be displayed in the display device with this 90° change to left.

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5. Data Communication:

In addition to the positioning ability described above, the embodiment may have the function of data communication. Thus, in contrast to a UWB device which is purely for communication, the embodiment may combine the
30 communication and the positioning functions simultaneously. In this case, the

reference 102 must be an active responder to implement the communication function. The scheme is described as follows.

For the communication physical layer to be compatible with the positioning,
5 the communication data also is carried by the pulses. Although there are
different kinds of pulse modulation scheme which might be used, such as
pulse-position-modulation (PPM) and pulse-amplitude-modulation (PAM), the
preferred modulating scheme in the embodiment uses a bi-phase-shift-key
(BPSK). In this modulation scheme, multiple pulses are transmitted with equal
10 amplitudes at equal intervals. Only the polarity of the pulses are changed to
carry the information. In a first polarity the signal has a certain time profile,
while in the other polarity the time profile of the signal is reversed. This will
greatly facilitate the positioning process in which the centre or leading edge of
the pulse is used to measure the range, and the amplitude of the pulse is
15 used to measure the direction. The situation is shown in Fig. 7. For example,
if the transceiver 101 wants to transmit a bit '1' to responder 102, a positive
polarity pulse is transmitted (i.e. one beginning with a rising signal). When the
responder 102 receives this positive pulse, the responder 102 decodes it as
'1'. Then if a bit '1' is needed to be transmitted back to transceiver 101, the
20 responder 102 will send out a positive polarity pulse. The transceiver 101 will
decode the received positive pulse as '1' from the responder 102. At the same
time, the centre or leading edge position and amplitude of the received pulse
can be used for positioning. Similarly, a negative polarity pulse is used to
represent bit '0'.

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In practice, accumulation (i.e. repeated transmission of each bit) may be used
to increase the signal-to-noise ratio (SNR). Either or both of the transceiver
101 and responder 102 may send the same pulse more than once, such as
many times.

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Note that it is also possible for the embodiment to use other kinds of communication schemes. The communication and positioning functions can also be implemented separately in time

5 One useful application of the embodiment described above is for a UWB radio-frequency-identification (RFID) system. The active responder 102 can be used as a tag and the transceiver 101 can be used as an RFID reader. The tag 102 can store information such as an ID (and optionally other information) and can be triggered to send out this information after receiving an inquiry from the reader 101. The communication scheme illustrated above can be used to implement this function. In contrast to a conventional RFID system which only has communication ability, the proposed RFID system also has positioning ability. This property would be desirable in many RFID applications. For example, in a warehouse management system, the UWB RFID can not only determine that a specific good is within the warehouse, but also can find where it is. That will greatly increase the efficiency of the management system.

6. 3-D Positioning:

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The first embodiment of the invention shown in Fig. 2 is a single-transceiver-single-reference scheme and is particularly suitable for 2-D positioning. However, as mentioned before in relation to Fig. 2, if the height difference Δh between the reference 102 and transceiver 101 is known a priori, it can also be used to do the positioning in 3-D space. In many applications, however, the height difference is unknown, so the positioning result will not be correct.

Fig. 8 illustrates a second embodiment of the invention to provide more general 3-D space positioning. This embodiment implements 3-D positioning

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- using a transceiver 201 and two references 202, 203 in 3-D space. It is assumed that the coordinate system is pre-established and the positions of the two references 202, 203 in this coordinate system are known to the transceiver 201. Assume that the position of the first reference 202 is
- 5 (x_1, y_1, z_1) and the position of the second reference is (x_2, y_2, z_2) . The transceiver 201 can measure its position relative to each of these two references using the method described before. Assume that the measurement results are (r_1, θ_1) and (r_2, θ_2) respectively. Further assume that what needs to be determined is the position of the transceiver 201 denoted by (x_0, y_0, z_0) .
- 10 Another unknown parameter is the self rotation angle of the transceiver relative to previous measurement.

Note that since the mono-pulse direction measurement is only implemented in azimuth direction, the measured angles θ_1 and θ_2 are azimuth angles.

- 15 Assuming the self rotation angle of the transceiver 101 is θ_0 , the following relationships can be established (where the various variables are defined by reference to Fig. (8)):

$$(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2 = r_1^2 \quad (5)$$

$$(x_2 - x_0)^2 + (y_2 - y_0)^2 + (z_2 - z_0)^2 = r_2^2 \quad (6)$$

20 $\frac{y_1 - y_0}{x_1 - x_0} = \tan(\theta_1 + \theta_0) \quad (7)$

$$\frac{y_2 - y_0}{x_2 - x_0} = \tan(\theta_2 + \theta_0) \quad (8)$$

By solving the above 4 equations, the position of the transceiver 201 and rotation angle θ_0 in the pre-established coordinate system can be determined.

- 25 Note that one advantage of 3-D positioning using two references is that, in contrast to the case described above in which a single reference is used to determine the position of the transceiver in 2-D, in the 3-D case no compass

or gyroscope needed since θ_0 can be always be determined as an additional unknown.

Another possible way of performing 3D positioning would be to use the
 5 transceiver to measure the elevation angle of echoes. This may be done in a way similar to the method described above for direction estimation. Specifically, a plurality of directional antennas may be provided on the transceiver device having their respective maximum sensitivity directions at different elevation angles (but generally at the same azimuth angle). Since,
 10 more most applications of this concept, the elevation angle will be within a fairly small range around the horizontal direction, typically it is sufficient for there to be two directional antennas at different elevation angles.

One of these antennas may be one of the antennas 103 described above. In
 15 other words, one or more of the directional antennas 103 of Fig. 4(a) may be supplemented by further directional antennas at the same azimuth angle, but out of the 2-D plane shown in Fig. 4(a).

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- [9]. Sun Xiaobing and Kanzo Okada "Smart Personal Audio Space SPAS" Singapore Patent Application Number 200403021, 2004
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Claims

1. A position determination system comprising:

a transceiver for transmitting a UWB pulse, the transceiver including a plurality of directional antennas having respective maximum sensitivity directions, the directions of the respective antennas being spaced apart;

at least one reference device for receiving the UWB pulse and generating a response UWB pulse;

the transceiver being arranged to obtain amplitude signals indicative of the respective amplitudes of signals received by the antennas from the response UWB pulse, and determine from the amplitude signals the range and direction of the reference device relative to the transceiver.
2. A position determination system according to claim 1 in which each of the maximum sensitivity directions is arranged substantially on a common two-dimensional plane.
3. A position determination system according to claim 2 in which each of the antennas is associated with a beam width, the beam widths collectively spanning the full 360° angular range on the plane.
4. A position determination system according to any preceding claim in which the reference device is a passive UWB reflector.
5. A position determination system according to any of claims 1 to 3 in which the reference device generates the response pulse after a predetermined delay τ_0 following receiving the pulse from the transceiver.

6. A position determination system according to any preceding claim in which the transceiver includes a direction monitoring device for measuring its orientation relative to an absolute direction.
- 5 7. A position determination system according to any preceding claim in which there is exactly one reference device, the transceiver being arranged to output data indicating the distance and direction of the transceiver relative to the reference device.
- 10 8. A position determination system according to any of claims 1 to 6 in which there are multiple said reference devices, the transceiver being arranged to derive data indicative of a respective angular direction and range for each of said reference devices.
- 15 9. A position determination system according to claim 8 in which the transceiver is arranged to use the angular directions and ranges of the multiple reference devices to obtain data indicative of the position of the transceiver in three dimensions.
- 20 10. A position determination system according to any preceding claim in which each of the directional antennas is connected via a switching system to a common receive channel, the switching system connecting the directional antennas to the receive channel in turn, to obtain at different times the respective amplitude signals from different response UWB pulses.
- 25 11. A position determination system according to any preceding claim in which the transceiver is attached to a robot device and the receiver device is attached to a power-recharge apparatus for charging the robot device, the robot device including guidance circuitry for directing the robot to move to the reference device based on the output of the transceiver.

12. A position determination system according to any preceding claim in which at least one of the transceiver and receiver device is arranged to encode at least one bit of data into each UWB pulse it generates, the other of the transceiver and receiver device being arranged to decode that data.
- 5 13. A position determination system according to claim 12 in which the data is encoded using BPSK modulation.
14. A position determination system according to claim 12 or claim 13 in which the receiver is an RFID device having an ID code.
15. A transceiver device for a positioning system according to any
10 preceding claim, the transceiver including:
- a plurality of directional antennas having respective maximum sensitivity directions, the directions of the respective antennas being spaced apart; and
 - a processor for receiving amplitude signals indicative of the respective
15 amplitudes of signals received by the antennas from the response UWB pulse, and determining from the amplitude signals the range and direction of the reference device relative to the transceiver.
16. A position determination method comprising:
- a transceiver transmitting a UWB pulse, the transceiver including a
20 plurality of directional antennas having respective maximum sensitivity directions, the directions of the respective antennas being spaced apart;
 - at least one reference device receiving the UWB pulse and generating a response UWB pulse;
 - obtaining amplitude signals indicative of the respective amplitudes of
25 signals received by the antennas due to the response UWB pulse; and

determining from the amplitude signals the range and direction of the reference device relative to the transceiver.

17. A position determination method according to claim 16 in which each of the maximum sensitivity directions is arranged substantially on a common
5 two-dimensional plane.

18 A position determination method according to claim 17 in which each of the antennas is associated with a beam width, the beam widths collectively spanning the full 360° angular range on the plane.
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19. A position determination method according to any of claims 16 to 18 in which the reference device is a passive UWB reflector.

20. A position determination method according to any of claims 16 to 18 in
15 which the reference device generates the response pulse after a predetermined delay τ_0 following receiving the pulse from the transceiver.

21. A position determination method according to any of claims 16 to 20 further including monitoring the orientation of the transceiver relative to an
20 absolute direction, the orientation of the transceiver being used in said position determination step to obtain an indication of the angular position of the receiver which is compensated for any change in said orientation of the transceiver.

22. A position determination method according to any of claims 16 to 21 in
25 which the transceiver receives a response UWB pulse from exactly one reference device, the method further including the transceiver outputting data indicating the distance and direction of the transceiver relative to the reference device.

23. A position determination method according to any of claims 16 to 21 in which there are multiple said reference devices, the method further including the transceiver deriving data indicative of a respective angular direction and
5 range for each of said reference devices.

24. A position determination method according to claim 23 in which the transceiver uses the angular directions and ranges of the multiple reference devices to obtain data indicative of the position of the transceiver in three
10 dimensions.

25. A positioning method according to any of claims 16 to 24 further including:

(i) at least one of the transceiver and receiver device encoding at least
15 one bit of data into the UWB pulse it transmits,

(ii) the other of the transceiver and receiver device decoding that data.

26. A positioning method according to claim 25 in which said data encoding is by BPSK modulation.

27. A positioning method according to claim 25 or claim 26 in which the
20 receiver device encodes an ID code associated with the receiver device into one or more said response UWB pulses.