Cywee Group LTD v. Apple Inc.
Doc. 1 Att. 1

EXHIBIT A

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Ye et al.

(10) **Patent No.: US 8,552,978 B2**
(45) **Date of Patent: Oct. 8, 2013**

(54) **3D POINTING DEVICE AND METHOD FOR COMPENSATING ROTATIONS OF THE 3D POINTING DEVICE THEREOF**

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(73) Assignee: **Cywee Group Limited**, Tortola (VG)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 144 days.

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(22) Filed: **Jul. 6, 2011**

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Related U.S. Application Data

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(60) Provisional application No. 61/292,558, filed on Jan. 6, 2010.

(51) **Int. Cl.**
G06F 3/033 (2013.01)
G09G 5/08 (2006.01)

(52) **U.S. Cl.**
USPC **345/157**; 345/156; 345/158; 345/173; 178/18.01; 178/18.03; 178/19.01

(58) **Field of Classification Search**
USPC ... 345/156–168, 173–183; 178/18.01–18.04, 178/19.01–19.04
See application file for complete search history.

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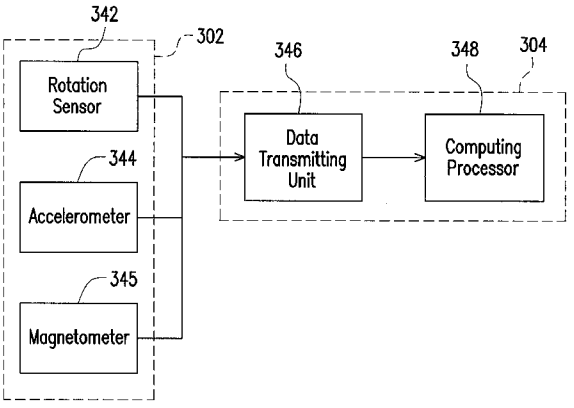
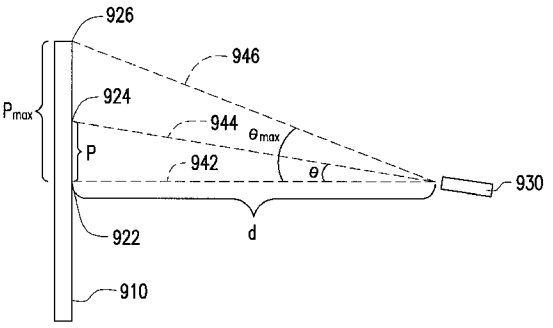
Assistant Examiner — Insa Sadio
(74) *Attorney, Agent, or Firm* — Ding Yu Tan

(57) **ABSTRACT**

A 3D pointing device utilizing an orientation sensor, capable of accurately transforming rotations and movements of the 3D pointing device into a movement pattern in the display plane of a display device is provided. The 3D pointing device includes the orientation sensor, a rotation sensor, and a computing processor. The orientation sensor generates an orientation output associated with the orientation of the 3D pointing device associated with three coordinate axes of a global reference frame associated with the Earth. The rotation sensor generates a rotation output associated with the rotation of the 3D pointing device associated with three coordinate axes of a spatial reference frame associated with the 3D pointing device itself The computing processor uses the orientation output and the rotation output to generate a transformed output associated with a fixed reference frame associated with the display device above. The transformed output represents a segment of the movement pattern.

18 Claims, 12 Drawing Sheets





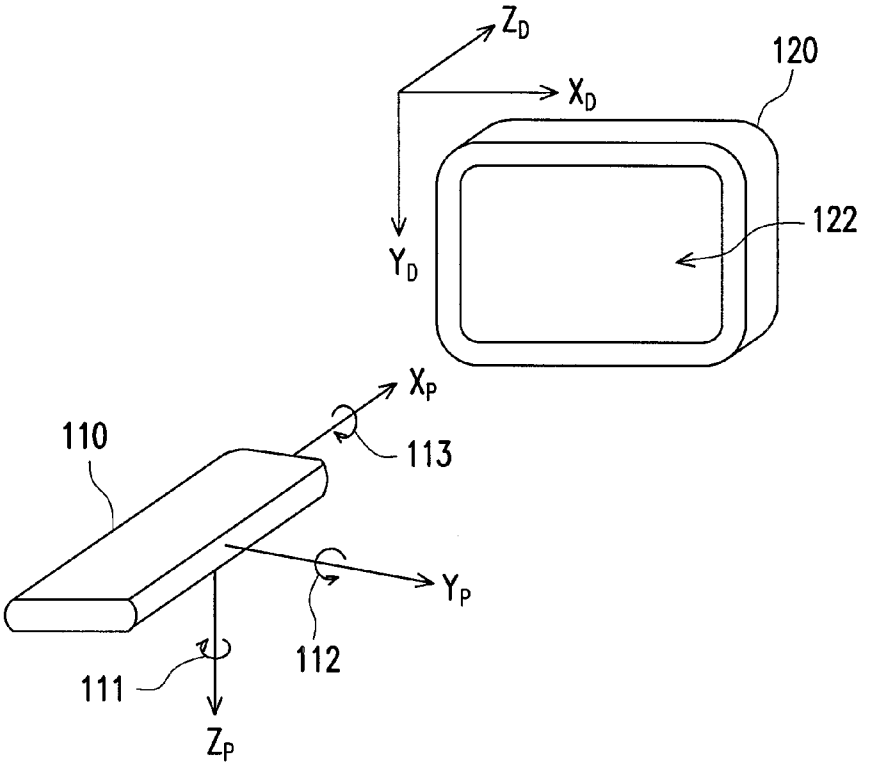


FIG. 1 (RELATED ART)

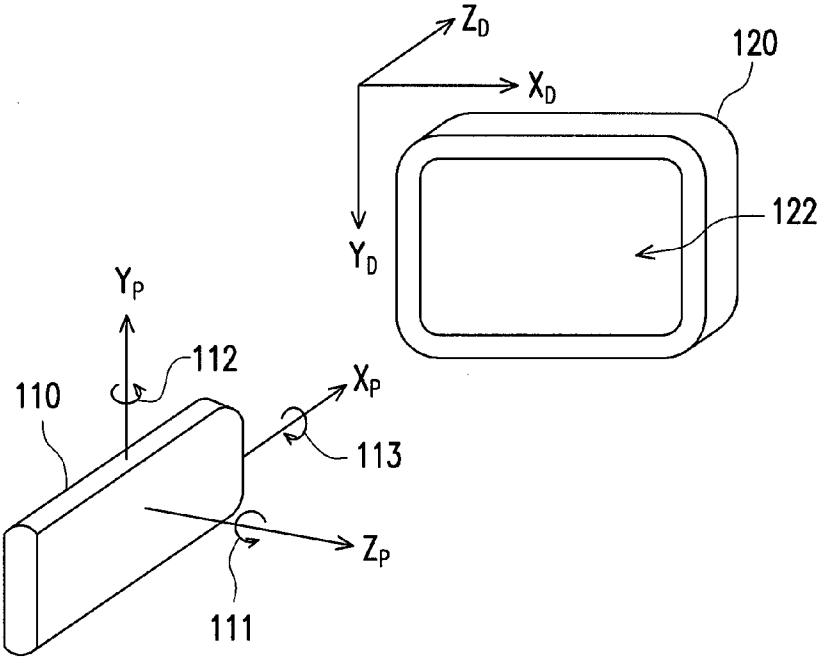


FIG. 2 (RELATED ART)

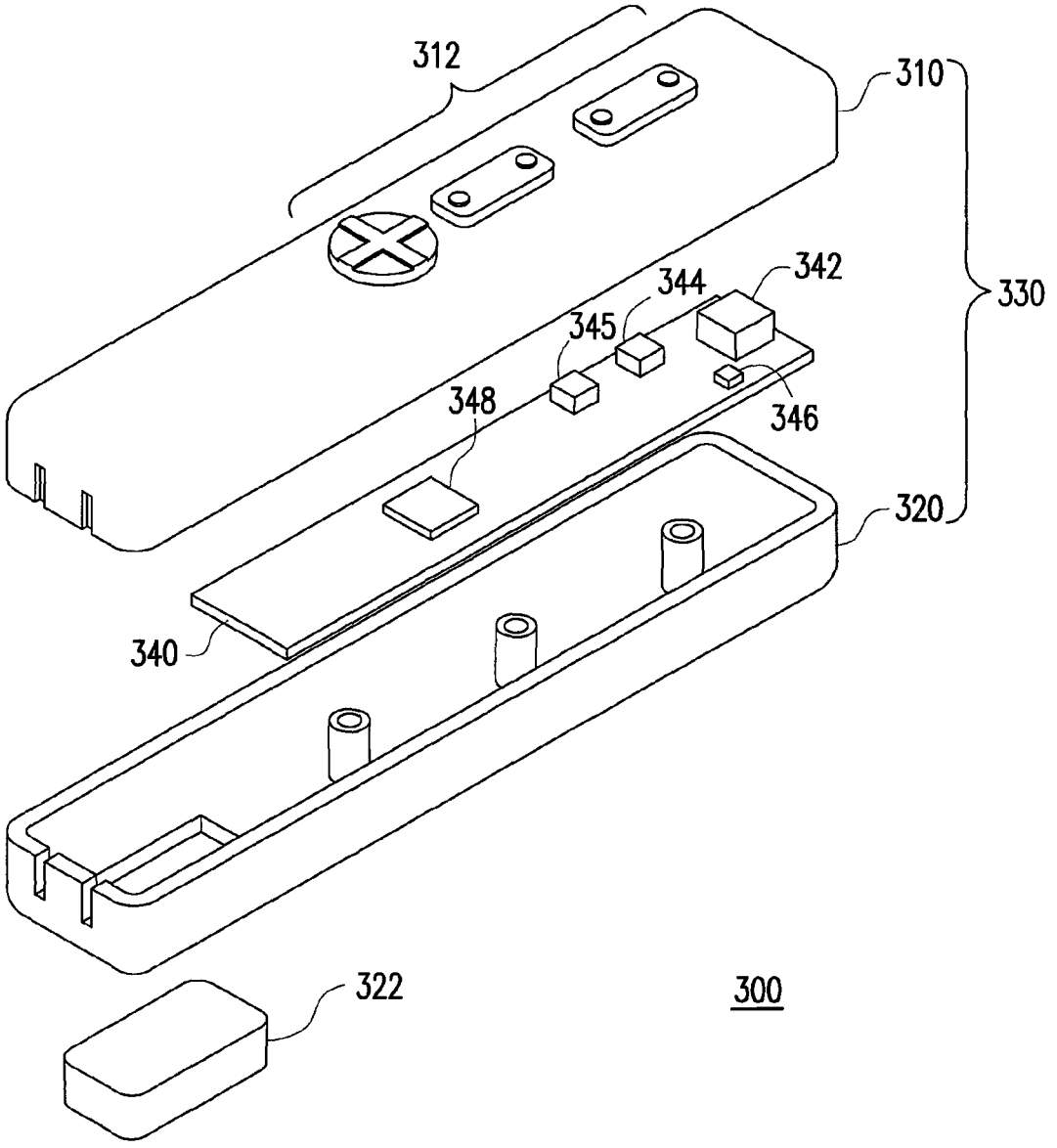


FIG. 3

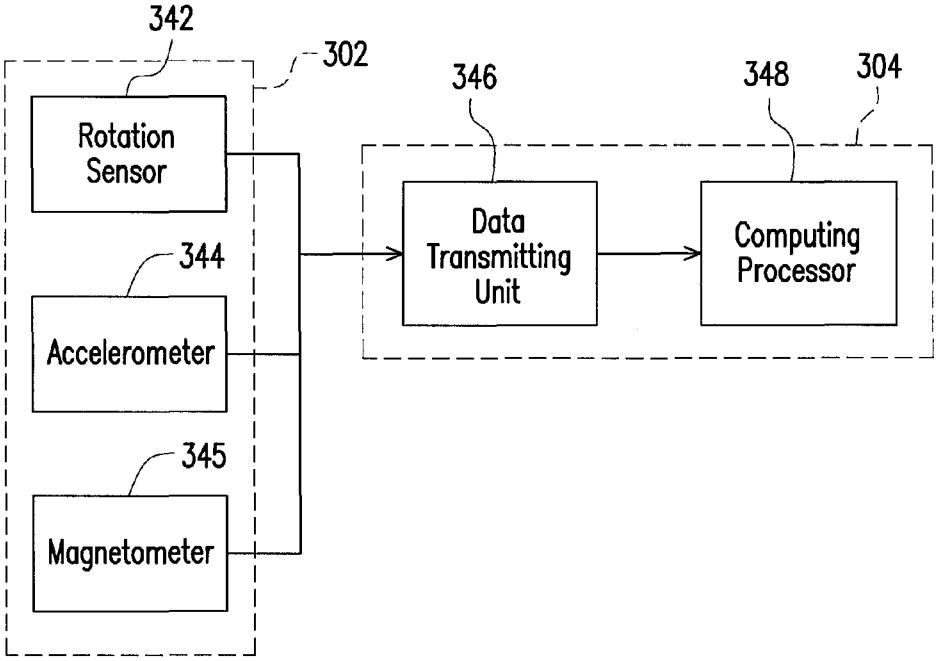

342
302
346
348
304
Rotation Sensor
344
Accelerometer
345
Magnetometer
Data Transmitting Unit
Computing Processor

FIG. 4

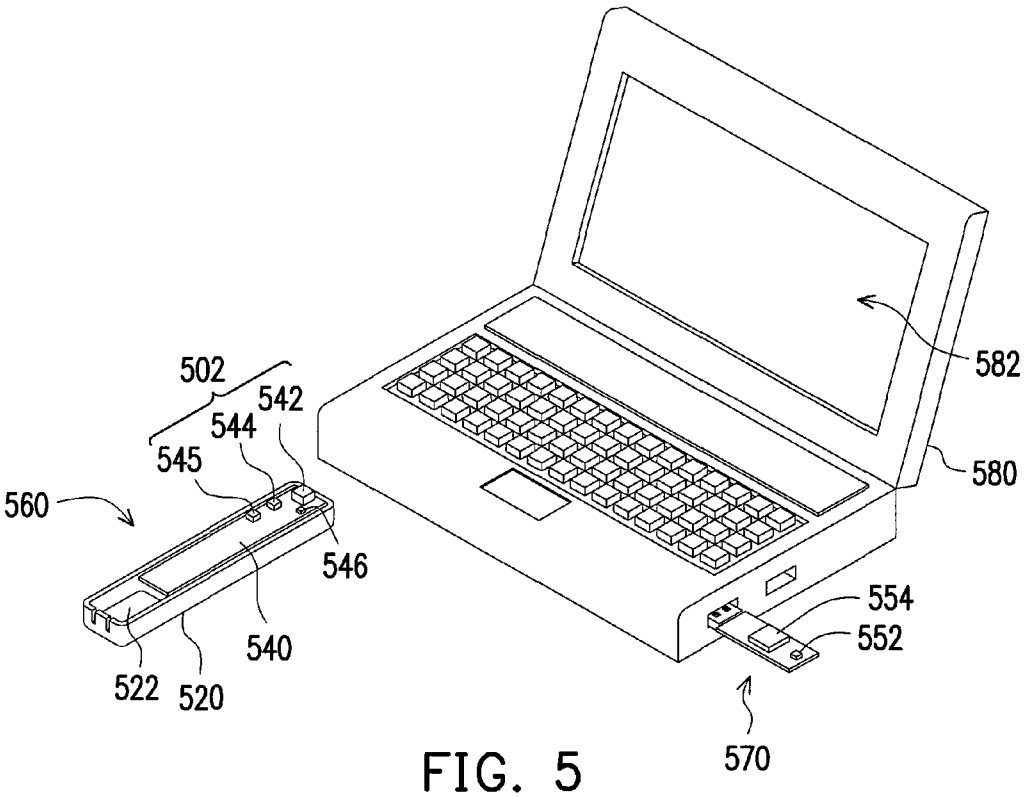

502
542
544
545
560
546
540
522
520
582
580
554
552
570

FIG. 5

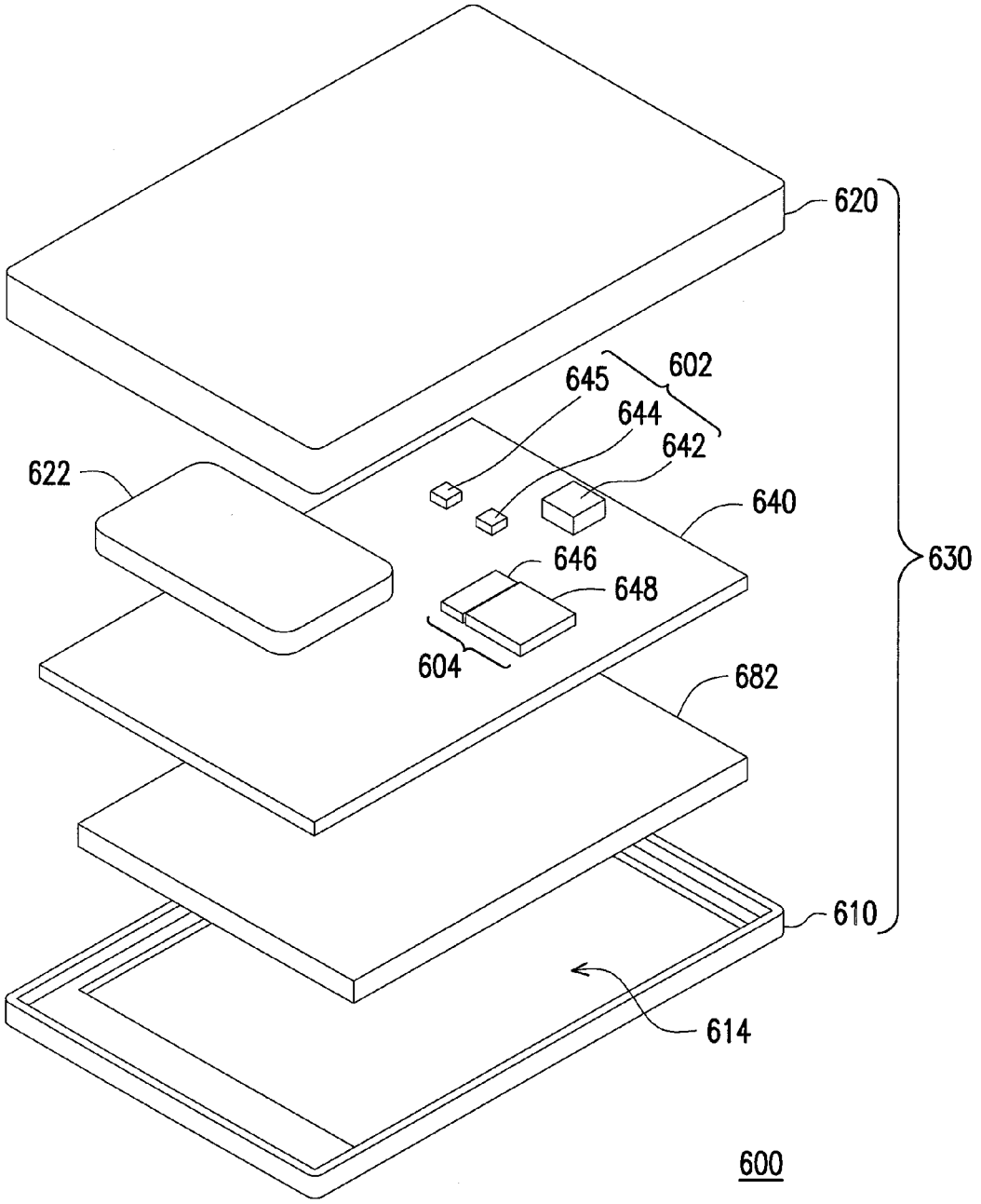


FIG. 6

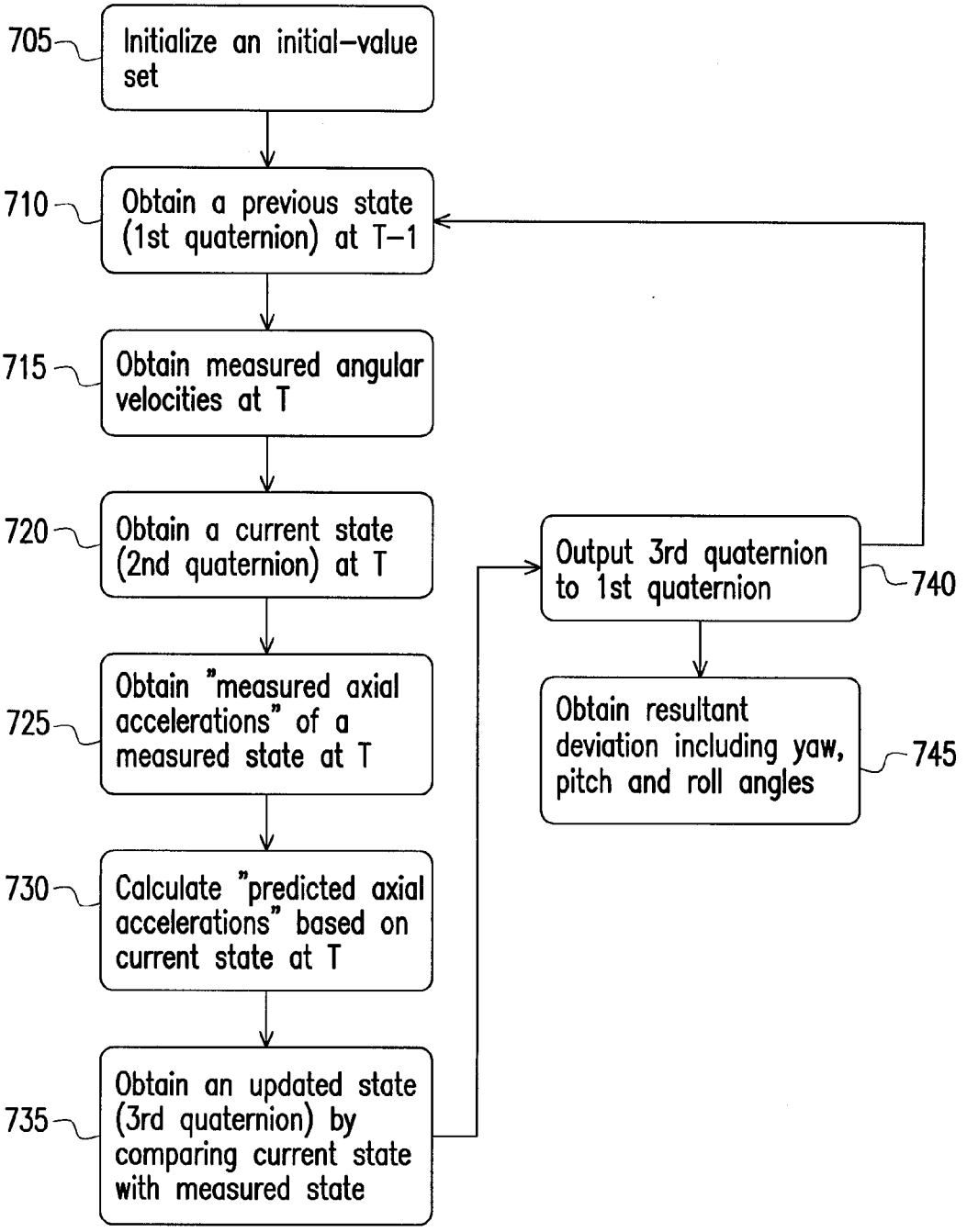

705
Initialize an initial-value set
710
Obtain a previous state (1st quaternion) at T-1
715
Obtain measured angular velocities at T
720
Obtain a current state (2nd quaternion) at T
725
Obtain "measured axial accelerations" of a measured state at T
730
Calculate "predicted axial accelerations" based on current state at T
735
Obtain an updated state (3rd quaternion) by comparing current state with measured state
740
Output 3rd quaternion to 1st quaternion
745
Obtain resultant deviation including yaw, pitch and roll angles

FIG. 7

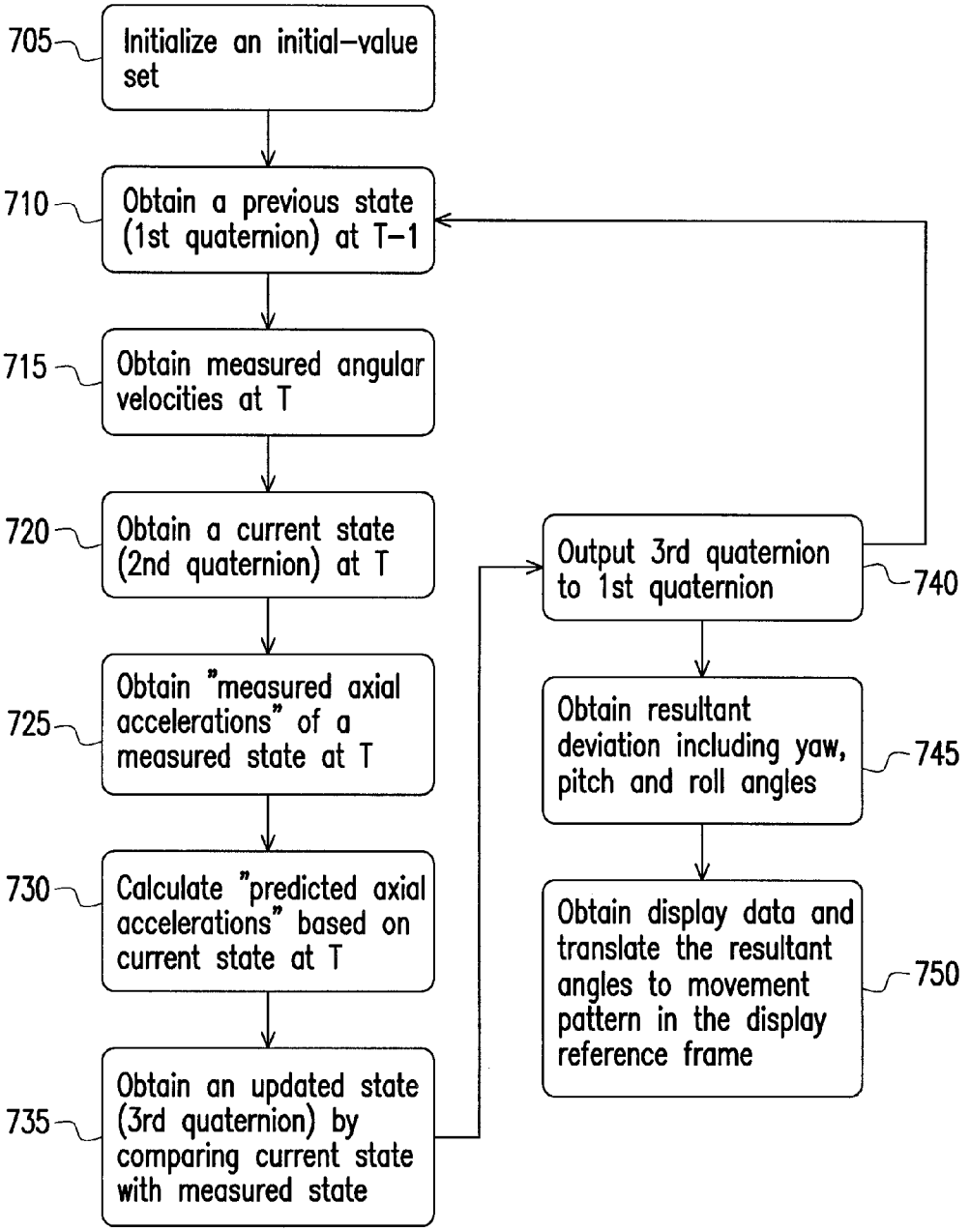

705
Initialize an initial-value set
710
Obtain a previous state (1st quaternion) at T-1
715
Obtain measured angular velocities at T
720
Obtain a current state (2nd quaternion) at T
725
Obtain "measured axial accelerations" of a measured state at T
730
Calculate "predicted axial accelerations" based on current state at T
735
Obtain an updated state (3rd quaternion) by comparing current state with measured state
740
Output 3rd quaternion to 1st quaternion
745
Obtain resultant deviation including yaw, pitch and roll angles
750
Obtain display data and translate the resultant angles to movement pattern in the display reference frame

FIG. 8

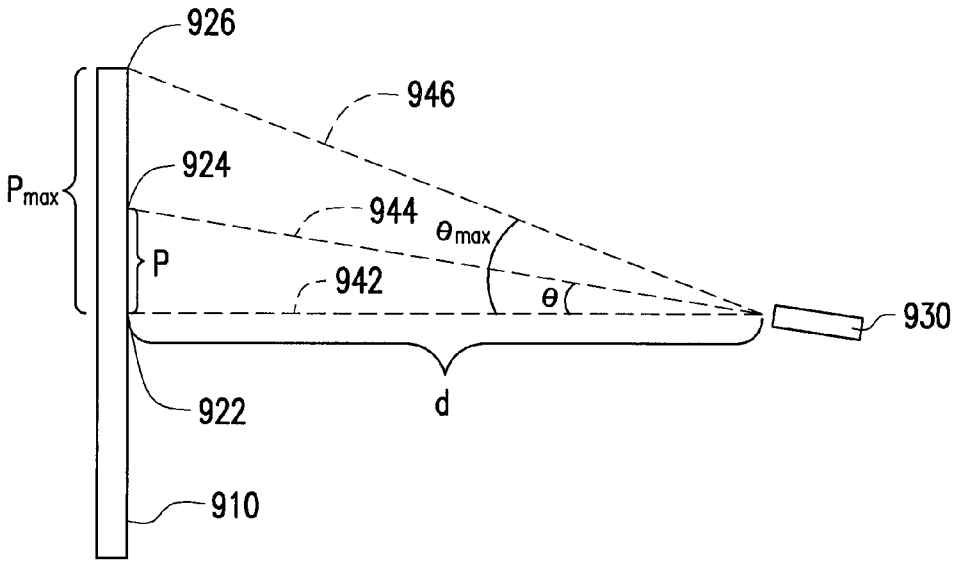


FIG. 9

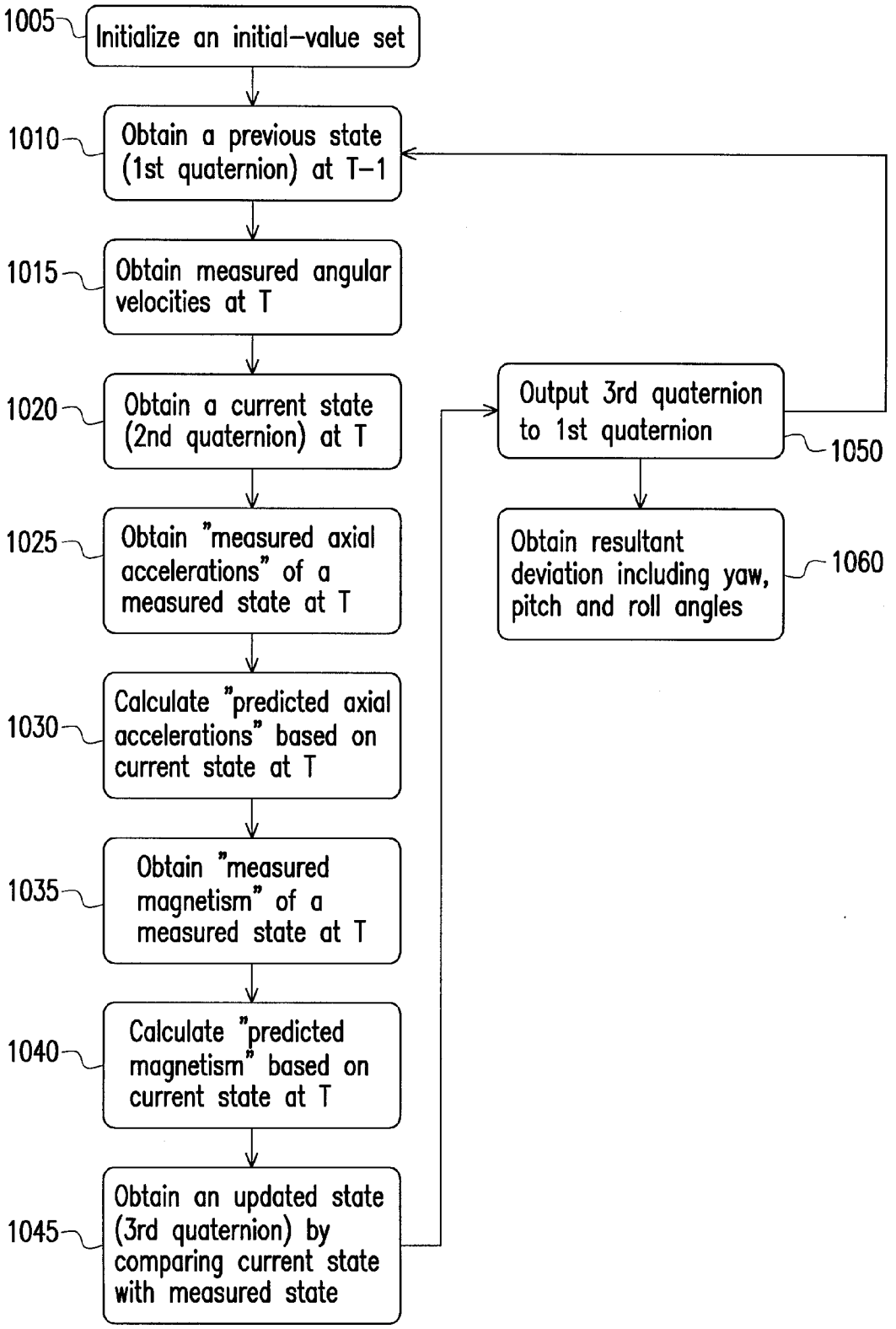

1005
Initialize an initial-value set
1010
Obtain a previous state (1st quaternion) at T-1
1015
Obtain measured angular velocities at T
1020
Obtain a current state (2nd quaternion) at T
1025
Obtain "measured axial accelerations" of a measured state at T
1030
Calculate "predicted axial accelerations" based on current state at T
1035
Obtain "measured magnetism" of a measured state at T
1040
Calculate "predicted magnetism" based on current state at T
1045
Obtain an updated state (3rd quaternion) by comparing current state with measured state
Output 3rd quaternion to 1st quaternion
1050
Obtain resultant deviation including yaw, pitch and roll angles
1060

FIG. 10

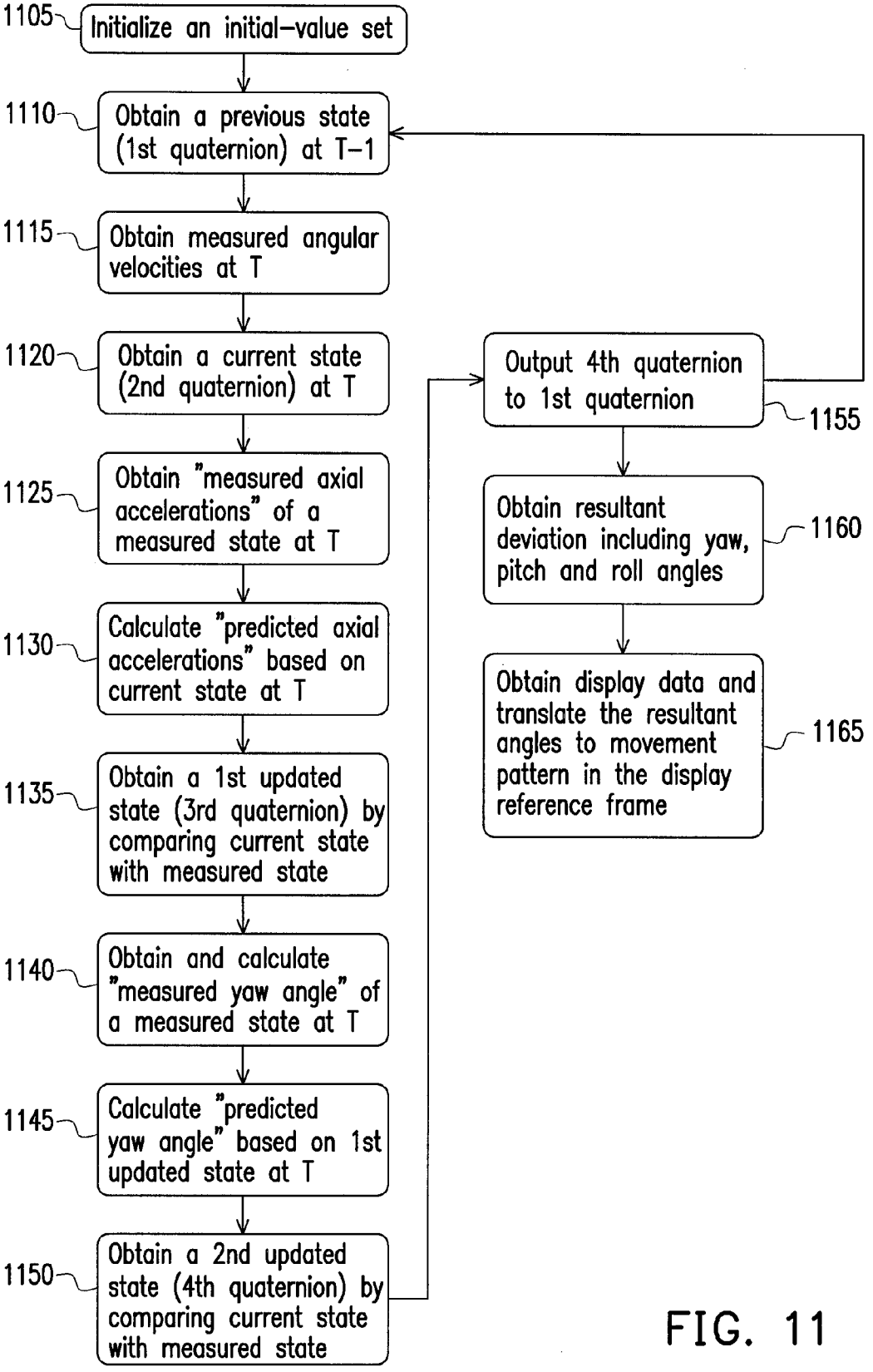

1105
Initialize an initial-value set
1110
Obtain a previous state (1st quaternion) at T-1
1115
Obtain measured angular velocities at T
1120
Obtain a current state (2nd quaternion) at T
1125
Obtain "measured axial accelerations" of a measured state at T
1130
Calculate "predicted axial accelerations" based on current state at T
1135
Obtain a 1st updated state (3rd quaternion) by comparing current state with measured state
1140
Obtain and calculate "measured yaw angle" of a measured state at T
1145
Calculate "predicted yaw angle" based on 1st updated state at T
1150
Obtain a 2nd updated state (4th quaternion) by comparing current state with measured state
Output 4th quaternion to 1st quaternion
1155
Obtain resultant deviation including yaw, pitch and roll angles
1160
Obtain display data and translate the resultant angles to movement pattern in the display reference frame
1165

FIG. 11

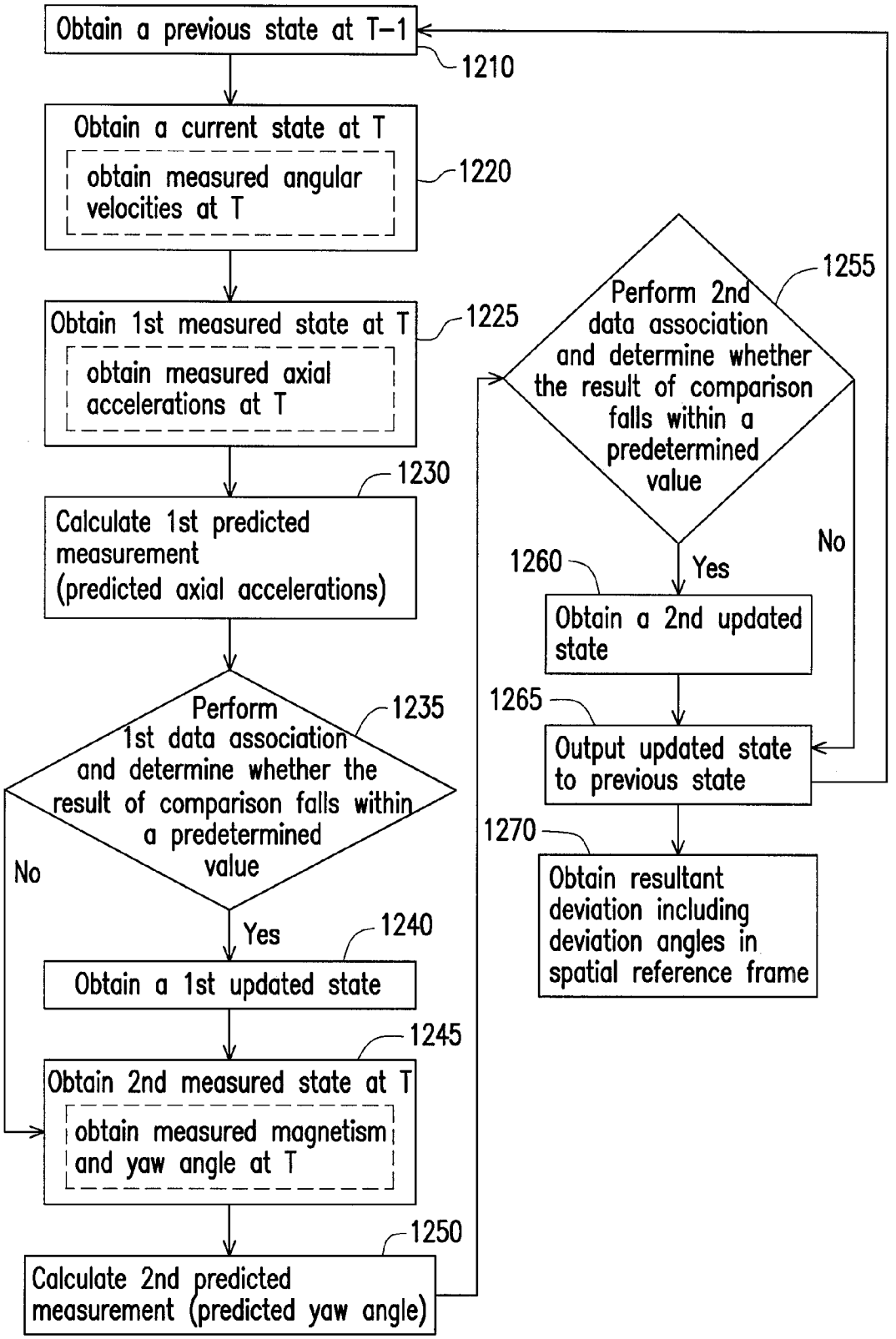

Obtain a previous state at T−1
1210
Obtain a current state at T
obtain measured angular velocities at T
1220
Obtain 1st measured state at T
obtain measured axial accelerations at T
1225
1230
Calculate 1st predicted measurement (predicted axial accelerations)
Perform 1st data association and determine whether the result of comparison falls within a predetermined value
1235
No
Yes
1240
Obtain a 1st updated state
1245
Obtain 2nd measured state at T
obtain measured magnetism and yaw angle at T
1250
Calculate 2nd predicted measurement (predicted yaw angle)
Perform 2nd data association and determine whether the result of comparison falls within a predetermined value
1255
No
Yes
1260
Obtain a 2nd updated state
1265
Output updated state to previous state
1270
Obtain resultant deviation including deviation angles in spatial reference frame

FIG. 12

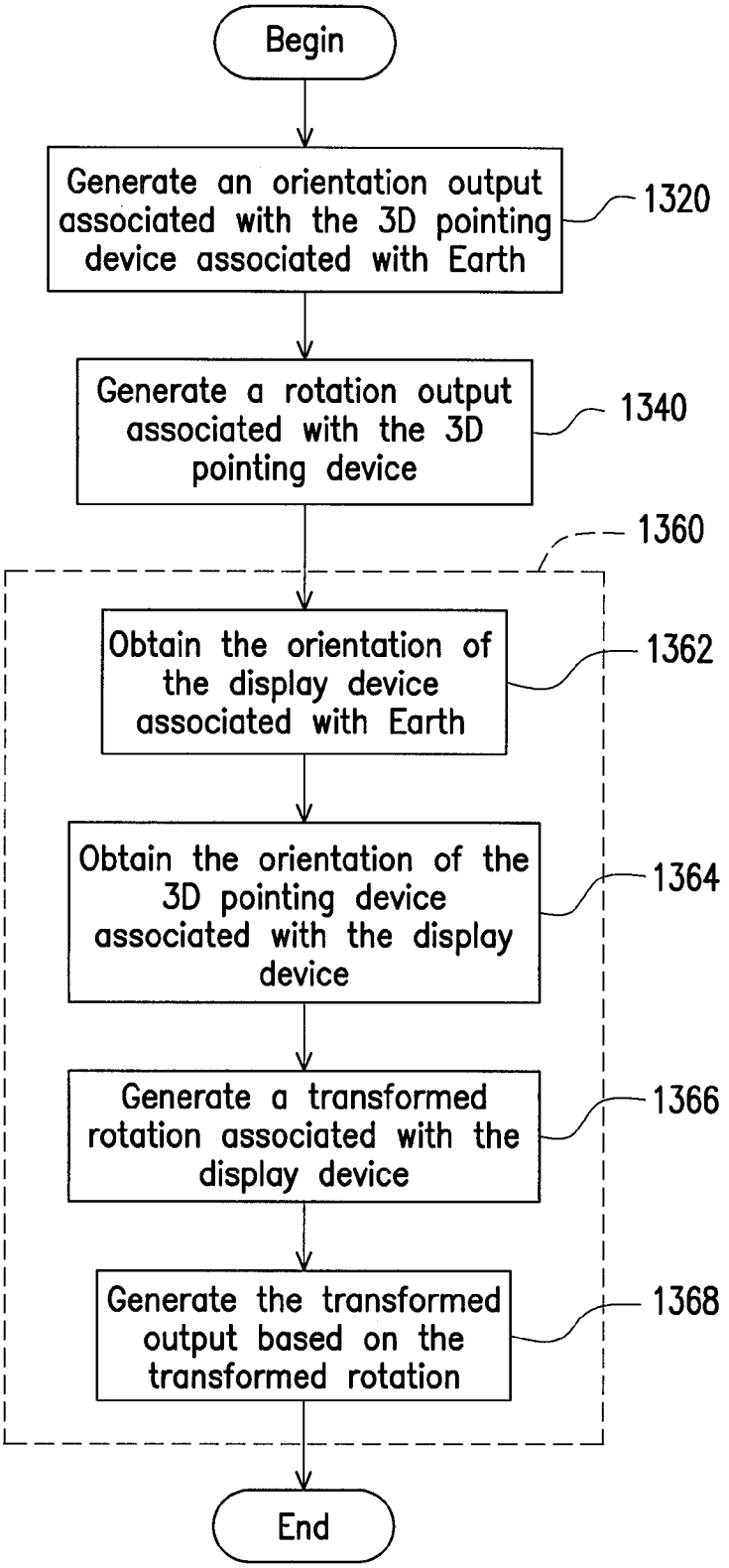

Begin
Generate an orientation output associated with the 3D pointing device associated with Earth
1320
Generate a rotation output associated with the 3D pointing device
1340
1360
Obtain the orientation of the display device associated with Earth
1362
Obtain the orientation of the 3D pointing device associated with the display device
1364
Generate a transformed rotation associated with the display device
1366
Generate the transformed output based on the transformed rotation
1368
End

FIG. 13

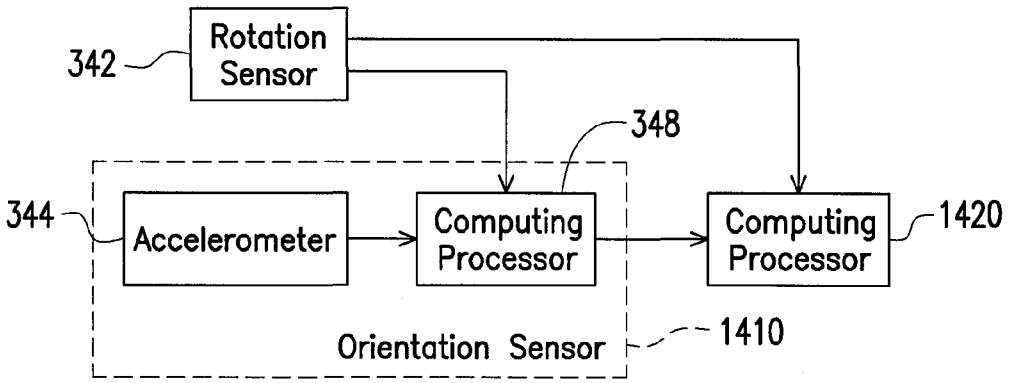


FIG. 14

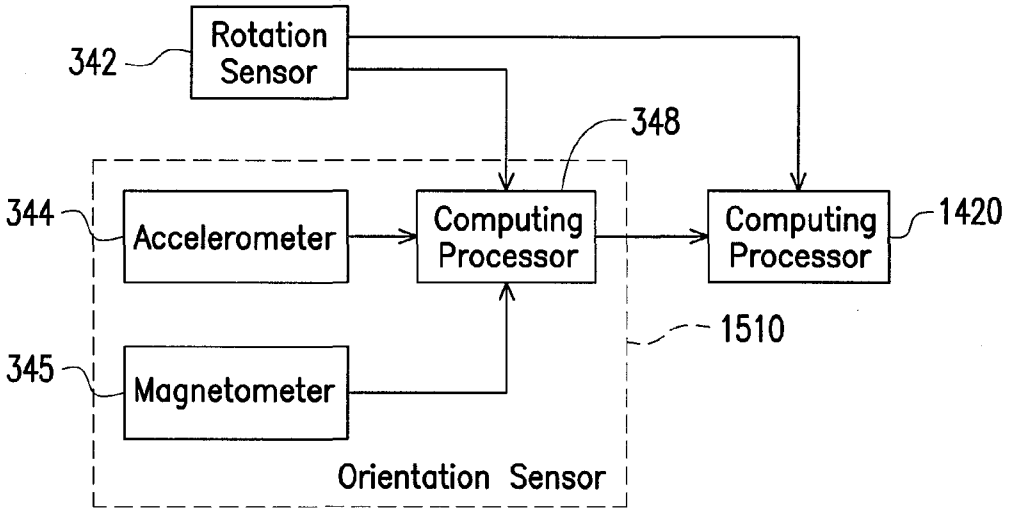


FIG. 15

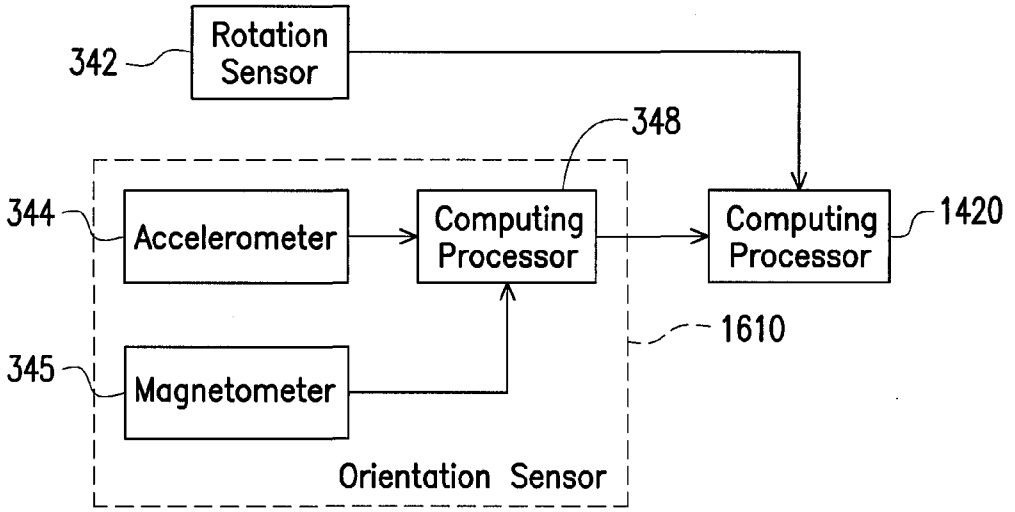


FIG. 16

3D POINTING DEVICE AND METHOD FOR COMPENSATING ROTATIONS OF THE 3D POINTING DEVICE THEREOF

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation in part application of and claims the priority benefit of U.S. application Ser. No. 13/072,794, filed on Mar. 28, 2011, now pending. The prior application Ser. No. 13/072,794 is a continuation in part application of and claims the priority benefit of U.S. application Ser. No. 12/943,934, filed on Nov. 11, 2010, now pending, which claims the priority benefit of U.S. provisional application Ser. No. 61/292,558, filed on Jan. 6, 2010. The entirety of each of the above-mentioned patent applications is hereby incorporated by reference herein and made a part of this specification.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to a 3D pointing device, more particularly to a 3D pointing device for use in computers, motion detection or navigation utilizing a orientation sensor and a method for compensating signals of the orientation sensor subject to movements and rotations of said 3D pointing device.

2. Description of the Related Art

FIG. **1** is a schematic diagram showing a user using a portable electronic device **110**, such as a 3D pointing device or computer mouse, for detecting motions of the device and translating the detected motions to a cursor display such as a cursor pointing on the screen **122** of a 2D display device **120**. If the pointing device **110** emits a light beam, the corresponding point would be the location where the light beam hits the screen **122**. For example, the pointing device **110** may be a mouse of a computer or a pad of a video game console. The display device **120** may be a part of the computer or the video game console. There are two reference frames, such as the spatial pointer reference frame and the display frame, associated with the pointing device **110** and the display device **120**, respectively. The first reference frame or spatial pointer reference frame associated with the pointing device **110** is defined by the coordinate axes X_P, Y_P and Z_P as shown in FIG. **1**. The second reference frame or display frame associated with the display device **120** is defined by the coordinate axes X_D, Y_D and Z_D as shown in FIG. **1**. The screen **122** of the display device **120** is a subset of the X_DY_D plane of the reference frame $X_DY_DZ_D$ associated with the display device **120**. Therefore, the X_DY_D plane is also known as the display plane associated with the display device **120**.

A user may perform control actions and movements utilizing the pointing device for certain purposes including entertainment such as playing a video game, on the display device **120** through the aforementioned pointer on the screen **122**. For proper interaction with the use of the pointing device, when the user moves the pointing device **110**, the pointer on the screen **122** is expected to move along with the orientation, direction and distance travelled by the pointing device **110** and the display **120** shall display such movement of the pointer to a new location on the screen **122** of the display **120**. The orientation of the pointing device **110** may be represented by three deviation angles of the 3D pointing device **110** with respect to the reference frame $X_PY_PZ_P$, namely, the yaw angle **111**, the pitch angle **112** and the roll angle **113**. The yaw, pitch and roll angles **111**, **112**, **113** may be best understood in relation to the universal standard definition of spatial angles

related to commercial vehicles or transportation such as ships and airplanes. Conventionally, the yaw angle **111** may represent the rotation of the pointing device **110** about the Z_P axis; the pitch angle **112** may represent the rotation of the pointing device **110** about the Y_P axis; the roll angle **113** may represent the rotation of the pointing device **110** about the X_P axis.

In a known related art as shown in FIG. **1**, when the yaw angle **111** of the pointing device **110** changes, the aforementioned pointer on the screen **122** must move horizontally or in a horizontal direction with reference to the ground in response to the change of the yaw angle **111**. FIG. **2** shows what happens when the user rotates the pointing device **110** counterclockwise by a degree such as a 90-degree about the X_P axis. In another known related art as shown in FIG. **2**, when the yaw angle **111** changes, the aforementioned pointer on the screen **122** is expected to move vertically in response. The change of the yaw angle **111** can be detected by a gyro-sensor which detects the angular velocity ω_x of the pointing device **110** about the X_P axis. FIG. **1** and FIG. **2** show that the same change of the yaw angle **111** may be mapped to different movements of the point on the screen **122**. Therefore, a proper compensation mechanism for the orientation of the pointing device **110** is required such that corresponding mapping of the pointer on the screen **122** of the display **120** may be obtained correctly and desirably. The term compensation of the prior arts by Liberty (U.S. Pat. Nos. 7,158,118, 7,262,760 and 7,414,611) refers to the correction and compensation of signals subject to gravity effects or extra rotations about the axis related to "roll". The term of "comparison" of the present invention may generally refer to the calculating and obtaining of the actual deviation angles of the 3D pointing device **110** with respect to the first reference frame or spatial pointing frame $X_PY_PZ_P$ utilizing signals generated by motion sensors while reducing or eliminating noises associated with said motion sensors; whereas the term mapping may refer to the calculating and translating of said deviation angles in the spatial pointing frame $X_PY_PZ_P$ onto the aforementioned pointer on the display plane associated with the 2D display device **120** of a second reference frame or display frame $X_DY_DZ_D$.

It is known that a pointing device utilizing 5-axis motion sensors, namely, Ax, Ay, Az, ω_Y and ω_Z may be compensated. For example, U.S. Pat. No. 7,158,118 by Liberty, U.S. Pat. No. 7,262,760 by Liberty and U.S. Pat. No. 7,414,611 by Liberty provide such pointing device having a 5-axis motion sensor and discloses a compensation using two gyro-sensors ω_Y and ω_Z to detect rotation about the Yp and Zp axes, and accelerometers Ax, Ay and Az to detect the acceleration of the pointing device along the three axes of the reference frame $X_PY_PZ_P$. The pointing device by Liberty utilizing a 5-axis motion sensor may not output deviation angles of the pointing device in, for example, a 3D reference frame; in other words, due to due to the limitation of the 5-axis motion sensor of accelerometers and gyro-sensors utilized therein, the pointing device by Liberty cannot output deviation angles readily in 3D reference frame but rather a 2D reference frame only and the output of such device having 5-axis motion sensors is a planar pattern in 2D reference frame only. In addition, it has been found that the pointing device and compensation disclosed therein cannot accurately or properly calculate or obtain movements, angles and directions of the pointing device while being subject to undesirable interferences, external or internal, in the dynamic environment during the obtaining of the signals generated by the motion sensors, in particular, during unexpected drifting movements and/or accelerations along with the direction of gravity. In other words, it has been found that dynamic actions or extra accel-

erations including additional accelerations, in particular the one acted upon the direction substantially parallel to or along with the gravity imposed on the pointing device with the compensation methods provided by Liberty, said pointing device by Liberty cannot properly or accurately output the actual yaw, pitch and roll angles in the spatial reference frame $X_PY_PZ_P$ and following which, consequently, the mapping of the spatial angles onto any 2D display reference frame such as $X_DY_DZ_D$ may be greatly affected and erred. To be more specific, as the 5-axis compensation by Liberty cannot detect or compensate rotation about the X_P axis directly or accurately, the rotation about the X_P axis has to be derived from the gravitational acceleration detected by the accelerometer. Furthermore, the reading of the accelerometer may be accurate only when the pointing device is static since due to the limitation on known accelerometers that these sensors may not distinguish the gravitational acceleration from the acceleration of the forces including centrifugal forces or other types of additional accelerations imposed or exerted by the user.

Furthermore, it has been found that known prior arts may only be able to output a "relative" movement pattern in a 2D reference frame based on the result calculated from the signals of motion sensors. For example, the abovementioned prior arts by Liberty may only output a 2D movement pattern in a relative manner and a pointer on a display screen to show such corresponding 2D relative movement pattern. To be more specific, the pointer moves from a first location to a second new location relative to said first location only. Such relative movement from the previous location to the next location with respect to time cannot accurately determine and/or output the next location, particularly in situations where the previous location may have been an erred location or have been faultily determined as an incorrect reference point for the next location that is to be calculated therefrom and obtained based on their relative relationship adapted. One illustration of such defect of known prior arts adapting a relative relationship in obtaining a movement pattern may be clearly illustrated by an example showing the faultily outputted movements of a pointer intended to move out of a boundary or an edge of display screen. It has been found that as the pointer of known prior arts reaches the edge of a display and continues to move out of the boundary or edge at a certain extra extent beyond said boundary, the pointer fails to demonstrate a correct or "absolute" pattern as it moves to a new location either within the display or remaining outside of the boundary; in other words, instead of returning to a new location by taking into account said certain extra extend beyond the boundary made earlier in an "absolute" manner, the pointer of known arts discards such virtual distance of the extra extend beyond the boundary already made and an erred next position is faultily outputted due to the relative relationship adapted and utilized by the pointer.

Therefore, it is clear that an improved device for use in for example motion detection, computers or navigation with enhanced calculating or comparison method capable of accurately obtaining and calculating actual deviation angles in the spatial pointer frame is needed. For applications of navigations or computers including portable communication devices integrated with displays therein, the electronic device may too include the mapping of such actual angles onto a cursor, pointer or position information on the display frame in dynamic environments and conditions including undesirable external interferences. In addition, as the trend of 3D technology advances and is applicable to various fields including displays, interactive systems and navigation, there is a significant need for an electronic device, including for example a motion detector, a 3D pointing device, a navigation equipment, or a communication device integrated with motion sensors therein, capable of accurately outputting a deviation of such device readily useful in a 3D or spatial reference frame. Furthermore, there is a need to provide an enhanced comparison method and/or model applicable to the processing of signals of motion sensors such that errors and/or noises associated with such signals or fusion of signals from the motions sensors may be corrected or eliminated. In addition, according to the field of application, such output of deviation in 3D reference frame may too be further mapped or translated to a pattern useful in a 2D reference frame.

SUMMARY OF THE INVENTION

According to one aspect of an exemplary embodiment of the present invention, an electronic device utilizing a nine-axis motion sensor module for use in for example computers, motion detection or navigation is provided. The electronic device comprises an accelerometer to measure or detect axial accelerations Ax, Ay, Az, a magnetometer to measure or detect magnetism Mx, My, Mz and a rotation sensor to measure or detect angular velocities ω_x, ω_y, ω_z such that resulting deviation including resultant angles comprising yaw, pitch and roll angles in a spatial pointer frame of the electronic device subject to movements and rotations in dynamic environments may be obtained and such that said resulting deviation including said resultant angles may be obtained and outputted in an absolute manner reflecting or associating with the actual movements and rotations of the electronic device of the present invention in said spatial pointer reference frame and preferably excluding undesirable external interferences in the dynamic environments.

According to another aspect of the present invention, the present invention provides an enhanced comparison method and/or model to eliminate the accumulated errors as well as noises over time associated with signals generated by a combination of motion sensors, including the ones generated by accelerometers A_x, A_y, A_z, the ones generated by magnetometers M_x, M_y, M_z and the ones generated by gyroscopes ω_x, ω_y, ω_x in dynamic environments. In other words, accumulated errors associated with a fusion of signals from a motions sensor module comprising a plurality of motion sensors to detect movements on and rotations about different axes of a reference frame may be eliminated or corrected.

According to still another aspect of the present invention, the present invention provides an enhanced comparison method to correctly calculating and outputting a resulting deviation comprising a set of resultant angles including yaw, pitch and roll angles in a spatial pointer frame, preferably about each of three orthogonal coordinate axes of the spatial pointer reference frame, by comparing signals of rotation sensor related to angular velocities or rates with the ones of accelerometer related to axial accelerations and the ones of magnetometer related to magnetism such that these angles may be accurately outputted and obtained, which may too be further mapping to another reference frame different from said spatial pointer frame.

In the event of interferences including external interferences introduced by either the device user or the surrounding environment, such as external electromagnetic fields, according to still another aspect of the present invention, the present invention provides a unique update program comprising a data association model to intelligently process signals received from a motion sensor module to output a resultant deviation preferably in 3D reference frame such that the adverse effects caused by the interferences may be advantageously reduced or compensated.

According to still another aspect of the present invention, the present invention further provides a mapping of the abovementioned resultant angles, preferably about each of three orthogonal coordinate axes of the spatial pointer reference frame, including yaw, pitch and roll angles in a spatial pointer reference frame onto a display frame either external to the device of the present invention or integrated therein such that a movement pattern in a display frame different from the spatial pointer reference frame may be obtained according to the mapping or translation of the resultant angles of the resultant deviation onto said movement pattern.

According to another example embodiment of the present invention, an electronic device capable of generating 3D deviation angles and for use in for example computers, motion detection or navigation is provided. The electronic device may utilize a nine-axis motion sensor module with an enhanced comparison method or model for eliminating accumulated errors of said nine-axis motion sensor module to obtain deviation angles corresponding to movements and rotations of said electronic device in a spatial pointer reference frame. The comparison method or model may be advantageously provided by comparing signals from the abovementioned nine-axis motion sensor module capable of detecting rotation rates or angular velocities of the electronic device about all of the X_P, Y_P and Z_P axes as well as axial accelerations and ambient magnetism including such as Earth's magnetic field or that of other planets of the electronic device along all of the X_P, Y_P and Z_P axes such that deviation angles of the resultant deviation of the electronic device of the present invention may be preferably obtained or outputted in an absolute manner. In other words, the present invention is capable of accurately outputting the abovementioned deviation angles including yaw, pitch and roll angles in a 3D spatial pointer reference frame of the 3D pointing device to eliminate or reduce accumulated errors and noises generated over time in a dynamic environment including conditions such as being subject to a combination of continuous movements, rotations, external gravity forces, magnetic field and additional extra accelerations in multiple directions or movement and rotations that are continuously nonlinear with respect to time; and furthermore, based on the deviation angles being compensated and accurately outputted in 3D spatial reference frame may be further mapped onto or translated into another reference frame such as the abovementioned display frame, for example a reference in two-dimension (2D).

According to another example embodiment of the present invention, a 3D pointing device utilizing a nine-axis motion sensor module is provided; wherein the nine-axis motion sensor module of the 3D pointing device comprises at least one gyroscope, at least one accelerometer and at least one magnetometer. In one preferred embodiment of the present invention, the nine-axis motion sensor module comprises a rotation sensor capable of detecting and generating angular velocities of ω_x, ω_y, ω_z, an accelerometer capable of detecting and generating axial accelerations of Ax, Ay, Az, and a magnetometer capable of detecting and generating magnetism of Mx, My, Mz. It can be understood that in another embodiment, the abovementioned rotation sensor may comprise three gyroscopes corresponding to each of the said angular velocities of ω_x, ω_y, ω_z in a 3D spatial reference frame of the 3D pointing device; whereas the abovementioned accelerometer may comprise three accelerometers corresponding to each of the said axial accelerations Ax, Ay, Az in a 3D spatial reference frame of the 3D pointing device; and whereas the abovementioned magnetometer may comprise three magnetic sensors such as magneto-impedance (MI) sensors or magneto-resistive (MR) sensors corresponding to each of the said magnetism Mx, My, Mz in a 3D spatial reference frame of the electronic device. The rotation sensor detects the rotation of the 3D pointing device with respect to a reference frame associated with the 3D pointing device and provides a rotation rate or angular velocity output. The angular velocity output includes three components corresponding to the rotation rate or angular velocities ω_x, ω_y, ω_z of the 3D pointing device about the first axis, the second axis and the third axis of the reference frame, namely, Xp, Yp and Zp of the 3D spatial frame. The accelerometer detects the axial accelerations of the 3D pointing device with respect to the spatial reference frame such as a 3D-pointer reference frame and provides an acceleration output. The acceleration output includes three components corresponding to the accelerations, Ax, Az, Ay of the 3D pointing device along the first axis, the second axis and the third axis of the reference frame, namely, Xp, Yp and Zp of the 3D spatial reference frame. The magnetometer detects the magnetism of the electronic device with respect to the spatial reference frame such as a 3D reference frame and provides an magnetism output. The magnetism output includes three components corresponding to the magnetism, Mx, My, Mz of the 3D pointing device along the first axis, the second axis and the third axis of the reference frame, namely, Xp, Yp and Zp of the 3D spatial frame. It can, however, be understood that the axes of Xp, Yp and Zp of the 3D spatial reference frame may too be represented simply by the denotation of X, Y and Z.

According to another example embodiment of the present invention, a method for compensating accumulated errors of signals of the abovementioned nine-axis motion sensor module in dynamic environments associated in a spatial reference frame is provided. In one embodiment, the method may be performed or handled by a hardware processor. The processor is capable of compensating the accumulated errors associated with the resultant deviation in relation to the signals of the abovementioned nine-axis motion sensor module of the 3D pointing device subject to movements and rotations in a spatial reference frame and in a dynamic environment by performing a data comparison to compare signals of rotation sensor related to angular velocities with the ones of accelerometer related to axial accelerations and the ones of magnetometer related to magnetism such that the resultant deviation corresponding to the movements and rotations of the 3D pointing device in the 3D spatial reference frame may be obtained accurately over time in the dynamic environments.

According to another embodiment of the present invention, a method for obtaining a resulting deviation including resultant angles in a spatial reference frame of a three-dimensional (3D) pointing device utilizing a nine-axis motion sensor module therein and subject to movements and rotations in dynamic environments in said spatial reference frame is provided. Said method comprises the steps of: obtaining a previous state associated with previous angular velocities ω_x, ω_y, ω_z gained from the motion sensor signals of the nine-axis motion sensor module at a previous time T−1; obtaining a current state of the nine-axis motion sensor module by obtaining measured angular velocities ω_x, ω_y, ω_z gained from the motion sensor signals at a current time T; obtaining a measured state of the nine-axis motion sensor module by obtaining measured axial accelerations Ax, Ay, Az and measured magnetism M_x, M_y, M_z gained from the motion sensor signals at the current time T and calculating predicted axial accelerations Ax', Ay', Az' and predicted magnetism M_x', M_y', M_z' based on the measured angular velocities ω_x, ω_y, ω_z of the current state; obtaining an updated state of the nine-axis motion sensor module by comparing the current state with the measured state of the nine-axis motion sensor module; and

calculating and converting the updated state of the nine-axis motion sensor module to said resulting deviation comprising said resultant angles in said spatial reference frame of the 3D pointing device.

According to another aspect of the present invention, a method for mapping deviation angles associated with movements and rotations of a 3D pointing device in a spatial reference frame onto a display frame of a display having a predetermined screen size is provided. In one embodiment, the method for mapping or translating deviation angles including yaw, pitch and roll angles in a spatial reference frame to an pointing object, such as a pointer, having movements in a display frame, preferably a 2D reference frame, comprises the steps of obtaining boundary information of the display frame by calculating a predefined sensitivity associated with the display frame and performing angle and distance translation in the display frame based on said deviation angles and boundary information.

According to another embodiment of the present invention, a method for obtaining a resulting deviation including resultant angles in a spatial reference frame of a three-dimensional pointing device utilizing a nine-axis motion sensor module therein and subject to movements and rotations in dynamic environments in said spatial reference frame is provided. Said method comprises the steps of: obtaining a previous state of the nine-axis motion sensor module; wherein the previous state includes an initial-value set associated with at least previous angular velocities gained from the motion sensor signals of the nine-axis motion sensor module at a previous time T−1; obtaining a current state of the nine-axis motion sensor module by obtaining measured angular velocities ω_x, ω_y, ω_z gained from the motion sensor signals of the nine-axis motion sensor module at a current time T; obtaining a measured state of the nine-axis motion sensor module by obtaining measured axial accelerations Ax, Ay, Az gained from the motion sensor signals of the nine-axis motion sensor module at the current time T and calculating predicted axial accelerations Ax', Ay', Az' based on the measured angular velocities ωx, ωy, ωz of the current state of the nine-axis motion sensor module; obtaining a first updated state of the nine-axis motion sensor module by comparing the current state with the measured state of the nine-axis motion sensor module; obtaining the measured state of the nine-axis motion sensor module by obtaining and calculating a measured yaw angle gained from the motion sensor signals of the nine-axis motion sensor module at the current time T and calculating a predicted yaw angle based on the first updated state of the nine-axis motion sensor module; obtaining a second updated state of the nine-axis motion sensor module by comparing the current state with the measured state of the nine-axis motion sensor module; and calculating and converting the second updated state of the nine-axis motion sensor module to said resulting deviation comprising said resultant angles in said spatial reference frame of the electronic device.

According to another aspect of the present invention, a 3D pointing device is provided, which includes an orientation sensor, a rotation sensor, and a computing processor. The orientation sensor generates an orientation output associated with an orientation of the 3D pointing device associated with three coordinate axes of a global reference frame associated with the Earth. The rotation sensor generates a rotation output associated with a rotation of the 3D pointing device associated with three coordinate axes of a spatial reference frame associated with the 3D pointing device. The computing processor uses the orientation output and the rotation output to generate a transformed output associated with a fixed reference frame associated with a display device.

According to another aspect of the present invention, a method for compensating the rotations of a 3D pointing device is provided. The method includes the following steps. Generate an orientation output associated with an orientation of the 3D pointing device associated with three coordinate axes of a global reference frame associated with the Earth. Generate a rotation output associated with the rotation of the 3D pointing device associated with three coordinate axes of a spatial reference frame associated with the 3D pointing device. Use the orientation output and the rotation output to generate a transformed output associated with a fixed reference frame associated with a display device.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention, and are incorporated herein for illustrative purposes only. The drawings illustrate embodiments of the invention and, together with the description, serve to only illustrate the principles of the invention.

FIG. **1** shows a known related art having a 5-axis motion sensor in 2D reference frame.

FIG. **2** shows the known related art having a 5-axis motion sensor as shown in FIG. **1** being rotated or rolled about Xp axis and is subject to further dynamic interactions or environment.

FIG. **3** is an exploded diagram showing an electronic device of the present invention, such as a pointing device, utilizing a nine-axis motion sensor module according to one embodiment of the present invention.

FIG. **4** is a schematic block diagram illustrating hardware components of an electronic device according to one embodiment of the present invention.

FIG. **5** is a schematic diagram showing another embodiment of an electronic device of the present invention, such as a pointing device, utilizing a nine-axis motion sensor module as well as an external processor.

FIG. **6** is an exploded diagram showing still another embodiment of an electronic device of the present invention, such as a smartphone or navigation equipment, utilizing a nine-axis motion sensor module according to anther embodiment of the present invention.

FIG. **7** is a flow chart illustrating a method for obtaining a resultant deviation of an electronic device of the present invention subject to movements and rotations in a spatial reference frame.

FIG. **8** shows another exemplary flow chart illustrating a method for obtaining resultant deviation including mapping of said deviation to a display of an electronic device according to another embodiment of the present invention.

FIG. **9** is a schematic diagram showing the mapping of the resultant angles of the resultant deviation according to an embodiment of the present invention.

FIG. **10** is an exemplary flow chart illustrating another embodiment of a method for obtaining a resultant deviation of an electronic device of the present invention.

FIG. **11** shows an exemplary flow chart illustrating another embodiment of a method for obtaining a resultant deviation including mapping of such deviation to a display of an electronic device of the present invention.

FIG. **12** shows an exemplary flow chart illustrating a method for obtaining resultant deviation of an electronic device according to still another embodiment of the present invention.

FIG. **13** is a flow chart of a method for compensating rotations of a 3D pointing device according to an embodiment of the present invention.

FIG. **14**, FIG. **15** and FIG. **16** are schematic diagrams showing three 3D pointing devices according to three different embodiments of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Detailed descriptions of preferred embodiments of the present invention recited herein are provided for illustrative purposes only; examples of which are too illustrated in the accompanying drawings. In addition, similar reference numbers in the drawings and the description may too refer to similar parts or components.

FIG. **3** is an exploded diagram showing an electronic device **300** according to one embodiment of the present invention, such as a pointing device. The electronic device **300** is subject to movements and rotations in dynamic environments in a spatial reference frame such as a 3D reference frame. The spatial reference frame is analogous to the reference frame $X_PY_PZ_P$ also shown in FIG. **1** and FIG. **2**. The movements and rotations of the electronic device **300**, such as a pointing device, in the aforementioned dynamic environments in the spatial reference frame may be continuously nonlinear with respect to time. The term of "dynamic" recited herein may refer to moving or subject to motions in general.

The electronic device **300** includes a top cover **310**, a printed circuit board (PCB) **340**, a rotation sensor **342**, an accelerometer **344**, a magnetometer **345**, a data transmitting unit **346**, a computing processor **348**, a bottom cover **320**, and a battery pack **322**. The top cover **310** may include a few control buttons **312** for a user to issue predefined commands for remote control. In one embodiment, the housing **330** may comprise the top cover **310** and the bottom cover **320**. The housing **330** may move and rotate in the spatial reference frame according to user manipulation or any external forces in any direction and/or under the abovementioned dynamic environments. As shown in the FIG. **3**, in one embodiment, the rotation sensor **342**, the accelerometer **344**, the magnetometer **345**, the data transmitting unit **346**, and the computing processor **348** may be all attached to the PCB **340**. The PCB **340** is enclosed by the housing **330**. The PCB **340** includes at least one substrate having a longitudinal side configured to be substantially parallel to the longitudinal surface of the housing **330**. An additional battery pack **322** provides electrical power for the electronic device **300**.

Furthermore, in one embodiment, the abovementioned dynamic environments, in which the electronic device **300** of the present invention may be present or subject to, may include undesirable external interferences to the electronic device **300** of the present invention. In one example, the undesirable external interferences may refer to or include undesirable axial accelerations caused by undesirable external forces other than a force of gravity. In another example, the undesirable external interferences may also refer to or include undesirable magnetism caused by undesirable electromagnetic fields.

FIG. **4** is a schematic block diagram illustrating hardware components of the electronic device **300**. The electronic device **300** includes a nine-axis motion sensor module **302** and a processing and transmitting module **304**. The nine-axis motion sensor module **302** includes the rotation sensor **342**, the accelerometer **344** and the magnetometer **345**. The processing and transmitting module **304** includes the data transmitting unit **346** and the computing processor **348**.

The term "nine-axis" recited herein may refer to and generally include the three angular velocities ω_x, ω_y, ω_z, the three axial accelerations Ax, Ay, Az, and the three magnetism Mx, My, Mz. The rotation sensor **342** of the nine-motion sensor module **302** detects and generates the first signal set including angular velocities ω_x, ω_y, ω_z associated with the movements and rotations of the electronic device **300** about each of three orthogonal coordinate axes $X_PY_PZ_P$ of the spatial reference frame. The angular velocities ω_x, ω_y and ω_z are corresponding to the coordinate axes X_P, Y_P and Z_P respectively. The accelerometer **344** detects and generates the second signal set including axial accelerations Ax, Ay, Az associated with the movements and rotations of the electronic device **300** along each of the three orthogonal coordinate axes $X_PY_PZ_P$ of the spatial reference frame. The axial accelerations Ax, Ay and Az are corresponding to the coordinate axes X_P, Y_P and Z_P respectively. The magnetometer **345** of the nine-motion sensor module **302** detects and generates the third signal set including magnetism Mx, My, Mz associated with the movements and rotations of the electronic device **300** along each of the three orthogonal coordinate axes $X_PY_PZ_P$ of the spatial reference frame. The magnetism Mx, My and Mz represent the strength and/or direction of ambient magnetic field (such as the magnetic field of the Earth) of the electronic device **300**. The magnetism Mx, My and Mz are corresponding to the coordinate axes X_P, Y_P and Z_P respectively. It too can be understood that the abovementioned nine axes of $X_PY_PZ_P$ may not need to be orthogonal in a specific orientation and they may be rotated in different orientations; the present invention discloses such coordinate system for illustrative purposes only and any coordinates in different orientation and/or denotations may too be possible.

Furthermore, in one embodiment of the present invention, the motion sensor module or nine-axis motion sensor module **302** of the electronic device **300** may refer to a Micro-Electro-Mechanical-System (MEMS) type of sensor. In an explanatory example, the abovementioned rotation sensor **342** of the nine-axis motion sensor module **302** may further comprise at least one resonating mass such that a movement of said at least one resonating mass along an axis of said spatial reference frame may be detected and measured by said rotation sensor using the Coriolis acceleration effect to generate said first signal set comprising angular velocities ωx, ωy, ωz in said spatial reference frame. It can be understood that for a three-axis rotation sensor of a MEMS type sensor, there may be positioned three resonating masses along each of X, Y and Z axes of the spatial reference frame to generate and obtain movements or displacements of the three resonating masses thereof. It can too be understood that the nine-axis motion sensor **302** of the present invention may also include a three-axis accelerometer, a three-axis rotation sensor and a three-axis magnetometer in a MEMS structure.

The data transmitting unit **346** is electrically connected to the nine-axis motion sensor module **302** for transmitting the first, second and third signal sets. The data transmitting unit **346** transmits the first, second and third signal sets of the nine-axis motion sensor module **302** to the computing processor **348** preferably via electronic connections configured on the PCB **340**. The computing processor **348** receives and calculates the first, second and third signal sets from the data transmitting unit **346**. The computing processor **348** further communicates with the nine-axis motion sensor module **302** to calculate the resulting deviation of the electronic device **300** including three resultant angles preferably about each of the three axes of the spatial reference frame. The resultant angles include the yaw angle **111**, the pitch angle **112** and the roll angle **113** as shown in FIG. **1** and FIG. **2**. In order to calculate the resulting deviation, the computing processor **348** may utilize a comparison or algorithm to eliminate accumulated errors of the first, second and/or third signal sets of

the nine-axis motion sensor module **302**, whereby the resultant angles in the spatial reference frame, preferably about each of three orthogonal coordinate axes of the spatial reference frame, of the resulting deviation of the nine-axis motion sensor module **302** of the electronic device **300** is obtained under the aforementioned dynamic environments excluding the abovementioned undesirable external interferences and such that it is preferably obtained and outputted in an absolute manner reflecting or associating with the actual movements and rotations of the electronic device **300**, including such as a pointing device, of the present invention in said spatial reference frame. In addition, said comparison utilized by the computing processor **348** may further comprise an update program to obtain an updated state of the nine-axis motion sensor module based on a previous state associated with a first signal set in relation to the angular velocities ω_x, ω_y, ω_z and a measured state associated with both said second and third signal sets in relation to the axial accelerations Ax, Ay, Az as well as magnetism Mx, My, Mz. The abovementioned measured state may include a measurement of said second signal set or measured Ax, Ay, Az and a predicted measurement of Ax', Ay' and Az' obtained based on or calculated from a current state of the motion sensor module **302**. In addition, the abovementioned measured state may too include a measurement of said third signal set or measured Mx, My, Mz and a predicted measurement of Mx', My' and Mz' obtained based on or calculated from the current state of the motion sensor module **302**. Details of different "states" of the nine-axis motion sensor module **302** of the electronic device **300** of the present invention are provided in the later content.

In one embodiment, the computing processor **348** of the processing and transmitting module **304** may further include a mapping program for translating the resultant angles of the resulting deviation in the spatial reference frame to a movement pattern in a display reference frame different from the spatial reference frame. The display reference frame is analogous to the reference frame $X_DY_DZ_D$ in FIG. **1** and FIG. **2**. The movement pattern may be displayed on a screen of a 2D display device similar to the display device **120** in FIG. **1** and FIG. **2**. The mapping program translates the resultant angles, preferably about each of the three orthogonal coordinate axes of the spatial reference frame to the movement pattern according to a sensitivity input correlated to the display reference frame.

FIG. **5** is a schematic diagram showing an electronic device **500** utilizing a nine-axis motion sensor module according to anther embodiment of the present invention in a 3D spatial reference frame. As shown in FIG. **5**, the electronic device **500** may comprise two parts **560** and **570** in data communication with each other. In one embodiment, the first part **560** includes a top cover (not shown), a PCB **540**, a nine-axis motion sensor module **502** comprising a rotation sensor **542**, an accelerometer **544** and a magnetometer **545**, a data transmitting unit **546**, a bottom cover **520**, and a battery pack **522**. The data transmitting unit **546** transmits the first signal set (ω_x, ω_y, ω_z) generated by the rotation sensor **542** of the nine-motion sensor module **502** and the second signal set (Ax, Ay, Az) generated by the accelerometer **544** as well as the third signal set (Mx, My, Mz) generated by the magnetometer **545** of the nine-motion sensor module **502** to the data receiving unit **552** of the second part **570** via wireless communication or connection including wireless local area network (WLAN) based on IEEE 802.11 standards or Bluetooth™. It can be understood that in another embodiment, wired communication or connection via a physical cable or electrical wires connecting the first part **560** and the second part **570** may too be possible. In one embodiment of the present invention, the motion sensor module or nine-axis motion sensor module **502** of the electronic device **500** may refer to a MEMS type of sensor. In an explanatory example, the abovementioned rotation sensor **542** of the nine-axis motion sensor module **502** may further comprise at least one resonating mass such that a movement of said at least one resonating mass along an axis of said spatial reference frame may be detected and measured by said rotation sensor using the Coriolis acceleration effect to generate said first signal set comprising angular velocities ωx, ωy, ωz in said spatial reference frame. It can be understood that for a three-axis rotation sensor of a MEMS type sensor, there may be positioned three resonating masses along each of X, Y and Z axes of the spatial reference frame to generate and obtain movements or displacements of the three resonating masses thereof It can too be understood that the nine-axis motion sensor **502** of the present invention may also include a three-axis accelerometer, a three-axis rotation sensor and a three-axis magnetometer in a MEMS structure.

In one embodiment, the second part **570** may be an external processing device to be adapted to another electronic computing apparatus or system such as a standalone personal computer or server **580**; for instance, the second part **570** may be coupled or adapted to an laptop computer via a standard interface, such as the universal serial bus (USB) interface depicted as shown in FIG. **5**. The first part **560** and the second part **570** communicate via the data transmitting unit **546** and the data receiving unit **552**. As previously mentioned, the data transmitting unit **546** and the data receiving unit **552** may communicate through wireless connection or wired connection. In other words, in terms of hardware configuration and data transmission, in one embodiment of the present invention, the nine-axis motion sensor module **502** comprising the rotation sensor **542**, the accelerometer **544** and the magnetometer **545** may be disposed distally from the processing unit or computing processor **554**; the signals from the nine-axis motion sensor module **502** may then be transmitted via the data transmitting units **546**, **552** to the computing processor **554** via wired or wireless communication including for example IEEE 802.11 standards or Bluetooth™.

The second part **570** of the electronic device **500** according to one embodiment of the present invention comprises the data transmitting unit **552** and the processor **554**. The data transmitting unit **552** of the second part **570** may be in data communication with the other data transmitting unit **546** disposed distally therefrom in the first part **560** as previously mentioned. The data transmitting unit **552** in the second part **570** receives the first, second and third signal sets from the data transmitting unit **546** in the first part **560** and transmits the first, second and third signal sets to the computing processor **554**. In one embodiment, the computing processor **554** performs the aforementioned calculation as well as comparison of signals. In one embodiment, said comparison utilized by the computing processor **554** may further comprise an update program to obtain an updated state based on or from a previous state associated with said first signal set and a measured state associated with said second and third signal sets. The measured state may further include a measurement of said second and third signal sets and predicted measurements obtained based on the first signal set or based on a current state of the motion sensor module **502**. The computing processor **554** is external to the housing of the 3D pointing device as depicted in FIG. **5**. In one embodiment, the computing processor **554** also performs mapping by translating the resultant angles of the resulting deviation of the electronic device in the spatial pointer reference frame, preferably about each of three orthogonal coordinate axes of the spatial refer-

ence frame, to a movement pattern in a display reference frame associated with the notebook computer **580**. The movement pattern may be displayed on the screen **582** of the notebook computer **580**.

FIG. **6** is an exploded diagram showing a portable electronic device **600**, such as for example a 3D pointing device, utilizing a nine-axis motion sensor module according to anther embodiment of the present invention in a 3D spatial reference frame. The portable electronic device **600** may further comprises a built-in display **682**; examples of the portable electronic device **600** as an explanatory embodiment of the present invention may include such as smartphone, tablet PC or navigation equipment. In other words, the abovementioned display reference frame associated with a display may need not to be external to the spatial reference frame in terms of the hardware configuration of the present invention. In one embodiment, the electronic device **600** comprises a bottom cover **620**, a PCB **640**, a battery pack **622**, a rotation sensor **642**, an accelerometer **644**, a magnetometer **645**, a data transmitting unit **646**, a computing processor **648**, a display **682**, and a top cover **610**. Likewise, in one embodiment, the housing **630** may comprise the top and bottom covers **610**, **620**. A built-in display **682** may too be integrated on the housing **630**; the nine-axis motion sensor module **602** may comprise the rotation sensor **642**, the accelerometer **644** and the magnetometer **645**. The data transmitting unit **646** and the computing processor **648** may also be integrated as a processing and transmitting module **604** of the electronic device **600**. In one embodiment of the present invention, the motion sensor module or nine-axis motion sensor module **602** of the portable electronic device **600** may refer to a MEMS type of sensor. In an explanatory example, the abovementioned rotation sensor **642** of the nine-axis motion sensor module **602** may further comprise at least one resonating mass such that a movement of said at least one resonating mass along an axis of said spatial reference frame may be detected and measured by said rotation sensor using the Coriolis acceleration effect to generate said first signal set comprising angular velocities ωx, ωy, ωz in said spatial reference frame. It can be understood that for a three-axis rotation sensor of a MEMS type sensor, there may be positioned three resonating masses along each of X, Y and Z axes of the spatial reference frame to generate and obtain movements or displacements of the three resonating masses thereof. It can too be understood that the nine-axis motion sensor **602** of the present invention may also include a three-axis accelerometer, a three-axis rotation sensor and a three-axis magnetometer in a MEMS structure.

The computing processor **648** of the processing and transmitting module **604** may too perform the mapping of resultant deviation from or in said spatial reference frame or 3D reference frame to a display reference frame such as a 2D reference frame by translating the resultant angles of the resulting deviation of the electronic device **600** in the spatial reference frame, preferably about each of three orthogonal coordinate axes of the spatial reference frame to a movement pattern in a display reference frame associated with the electronic device **600** itself. The display **682** displays the aforementioned movement pattern. The top cover **610** includes a transparent area **614** for the user to see the display **682**.

FIG. **7** is an explanatory flow chart illustrating a method for obtaining and/or outputting a resultant deviation including deviation angles in a spatial reference frame of an electronic device, including such as a pointing device, navigation equipment or smartphone, having movements and rotations in a 3D spatial reference frame and in dynamic environments according to an embodiment of the present invention. The method in FIG. **7** may be a program such as an algorithm or a comparison model to be embedded or performed by the processing unit or computing processor **348**, **554**, **648** of the processing and transmitting module according to different embodiments of the present invention recited herein for illustrative purposes.

Accordingly, in one embodiment of the present invention, a method for obtaining a resultant deviation including deviation angles in a spatial reference frame of an electronic device utilizing a nine-axis motion sensor module therein in dynamic environments and preferably excluding undesirable external interferences thereof is provided. As the electronic device may be subject to movements and rotations in the dynamic environments, undesirable interferences may cause the measurements, calculations or outputs of the motion sensor module thereof to be errorsome. In one embodiment, said method may comprise the following steps. First of all, as shown in FIG. **7**, different states including "previous state", "current state", "measured state" and "update state" of the nine-axis motion sensor module may be provided to represent a step or a set of steps utilized by the method for obtaining the resulting deviation in 3D reference frame, and preferably in the abovementioned "absolute" manner. In one exemplary embodiment, the method comprises the steps of obtaining a previous state of the nine-axis motion sensor module (such as steps **705**, **710**); and wherein the previous state may too include an initial-value set predetermined to initialize said previous state of the nine-axis motion sensor module at a beginning of the method. The initial-value set may preferably be utilized at said beginning of the method or a start of the method where a previous state is not available to be obtained from an updated state (to be recited hereafter). In another embodiment where previous state may be obtained or updated from an updated state, said previous state may be a first quaternion inducing values associated with at least previous angular velocities ω_x, ω_y, ω_z gained from the motion sensor signals of the nine-axis motion sensor module at a previous time T−1. A current state of the nine-axis motion sensor module may then be subsequently obtained by obtaining measured angular velocities ω_x, ω_y, ω_z gained from the motion sensor signals of the nine-axis motion sensor module at a current time T (such as steps **715**, **720**). A measured state of the nine-axis motion sensor module may then be obtained by obtaining measured axial accelerations Ax, Ay, Az gained from the motion sensor signals of the nine-axis motion sensor module at the current time T (such as step **725**). Furthermore, the step of calculating predicted axial accelerations Ax', Ay', Az' based on the measured angular velocities ω_x, ω_y, ω_z of the current state of the nine-axis motion sensor module (such as step **730**); obtaining an updated state of the nine-axis motion sensor module by comparing the current state with the measured state of the nine-axis motion sensor module (such as step **735**); and calculating and converting the updated state of the nine-axis motion sensor module to said resulting deviation comprising said resultant angles in said spatial reference frame of the electronic device (**745**) may then be performed and obtained; and whereby the resultant deviation comprising deviation angles associated with the updated state of the nine-axis motion module may be obtained excluding said undesirable external interferences in the dynamic environments. In order to provide a continuous loop such as performed in a looped manner, the result of the updated state of the nine-axis motion sensor module may preferably be outputted to the previous state; in one embodiment, the updated state may be a quaternion, namely third quaternion as shown in the figure, such that it may be directly outputted to the

abovementioned previous state of another quaternion, namely the abovementioned first quaternion and as shown in the figure (such as step **740**).

In addition, it can be understood that the abovementioned comparison utilized by the processing and transmitting module and comprising the update program may too make reference to said different states of the nine-axis motion sensor module as shown in FIGS. **7** and **8**. As mentioned previously, the update program may be utilized by the processor to obtain the updated state of the nine-axis motion sensor module based on the previous state associated with a first signal set in relation to the angular velocities ω_x, ω_y, ω_z and the measured state associated with said second signal set in relation to the axial accelerations Ax, Ay, Az. The abovementioned measured state may include a measurement of said second signal set or measured Ax, Ay, Az and a predicted measurement of Ax', Ay' and Az' obtained based on or calculated from the first signal set. Details of each of the abovementioned states of the nine-axis motion sensor module and the related steps of the method for obtaining the resultant deviation of the electronic device in 3D reference frame are as follows.

Referring to FIG. **7** again, the method for obtaining a resultant deviation including resultant angles in a spatial reference frame of electronic device utilizing a nine-axis motion sensor module according to one embodiment of the present invention may begin at the obtaining of a previous state of the nine-axis motion sensor module. In one embedment, the previous state of the nine-axis motion sensor module may preferably be in a form of a first quaternion, and the first quaternion may be preferably initialized (step **705**) at a very beginning of the process or method and as part of the obtaining of the previous state thereof. In other words, according to one embodiment of the present invention, the signals of the nine-axis motion sensor are preferably to be initialized according to a predetermined value set or quaternion including such as zeros and in particular, the signal or value associated with the yaw angle in terms of a quaternion value. The four elements of the first quaternion may be initialized with predetermined initial values. Alternatively, the first quaternion may be initialized or replaced by another signal sets generated by the rotation sensor and the accelerometer at a next time frame such that the method as shown in FIG. **7** is a continuous loop between a previous time frame T−1 and a present time frame T; details on the replacement of the first quaternion at T−1 with the later outputted quaternion at T is to be provided in the later content. It can be understood that one may make reference to Euler Angles for definition on quaternion. Similarly, it can be easily comprehended that the abovementioned previous time T−1 and present time T may too be substitute by a present time T and a next time T+1 respectively and shall too fall within the scope and spirit of the present invention.

In addition, the abovementioned dynamic environments may include undesirable external interferences to the present invention as mentioned previously. For instance, the undesirable external interferences nay refer to or include undesirable axial accelerations caused by undesirable external forces other than a force of gravity and they may too include or refer to include undesirable magnetism caused by undesirable electromagnetic fields. In a preferred embodiment of the present invention, one of the technical effects of the perform of the method as shown in FIG. **7** include that the abovementioned updated state of the nine-axis motion sensor module to said resulting deviation comprising said resultant angles in said spatial reference frame of the electronic device (step **745**) may be preferably obtained excluding undesirable interferences in the dynamic environments, such as decoupling of undesirable external forces from the force of gravity to exclude undesirable axial accelerations and exclusion of undesirable external magnetism caused or induced by undesirable electromagnetic fields in the dynamic environments.

The method illustrated in FIG. **7** may be performed in consecutive time frames. According to one embodiment of the present invention, steps **710**-**745** may be performed in a looped manner by such as a data processing unit of an electronic device of the present invention. In another embodiment, multiple steps may be performed simultaneously, such as the obtaining of signals from the nine-axis motion sensor module may be performed simultaneously instead of one after another. It can therefore be understood that the steps recited herein are for illustrative purposes only and any other sequential orders or simultaneous steps are possible and shall too be considered to be within the scope of the present invention. The first quaternion with respect to the previous time T is obtained as shown in the figure as step **710**. When step **710** is performed, the first quaternion initialized in step **705** is obtained. Otherwise, the first quaternion used in the present time T is generated in the previous time T−1. In other words, the step **710** may generally refer to or represented by the abovementioned "previous state" of the nine-axis motion sensor module; according to another embodiment, the previous state may refer to the steps of **705** and **710**.

The next may be to obtain the first signal set generated by the rotation sensor, which includes the measured angular velocities ω_x, ω_y and ω_z as shown in step **715** according to an exemplary embodiment of the present invention. In step **720**, the second quaternion with respect to a present time T is calculated and obtained based on the angular velocities ω_x, ω_y and ω_z. The step **715** and **720** may generally refer to or may be represented by the abovementioned "current state" of the nine-axis motion sensor module. In one embodiment, the computing processor may use a data conversion utility including such as an algorithm to convert the angular velocities ω_x, ω_y, ω_z and first quaternion into the second quaternion. This data conversion utility may be a program or instruction represented by the following equation (1).

$$\begin{bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & -\omega_x & -\omega_y & -\omega_z \\ \omega_x & 0 & \omega_z & -\omega_y \\ \omega_y & -\omega_z & 0 & \omega_x \\ \omega_z & \omega_y & -\omega_x & 0 \end{bmatrix} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} \quad (1)$$

Equation (1) is a differential equation. The quaternion on the left side of the equal sign is the first order derivative with respect to time of the quaternion (q_0, q_1, q_2, q_3) on the right side of the equal sign. The data conversion utility uses the first quaternion as the initial values for the differential equation (1) and calculates the solution of the differential equation (1). The second quaternion may be represented by a solution of the differential equation (1).

As shown in the figure, the "measured state" of the nine-axis motion sensor module according to one embodiment of the present invention may generally refer or may be represented by steps **725** and **730**. In step **725**, the second signal set generated by the accelerometer may be obtained, which includes measured axial accelerations Ax, Ay and Az; or Ax, Ay and Az may refer to the measurement of the axial accelerations obtained. In order to obtain said measured state of the nine-axis motion sensor of the present invention, according to one embodiment, predicted axial accelerations Ax', Ay' and Az' may too be calculated and obtained based on the above-

mentioned current state of the nine-axis motion sensor module or the second quaternion as shown in step **730**. In other words, two sets of axial accelerations may be obtained for the measured state of the nine-axis motion sensor module; one may be the measured axial accelerations Ax, Ay, Az in step **725** and the other may be the predicted axial accelerations Ax', Ay', Az' in step **730** calculated based on the abovementioned current state or second quaternion in relation to the measured angular velocities thereof. Furthermore, in one embodiment, the computing processor may use a data conversion utility to convert quaternion into the predicted axial accelerations Ax', Ay' and Az'. This data conversion utility may be a software program represented by the following equations (2), (3) and (4).

$$2(q_1q_3-q_0q_2)=Ax' \tag{2}$$

$$2(q_2q_3+q_0q_1)=Ay' \tag{3}$$

$$q_0^2-q_1^2-q_2^2+q_3^2=Az' \tag{4}$$

The computing processor calculates the solution (Ax', Ay', Az') of the equations (2), (3) and (4).

According to an exemplary embodiment of the method for obtaining a resultant deviation including deviation angles in a spatial reference frame of an electronic device, including such as a 3D pointing device, a portable electronic device, a navigation equipment or a smartphone, utilizing a nine-axis motion sensor module, it may be preferable to compare the current state of the nine-axis motion sensor module with the measured state thereof with respect to the present time frame T by utilizing a comparison model. In other words, in one embodiment as shown in step **735**, it is preferable to compare the second quaternion in relation to the measured angular velocities of the current state at present time T with the measured axial accelerations Ax, Ay, Az as well as the predicted axial accelerations Ax', Ay', Az' also at present time T. Following which, a result may be advantageously obtained as an updated state of the nine-axis motion sensor module, excluding the abovementioned undesirable external interferences of the dynamic environments. In an explanatory example, the updated state may generally refer to the update of the current state of the nine-axis motion sensor module at preset time T. Instructions including equations related to the abovementioned current state, measured state and updated state may be illustrated in the following.

According to an exemplary embodiment of the comparison model utilized by the present invention in relation to step **735** as shown in the figure, the current state correlated to the abovementioned second quaternion and in relation to the angular velocities of gyroscope(s) may be obtained based on an exemplary equation of:

$$x(t|t-1)=f(x_{t-1},u_t) \tag{5}$$

Preferably, a first probability (state transition probability) associated with the said current state may be further obtained based on an exemplary equation of:

$$P(x_t \mid x_{t-1}, u_t) = F_x P(x_{t-1} \mid x_{t-1}) F_x^T + F_u P(u_{t-1} \mid u_{t-1}) F_u^T + Q_t \tag{6}$$

$$F_x = \frac{\partial f(x_{t-1}, u_t)}{\partial x_{t-1}}$$

$$F_u = \frac{\partial f(x_{t-1}, u_t)}{\partial u_t} \tag{7}$$

wherein Q_t=additional motion model noise

Likewise, the measured state correlated to the abovementioned predicted axial accelerations and in relation to the axial accelerations of accelerometers and current state may be obtained based on an exemplary equation of:

$$z_t(t|t-1)=h(x(t|t-1)) \tag{8}$$

Preferably, a second probability (measurement probability) associated with the measured state may be further obtained based on an exemplary equation of:

$$P(z_t \mid x_t) = H_x P(x_t \mid x_{t-1}) H_x^T + R_t \tag{9}$$

$$H_x = \frac{\partial h(x(t \mid t-1))}{\partial x(t \mid t-1)} \tag{10}$$

wherein R_t=measurement model noise

As an illustrative example, the abovementioned first and second probabilities may be further utilized to obtain the updated state of the nine-axis motion sensor module based on an exemplary method of data association of an exemplary equation of:

$$D_t=\{[z_t-h(x(t|t-1))]P(z_t|x_t)[z_t-h(x(t|t-1))]^{-1}\}^{1/2} \tag{11}$$

In one embodiment, the result of the updated state of the nine-axis motion sensor module, preferably involving comparison or data association represented by the equations, may be a third quaternion as shown in the figure. Furthermore, the result may then be further outputted and utilized to obtain a resultant deviation, excluding undesirable interferences of the dynamic environments under which the present invention is subject to, but including deviation angles in a spatial reference frame in the following steps as shown in the figure. In a preferred embodiment of the present invention, said undesirable external interferences may further comprise or refer to undesirable axial accelerations caused by undesirable external forces other than a force of gravity; in another preferred embodiment, said undesirable external interferences may further comprise or refer to undesirable magnetism caused by undesirable electromagnetic fields. In other words, the method and algorithm provided by the present invention may preferably generate or provide an output of the resultant deviation of the nine-axis motion sensor module excluding the abovementioned undesirable interferences. In one example, external forces exerted to cause axial accelerations of a nine-axis motion sensor of an electronic device of the present invention may be decoupled or separated from a force of gravity; and in another example, the undesirable magnetism caused by such as electromagnetic fields external or internal to an electronic device the present invention may be excluded. It can be understood that the examples of current state, measured state, state update, data association and probabilities of the comparison model and method of the present invention recited herein are provided for illustrative purposes only.

As mentioned previously, it may be preferable to output the result of the updated state, preferably in a form of third quaternion, to the previous state of the nine-axis motion sensor module as shown in step **740** in FIG.**7**. In a preferred embodiment, the updated state may further comprise a first data association model; and wherein the abovementioned and related data association model may be provided for comparing the measured state associated with said second signal set with a predicted measurement obtained from said current state. In other words, in one embodiment, the first quaternion may be replaced by the abovementioned third quaternion or substitute directly any previous values of first quaternion in

the previous time T for further process in a loop. In other words, the third quaternion with respect to the present time T becomes the first quaternion with respect to the next time such as T+1; or, the third quaternion at previous time frame T−1 outputted may now be the first quaternion at present time frame T.

In step **745**, the updated state of the nine-axis motion sensor module of the present invention may be further calculated and converted to the resultant deviation including deviation angles associated with the spatial reference frame, wherein the deviation angles includes the yaw angle, pitch angle and roll angle of the electronic device associated with the spatial reference frame, preferably about each of three orthogonal coordinate axes of the spatial reference frame; and whereby the resultant deviation comprising deviation angles associated with the updated state of the nine-axis motion module may be preferably obtained excluding said undesirable external interferences in the dynamic environments. In an explanatory example, said undesirable external interferences may refer to or further comprise undesirable axial accelerations caused by undesirable external forces other than a force of gravity. In another explanatory example, said undesirable external interferences may refer to or further comprise undesirable magnetism caused by undesirable electromagnetic fields. In one embodiment, the computing processor may use a data conversion utility to convert the third quaternion of the updated state of the nine-axis motion sensor module into the yaw, pitch and roll angles thereof This data conversion utility may be a program or instruction represented by the following equations (12), (13) and (14).

$$\text{yaw} = \arctan\left(\frac{2(q_0q_3 + q_1q_2)}{q_0^2 + q_1^2 - q_2^2 - q_3^2}\right) \tag{12}$$

$$\text{pitch} = \arcsin(2(q_0q_2 - q_3q_1)) \tag{13}$$

$$\text{roll} = \arctan\left(\frac{2(q_0q_1 + q_2q_3)}{q_0^2 - q_1^2 - q_2^2 + q_3^2}\right) \tag{14}$$

The variables q_0, q_1, q_2 and q_3 in equations (12), (13) and (**14**) are the four elements of the third quaternion.

For a looped method continuous with respect to time, in one embodiment of the present invention, the method utilized by for example the computing processor communicated with the nine-axis motion sensor module may return to step **710** to perform the comparison process or method with respect to the next time T+1. In addition, the abovementioned resultant deviation including deviation angles comprising yaw, pitch and roll angles in the spatial reference frame converted from the third quaternion is preferably obtained and outputted in an absolute manner reflecting or associating with the actual movements and rotations of the electronic device of the present invention in said spatial reference frame. It can be understood that said actual movements and rotations of the electronic device of the present invention in the spatial reference frame or 3D reference frame may refer to real-time movements and rotations associated with vectors having both magnitudes and directions along or about orthogonal axes in the spatial reference frame under the dynamic environments.

FIG. **8** shows a flow chart illustrating a method of mapping resultant deviation angles of an electronic device having movements and rotations in a 3D spatial reference frame and in a dynamic environment onto a display reference frame according to another embodiment of the present invention. FIG. **9** is a schematic diagram showing the aforementioned mapping of the resultant angles of the resultant deviation of an electronic device according to this embodiment. For illustrative purposes, the difference between FIG. **7** and FIG. **8** may be represented by the additional mapping step **750** as shown in FIG. **8**. Steps **705-745** in FIG. **8** are the same as their counterparts in FIG. **7**, which perform the comparison process for the 3D pointing device. Step **750** performs the mapping process for the electronic device. The computing processor may include a mapping program that performs the mapping step **750**. At step **750**, the processing and transmitting module may obtain display data including for example, display screen size such as boundary information, and translates the deviation angles of the resultant deviation associated with the spatial reference frame, preferably about each of three orthogonal coordinate axes of the spatial reference frame, to a movement pattern in a mapping area in a display reference frame based on a sensitivity input correlated to the display reference frame. It can be understood that the abovementioned display data may too include or refer to the type of display such as LED, LCD, touch panel or 3D display as well as frequency rate of display such as 120 Hz or 240 Hz. In one embodiment, the display reference frame associated with the display to be mapped may be a 2D display reference frame; in another embodiment, the display reference frame may be a 3D display reference frame of a 3D display.

The aforementioned display data may further include a sensitivity input. The aforementioned sensitivity input is a parameter which may be inputted and adjusted by a user through control buttons attached on the housing of the electronic device. The sensitivity input may represent the sensitivity of the display device with respect to the movement of the electronic device. For details of the mapping process, please refer to FIG. **9**. In one embodiment, the sensitivity input is a parameter representing the relationship between the display to be mapped with deviation to a movement pattern in 2D display reference frame and the electronic device of the present invention outputted with said deviation including yaw, pitch and roll angles in 3D reference frame; wherein the relationship may be a distance relationship. In another embodiment, the sensitivity input may be a display screen size including boundary information predetermined by a user; wherein the boundary information may be obtained based on a user input or manual input data from the user. In still another embodiment, the sensitivity input may be predefined or preset in the mapping program such that the parameter of the sensitivity input is a preset value for either increase or decrease the movement patterns including distance or number of pixels to be moved or mapped from said resultant deviation of the electronic device of the present invention.

FIG. **9** is a bird's-eye view of an electronic device **930** according to one embodiment of the present invention directed to a display screen **910** of a display device. The display screen has a central point **922**, a target point **924** and a boundary point **926**. The central point **922** is the geometric center of the display screen **910**. The target point **924** is the position that the electronic device **930** is aiming at. The boundary point **926** is a point on the right boundary of the display screen **910**. The points **922**, **924**, **926** and the electronic device **930** are on a common plane parallel to both the X_D axis and the Z_D axis of the display reference frame $X_DY_DZ_D$. Virtual beams **942**, **944** and **946** are imaginary light beams from the electronic device **930** to the central point **922**, the target point **924** and the boundary point **926**, respectively. The distance P is the distance between the central point **922** and the target point **924**, while the distance P_{max} is the distance between the central point **922** and the boundary point **926**. The distance d is the distance between the central point **922** and the electronic device **930**. The aforementioned yaw

angle of the resultant deviation of the electronic device **930** of the present invention is the angle θ between the virtual beams **942** and **944**, while the angle θ_{max} is the angle between the virtual beams **942** and **946**. The aforementioned mapping area is a plane including the display surface of the display screen **910** in the display reference frame. The display surface of the display screen **910** is a subset of the mapping area.

In this embodiment, the aforementioned sensitivity input is provided by the user of the electronic device **930**. The sensitivity β is defined by the following equation (15).

$$\beta = \frac{P_{max}}{\theta_{max}} \tag{15}$$

The variable β in equation (16) is the sensitivity input defined by user.

The following equation (16) may be derived from equation (15) and geometry.

$$d = \frac{P_{max}}{\tan\left(\frac{P_{max}}{\beta}\right)} \tag{16}$$

The following equation (17) may be derived from equations (16).

$$P = f(\theta) = d \times \tan\theta = \frac{P_{max} \times \tan\theta}{\tan\left(\frac{P_{max}}{\beta}\right)} \tag{17}$$

In equation (17), the distance P_{max} may be obtained from the width of the display screen of the display data obtained at step **750**; the angle θ is the yaw angle obtained at step **745**; the sensitivity input β is provided by the user. Therefore, the computing processor of the electronic device **930** can calculate the distance P according to equation (17). Next, the computing processor can easily obtain the horizontal coordinate of the target point **924** on the display screen **910** according to the distance P and the width of the display screen **910**. In addition, the computing processor can easily obtains the vertical coordinate of the target point **924** on the display screen **910** according to the pitch angle in a similar way.

The mapping process performed at step **750** may be exemplified by the process of translating the yaw angle and the pitch angle of the resultant angles to the 2D coordinates of the target point **924** on the display screen **910** discussed above. Now the computing processor has the coordinates of the target point **924** of the present time frame. The computing processor subtracts the coordinates of the target point **924** of the previous time frame from the coordinates of the target point **924** of the present time frame. The result of the subtraction is the horizontal offset and the vertical offset of the target point **924** in the present time frame. The horizontal and vertical offsets may be transmitted to the display device so that the display device can track the position of the target point **924**. The display device may display a cursor or some video effect on the display screen **910** to highlight the position of the target point **924**. The cursor or video effect may exhibit a movement pattern on the display screen **910** when the user moves the electronic device **930** of the present invention.

Likewise, according to another embodiment of the present invention, the comparison method of the present invention may be a lopped method. For a looped method continuous with respect to time, in one embodiment, the method utilized by for example the computing processor communicating with the nine-axis motion sensor module may return to step **710** to perform the comparison process or method with respect to the next time T+1, following which the comparison and mapping process with respect to the next time frame may then be performed.

FIG. **10** shows another embodiment of the comparison method of the present invention. The flow chart illustrates a method of obtaining resultant deviation including deviation angles in a spatial reference frame of an electronic device utilizing a nine-axis motion sensor module therein and subject to movements and rotations in dynamic environments in the spatial reference frame and mapping resultant deviation of the electronic device of the present invention having movements and rotations in a 3D spatial reference frame and in a dynamic environment onto a display reference frame according to another embodiment of the present invention; and whereby the resultant deviation comprising deviation angles associated an output or state such as an updated state (details below) of the nine-axis motion module may be preferably obtained excluding said undesirable external interferences in the dynamic environments. In an explanatory example, said undesirable external interferences may refer to or further comprise undesirable axial accelerations caused by undesirable external forces other than a force of gravity. In another explanatory example, said undesirable external interferences may refer to or further comprise undesirable magnetism caused by undesirable electromagnetic fields. The steps **1005-1030** in FIG. **10** may make reference to the ones shown in another embodiment of the present invention as shown in FIG. **7**.

For an electronic device, including such as a pointing device, a navigation equipment, a smartphone or other portable electronic apparatus, utilizing a nine-axis motion sensor module, the signals of the magnetometer of the motion sensor module may be preferably be used to facilitate the obtaining of the resultant deviation including deviation angles in 3D reference and preferably in an absolute manner. The third signal set generated by the magnetometer may be obtained as shown in step **1035** in FIG. **10**, which includes measured magnetism Mx, My and Mz. In one embodiment, the Mx, My and Mz may refer to the measurement of the magnetism obtained. In order to obtain said measured state of the nine-axis motion sensor, according to one embodiment of the present invention, predicted magnetism Mx', My' and Mz' may too be calculated and obtained based on the abovementioned current state of the nine-axis motion sensor module or the second quaternion as shown in step **1040**. In other words, two sets of magnetism may be obtained for the measured state of the nine-axis motion sensor module; one may be the measured magnetism Mx, My, Mz in step **1035** and the other may be the predicted magnetism Mx', My', Mz' in step **1040** calculated based on the abovementioned current state or second quaternion in relation to the measured angular velocities thereof. Furthermore, in one embodiment, the computing processor may use a data conversion utility to convert the current state or second quaternion into predicted magnetism Mx', My' and Mz' and vice versa. This data conversion utility may be a software program represented by the following equations (18), (19) and (20).

$$(q_0^2+q_1^2-q_2^2-q_3^2)\cos\lambda+2(q_1q_3-q_0q_2)\sin\lambda=Mx' \tag{18}$$

$$2(q_1q_2-q_0q_3)\cos\lambda+2(q_2q_3+q_0q_1)\sin\lambda=My' \tag{19}$$

$$2(q_1q_3+q_0q_2)\cos\lambda+(q_0^2-q_1^2-q_2^2+q_3^2)\sin\lambda=Mz' \tag{20}$$

The variable λ in equations (18), (19) and (20) is the dip angle between the direction of the ambient magnetic field measured by the magnetometer and a horizontal plane in the spatial reference frame. The dip angle λ may be measured or calculated through an initial calibration process of the electronic device of the present invention and then be used as a parameter. The computing processor calculates the solution (Mx', My', Mz') of the equations (18), (19) and (20).

According to an exemplary embodiment of the method for obtaining a resultant deviation including deviation angles in a spatial reference frame of an electronic device, including such as a pointing device, a navigation equipment, a smartphone or other portable electronic apparatus, utilizing a nine-axis motion sensor module, it may be preferable to compare the current state of the nine-axis motion sensor module with the measured state thereof with respect to the present time frame T by utilizing a comparison model. In other words, in one embodiment as shown in step **1045**, it is preferable to compare the second quaternion in relation to the measured angular velocities of the current state at present time T with the measured axial accelerations Ax, Ay, Az, the predicted axial accelerations Ax', Ay', Az', the measured magnetism Mx, My, Mz, and the predicted magnetism Mx', My', Mz' also at present time T. Following which, a result may be obtained as an updated state of the nine-axis motion sensor module. In general and in an explanatory example of the present invention, the updated state may generally refer to the update of the previous state of the nine-axis motion sensor module at a previous time T−1 with reference to the current state and/or measured state thereof. The comparison model in step **1045** utilizes the measured axial accelerations Ax, Ay, Az and measured magnetism Mx, My, Mz, as well as the predicted axial accelerations Ax', Ay', Az' and the predicted magnetism Mx', My', Mz'.

In one embodiment, the result of the updated state of the nine-axis motion sensor module, preferably involving comparison or data association represented by the equations associated to the comparison model, may be a third quaternion as shown in the figure. Furthermore, as shown in steps **1050~1060**, the result may then be further outputted and utilized to obtain a resultant deviation including deviation angles in a spatial reference frame in the steps as shown in the figure. It can be understood that the examples of current state, measured state, state update, data association and probabilities of the comparison model and method of the present invention are provided for illustrative purposes only.

FIG. **11** shows a further exemplary embodiment of the comparison method of the present invention. The flow chart illustrates a method of obtaining resulting deviation including resultant angles in a spatial reference frame of an electronic device, including such as a pointing device, a navigation equipment, a smartphone or other portable electronic device, utilizing a nine-axis motion sensor module therein and subject to movements and rotations in dynamic environments in the spatial reference frame and mapping resultant deviation angles of said electronic device having movements and rotations in the 3D spatial reference frame and in a dynamic environment onto a display reference frame according to another embodiment of the present invention. Likewise, steps **1105~1130** may include obtaining a previous state and a current state of the motion sensor module as well as a measured state related to the axial accelerations of the motion sensor module. Additionally, in step **1135**, it may be preferable to compare the current state of the nine-axis motion sensor module with the measured state thereof with respect to the present time frame T by utilizing a comparison model. In other words, as shown in step **1135**, it is preferable to compare the second quaternion in relation to the measured angular velocities of the current state at present time T with the measured axial accelerations Ax, Ay, Az as well as the predicted axial accelerations Ax', Ay', Az' also at present time T. Following which, a result may be obtained as the first updated state of the nine-axis motion sensor module. In an explanatory example, the first updated state may generally refer to the first update of the current state of the nine-axis motion sensor module at preset time T. Furthermore, one of the technical effects of the present invention may too be obtained or achieved. In step **1135**, one of the advantages or effects by performing steps from **1105~1135** may be that the first updated state or third quaternion as shown in FIG. **11** may be advantageously obtained excluding undesirable axial accelerations caused by for example undesirable external forces such as the ones decoupled from a force of gravity.

In one embodiment, the result of the first updated state of the nine-axis motion sensor module, preferably involving comparison or data association represented by the equations associated to the comparison model, may be a third quaternion as shown in the figure. In addition, one of the technical effects of the present invention may include the exclusion of undesirable external interferences in the dynamic environment as previously mentioned; and wherein the undesirable external interferences may refer to or further include undesirable axial accelerations caused by undesirable external forces, preferably decoupled from a force of gravity, and/or undesirable magnetism caused by for example undesirable electromagnetic fields either adjacent to the motion sensor module. As shown in step **1140** of FIG. **11**, the first updated state of the nine-axis motion sensor module of the present invention may be further calculated and converted to a temporary pitch angle and a temporary roll angle based on the third quaternion. The first updated state, as shown in the figure, may be advantageously obtained such that or whereby undesirable axial accelerations associated with said undesirable external interferences in the dynamic environments may be preferably excluded; in an explanatory example, the first updated state may be preferably obtained excluding the abovementioned undesirable axial accelerations caused by undesirable external forces, such as external forces decoupled from a force of gravity. The third signal set generated by the magnetometer may be obtained, which includes measured magnetism Mx, My and Mz. The measured state of the nine-axis motion sensor module may be obtained by obtaining and calculating a measured yaw angle gained from the motion sensor signals of the nine-axis motion sensor module at the current time T according to the following equation (21).

$$Ty = \frac{-My\cos(Tr) + Mz\sin(Tr)}{Mx\cos(Tp) + My\sin(Tp)\cos(Tr) + Mz\sin(Tp)\cos(Tr)} \quad (21)$$

In equation (21), Ty is the measured yaw angle, Tp is the temporary pitch angle and Tr is the temporary roll angle.

In order to obtain said measured state of the nine-axis motion sensor, according to one embodiment of the present invention, a predicted yaw angle may be calculated and obtained based on the abovementioned first updated state of the nine-axis motion sensor module or the third quaternion at present time T as shown in step **1145**. In other words, the measured yaw angle in step **1140** and the predicted yaw angle in step **1145** may be obtained for the measured state of the nine-axis motion sensor module.

Furthermore, it may be preferable to compare the current state of the nine-axis motion sensor module with the mea-

sured state thereof with respect to the present time frame T by utilizing a comparison model. In other words, as shown in step **1150**, it is preferable to compare the second quaternion in relation to the measured angular velocities of the current state at present time T with the measured axial accelerations Ax, Ay, Az, the predicted axial accelerations Ax', Ay', Az', the measured yaw angle and the predicted yaw angle also at present time T. Following which, a result may be obtained as the second updated state of the nine-axis motion sensor module. In an explanatory example, the second updated state may generally refer to the second update of the current state of the nine-axis motion sensor module at preset time T. The comparison model in step **1150** is very similar to the abovementioned comparison models. Related details are omitted here for brevity. In one embodiment, the result of the second updated state of the nine-axis motion sensor module may be a fourth quaternion as shown in the figure. Furthermore, the result may then be further outputted and utilized to obtain a resulting deviation including resultant angles in a spatial reference frame in the following steps as shown in the figure. In addition to the abovementioned technical effects of the present invention in which undesirable axial accelerations of undesirable external interferences in the dynamic environments may be advantageously excluded as a result of the first updated state of the motion sensor module in step **1135**, another technical effect or merit may too be obtained along with result of the second updated state of the motion sensor as shown in step **1150** of FIG. **11**. One of the advantages or effects by performing steps such as from **1140~1150** may be that the second updated state or fourth quaternion as shown in FIG. **11** may be advantageously obtained excluding undesirable magnetism such as the ones caused by for example undesirable external or internal electromagnetic fields adjacent to the motion sensor module in the dynamic environments of the present invention.

It may be preferable to output the result of the second updated state, preferably in a form of the fourth quaternion, to the previous state of the nine-axis motion sensor module as shown in step **1155** in the figure. In other words, in one embodiment, the first quaternion may be replaced by the abovementioned fourth quaternion or substitute directly any previous values of first quaternion in the previous time T for further process in a loop. In other words, the fourth quaternion with respect to the present time T becomes the first quaternion with respect to the next time such as T+1; or, the fourth quaternion at previous time frame T−1 outputted may now be the first quaternion at present time frame T.

In step **1160**, the second updated state of the nine-axis motion sensor module of the present invention may be further calculated and converted to the resulting deviation including resultant angles associated with the spatial reference frame, wherein the resultant angles includes the yaw angle, pitch angle and roll angle of the 3D pointing device associated with the spatial reference frame, preferably about each of three orthogonal coordinate axes of the spatial reference frame. In addition, the second updated state, as shown in the figure, may be advantageously obtained such that or whereby undesirable magnetism associated with said undesirable external interferences in the dynamic environments may be preferably excluded; in an explanatory example, the second updated state may be preferably obtained excluding the abovementioned undesirable magnetism caused by for example undesirable electromagnetic fields, or magnetism other than the planetary geomagnetism, adjacent or of a magnitude influencing magnetometer of the motion sensor module. The resultant angles may be calculated according to equations (12), (13) and (14), wherein the variables q_0, q_1, q_2 and q_3 in equations (12), (13) and (14) are the four elements of the fourth quaternion. Furthermore, the resultant deviation in step **1160** may be advantageously obtained excluding undesirable interferences including such as the ones of undesirable axial accelerations caused by undesirable external forces decoupled from a force of gravity mentioned previously in step **1135** and the ones of undesirable magnetism caused by for example undesirable electromagnetic fields as mentioned previously in step **1150**. Likewise, in step **1165** as shown in FIG. **11**, the resultant deviation including deviation angles in 3D pointer reference may be further mapped to a display reference such as a 2D display reference of a display.

As illustrated by FIG. **12**, in one preferred embodiment, the first and second updated states may further comprise a first data association model and a second data association model respectively. The first data association model may be advantageously provided for comparing the first measured state associated with said second signal set with a first predicted measurement obtained from said current state; in addition, the second data association model may too be advantageously provided for comparing the second measured state associated with said third signal set with a second predicted measurement obtained from said first updated state. Furthermore, in another preferred embodiment, the first and second updated states may further comprise a first data association model and a second data association model respectively; and wherein the first data association model may be advantageously provided for comparing the first measured state associated with said second signal set with a first predicted measurement obtained from said current state; and wherein the second data association model may be advantageously provided for comparing the second measured state associated with said third signal set with a second predicted measurement obtained from said current state. Details on the differences of the obtaining of said second predicted measurement based on either the first updated state or the current state of the motion sensor module depending upon a comparison result are further described in FIG. **12**, as the routes presented or denoted by "Yes" and "No" shown therein.

FIG. **12** shows an exemplary flow chart of another embodiment of the present invention of a method for obtaining a resultant deviation comprising deviation angles of an electronic device, including such as a pointing device, navigation equipment, a smartphone or other portable electronic apparatus. Accordingly, the method for obtaining a resultant deviation including deviation angles in a spatial reference frame of an electronic device utilizing a nine-axis motion sensor module therein and subject to movements and rotations in dynamic environments in said spatial reference frame includes the following steps. As shown in the figure, at step **1210**, a previous state of the nine-axis motion sensor module may be obtained; and wherein the previous state is associated with at least previous angular velocities gained from the motion sensor signals of the nine-axis motion sensor module at a previous time T−1. In another embodiment, the previous state is associated with previous angular velocities, previous axial accelerations and previous magnetism gained from the motion sensor signals of the nine-axis motion sensor module at a previous time T−1. Next, at step **1220**, it may be to obtain a current state of the nine-axis motion sensor module by obtaining measured angular velocities ω_x, ω_y, ω_z gained from the motion sensor signals of the nine-axis motion sensor module at a current time T. At step **1225**, it may be to obtain a first measured state of the nine-axis motion sensor module by obtaining measured axial accelerations Ax, Ay, Az gained from the motion sensor signals of the nine-axis motion sensor module at the current time T. Following which and at step

1230 is calculating and obtaining a first predicted measurement of the nine-axis motion sensor module based on said current state thereof. At step 1235, a comparison may be performed to determine whether the signals related to the measured state including such as measured axial accelerations and/or measured magnetism are "good enough" to be used to compensate the current state of the motion sensor module and therefore an updated state thereof can be obtained.

According to the previously mentioned objectives of the present invention, it is preferable to provide an advantageous comparison or compensation method capable of outputting resultant deviation of a motion sensor module of a relatively high accuracy in the presence of external or internal interferences including such as electromagnetic fields generated by other electronic components adjacent to the motion sensor modules or of a magnitude strong enough to distort or affect the normal operations or signals of motion sensor module. Under such circumstances, a comparison utilizing data association may be advantageously provided or used to compare measured state of the motion sensor modules with an expected or predicted measurement thereof to determine the compensation for updating an updated state of the previous state. In step 1235 as previously mentioned, the data association may also include a predetermined value preset or preselected in accordance with for example the performance of motion sensor module utilized, and such that the comparison result of the measured state and the predicted measurement may make reference to the data association and the predetermined value or range to determine the compensation needed to take place to update the state of the motion sensor module including such as the previous and/or current states thereof.

Accordingly, updated state(s) of the motion sensor module may be obtained based on the result of the data association(s). As shown in the figure, if the result of abovementioned comparison falls within the predetermined result of for example a predetermined value or range of the data association, then in one embodiment of the present invention, in step 1240, a first updated state of the nine-axis motion sensor module may be obtained based on a first comparison between said first predicted measurement and said first measured state of the nine-axis motion sensor module. Otherwise, if the result is not within the predetermined value of range of the data association, then the first updated state may not be performed or obtained. Such method of the use of data association and comparison may be particularly useful in the abovementioned scenario of external or internal "interferences" such as the ones caused by undesired electromagnetic fields. In the case where the result falls outside of expected range, or denoted by "No" as shown in FIG. 12, the next step would be to obtain another measured state or the second measured state of the motion sensor module to determine whether another data association may be utilized to obtain the second updated state. It can however be understood that the second updated state may be provided as an additional step to the method of the present invention. One may only perform the abovementioned steps and obtain a result of the first updated state based on the measured state including the measured axial accelerations associated with the motion sensor module; in other words, either performing steps to obtain only the first updated state, steps to obtain only the second updated state, and/or steps to obtain both the first and second updated states as shown in the figure, shall all be considered to be within the scope of the present invention and within the spirit of the present invention. Furthermore and likewise, one of the technical effects of the present invention may too be obtained or achieved. In step 1240, one of the advantages or effects by performing steps from 1210~1240 may be that the first updated state as shown in FIG. 12 may be advantageously obtained excluding undesirable axial accelerations caused by for example undesirable external forces such as the ones decoupled from a force of gravity.

In another embodiment of the present invention or in the case where the abovementioned second updated state is to be obtained, one may further perform steps 1245~1260 as shown in FIG. 12. In step 1245, one may obtain a second measured state of the nine-axis motion sensor module by obtaining a measured yaw angle based on measured magnetism Mx, My, Mz gained from the motion sensor signals of the nine-axis motion sensor module at the current time T. Furthermore, as shown in step 1250, a second predicted measurement of the nine-axis motion sensor module may be calculated and obtained, following which a predicted yaw angle may too be obtained based on said first updated state thereof depending upon the result of the comparison such as the route denoted by "Yes" in FIG. 12. In another embodiment, the predicted yaw angle may be obtained based on said current state of the motion sensor module depending upon the result of the comparison such as a result or route of "No" denoted in FIG. 12. Once the measured state and the predicted measurements are obtained and available, a second comparison may be performed to determine whether compensation may be carried out based on the result of the comparison and the second data association. As shown in step 1255, the second data association including a predetermined value or range may be performed to determine whether the comparison falls within said predetermined value or range. If the result falls within said value or range, then a second updated state may be obtained and compensation may too take place as shown in step 1260 with the denotation of "Yes". Otherwise, if the result is not within the predetermined value, then step 1265 shall be carried out, following the direction shown and denoted by "No" in the figure; and in other words, compensation may utilize the second predicted measurement of the motion sensor module thereof for updating instead of using the second measured state thereof Likewise, in addition to the abovementioned technical effects of the present invention in which undesirable axial accelerations of undesirable external interferences in the dynamic environments may be advantageously excluded as a result of the first updated state of the motion sensor module in step 1240, another technical effect or merit may too be obtained along with result of the second updated state of the motion sensor as shown in step 1260 of FIG. 12. One of the advantages or effects by performing steps such as from 1245~1260 may be that the second updated state as shown in FIG. 12 may be advantageously obtained excluding undesirable magnetism such as the ones caused by for example undesirable external or internal electromagnetic fields adjacent to the motion sensor module in the dynamic environments of the present invention.

Following the above steps, in one embodiment of the present invention in which said comparison method may be provided in a continuous loop or a looped manner with respect to time, the result of the updated state at present time T may then be outputted to the previous state at previous time T−1 and become another beginning of the loop for the abovementioned steps to carry out again. The terminology of time (s) T, T−1 or T+1 shall be clear and apparent and shall too fall within the scope and spirit of the present invention. For example, in step 1260 as shown in FIG. 12, the second updated state of the nine-axis motion sensor module may be obtained by, or may too include, the updating said first updated state thereof based on a second comparison between said second predicted measurement and said second mea-

sured state of the nine-axis motion sensor module; and in step **1265**, the result of the second updated state thereof may be further outputted to the previous state in a looped manner with respect to time.

After step **1265**, the resultant deviation including the deviation angles in the spatial reference frame, namely the yaw, pitch and roll angles, may be obtained in step **1270** in a similar way as those in steps **745**, **1060** and **1160**. Furthermore, the resultant deviation in step **1270** may be advantageously obtained excluding undesirable interferences including such as the ones of undesirable axial accelerations caused by undesirable external forces decoupled from a force of gravity mentioned previously in step **1240** and the ones of undesirable magnetism caused by for example undesirable electromagnetic fields as mentioned previously in step **1260**.

As mentioned previously, in one embodiment of the present invention, the method for obtaining a resultant deviation of an electronic device utilizing a nine-axis motion sensor module, data associations may be provided to obtain a relatively accurate result under for example the existence of external or internal interferences to the sensor module. Accordingly, the abovementioned step of obtaining the first updated state of the nine-axis motion sensor module may further comprise performing a first data association to determine whether said first comparison between said first predicted measurement and said first measured state thereof falls within a first predetermined value of the nine-axis motion sensor module; and wherein the step of obtaining the second updated state of the nine-axis motion sensor module may too further comprise performing a second data association to determine whether said second comparison between said second predicted measurement and said second measured state thereof falls within a second predetermined value of the nine-axis motion sensor module.

Likewise, in accordance to the abovementioned continuous loop of the method of the present invention with respect to time and in one embodiment, the method for obtaining a resultant deviation of an electronic device utilizing a nine-axis motion sensor module may further comprise outputting said second updated state of the nine-axis motion sensor module to said previous state thereof; and wherein said previous state of the nine-axis motion sensor module may be a first quaternion with respect to said previous time T−1; and wherein said current state of the nine-axis motion sensor module may be a second quaternion with respect to said current time T; and wherein said first and second updated states of the nine-axis motion sensor module may too be a third and a fourth quaternion with respect to said current time T respectively.

In summary, the present invention also provides a nine-axis comparison method that compares the detected signals generated by and converted from the rotation of the electronic device, utilizing a nine-axis motion sensor module, about all of the three axes with the detected signals generated by and converted from the acceleration of the device along all of the three axes. In one embodiment, the nine-axis comparison method may then output the resultant deviation including yaw, pitch and roll angles in a spatial reference frame such as a 3D reference frame of the device. In another embodiment, the nine-axis comparison method may also include the mapping of the resultant deviation including yaw, pitch and roll angles in the spatial reference to a display reference frame such as a 2D display reference frame of a display screen of a display device. The nine-axis comparison method involving the comparison of different states of the motion sensor module and the utilization of data association of the present invention in order to output a resultant deviation having yaw, pitch and roll angles in for example 3D reference frame is novel and cannot be easily achieved by any know arts or their combinations thereof.

In view of the above, it is clear that such obtaining and outputting of deviation including 3D angles in a spatial reference frame in an "absolute" manner of the present invention is too novel, and the fact that the electronic device utilizing a motion sensor module therein having a novel comparison method and program of the present invention to obtain and output such deviation in "absolute" manner cannot be easily achieved by any known arts or their combination thereof. The term "absolute" associated with the resulting deviation including resultant angles such as yaw, pitch and roll in a spatial reference frame or 3D reference frame obtained and outputted by the device of the present invention may refer to the "actual" movements and rotations of the 3D pointer device of the present invention in said spatial reference frame. Moreover, the nine-axis comparison method of the present invention may accurately output said deviation including angles in 3D reference frame as noises associated with the nine-axis motion sensor module subject to movement and rotations in dynamic environments and accumulated over time may be effectively eliminated or compensated. Furthermore, the term "a", "an" or "one" recited herein as well as in the claims hereafter may refer to and include the meaning of "at least one" or "more than one". It can be understood that, as previously mentioned, the term of "dynamic" recited herein may refer to moving or subject to motions in general. It too can be understood that the term "excluding" recited herein to describe the exclusion of undesirable interferences is provided for illustrative purposes and shall not be limited to a certain or specific degree or magnitude of the effect of exclusion; any degree or magnitude associated thereto shall be considered to be within the spirit and scope of the present invention.

FIG. **13** is a flow chart of a method for compensating rotations of a 3D pointing device according to an embodiment of the present invention. The purpose of the method is transforming rotations and movements of the 3D pointing device to a movement pattern in the display plane of a display device (such as the plane X_DY_D of the display device **120** shown in FIG. **1** and FIG. **2**). The method may be executed by the 3D pointing device shown in FIG. **14**. FIG. **14** is a schematic diagram showing a 3D pointing device according to an embodiment of the present invention. The 3D pointing device in FIG. **14** includes a rotation sensor **342**, an orientation sensor **1410**, and a computing processor **1420**. The orientation sensor **1410** includes an accelerometer **344** and another computing processor **348**.

The flow in FIG. **13** is discussed as follows. In step **1320**, the orientation sensor **1410** generates an orientation output associated with the orientation of the 3D pointing device associated with three coordinate axes of a global reference frame associated with the Earth. The computing processor **348** of the orientation sensor **1410** may generate the aforementioned orientation output by executing steps **710** to **745** illustrated in FIG. **7** and FIG. **8**. In brief, in steps **710** to **745** illustrated in FIG. **7** and FIG. **8**, the rotation sensor **342** generates a rotation output (ω_x, ω_y, ω_z) associated with the rotation of the 3D pointing device associated with the three coordinate axes of a spatial reference frame associated with the 3D pointing device (such as the reference frame $X_PY_PZ_P$ shown in FIG. **1** and FIG. **2**), the accelerometer **344** generates a first signal set including axial accelerations Ax, Ay and Az associated with the movements and rotations of the 3D pointing device in the spatial reference frame, and then the computing processor **348** generates the orientation output based

on the first signal set and the rotation output. For more details, please refer to the discussions related to FIG. **7** and FIG. **8** above.

The computing processor **348** may generate the aforementioned orientation output in the form of a rotation matrix, a quaternion, a rotation vector, or in a form including the three orientation angles yaw, pitch and roll. The orientation output in the quaternion form may be the third quaternion generated in step **740** in FIG. **7** and FIG. **8**. The three orientation angles, namely yaw, pitch and roll, may be generated in step **745** in FIG. **7** and FIG. **8**. The computing processor **348** may obtain the rotation matrix from the orientation angles according to the following equation (22).

$$[R]_{3\times3}=\begin{bmatrix}\cos\theta\cos\psi & \sin\theta\sin\phi\cos\psi-\cos\phi\sin\psi & \sin\theta\cos\phi\cos\psi+\sin\phi\sin\psi\\ \cos\theta\sin\psi & \sin\theta\sin\phi\sin\psi+\cos\phi\cos\psi & \sin\theta\cos\phi\sin\psi-\sin\phi\cos\psi\\ -\sin\theta & \cos\theta\sin\phi & \cos\theta\cos\phi\end{bmatrix} \quad (22)$$

$[R]_{3\times3}$ is the orientation output in the form of a rotation matrix, θ is the pitch angle, ϕ is the roll angle and ψ is the yaw angle.

The computing processor **348** may also obtain the orientation output in the rotation matrix form from the quaternion form according to the following equation (23), wherein the quaternion form is represented as $<e_0, e_1, e_2, e_3>$.

$$[R]_{3\times3}=\begin{bmatrix}e_0^2+e_1^2-e_2^2-e_3^2 & 2(e_1e_2-e_0e_3) & 2(e_1e_3+e_0e_2)\\ 2(e_1e_2+e_0e_3) & e_0^2-e_1^2+e_2^2-e_3^2 & 2(e_2e_3-e_0e_1)\\ 2(e_1e_2+e_0e_3) & 2(e_2e_3+e_0e_1) & e_0^2-e_1^2-e_2^2+e_3^2\end{bmatrix} \quad (23)$$

Assume that the orientation output in the rotation vector form is represented as $<e_1, e_2, e_3>$ and the orientation output in the quaternion form is represented as $<e_0, e_1, e_2, e_3>$. The computing processor **348** may convert the rotation vector form to the quaternion form and convert the quaternion form to the rotation vector form according to the following equation (24).

$$\because e_0^2+e_1^2+e_2^2+e_3^2=1$$

$$\therefore e_0^2=1-(e_1^2+e_2^2+e_3^2) \quad (24)$$

One of the four forms of the orientation output may be converted to another of the four forms easily based on equations (22), (23) and (24).

In step **1340**, the rotation sensor **342** generates a rotation output associated with the rotation of the 3D pointing device associated with the three coordinate axes of a spatial reference frame associated with the 3D pointing device itself (such as the reference frame $X_PY_PZ_P$ shown in FIG. **1** and FIG. **2**). In step **1360**, the computing processor **1420** uses the orientation output and the rotation output to generate a transformed output $<d_x, d_y>$ associated with the fixed reference frame associated with the display device. The transformed output $<d_x, d_y>$ represents a 2-dimensional movement in a display plane in the fixed reference frame parallel to the screen of the display device, such as the display plane X_DY_D of the display device **120** shown in FIG. **1** and FIG. **2**, wherein d_x represents the movement along the X_D axis and d_y represents the movement along the Y_D axis. In addition, the transformed output $<d_x, d_y>$ may represent a segment of movement in the display plane. Multiple segments of movement plotted by the 3D pointing device may constitute a movement pattern in the display plane and the display device may be controlled to move a virtual object or a cursor along the movement pattern.

The step **1360** includes four sub-steps **1362**, **1364**, **1366** and **1368**. In step **1362**, the computing processor **1420** obtains the orientation of the display device associated with the global reference frame associated with the Earth. For example, the 3D pointing device may include a reset button. The user may point the 3D pointing device at the display device and press the reset button. The reset button may transmit a reset signal to the computing processor **1420**. The computing processor **1420** may record the current orientation output generated by the orientation sensor **1410** as the orientation of the display device associated with the global reference frame upon receiving the reset signal. The orientation of the display device associated with the global reference frame associated with the Earth may be recorded as a reset yaw angle.

In step **1364**, the computing processor **1420** obtains the orientation of the 3D pointing device associated with the fixed reference frame associated with the display device based on the orientation output and the orientation of the display device associated with the global reference frame associated with the Earth. As mentioned above, the current orientation output recorded by the computing processor **1420** may include a reset yaw angle associated with one of the three coordinate axes (such as the Z axis) of the global reference frame associated with the Earth. The computing processor **1420** may obtain the orientation of the 3D pointing device associated with the fixed reference frame associated with the display device by subtracting the reset yaw angle from the orientation output.

Step **705** shown in FIG. **7** and FIG. **8** is equivalent to steps **1362** and **1364**. In an alternative embodiment of the present invention, in order to generate the orientation output in step **1320**, the computing processor **348** may execute steps **705** to **745** shown in FIG. **7** and FIG. **8**. In this case, the orientation output generated by the orientation sensor **1410** represents the orientation of the 3D pointing device associated with the fixed reference frame associated with the display device. Therefore, the computing processor **1420** skips steps **1362** and **1364** in the alternative embodiment.

In step **1366**, the computing processor **1420** generates a transformed rotation associated with the fixed reference frame associated with the display device based on the orientation of the 3D pointing device associated with the fixed reference frame associated with the display device and the rotation output. For example, the computing processor **1420** may generate the transformed rotation according to the following equation (25).

$$\begin{bmatrix}\omega_x\\ \omega_y\\ \omega_z\end{bmatrix}_D=\begin{bmatrix}R_{11} & R_{12} & R_{13}\\ R_{21} & R_{22} & R_{23}\\ R_{31} & R_{32} & R_{33}\end{bmatrix}\begin{bmatrix}\omega_x\\ \omega_y\\ \omega_z\end{bmatrix}_P \quad (25)$$

R_{11}-R_{13}, R_{21}-R_{23} and R_{31}-R_{33} are the elements of the 3×3 rotation matrix obtained from the orientation of the 3D pointing device associated with the fixed reference frame associated with the display device. $[\omega_x\ \omega_y\ \omega_z]_D$ is the transformed rotation associated with the fixed reference frame associated with the display device. $[\omega_x\ \omega_y\ \omega_z]_P$ is the rotation output generated by the rotation sensor **342**. The transformed rotation $[\omega_x\ \omega_y\ \omega_z]_D$ includes three angular velocities ω_x, ω_y and ω_z respectively associated with the three coordinate axes X_D, Y_D and Z_D of the fixed reference frame associated with the display device. The rotation output $[\omega_x\ \omega_y\ \omega_z]_P$ includes three

angular velocities ω_x, ω_y and ω_z respectively associated with the three coordinate axes X_P, Y_P and Z_P of the spatial reference frame associated with the 3D pointing device.

In step **1368**, the computing processor **1420** generates the transformed output $<d_x, d_y>$ based on the transformed rotation $[\omega_x\ \omega_y\ \omega_z]_D$. d_x is the first movement component of the transformed output associated with the coordinate axis X_D of the fixed reference frame associated with the display device, while d_y is the second movement component of the transformed output associated with the coordinate axis Y_D of the fixed reference frame associated with the display device. For example, the computing processor **1420** may multiply the angular velocity ω_y of the transformed rotation by a predetermined scale factor to generate the second movement component d_y and multiply the angular velocity ω_z of the transformed rotation by the same scale factor to generate the first movement component d_x. The value of the scale factor may be set by the user.

The method for compensating rotations of a 3D pointing device shown in FIG. **13** may be executed by the 3D pointing device shown in FIG. **15** as well. FIG. **15** is a schematic diagram showing another 3D pointing device according to an embodiment of the present invention. The 3D pointing device in FIG. **15** includes a rotation sensor **342**, an orientation sensor **1510**, and a computing processor **1420**. The orientation sensor **1510** includes an accelerometer **344**, a magnetometer **345**, and a computing processor **348**.

In step **1320**, the orientation sensor **1510** generates an orientation output associated with the orientation of the 3D pointing device associated with the three coordinate axes of the global reference frame associated with the Earth. The computing processor **348** of the orientation sensor **1510** may generate the aforementioned orientation output by executing steps **1010** to **1060** illustrated in FIG. **10**, steps **1110** to **1160** illustrated in FIG. **11**, or steps **1210** to **1270** illustrated in FIG. **12**. In brief, in the aforementioned steps shown in FIG. **10**, FIG. **11** or FIG. **12**, the rotation sensor **342** generates a rotation output $(\omega_x, \omega_y, \omega_z)$ associated with the rotation of the 3D pointing device associated with the three coordinate axes of the spatial reference frame associated with the 3D pointing device (such as the reference frame $X_PY_PZ_P$ shown in FIG. **1** and FIG. **2**), the accelerometer **344** generates a first signal set including axial accelerations Ax, Ay and Az associated with the movements and rotations of the 3D pointing device in the spatial reference frame, the magnetometer **345** generates a second signal set (Mx, My, Mz) associated with the magnetism of the Earth, and then the computing processor **348** generates the orientation output based on the first signal set, the second signal set and the rotation output. For more details, please refer to the discussions regarding FIG. **10**, FIG. **11** and FIG. **12** above.

The computing processor **348** may generate the aforementioned orientation output in the form of a rotation matrix, a quaternion, a rotation vector, or in a form including the three orientation angles yaw, pitch and roll. The orientation output in the quaternion form may be the third quaternion generated in step **1050** in FIG. **10**, the fourth quaternion generated in step **1155** in FIG. **11**, or may be obtained from the updated state in step **1265** in FIG. **12**. The three orientation angles, namely yaw, pitch and roll, may be generated in step **1060** in FIG. **10**, step **1160** in FIG. **11**, or step **1270** in FIG. **12**. The rotation matrix form and the rotation vector form may be obtained according to the aforementioned equations (22), (23) and (24).

In this embodiment, the rotation sensor **342** in FIG. **15** executes step **1340** as the rotation sensor **342** in FIG. **14** does, and the computing processor **1420** in FIG. **15** executes step **1360** as the computing processor **1420** in FIG. **14** does.

Step **1005** shown in FIG. **10** and step **1105** shown FIG. **11** are equivalent to steps **1362** and **1364**. In an alternative embodiment of the present invention, in order to generate the orientation output in step **1320**, the computing processor **348** in FIG. **15** may execute steps **1005** to **1060** shown in FIG. **10** or steps **1105** to **1160** shown in FIG. **8**. In this case, the orientation output generated by the orientation sensor **1510** represents the orientation of the 3D pointing device associated with the fixed reference frame associated with the display device. Therefore, the computing processor **1420** in FIG. **15** skips steps **1362** and **1364** in the alternative embodiment.

The method for compensating rotations of a 3D pointing device shown in FIG. **13** may be executed by the 3D pointing device shown in FIG. **16** as well. FIG. **16** is a schematic diagram showing another 3D pointing device according to an embodiment of the present invention. The 3D pointing device in FIG. **16** includes a rotation sensor **342**, an orientation sensor **1610**, and a computing processor **1420**. The orientation sensor **1610** includes an accelerometer **344**, a magnetometer **345**, and a computing processor **348**.

In step **1320**, the orientation sensor **1610** generates an orientation output associated with the orientation of the 3D pointing device associated with the three coordinate axes of the global reference frame associated with the Earth. In order to generate the orientation output, the accelerometer **344** generates a first signal set including axial accelerations Ax, Ay and Az associated with the movements and rotations of the 3D pointing device in the spatial reference frame associated with the 3D pointing device itself, the magnetometer **345** generates a second signal set (Mx, My, Mz) associated with the magnetism of the Earth, and then the computing processor **348** in FIG. **16** generates the orientation output based on the first signal set and the second signal set. The details of the generation of the orientation output are discussed below.

The orientation output may be provided in a form including a yaw angle ψ, a pitch angle θ, and a roll angle ϕ respectively associated with the three coordinate axes of the global reference frame associated with the Earth. The first signal set includes axial accelerations Ax, Ay and Az respectively associated with the movements and rotations of the 3D pointing device along the X_P, Y_P and Z_P axes of the spatial reference frame associated with the 3D pointing device itself The second signal set includes magnetism Mx, My, Mz associated with the movements and rotations of the 3D pointing device along each of the three orthogonal coordinate axes $X_PY_PZ_P$ of the spatial reference frame associated with the 3D pointing device, respectively.

The computing processor **348** may calculate the pitch angle θ and the roll angle ϕ according to the following equations (26) and (27).

$$\theta = \sin^{-1}\left(\frac{Ax}{g}\right) \tag{26}$$

$$\phi = \sin^{-1}\left(\frac{Ay}{g\cos\theta}\right) \text{ or } \phi = \cos^{-1}\left(\frac{Ax}{g\cos\theta}\right) \tag{27}$$

In equations (26) and (27), Ax, Ay and Az are axial accelerations of the first signal set, while g is the gravitational acceleration. In addition, the computing processor **348** may calculate the yaw angle ψ according to the following equation (28).

$$\psi = \tan^{-1}\left(\frac{-My\cos\phi + Mz\sin\phi}{Mx\cos\theta + My\sin\theta\sin\phi + Mz\sin\theta\cos\phi}\right) \quad (28)$$

In equation (28), Mx, My and Mz are the aforementioned elements of the second signal set. The computing processor **348** in FIG. **16** may generate the orientation output including the yaw angle ψ, the pitch angle θ, and the roll angle ϕ according to equations (26), (27) and (28).

In this embodiment, the rotation sensor **342** in FIG. **16** executes step **1340** as the rotation sensor **342** in FIG. **14** does, and the computing processor **1420** in FIG. **16** executes step **1360** as the computing processor **1420** in FIG. **14** does.

The method shown in FIG. **13** and the 3D pointing devices shown in FIG. **14** to FIG. **16** can transform 3D rotations and movements of the pointing devices into a 2D movement pattern in the display plane of the display device. The transformation of conventional pointing devices fails to take every one of the yaw, pitch and roll angles into account and their transformation is erroneous in some circumstances. For example, a conventional pointing device may transform its rotation to movement along an exactly opposite direction when the conventional pointing device is flipped over. On the other hand, the method shown in FIG. **13** and the 3D pointing devices shown in FIG. **14** to FIG. **16** can transform the rotations and movements of the 3D pointing devices correctly no matter how they are oriented or turned because the transformation of the embodiments of the present invention takes every one of the yaw, pitch and roll angles into account.

It may be understood that the present invention may be applied to various scenarios and application fields including such as gaming, computers and navigation. It may too be understood that the scope of the present invention shall be determined by the accompanying claims and shall include variations of applications of the present invention as well as differences in the term definitions used or related to including such as pointing devices, navigation equipment, smartphone and/or electronic devices.

What is claimed is:

1. A 3D pointing device, comprising:

an orientation sensor, generating an orientation output associated with an orientation of the 3D pointing device associated with three coordinate axes of a global reference frame associated with Earth;

a rotation sensor, generating a rotation output associated with a rotation of the 3D pointing device associated with three coordinate axes of a spatial reference frame associated with the 3D pointing device; and

a first computing processor, using the orientation output and the rotation output to generate a transformed output associated with a fixed reference frame associated with a display device,

wherein the orientation sensor comprises:

an accelerometer, generating a first signal set comprising axial accelerations associated with movements and rotations of the 3D pointing device in the spatial reference frame;

a magnetometer, generating a second signal set associated with Earth's magnetism; and

a second computing processor, generating the orientation output based on the first signal set, the second signal set and the rotation output or based on the first signal set and the second signal set;

wherein the rotation sensor, the accelerometer, and the magnetometer forming a nine-axis motion sensor module; the 3D pointing device is configured for obtaining one or more resultant deviation including a plurality of deviation angles using a plurality of measured magnetisms Mx, My, Mz and a plurality of predicted magnetism Mx', My' and Mz'.

2. The 3D pointing device of claim **1**, wherein the orientation output comprises a yaw angle, a pitch angle, and a roll angle associated with the three coordinate axes of the global reference frame; the first signal set comprises a first axial acceleration, a second axial acceleration, and a third axial acceleration; the second computing processor calculates the pitch angle based on the first axial acceleration, calculates the roll angle based on the second axial acceleration and the pitch angle or based on the third axial acceleration and the pitch angle, and calculates the yaw angle based on the pitch angle, the roll angle, and the second signal set.

3. The 3D pointing device of claim **1**, wherein the orientation output provided by the orientation sensor is a rotation matrix, a quaternion, a rotation vector, or comprises three orientation angles.

4. The 3D pointing device of claim **1**, wherein the transformed output represents a segment of a movement in a plane in the fixed reference frame parallel to a screen of the display device.

5. The 3D pointing device of claim **1**, wherein the first computing processor obtains an orientation of the display device associated with the global reference frame, obtains an orientation of the 3D pointing device associated with the fixed reference frame based on the orientation output and the orientation of the display device associated with the global reference frame, generates a transformed rotation associated with the fixed reference frame based on the orientation of the 3D pointing device associated with the fixed reference frame and the rotation output, and generates the transformed output based on the transformed rotation.

6. The 3D pointing device of claim **5**, wherein when the first computing processor receives a reset signal, the first computing processor records a current orientation output generated by the orientation sensor as the orientation of the display device associated with the global reference frame.

7. The 3D pointing device of claim **6**, wherein the current orientation output comprises a yaw angle associated with one of the three coordinate axes of the global reference frame, the first computing processor obtains the orientation of the 3D pointing device associated with the fixed reference frame by subtracting the yaw angle from the orientation output.

8. The 3D pointing device of claim **5**, wherein the first computing processor obtains a rotation matrix from the orientation of the 3D pointing device associated with the fixed reference frame, and multiplies the rotation matrix and the rotation output together to generate the transformed rotation.

9. The 3D pointing device of claim **8**, wherein the transformed rotation comprises a first angular velocity, a second angular velocity, and a third angular velocity associated with three coordinate axes of the fixed reference frame; the transformed output comprises a first movement component and a second movement component associated with two of the three coordinate axes of the fixed reference frame; the first computing processor multiplies the second angular velocity by a scale factor to generate the second movement component and multiplies the third angular velocity by the scale factor to generate the first movement component.

10. A method for compensating rotations of a 3D pointing device, comprising:

generating an orientation output associated with an orientation of the 3D pointing device associated with three coordinate axes of a global reference frame associated with Earth;

generatinq a first signal set comprising axial accelerations associated with movements and rotations of the 3D pointing device in the spatial reference frame;

generating a second signal set associated with Earth's magnetism; generating the orientation output based on the first signal set, the second signal set and the rotation output or based on the first signal set and the second signal set;

generating a rotation output associated with a rotation of the 3D pointing device associated with three coordinate axes of a spatial reference frame associated with the 3D pointing device; and

using the orientation output and the rotation output to generate a transformed output associated with a fixed reference frame associated with a display device, wherein the orientation output and the rotation output is generated by a nine-axis motion sensor module; obtaining one or more resultant deviation including a plurality of deviation angles using a plurality of measured magnetisms Mx, My, Mz and a plurality of predicted magnetism Mx', My' and Mz' for the second signal set.

11. The method of claim **10**, wherein the orientation output comprises a yaw angle, a pitch angle, and a roll angle associated with the three coordinate axes of the global reference frame; the first signal set comprises a first axial acceleration, a second axial acceleration, and a third axial acceleration; the step of generating the orientation output based on the first signal set and the second signal set comprises:

calculating the pitch angle based on the first axial acceleration;

calculating the roll angle based on the second axial acceleration and the pitch angle or based on the third axial acceleration and the pitch angle; and

calculating the yaw angle based on the pitch angle, the roll angle, and the second signal set.

12. The method of claim **10**, wherein the orientation output is a rotation matrix, a quaternion, a rotation vector, or comprises three orientation angles.

13. The method of claim **10**, wherein the transformed output represents a segment of a movement in a plane in the fixed reference frame parallel to a screen of the display device.

14. The method of claim **10**, wherein the step of generating the transformed output comprises:

obtaining an orientation of the display device associated with the global reference frame;

obtaining an orientation of the 3D pointing device associated with the fixed reference frame based on the orientation output and the orientation of the display device associated with the global reference frame;

generating a transformed rotation associated with the fixed reference frame based on the orientation of the 3D pointing device associated with the fixed reference frame and the rotation output; and

generating the transformed output based on the transformed rotation.

15. The method of claim **14**, wherein the step of generating the transformed rotation comprises:

obtaining a rotation matrix from the orientation of the 3D pointing device associated with the fixed reference frame; and

multiplying the rotation matrix and the rotation output together to generate the transformed rotation.

16. The method of claim **15**, wherein the transformed rotation comprises a first angular velocity, a second angular velocity, and a third angular velocity associated with three coordinate axes of the fixed reference frame; the transformed output comprises a first movement component and a second movement component associated with two of the three coordinate axes of the fixed reference frame; the step of generating the transformed output based on the transformed rotation comprises:

multiplying the second angular velocity by a scale factor to generate the second movement component; and

multiplying the third angular velocity by the scale factor to generate the first movement component.

17. The method of claim **14**, wherein the step of obtaining the orientation of the display device associated with the global reference frame comprises:

recording a current orientation output as the orientation of the display device associated with the global reference frame in response to a reset signal.

18. The method of claim **17**, wherein the current orientation output comprises a yaw angle associated with one of the three coordinate axes of the global reference frame, and the step of obtaining the orientation of the 3D pointing device associated with the fixed reference frame comprises: obtaining the orientation of the 3D pointing device associated with the fixed reference frame by subtracting the yaw angle from the orientation output.

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