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Positioning System and Method for Determining Object Position

Field of the Invention

The present invention relates to positioning systems and methods for determining a position of a moving object.

5 Background of the Invention

Positioning systems are used in a wide variety of applications such as, for example, mixed reality gaming applications (see, for example, Singapore Patent Application No. 200603968-9 [1]), pen input applications and robotic applications, to identify the location of a moving object.

10 With recent technological developments, motion detection devices such as accelerometers and gyroscopes are now being used in positioning systems to estimate a location of a moving object. An example of such an application is disclosed in U.S. Patent No. 6,917,893 [2], which teaches the use of a rate
15 gyroscope and/or an accelerometer to generate positional data. One limitation of using motion detection devices in positioning systems is the need for an accurate starting point in order to obtain an accurate estimate of the real position of an object. Cumulative error is also a problem in such positioning systems as motion detection devices estimate the location of a
20 moving object based on cumulative measurements of the object's movements. So, for example, if an accelerometer gives an acceleration estimation a with an error Δa , the error Δa is accumulated over a running period T . Consequently, the distance measurement S calculated with the following equation:

$$S = a \times T^2 / 2 \quad (1)$$

25 will have a significant error ΔS , as expressed by the following equation:

$$\Delta S = \Delta a \times T^2 / 2 \quad (2)$$



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after a period of time. Thus, as calculated from equation (2), even an acceleration estimation error Δa as small as 0.01 metres per second squared (ms^{-2}) can result in a significant motion estimation error of 0.5 metres (m) after a running time T of just 10 seconds (s); small motion estimation errors
5 accumulate over time and cause significant motion estimation errors. Whilst variations in the acceleration error Δa can offset some errors, it complicates distance error estimation.

Positioning techniques based on radio frequency (RF) signals are known. One such application is disclosed in Singapore Patent Application No.
10 200504866-5 [3]. Such a system, however, requires a very high clock resolution to process the RF signals and thus requires a high computational load. System complexity and computational load requirements make it costly to implement such a system.

Thus, there exists a need for a positioning system and method for
15 determining a position of an object that provides accurate results and that is simple to implement.

Summary of the Invention

The present invention provides, in a first aspect, a method for determining a position of an object, the method comprising: measuring
20 movement information of the object during a movement; determining a direction of the object relative to a point of reference before and after the movement; and determining the position of the object based on an object displacement estimate derived from the movement information and the determined direction of the object before and after the movement.

25 A cumulative parameter derived from the movement information may be reset when the object is stationary. An initialisation operation may be performed. Respective rates at which the movement information and the determined direction of the object are updated may be synchronised with one of a prediction method and an interpolation method. The movement
30 information may comprise one of acceleration data, angular motion data and

displacement data. The movement information may be communicated via one or more UWB signals

In a second aspect, the invention further provides a positioning system for determining a position of an object, comprising: a motion detection device
5 coupled to the object, wherein the motion detection device is configured to measure movement information of the object during a movement; an ultra-wideband (UWB) responder; an UWB requestor, wherein the UWB responder and requestor are configured to determine a direction of the object relative to a point of reference before and after the movement; and a computation unit
10 configured to determine the position of the object based on an object displacement estimate derived from the movement information and the determined direction of the object before and after the movement.

The UWB requestor or the computation unit may be configured to reset a cumulative parameter derived from the movement information when the
15 object is stationary.

The motion detection device and the UWB requestor may be configured to align their respective coordinates.

The UWB requestor or the computation unit may be configured to synchronise respective rates at which the movement information and the
20 determined direction of the object are updated with one of a prediction method and an interpolation method.

The motion detection device may be one of an accelerometer, a gyroscope and a trackball.

In one embodiment, the UWB responder may be coupled to the object
25 and configured to communicate the movement information generated by the motion detection device to the UWB requestor. The UWB responder may be coupled to the object in another embodiment.

In a third aspect, the invention further provides a positioning system for determining a position of an object, comprising: a motion detection device

coupled to the object, wherein the motion detection device is configured to measure movement information of the object during a movement; an ultra-wideband (UWB) responder; and an UWB requestor, wherein the UWB responder and requestor are configured to determine a direction of the object
5 relative to a point of reference before and after the movement and whereby the position of the object is determined based on an object displacement estimate derived from the movement information and the determined direction of the object before and after the movement.

In the third aspect, corresponding further features as described above
10 in respect of the second aspect may also be employed.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

15 Brief Description of the Drawings

The following detailed description of preferred embodiments of the invention will be better understood when read in conjunction with the appended drawings. The present invention is illustrated by way of example and is not limited by the accompanying figures, in which like references
20 indicate similar elements.

FIG. 1 is a schematic diagram of a positioning system in accordance with one embodiment of the present invention;

FIG. 2 is a graphical diagram illustrating a change in the position of an UWB responder relative to that of the UWB requestor in the positioning
25 system of FIG. 1;

FIG. 3 is a schematic flow diagram of a method for determining a position of an object in accordance with one embodiment of the present invention; and

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 UWB requestor.

Detailed Description of the Drawings

5 The detailed description set forth below in connection with the appended drawings is intended as a description of the presently preferred embodiments of the invention, and is not intended to represent the only form in which the present invention may be practiced. It is to be understood that the same or equivalent functions may be accomplished by different
10 embodiments that are intended to be encompassed within the scope of the invention.

Referring now to FIG. 1, a positioning system 10 in accordance with one embodiment of the present invention is shown. The positioning system 10 includes a plurality of objects 12, an UWB requestor 14 and a computation
15 unit 16. Each of the objects 12 is coupled with a motion detection device 18 and an UWB responder 20. Each motion detection device 18 is configured to measure movement information of the object 12 to which it is coupled during a movement, while the corresponding UWB responder 20 is configured to communicate the movement information measured by the motion detection
20 device 18 to the UWB requestor 14. The UWB requestor 14 and the respective UWB responders 20 are configured to determine a direction of each of the objects 12 relative to a point of reference before and after the movement. The computation unit 16 is configured to determine a position of each of the objects 12 based on an object displacement estimate derived from
25 the movement information and the determined direction of the object 12 before and after the movement.

The objects 12 may be, but are not limited to, one or a combination of robots, remote control toys and the like. The motion detection devices 18 may be one or a combination of accelerometers, gyroscopes, trackballs and other
30 devices that are capable of detecting the movement of the objects 12. Although the computation unit 16 is described as being integrated into the

positioning system 10 in the present embodiment, those of skill in the art will understand that the computation unit 16 may alternatively be provided independently of the positioning system 10 in another embodiment, for example, the computation unit 16 could be a function of a personal computer
5 (PC) running game software. It should be understood also that the computation unit 16 could be integrated into the UWB requestor 14 in alternative embodiments.

Having described the various components of the positioning system 10, the operation of these components will now be described in greater detail
10 below with reference to FIGS. 1 through 3.

Referring now to FIG. 2, a graphical diagram illustrating a change in the position of one of the UWB responders 20 relative to that of the UWB requestor 14 is shown. The position of the UWB requestor 14 is taken as the point of reference or origin (0,0) in the two-dimensional (2D) coordinate
15 system 22 shown in FIG. 2. As can be seen from FIG. 2, the UWB responder 20 is displaced a distance of Δx along the X-axis, a distance of Δy along the Y-axis and an azimuthal angle of $\theta - \theta'$ as it moves from a first position (x, y) to a second position (x', y') in the coordinate system 22.

Referring now to FIG. 3, a method 50 for determining a position of the
20 object 12 to which the UWB responder 20 of FIG. 2 is coupled is shown.

In a first step 52, an initialisation operation is performed to align respective coordinates of the UWB requestor 14 and the motion detection device 18 coupled to the object 12. This eliminates any differences between the coordinates of the UWB requestor 14 and the motion detection device 18,
25 and in so doing, increases the accuracy of the position determining method 50. In the embodiment where the motion detection device 18 is an accelerometer, initialization is performed by adjusting the rotation of the accelerometer such that the coordinates of the accelerometer are aligned with that of the UWB requestor 14, more particularly, by moving the accelerometer
30 along the X- or Y-axis of the UWB requestor 14 shown in FIG. 2 and rotating

the accelerometer until it gives a zero (0) reading in the respective traversed direction.

Movement information of the object 12 during a movement is measured by the motion detection device 18 at step 54. Depending on the type of motion detection device 18 employed, the movement information may comprise one of acceleration data (a'_x, a'_y) , angular motion data Ω' (in a two-dimensional application) or (Ω'_x, Ω'_y) (in a three-dimensional application) and displacement data $(\Delta x, \Delta y)$. For example, in the embodiment where the motion detection device 18 is an accelerometer, the motion detection device 18 measures the two-dimensional (2D) acceleration (a'_x, a'_y) of the object 12 at time t . An object displacement estimate $(\Delta x, \Delta y)$ derived from the movement information (a'_x, a'_y) is subsequently computed with the following equations:

$$\Delta x = (\sum_t a'_x \Delta t) \times \Delta t \quad (3)$$

$$\Delta y = (\sum_t a'_y \Delta t) \times \Delta t \quad (4)$$

In the embodiment where the motion detection device 18 is a gyroscope, the motion detection device 18 measures the rotational velocity Ω' of the object 12 at time t . A rotational displacement estimate D is subsequently derived from the measured movement information Ω' with the following equation:

$$D = L \times \Omega' \times t \quad (5)$$

where L represents a distance from a point of rotation on the gyroscope to a static reference point on the object 12. The movement information measured by the motion detection device 18 is communicated to the UWB requestor 14 through the UWB responder 20 via one or more UWB signals.

A direction of the object 12 relative to the point of reference (0,0) before and after the movement θ and θ' , respectively, is determined at step 56 by the UWB requestor 14.

5 The direction of the UWB responder 20 relative to the UWB requestor 14 can in principle be measured in several ways. The simplest way to do this would be as in 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 UWB requestor 14 could transmit an UWB pulse and measure the amplitude of the response
10 from the UWB responder 20. The angular position of with the maximum amplitude may be taken as the direction of the UWB responder 20, or amplitude values from multiple ones of the angular positions may be used to estimate the correct direction of the UWB responder 20.

15 Another approach to estimating direction which could in principle be employed in the present invention is as shown in [4]: two or more antennas are placed in spaced apart locations (e.g. on the UWB requestor 14) and the difference between the time-of-arrivals (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
20 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 steer the beam.

Another embodiment of the invention uses a method similar to the mono-pulse principle known in radar. It is illustrated in FIG. 4(a), which is a
25 view looking towards the x-y plane of FIG. 2. In the UWB requestor 14 are provided multiple directional antennas 24, having respective "beam patterns" referred to as "beam 1", "beam 2", "beam 3" and "beam 4", each centred on a respective maximum sensitivity directions. The antennas are arranged with their maximum sensitivity directions lying in the x-y plane, in a circular
30 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 24, each may have a 90° beamwidth (-3dB). The

antennas 24 are arranged in such a regular 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).

5 FIG. 4(b) shows for the full 360° range of angles the respective gain functions of each of the four antennas 24. 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
 10 $g_1(\theta) + g_2(\theta)$ 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 direction of arrival (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
 15 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

$$f(\theta) = \frac{g_1(\theta) - g_2(\theta)}{g_1(\theta) + g_2(\theta)} \quad (6)$$

20 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
 25 process in (6) 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.

This mono-pulse DOA estimating method is different from the 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. 2~5°). 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.

In some embodiments of the invention the complexity of the UWB requestor 14 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.

Note that the text above has not discussed how the UWB requestor 14 generates the pulse which it transmits. In principle one possibility would be for the UWB requestor 14 to include an omni-directional antenna used for the transmission, but this solution is not preferred. Rather, if each of the antennas 24 is used to simultaneously transmit an identical UWB signal, the result will be a substantially omni-directional transmitted signal (within the plane spanned by the antennas 24). Further variations are possible in which the antennas 24 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 receive the echo(es) - such as the antenna which is connected at that time to the receive channel.

Whilst a number of direction estimation methods have been described in the foregoing paragraphs, it should be understood by those of skill in the art that the present invention is not limited to the direction estimation methods described herein; other angle estimation methods are also workable in the positioning system 10.

At step 58, the position of the object 12 is determined by the computation unit 16 based on an object displacement estimate ($\Delta x, \Delta y$) derived from the movement information and the determined direction of the

object 12 before and after the movement θ and θ' . More particularly, the computation unit 16 calculates the position (x, y) of the object 12 before the movement with the following equations:

$$x = \frac{\Delta y - \Delta x \times \tan \theta'}{\tan \theta' - \tan \theta} \quad (7)$$

$$5 \quad y = x \times \tan \theta \quad (8)$$

where, as seen from FIG. 2:

$$y' = y + \Delta y \quad (9)$$

$$x' = x + \Delta x \quad (10)$$

$$y = x \times \tan \theta \quad (11)$$

$$10 \quad y' = x' \times \tan \theta' \quad (12)$$

The positional data (x, y) generated by the computation unit 16 is used in further applications.

As is evident from the foregoing, no ranging function is required in the positioning system 10; the displacement d of the moving object 12 from the point of reference $(0,0)$ is not required for determining the position of the object 12. It follows therefore that strict synchronization between the UWB requestor 14 and the UWB responder 20 is not required. When no communication data is being sent from the UWB requestor 14 to the UWB responder 20, there is only one-way communication in the positioning system 10 (i.e. the UWB responder 20 only sends out UWB signals, but does not receive pulse; the UWB requestor 14 only receives incoming UWB signals, but does not send out pulse). The positioning system 10 is thus simple and easily implemented. Further advantageously, the communication channel is capable of carrying more data for a wider application area in the simplified scenario.

The rate at which the positional data (x, y) is generated or updated by the computation unit 16 is dependent on the rates at which the movement information and the direction of the object 12 are updated. However, as these may be updated at different rates, the speed at which the positional data (x, y) is generated or updated is limited by the slower rate. To overcome this limitation, either the UWB requestor 14 or the computation unit 16 is configured to synchronise respective rates at which the movement information and the determined direction of the object 12 are updated with one of a prediction method and an interpolation method. The prediction or interpolation method is used to generate additional movement or directional data on the object 12 for the parameter that is updated at a slower rate. Advantageously, this increases the speed at which positional data (x, y) is generated by the positioning system 10.

To compensate for cumulative error in the movement information measured by the motion detection device 18, either the UWB requestor 14 or the computation unit 16 is configured to reset a cumulative parameter derived from the movement information when the object 12 is stationary. For example, in an embodiment where the motion detection device 18 is an accelerometer and the direction of the object 12 is determined by the UWB requestor 14 using the preferred direction estimation method described in Singapore Patent Application No. 200504866-5 [3], the computation unit 16 is configured to reset the accumulative velocity measured by the accelerometer when the following conditions are met by the positioning system 10:

(i) the reading on the accelerometer remains at zero (0) (i.e., there is no change in the velocity of the object 12);

(ii) the angle estimated by the UWB requestor 14 remains constant (i.e. the object 12 is either not moving or moving in the same direction relative to the UWB requestor 14); and

(iii) optionally, the signal strength received by each directional antenna remains constant (i.e. the distance between the UWB requestor 14 and the UWB responder 20 is unchanged).

The foregoing conditions are met when the object 12 is stationary. In such an embodiment, the displacement $(\Delta x, \Delta y)$ of the object 12 between times t and $t-1$ is computed with the following equations:

$$\Delta x = (v_x^{t-1} + a_x^t \Delta t) \times \Delta t \quad (13)$$

$$5 \quad \Delta y = (v_y^{t-1} + a_y^t \Delta t) \times \Delta t \quad (14)$$

where:

$$v_x^{t-1} = a_x^{t-1} \Delta t + v_x^{t-2} \quad (15)$$

$$v_y^{t-1} = a_y^{t-1} \Delta t + v_y^{t-2} \quad (16)$$

when the object 12 is moving, and

$$10 \quad v_x^{t-1} = 0 \quad (17)$$

$$v_y^{t-1} = 0 \quad (18)$$

when the object is stationary. Such an embodiment is applicable in a multitude of areas where the UWB responder 20 has a frequent stop status including, but not limited to, virtual gaming applications, pen input applications and robotic applications.

As is evident from the foregoing discussion, the present invention provides a positioning system and method for determining a position of an object. By combining movement information of an object measured by a motion detection device with a direction of the object determined by an UWB requestor, the invention detects the position of the object in real time. Advantageously, the invention is easily implemented and is capable of achieving higher data communication rates compared to other UWB positioning systems. Further advantageously, only a single reference point (i.e. the UWB requestor) is required by the invention to locate the object. Still further advantageously, the invention is capable of controlling cumulative error generated by the motion detection device. The invention has a wide area of

application including, but not limited to, mixed reality gaming, pen input devices and robotics.

The description of the preferred embodiments of the present invention have been presented for purposes of illustration and description, but are not intended to be exhaustive or to limit the invention to the forms disclosed. It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. For example, the invention can be applied in a moveable environment. In certain applications such as robotics, the UWB requestor is coupled to the object and moves around with it. In such applications, the position of the UWB responder is fixed. The motion detection device is coupled to the object and measures the movement information of the UWB requestor during a movement. The inverse of this movement information is used to determine the position of the UWB responder in the UWB requestor coordinate system. Further, the invention is not limited to two-dimensional applications, but can also be implemented in three-dimensional applications as well by projecting a three-dimensional position of the object onto an x-y plane and an x-z plane. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but covers modifications within the scope of the present invention as defined by the appended claims.

Further, unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise", "comprising" and the like are to be construed in an inclusive as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to".

References

- [1] Zhang Jian, Sun Xiaobing, Xu Jin, Ma Yugang, "*Method, System and Apparatus for Mixed Reality*", Sony Corporation, Singapore Patent Application No. 200603968-9 filed on 14 June 2006;
- [2] Jeanne Dietsch, William Kennedy, Matthew LaFary, "*Spatial Data Collection Apparatus and Method*", ActivMedia Robotics, LLC, U.S. Patent No. 6,917,893, 12 July 2005;

[3] Sun Xiaobing, Xu Jin, Ma Yugang, Kanzo Okada, "*Positioning Methods & Systems for UWB Devices*", Sony Corporation, Singapore Patent Application No. 200504866-5 filed on 12 July 2005; and

[4] James L. Richards etc "System and Method for Person or Object
5 Position Location Utilizing Impulse Radio" U. S. Patent No. 6,300,903, Oct.
2001.

CLAIMS

1. A method for determining a position of an object, the method comprising:
 - 5 measuring movement information of the object during a movement;
 determining a direction of the object relative to a point of reference before and after the movement; and
 determining the position of the object based on an object displacement estimate derived from the movement information and the determined direction
 - 10 of the object before and after the movement.
2. The method for determining a position of an object according to claim 1, further comprising resetting a cumulative parameter derived from the movement information when the object is stationary.
- 15 3. The method for determining a position of an object according to claim 1 or 2, further comprising performing an initialisation operation.
4. The method for determining a position of an object according to any
 - 20 one of the preceding claims, further comprising synchronising respective rates at which the movement information and the determined direction of the object are updated with one of a prediction method and an interpolation method.
5. The method for determining a position of an object according to any
 - 25 one of the preceding claims, wherein the movement information comprises one of acceleration data, angular motion data and displacement data.
6. The method for determining a position of an object according to any
 - 30 one of the preceding claims, further comprising communicating the movement information via one or more UWB signals.
7. A positioning system for determining a position of an object, comprising:

a motion detection device coupled to the object, wherein the motion detection device is configured to measure movement information of the object during a movement;

an ultra-wideband (UWB) responder;

5 an UWB requestor, wherein the UWB responder and requestor are configured to determine a direction of the object relative to a point of reference before and after the movement; and

a computation unit configured to determine the position of the object based on an object displacement estimate derived from the movement
10 information and the determined direction of the object before and after the movement.

8. The positioning system for determining a position of an object according to claim 7, wherein one of the UWB requestor and the computation
15 unit is configured to reset a cumulative parameter derived from the movement information when the object is stationary.

9. The positioning system for determining a position of an object according to claim 7 or 8, wherein the motion detection device and the UWB
20 requestor are configured to align their respective coordinates.

10. The positioning system for determining a position of an object according to any one of claims 7 to 9, wherein one of the UWB requestor and the computation unit is configured to synchronise respective rates at which the
25 movement information and the determined direction of the object are updated with one of a prediction method and an interpolation method.

11. The positioning system for determining a position of an object according to any one of claims 7 to 10, wherein the motion detection device is
30 one of an accelerometer, a gyroscope and a trackball.

12. The positioning system for determining a position of an object according to any one of claims 7 to 11, wherein the UWB responder is

coupled to the object and is configured to communicate the movement information generated by the motion detection device to the UWB requestor.

13. The positioning system for determining a position of an object
5 according to any one of claims 7 to 11, wherein the UWB requestor is coupled to the object.

14. A positioning system for determining a position of an object, comprising:

10 a motion detection device coupled to the object, wherein the motion detection device is configured to measure movement information of the object during a movement;

an ultra-wideband (UWB) responder; and

an UWB requestor, wherein the UWB responder and requestor are
15 configured to determine a direction of the object relative to a point of reference before and after the movement and whereby the position of the object is determined based on an object displacement estimate derived from the movement information and the determined direction of the object before and after the movement.