

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

Samsung Electronics Co., Ltd.
Petitioner

v.

CM HK LIMITED
Patent Owner

Patent No. 10,852,846

**DECLARATION OF DR. MAJID SARRAFZADEH
IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW
OF U.S. PATENT NO. 10,852,846**

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I, Majid Sarrafzadeh, declare as follows:

I. INTRODUCTION

1. I have been retained as an independent expert consultant in this proceeding before the United States Patent and Trademark Office (“PTO”) regarding U.S. Patent No. 10,852,846 (“the ’846 patent”) (Ex. 1001).¹ I have been asked to consider whether prior art references disclose or suggest the features recited in claims 1, 3, 7 and 9 (“the challenged claims”) of the ’846 patent. My opinions are set forth below.

II. BACKGROUND AND QUALIFICATIONS

2. My qualifications are stated more fully in my curriculum vitae, which is attached as Ex. 1003. Below is a summary of my education, work experience, and other qualifications.

3. I currently hold the title of Distinguished Professor and Director of Embedded and Reconfigurable Computing (ER) Laboratory in the Computer Science Department at the University of California, Los Angeles (UCLA). I also have a courtesy appointment in the Department of Electrical Engineering at UCLA.

¹ In this Declaration, I refer to exhibits that I understand are to be attached to the petition for *Inter Partes* Review of the ’846 patent.

4. I believe that I qualify as an expert in the field of sensors and sensor data processing, and as at least a person of ordinary skill in the art. I understand that my current Curriculum Vitae is being submitted by Petitioner as Exhibit 1003, and summarizes my qualifications.

5. I received my Bachelor's Degree from the University of Illinois at Urbana-Champaign in Electrical and Computer Engineering in 1982, a Master of Science Degree in Electrical and Computer Engineering University of Illinois in 1984, and a Ph.D. in Electrical and Computer Engineering University of Illinois in 1987.

6. From 1987 to 1991, I was an Assistant Professor in the Department of Electrical and Computer Engineering at Northwestern University. From 1991-1997, I held the title of Associate Professor, also in the Department of Electrical and Computer Engineering at Northwestern University. From 1997-2000, I held the title of Full Professor in that department.

7. I am an author or co-author on more than 600 publications in electrical engineering and computer sciences. Many of my publications relate to the use of sensors and sensor networks to track human body movement and health indicators. My publications also concern sensor fusion algorithms, including the various types of Kalman Filters.

8. I have used various sensors including motion sensors in my research. I have designed and built hardware and software systems for motion tracking, gait analysis, 3D rehab systems, and gaming just to name a few.

9. I have performed data capture, data processing and analytics with these mobile systems. I have utilized these mobile systems in remote monitoring systems. In many of my projects too I have developed algorithms relating to sensor fusion. For example, I have used motion sensor fusion to cancel motion noise in other signals, such as when working with photoplethysmography (PPG). I have used pressure sensors, accelerator and gyroscope fusion to construct motion data.

10. I have worked on a finger worn device for remote controlling a document such as a PowerPoint document. The user could remotely perform basic control of a document (such as advancing a slide or zooming in on a slide) by moving her finger. The system, including the ring prototype, was built around 2008.

III. MATERIALS REVIEWED

11. The opinions contained in this Declaration are based on the documents I reviewed, my professional judgment, as well as my education, experience, and knowledge regarding systems and processes in the field of sensors, sensor fusion, and graphics interface technology.

12. In forming my opinions expressed in this Declaration, I reviewed the following materials:

Ex. 1001	U.S. Patent No. 10,852,846 to Liou et al. (“the ‘846 patent”)
Ex. 1004	Prosecution History of U.S. Patent No. 10,852,846
Ex. 1005	WO 2009/156499 to Bassompierre et al.
Ex. 1006	Certified Translation of WO 2009/156499 to Bassompierre et al. (“Bassompierre”)
Ex. 1007	A. Kim and M. Golnaraghi, “A quaternion-based orientation estimation algorithm using an inertial measurement unit,” <i>PLANS 2004. Position Location and Navigation Symposium (IEEE Cat. No. 04CH37556)</i> , pp. 268-272, 2004 (“Kim”)
Ex. 1008	U.S. Patent No. 8,462,109 to Nasiri (“Nasiri”)
Ex. 1009	U.S. Patent No. 8,441,438
Ex. 1010	U.S. Patent No. 8,552,978
Ex. 1011	IPR2018-01258, Paper 86 (Final Written Decision)
Ex. 1012	IPR2019-00143, Paper 87 (Final Written Decision)
Ex. 1013	IPR2018-01257, Paper 87 (Final Written Decision)
Ex. 1014	Provisional Application No. 61/292,558
Ex. 1015	3/7/2018 Deposition Trans. of Dr. LaViola in <i>CyWee Group Ltd. v. Samsung Elecs. Co., Ltd.</i> , 17-cv-00140 (E.D. Tx.)
Ex. 1016	5/22/2019 Deposition Trans. Of Dr. Joseph LaViola in IPR-2018-01257 and IPR-2018-01258

I also considered any other documents and materials I refer to in this Declaration.

13. My opinions contained in this declaration are based on the documents I reviewed and my knowledge and professional judgment. My opinions have also been guided by my appreciation of how a person of ordinary skill in the art would have understood the state of the art, the prior art, and the claims and the specification of the '846 patent at the time of the alleged invention, which I discuss below.

14. I have been asked to consider that the time of the alleged invention of the '846 patent was around 2010 (including and up to November 11, 2010), which corresponds to the filing date of the earliest non-provisional application associated with the '846 patent. (Ex. 1001, Cover.)

15. Based on my experience and expertise, it is my opinion that certain references disclose and/or suggest all the features recited in challenged claims of the '846 patent, as I discuss in detail below.

16. I was an expert on behalf of petitioner in IPR2018-01257, challenging U.S. Patent No. 8,552,978 ('978 patent), and IPR2018-01258, challenging U.S. Patent No. 8,441,438 ('438 patent), both of which are related to the '846 patent, and both of which include specifications that are similar to the specification of the '846 patent in ways that I will describe later in my declaration. I submitted a declaration and gave deposition testimony in both proceedings.

IV. PERSON OF ORDINARY SKILL IN THE ART

17. I am familiar with the level of ordinary skill in the art regarding the '846 patent as of around November 11, 2010, including late 2009 through early 2010. Considering the '846 patent, the technology, the educational level and experience of workers in the field relating to the patent, and problems and solutions in that field, and drawing on my own experience, I believe a person of ordinary skill in the art at the time of the alleged invention (around November 11, 2010, including late 2009 through early 2010) would have had an undergraduate degree in electrical engineering, computer engineering, computer science, physics or a related field along with two years of work experience in the field of sensors (such as accelerometers, gyroscopes and magnetometers), sensor fusion algorithms, including Kalman Filters, quaternion mathematics, and mobile computing technologies. More education can supplement practical experience and vice versa.

18. My opinions in this Declaration regarding the '846 patent and the prior art (including the state of the art) are from the perspective of one of ordinary skill in the art as I defined above, during the relevant timeframe.

V. TECHNICAL BACKGROUND

19. Below, I present a brief overview of certain aspects of systems and processes relating to sensors, sensor fusion algorithms, and two-dimensional

graphics interface technology at the time of the alleged invention for the '846 patent. The functionalities and concepts I describe below in this technical background section reflect the state of the art that a person of ordinary skill in the art would have had knowledge of and understood prior to and at the time of the alleged invention of the 846 patent. I rely on, and incorporate as applicable (even if not expressly mentioned below), the following disclosures and opinions to support my opinions in this Declaration, including those opinions relating to how the prior art discloses and/or suggests the challenged claims of the '846 patent and how and why a person of ordinary skill in the art would have been motivated to consider and combine the disclosures and suggestions from that prior art as I explain below in Section VIII and the Appendix to my declaration. The concepts below would have been within the knowledge and mindset of a person of ordinary skill in the art at the time.

A. Gyroscopes and Accelerometers

20. A sensor is a device capable of representing a characteristic of an object in numerical form. One kind of sensor is a gyroscope, which is also known as a gyrometer. It can describe the velocity of an object along one to three axes. An accelerometer can represent the acceleration of an object in one to three axes. An accelerometer can be particularly useful in determining the direction of gravity (down) acting on an object in three dimensions. This is sometime referred to as a

gravity vector. As a general matter, neither a gyroscope, nor an accelerometer, can represent heading. In other words, neither a gyroscope nor an accelerometer can tell you in which direction (north, south, east or west) an object is pointing.

Heading is also most commonly referred to as yaw.

21. MEMS sensor modules were well known by 2010. MEMS is an acronym for “Micro-Electro-Mechanical-System.” (Ex. 1001, 10:23-26.) A MEMS sensor module could include a gyroscope and accelerometer in a single package that could be included on small electronic devices, like a cell phone or pointer device, to provide orientation data. (Ex. 1007, 268.)

B. Sensor Fusion Algorithms (Extended Kalman Filters) with Quaternions

22. It was well known to persons of skill in the art to use sensor fusion algorithms to achieve the best estimate of the orientation of an object in three-dimensional space. (Ex. 1007.) For example, it was well known to those of ordinary skill that extended Kalman Filters utilizing gyroscope and accelerometer readings and quaternion algebra could be used to achieve optimal estimates of object orientation. (*See id.*)

23. In the Final Written Decisions of the '438 patent and '978 patent, the Board found that equations 5-11 in the '438 patent and '978 patent (which are the same as equations 5-11 in the '846 patent), “represent a non-linear recursive estimator (as any [person of ordinary skill in the art] would understand by

examining the mathematical equations) which, in the case of this embodiment of the '978 Patent, combines elements of an extended Kalman Filter coupled with a weighted vector norm.” (Ex. 1013, p. 43-44.) I did not disagree with that characterization then and I do not disagree presently. In fact, as a person of skill in the art, I understand the '846 patent to disclose and claim the implementation of an extended Kalman Filter, which was well-known in 2010 and many years before.

24. Further, the use of quaternions with Kalman Filters was well-known to a person of ordinary skill in the art. A quaternion is a four-valued vector generalization of complex numbers with special mathematical properties that allow them to describe rotations efficiently. Quaternions were first described in the 19th century by Irish mathematician William Rowan Hamilton. The Board has previously found “knowledge of quaternion mathematics to be within the level of ordinary skill.” (Ex. 1013, p. 6, 44.) The use of quaternions with Kalman Filters was also well known. (Ex. 1007).

25. When considering the related '978 and '438 patents, the Board found that a person of ordinary skill in the art would have had “knowledge of sensor systems, mobile computing technologies, Kalman Filters, and quaternion mathematics” by 2010. (Ex. 1013, p. 45.) Patentee’s expert in IPR proceedings of the related '978 and '438 patent confirmed the common use of quaternions in graphics applications at least as early as 2009. (Ex. 1016, 33:14-18 (“Q Are

quaternions, in fact, widely used in graphics applications? A Yes. Q And was that also true in 2009? A Yes.”.)

26. Patentee’s expert also confirmed that it was known how to convert a quaternion in a given state vector into yaw, pitch and roll angles:

Q In the novel-enhanced comparison method of the ’438 patent that you’re referring to in paragraph 36, and also I believe in paragraph 36 of the ’978 declaration, is orientation expressed as a quaternion?

A Yes, it is.

Q What is a quaternion, sir?

A Quaternion is a mathematical representation for orientation that uses four numbers. A three-element vector and a scalar quantity. And it makes certain computations easier to do as opposed to other orientation representations.

Q Can you derive the offset angles to some coordinate system that you established from an orientation quaternion?

A So, given a quaternion, I should be able to tell you or would be able to determine what the orientation or the -- let’s say, if you have the offset angles. **If you want to talk about -- talk about a coordinate system and X, Y, and Z axes, it would be able to tell you the amount of the rotation about the X axis, about the Y axis and about the Z axis.**

Q Is that yaw, pitch, and roll?

A That is another way of describing it, yes.

(Ex. 1016, 32:3-25 (emphases added).)

27. It was known to a person of ordinary skill in the art that an angle could be represented in multiple formats. A person of ordinary skill would have known how to convert an angle from one form to another, for example, from Euler angle representation to quaternion representation. (Ex. 1006, 20:13-17.) To a person of ordinary skill in the art, this concept of representing angles is similar to being able to measure distance in feet or meters. The conversion between the two is known and straight-forward and represents the same thing, i.e., distance.

C. Projecting Orientation Changes to Two-Dimensional Displays

28. It was well known to a person of ordinary skill in the art how to convert or translate three-dimensional orientation in quaternion or Euler angle form into a two dimensional representation on a screen or display. A person of ordinary skill in the art would have known how to map an orientation in a given coordinate system or reference frame to another coordinate system or reference frame.

29. In the IPR of the related '978 patent, patentee's expert admitted that it was known to a person of ordinary skill in the art how to convert a three-dimensional orientation to a display screen of two dimensions:

A . . . I believe anyone of ordinary skill in the art would be able to take that orientation and map it to a 2D display, or map it as a -- whatever pattern that they would want, they would -- they would be so choose in doing.

Q Is that because it's just a geometric calculation or why do you say that?

A Yeah. Because it was simply just a geometric calculation.

Q Doesn't the calculation, though, depend on the method you used to determine the object's orientation?

A I don't see why it would.

Q Are they completely uncoupled?

A I mean, once you have a[n] orientation in a given coordinate system, it doesn't really matter how you got it. You simply can map that into a different coordinate system, in this case, the display coordinate system to get some type of movement pattern on the screen.

(Ex. 1013, p. 59, citing testimony of patentee's expert Dr. LaViola (Ex. 1016, 48:10-49:2).)

30. In the deposition from which that quote was taken, patentee's expert also testified that a person of ordinary skill in the art would be able to convert a three-dimensional orientation to a display screen of two dimensions even in the case where the display screen was part of the same handheld device:

Q. And does the mapping or the ability of a person of ordinary skill in the art to do the mapping, does that depend on whether it's a built-in display or a display that is, say, somewhere across the room from the 3D pointing device?

A. It does make a difference as to where the quote, unquote, display reference frame is. If it's coupled with the 3D -- by the handheld 3D pointing device versus some screen somewhere in some distance away, you have to understand the relationship between the two coordinate systems in order to properly perform the mapping.

Q. So, would your answer be different than specifically to the question, did a person of ordinary skill in the art in the 2009 or earlier time frame have the ability to do that transformation, if it's a built-in display?

A. A person of ordinary skill in the art would be able to do that.

Q. Would it require a lot of experimentation?

A. It's hard to say. I mean, there's various levels of skill in the art, so... I would say if that person was following proper procedure for how you do transformations from one coordinate system to another, then there wouldn't be a lot of experimentation needed.

(Ex. 1016, 49:22-50:23.)

VI. THE '846 PATENT

31. The '846 patent describes a three-dimensional (3D) pointing device that can be moved and rotated by a user and that has sensor modules allowing the device to “obtain actual resulting deviation angles in [a] spatial reference frame and under dynamic environments.” (Ex. 1001, 1:18–34.) The '846 patent admits that 3D pointing devices were known in the prior art, as shown in Figure 1:

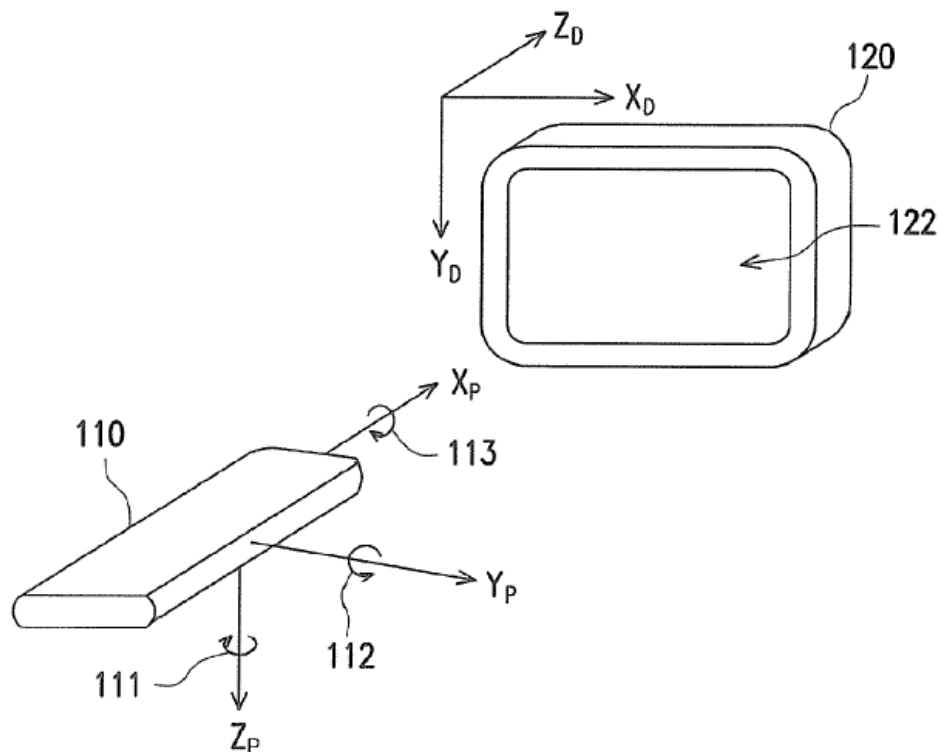


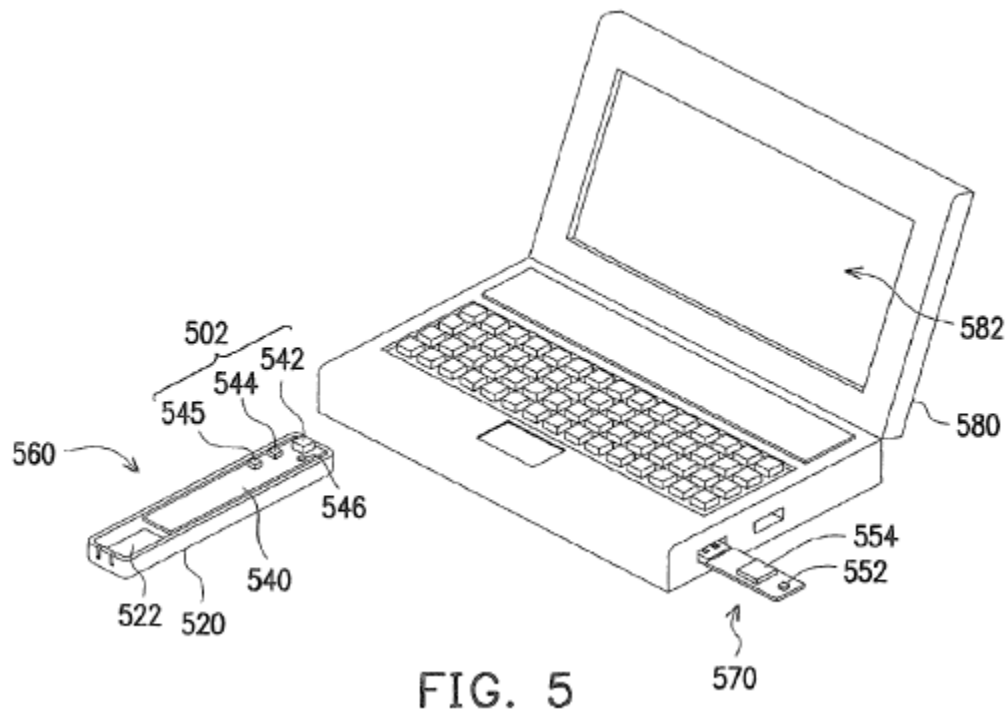
FIG. 1 (RELATED ART)

(*Id.*, FIG. 1.)

32. Figure 1 shows that a user can point a 3D pointing device 110 at a screen 122 of a display device 120. (*Id.*, 1:35–2:2.) Figure 1 illustrates sets of axes representing two different reference frames: a “spatial pointer reference

frame” for pointing device 110, and a “display frame” for display device 120. (*Id.*, 1:45–48.) The spatial pointer reference frame is defined by axes X_P , Y_P , and Z_P . (*Id.*, 1:51–58.) The system keeps track of the “orientation” of pointing device 110 by measuring three deviation angles: yaw angle 111 representing the device’s rotation about axis Z_P , pitch angle 112 representing its rotation about axis Y_P , and roll angle 113 representing its rotation about axis X_P . (*Id.*, 2:2-14.) The system can then perform “mapping” by translating the deviation angles in the spatial pointer reference frame to a corresponding movement of the pointer on display screen 122. (*Id.*, 2:44–48; *see also id.*, 2:15–48.)

33. Figure 5 shows an “electronic device (500)” with a first part 560 and a second part 570. (*Id.*, 11:40-13:3.) The first part 560 (which is a pointer device) and the second part 570 are not physically connected, and need not be in the same housing. (*Id.*, 11:46-60.) Thus, a person of ordinary skill in the art would understand from the ’846 patent that the term “electronic device” covers a device encompassing physically disconnected components.



(*Id.*, FIG. 5.) The first part 560 has a nine-axis motion sensor module 503 with a rotation sensor 542, an accelerometer 544, and a magnetometer 545. (*Id.*, 11:44-60.) An algorithm maps movements of the first part 560 to movements on screen 582 of the notebook computer 580. (*Id.*, 12:17-13:3.)

34. One such algorithm is described in Figure 7. This algorithm uses only the measured angular velocities and accelerometer readings of the motion sensor module (not the magnetometer).

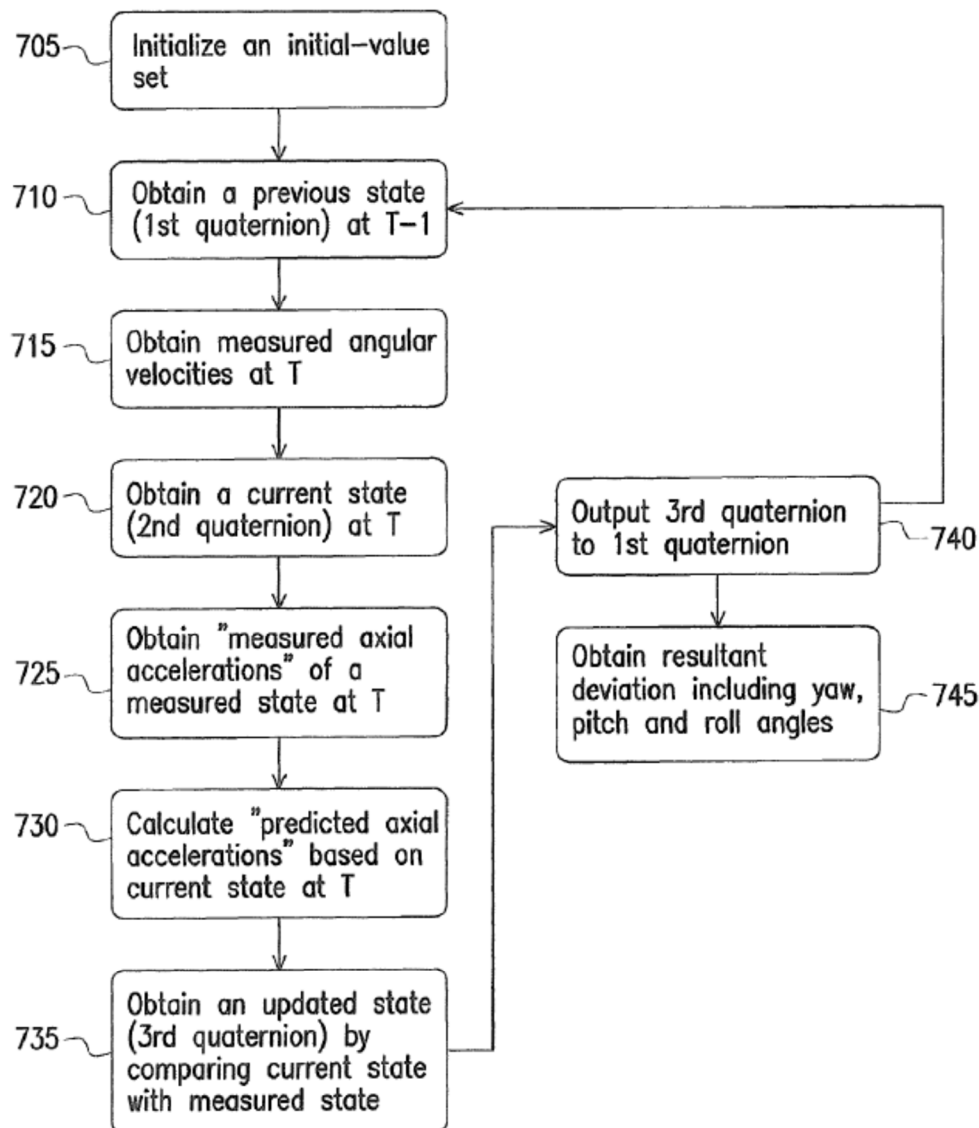


FIG. 7

(*Id.*, FIG. 7.) Figure 7 presents a method of calculating deviation angles of a 3D pointing device's spatial pointer reference frame. (*Id.*, 13:42–47.) The method beings either initializing a new state or “obtaining a previous state of the nine-axis motion sensor module (. . . steps 705, 710).” (*Id.*, 14:24–28.) This state is in the

form of “a first quaternion² 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 $T-1$.” (*Id.*, 14:34–39.)

35. The method then obtains “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 (. . . steps 715, 720)”, to calculate a second quaternion of the “current state” with respect to current time T . (*Id.*, 14:39-44, 16:31-39.)

According to the '846 patent, one way to convert ω_x , ω_y , ω_z into the “second quaternion” is by using equation 1.

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

² As noted earlier, quaternions are a well-known four-dimensional extensions of complex numbers that have the unique property of maintaining rotational relationships with relatively limited computational complexity. The '846 patent says, as any person skilled in the art would appreciate, that Euler angles can be used and defined from a quaternion. (Ex. 1001, 15:48-50 (“It can be understood that one may make reference to Euler Angles for definition on quaternion.”).)

(*Id.*, 16:46-53 (equation 1).) Equation 1 is a differential equation with respect to the “first quaternion” (q_0, q_1, q_2, q_3), and the ’846 patent suggests solving it using a data conversion utility. (*Id.*, 16:39-61.)

36. After that, the method in Figure 7 gets the “measured state” of the motion sensor module in steps 725 and 730. (*Id.*, 16:62–66.) This measured state has two parts: a set of “measured axial accelerations A_x, A_y, A_z ” obtained from the accelerometer signals (step 725), and “predicted axial accelerations A_x', A_y', A_z' ,” which are calculated based on the measured angular velocities (step 730). (*Id.*, 16:65-17:14.) The predicted axial accelerations in step 730 are “calculated based on the . . . current state or second quaternion in relation to the measured angular velocities thereof.” (*Id.*, 17:11-14.) The ’846 patent provides known equations for calculating each of A_x', A_y', A_z' of the predicted axial acceleration, which the ’846 characterizes as a “conversion utility”:

$$2(q_1 q_3 - q_0 q_2) = A_x'$$

$$2(q_2 q_3 + q_0 q_1) = A_y'$$

$$q_0^2 - q_1^2 - q_2^2 + q_3^2 = A_z'$$

(*Id.*, 17:18-28, Equations 2-4.)

37. Next, in step 735, the process obtains a “third quaternion,” representing an “updated state,” by comparing the current state with the measured state. (*Id.* at 14:63–15:15.) It does this by using a “comparison model” involving

equations 5–11. (*Id.*, 17:34-38; *see also id.*, 17:29-18:38.) In testimony that the Board found persuasive concerning related patent '438, which has the same Figure 7 process and same equations, the patentee's expert characterized equations 5–10 of the '846 patent as Extended Kalman Filter ("EKF") equations, which were known in the art, and described equation 11 as an error minimization. (Ex. 1012, IPR2019-00143 Final Written Decision, Paper 87, p. 11, *citing* Ex. 2021 ¶46.) Patentee's expert stated that in the general framework of an extended Kalman Filter of equations 5–10 represent a process model (equation 5) and its corresponding covariance matrix, a measurement model (equation 8) and its corresponding covariance matrix, as well as Jacobians associated with each of the two models (equations 6, 7, and 10) that linearize the nonlinear functions represented by each model. (Ex. 1012, IPR2019-00143 Final Written Decision, Paper 87, 11-12 (*citing* Ex. 1048, 102:15–103:7).)

38. Next, "to provide a continuous loop," the method in step 740 outputs and substitutes the third quaternion (updated state) into the first quaternion (previous state) (step 710). (Ex. 1001, 14:63–15:4.) In step 745, the method uses the third quaternion to generate a "resulting deviation," in terms of yaw, pitch, and roll angles, with respect to the axes of the spatial pointer reference frame. (*Id.*, 14:55-63, 19:16-24.) According to the '846 patent, these resulting deviation angles are used to map locations from 3D space to corresponding locations that indicate

where the device is pointing on a 2D display device. (*Id.*, 11:27-40, 20:5-20, Figures 8 (Step 750), 9.)

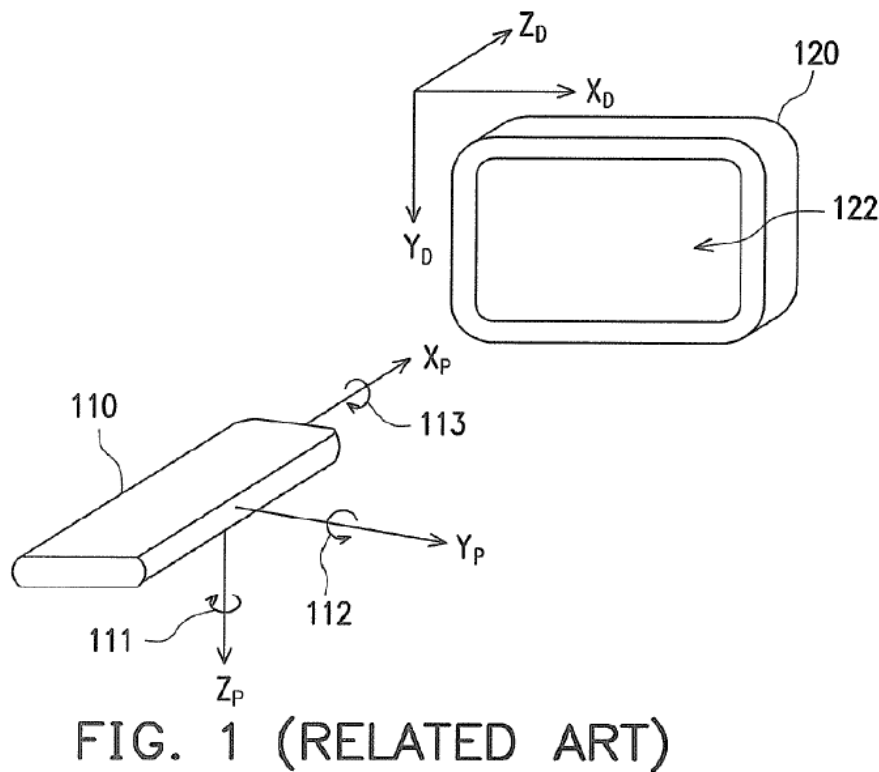
VII. CLAIM CONSTRUCTION

39. I understand that when considering the meaning of patent claims, one must consider the language of the claims, the specification, and the prosecution history of the patent. I also understand that claim terms are typically given their ordinary and customary meanings as would have been understood by a person of ordinary skill in the art at the time of the invention for the patent. For purposes of my opinions in this declaration, I have applied the plain and ordinary meaning as understood by a person of ordinary skill in the art at the time of the alleged invention.

40. Claims 1 and 7 use the phrase “spatial reference frame.” My opinion is that the term means a “reference frame associated with a 3D pointing device, which always has its origin at the same point in the device and in which the axes are always fixed with respect to the device.”

41. The '846 patent explains that the “spatial reference frame” refers to a 3-axis reference frame of a 3D pointing device. (*See, e.g.*, Ex. 1001, 9:5-17, 9:49-65, FIGS. 1-4.) “The spatial reference frame is analogous to the reference frame $X_P Y_P Z_P$ also shown in FIG. 1 and FIG. 2.” (*Id.*, 9:5-17.) In particular, the “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.” (*Id.*, 1:45–1:51.)



(*Id.*, FIG. 1.)

42. Thus, the “spatial pointer reference frame” is shown by the coordinate axes X_P , Y_P and Z_P in Figure 1. (*Id.*, FIG. 1.) As shown in Figure 1, the spatial pointer reference frame is a reference frame associated with the 3D pointing device, which has its origin at a point in the device. (*Id.*, FIG. 1.) Furthermore, as shown in Figure 2, when the device is rotated, the axes X_P , Y_P and Z_P rotate with the device. (*Id.*, FIG. 2.) The rotation of the device in Figure 2 shows a 90-degree roll of the device, with correspondingly rotated axes Y_P and Z_P . (*Id.*, FIG. 2.) For

that reason, in the spatial pointer reference frame, the origin and axes of the frame stay fixed with respect to the device.

VIII. THE PRIOR ART APPLIED TO THE '846 PATENT

43. It is my opinion that Bassompierre (Ex. 1006) discloses or suggests every limitation of claims 1, 3, 7, and 9 of the '846 patent. It is my further opinion that Bassompierre in combination with Nasiri (Ex. 1008) discloses or suggests claims 1 and 3 of the '846 patent. I provide a detailed explanation for my opinions with regard to each claim element in the Appendix attached to my declaration. In Sections VIII.A and VIII.B, I provide more focused testimony on the relevant disclosures of Bassompierre and Nasiri, an explanation of terms and equations, and a discussion of concepts known in the art, such as quaternion math and Euler angle conversions.

A. Bassompierre

1. Bassompierre's Pointer, Display, and Sensors

44. Bassompierre describes a pointer device “for pointing by a user at a mobile element in a plane surface.” (Ex. 1006, 4:1-12, 8:24-25, FIGS. 1, 2.) In Figure 1, the pointer “has the shape and appearance of a television remote control, i.e., it is of elongate form, able to be held in the user's hand.” (*Id.*, 8:25-27.) “The pointer is associated with a mobile element able to move in a plane surface, for example, a screen or a writing surface. The displacements of this mobile element

are controlled by the displacements of the pointer.” (*Id.*, 9:1-4, FIG. 2.) The pointer includes an angular velocity sensor 20 and a linear acceleration sensor 30. (*Id.*, Fig. 1, 9:24-26, 10:14-17.)

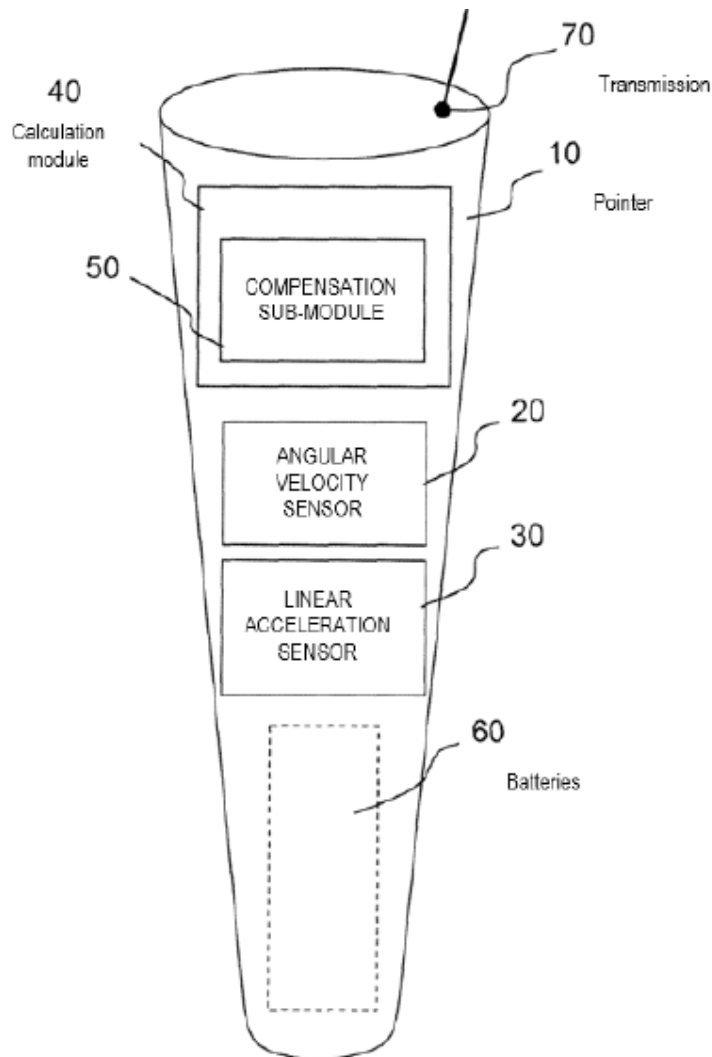
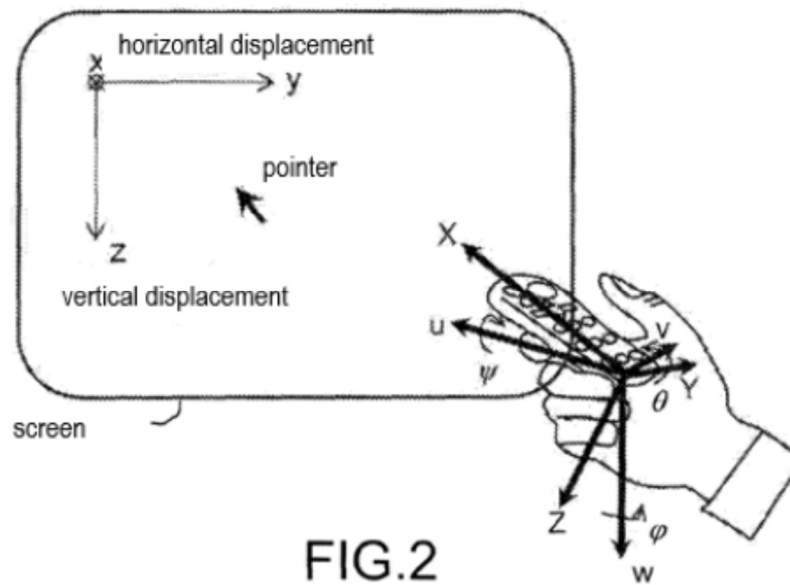


FIG.1

(*Id.*, FIG. 1.) The pointer is shown with a display and a user’s hand moving the pointer in the system of Figure 2.



(*Id.*, FIG. 2.)

45. The accelerometer (i.e., sensor 30) and gyroscope (i.e., sensor 20) “respectively return measurements noted (a_x, a_y, a_z) and (ω_y, ω_z) in the frame of reference (XYZ) of the pointing device.” (*Id.*, 12:14-15.) These measurements are used to estimate pitch and roll angles (θ and ψ) of the pointer through a sensor fusion algorithm, specifically, an extended Kalman Filter. (*Id.*, 13:15–32; *see also id.*, 18:15-19:12.)

46. Bassompierre is analogous art to the '846 patent. The '846 patent's field of endeavor is the fusing of data from small microsensor, like MEMS gyrometers and accelerators, in order to provide orientation of a device in three-dimensional space. The orientation data is then used to present some kind of content on a screen that can be changed depending on, and subject to, the

orientation. (*See, e.g.*, Ex. 1001, Abstract, 5:27-61, FIGS. 1, 2.) Bassompierre too describes a device with a gyrometer and accelerometer producing orientation data that is corrected using a sensor fusion algorithm so to allow presentation of two-dimensional data on a screen that can be modified based on the 3D orientation of the device as determined by the sensor fusion algorithm. (Ex. 1006, 1:2-26, 3:25-4:12, FIGS. 1, 2.)

2. Bassompierre's EKF Algorithm

47. Bassompierre describes a two-step process as follows: “a step 1 of estimating the angles θ and ψ of pitch and of roll by an EKF and a step 2 of computing the angular rate components ω_v , ω_w , related to the displacement of the mobile element with respect to the frame of reference of the user.” (*Id.*, 15:3-8.)

48. To estimate the pitch θ angle and roll angle ψ by an EKF, Bassompierre defines the angles θ and ψ as a state vector. (*Id.*, 17:5-6 (“the state vector chosen to solve the problem is: $x=[\theta \ \psi]$. Where θ and ψ are respectively the pitch and roll angles.”).) The state vector, at sampling step k , i.e., $\hat{x}_k$, is calculated using the following EKF equation.

$$\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$$

(*Id.*, 5:4-6, 19:8-9 (equation 23), 29:1-4 (claim 10).) In this equation, $\hat{x}_k^-$ is an “a priori estimate of the state vector” (*id.*, 19:1-3, *see also* 8:24, 28:11) at present time k. As seen in equation 21 below, Bassompierre represents $\hat{x}_k^-$ as the estimated pitch and roll angles $\begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix}$ (*id.*), but also provides that the “state vector (x) is a quaternion.” (*Id.*, 6:3-4, 20:10-11, 27:11-14, 30:1-3 (claim 13).) Below, in Section VIII.A.4, I describe how a person of skill in the art would move between Euler angle and quaternions representations of variables in the EKF and related equations using known relationships between Euler angles and quaternions.

i) Calculating the *a priori* estimate $\hat{x}_k^-$

49. The state vector ($\hat{x}_k^-$) is calculated by adding the pitch and roll angles from the previous iteration k-1 of the EKF, i.e., $\begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix}$ to the current gyroscope readings $(\omega_x, \omega_y, \omega_z)$, multiplied by a sampling period T_e , using the following equation:

$$\hat{x}_k^- = \begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix} = \begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix} + T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$$

(*Id.*, 19:3 (equation 21), *see also id.*, 4:23-26, 28:9-13 (claim 7).)

ii) Calculating the updated state vector $\hat{x}_k$

50. Next, Bassompierre determines the estimated acceleration ($\hat{y}_k^-$) at time step k, based on the *a priori* estimation of the state vector, i.e., $\hat{x}_k^-$ or $\begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix}$.

$$\hat{y}_k^- = \begin{bmatrix} -\sin \hat{\theta}_k^- \\ \cos \hat{\theta}_k^- \cdot \sin \hat{\psi}_k^- \\ \cos \hat{\theta}_k^- \cdot \cos \hat{\psi}_k^- \end{bmatrix}$$

(*Id.*, 19:4-5 (equation 21), 28:14-17 (claim 8).)

51. The estimated acceleration is compared against the measured acceleration from the accelerometer readings ($y = [a_x \ a_y \ a_z]$) at time step k and added to the *a priori* estimate of the state vector ($\hat{x}_k^-$) to yield an **updated** state vector $\hat{x}_k$:

$$\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$$

(*Id.*, 19:9 (equation 23), *see also id.*, 5:6, 29:3-5 (claim 10).)

52. For ease of reference and understanding, replacing $\hat{x}_k^-$ in equation 23 for the *a priori* estimate of the state vector and replacing $\hat{y}_k^-$ with the equation for determining the predicted acceleration, yields the following equation for $\hat{x}_k$:

$$\hat{x}_k = \begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix} + T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix} + K_k \left(\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix} - \begin{bmatrix} -\sin \hat{\theta}_k^- \\ \cos \hat{\theta}_k^- \cdot \sin \hat{\psi}_k^- \\ \cos \hat{\theta}_k^- \cdot \cos \hat{\psi}_k^- \end{bmatrix} \right)$$

The above equation shows that the EKF of Bassompierre determines $\hat{x}_k$ based on the pitch and roll angles from the previous iteration $k-1$, i.e., $(\hat{\theta}_{k-1}^-, \hat{\psi}_{k-1}^-)$, the gyroscope readings of the present iteration $(\omega_x, \omega_y, \omega_z)$ and the difference between the accelerometer readings at present time k ($a_{x,k}, a_{y,k}, a_{z,k}$) and the predicted acceleration

$$\begin{bmatrix} -\sin \hat{\theta}_k^- \\ \cos \hat{\theta}_k^- \cdot \sin \hat{\psi}_k^- \\ \cos \hat{\theta}_k^- \cdot \cos \hat{\psi}_k^- \end{bmatrix}$$

53. With respect to the language of the claims of the '846 patent, the above EKF equation can be understood to determine $\hat{x}_k$ as follows.

$$\hat{x}_k = \underbrace{\begin{pmatrix} \theta_{k-1}^- \\ \psi_{k-1}^- \end{pmatrix}}_{\text{previous quaternion (T-1)}} + T_e \underbrace{\left(\alpha \sqrt{\omega_y^2 + \omega_z^2} \right)}_{\substack{\text{measured} \\ \text{angular} \\ \text{velocities} \\ \text{(time T)}}} + K_k \left(\underbrace{\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix}}_{\text{measured acceleration (time T)}} - \underbrace{\begin{bmatrix} -\sin \theta_k^- \\ \cos \theta_k^- \cdot \sin \psi_k^- \\ \cos \theta_k^- \cdot \cos \psi_k^- \end{bmatrix}}_{\text{predicted acceleration (time T)}} \right)$$

current quaternion (time T) (Ψ_k^-, θ_k^-)

3. Real-Time Display in Bassompierre

54. Step 1 of Bassompierre provides pitch and roll angles in Euler angle form. Step 2 of Bassompierre's process computes the angular rate components ω_v , ω_w , related to the displacement of the pointer device with respect to the frame of reference of the user (u, v, w). (See Ex. 1006, 11:18-20, 11:26-30.) Bassompierre

teaches that the components ω_v and ω_w of the angular rate in the reference frame of the user are computed through the following formulae:

$$\omega_v = \cos \hat{\Psi} \cdot \omega_y - \sin \hat{\Psi} \cdot \omega_z$$

$$\omega_w = -\sin \hat{\theta} \cdot \omega_x + \cos \hat{\theta} \cdot \sin \hat{\Psi} \cdot \omega_y + \cos \hat{\theta} \cdot \cos \hat{\Psi} \cdot \omega_z$$

(*Id.*, 19:10-11 (equation 24), 5:7-9, 29:6-9 (claim 11).)

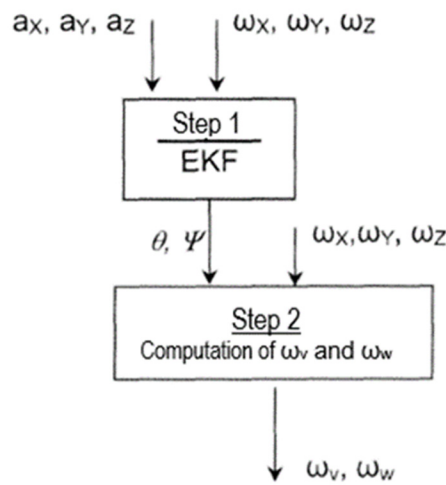


FIG.6

(*Id.*, FIG. 6.) Specifically, “ ω_v and ω_w . . . give direct information on the horizontal displacements (rotation about the axis w represented by ω_w) and vertical displacements (rotation about the axis v represented by ω_v) and therefore the displacement of the mobile element on the screen (d_y and d_z).” (*Id.*, 11:25-12:9.)

4. Replacing Equations 21-23 in Bassompierre With State Vectors in Quaternion Form

55. While the state vectors in equations 21 and 23 are represented in Euler angle form, Bassompierre discloses a first variation of this embodiment in which the state vector (x) is a “quaternion.” (Ex. 1006, 20:10–19; *see also id.*, 6:3–4, 27:11–14 (claim 1), 30:1–3 (claim 13).) In this variation, “the angles of torsion θ and ψ ” are replaced by a “quaternion formulation of the same torsion.” (*Id.*, 20:10–11.) Bassompierre acknowledges the benefits of using quaternions over Euler angles for performing sensor fusion. (*Id.*, 20:10–14 (“This variant exhibits the advantage of avoiding the computations of the sines and cosines of the pitch and roll angles that are greedy in terms of computational power.”).) The benefits of using quaternions over Euler angles were well-known. (*See* Ex. 1007 at 269–270 (“For modeling the rotational motion, quaternions are used rather than direction cosines and Euler angles because the quaternion representation does not have a problem with singularities; handles normalization better; and exchanges the bulky trigonometry of Euler angles with multiplication and addition”).) This is to say performing operation with quaternion is more efficient than performing the same operation using Euler angles.

56. Thus, a person of ordinary skill would have been motivated to modify equations 21–23 to include quaternions instead of Euler angles. In such a modification, the state vectors $\hat{x}_k^-$ and $\hat{x}_{k-1}^-$ would have been represented using

quaternions. As, I explain below, a person of ordinary skill would have a reasonable expectation of success in using quaternions because quaternions had been successfully used by persons of skill in the art with sensor fusion algorithms, such as extended Kalman filters, to achieve computational efficiencies in real time applications with gyroscope and accelerometers. (*See, e.g.*, Ex. 1007.) Also, Patent Owner's expert in IPR proceedings for the related '438 patent and '978 patent admitted that quaternions "would be known to someone of ordinary skill in the art." (Ex. 1013, p. 44.) The Board consequently found that "knowledge of quaternion mathematics [was] within the level of ordinary skill." (*Id.*, pp. 44–45.)

57. Below, I explain how a person of ordinary skill would use quaternions in place of equations 21-23 in Bassompierre. Using quaternions in place of Euler angles was something well known to those of ordinary skill. For example, Bassompierre discloses well-known equations for converting between quaternions and Euler angles. Bassompierre explains that "a rotation quaternion is defined by 4 elements," as noted below:

$$q = \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} \text{ with } \begin{cases} q_0 = \cos \frac{a}{2} \\ \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} = \sin \frac{a}{2} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} \end{cases} \quad \text{Eq. 25}$$

a being the angle of rotation and $u = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}$ the axis of rotation.

(Ex. 1006, 20:13-16 (equation 25).) Bassompierre also describes the well-known quaternion operations, such as how to calculate the conjugate of a quaternion:

$\bar{q}$ being the quaternion conjugate to q (i.e. if $q = q_0 + q_1.i + q_2.j + q_3.k$,
 $\bar{q} = q_0 - q_1.i - q_2.j - q_3.k$).

(*Id.*, 21:4-6.) With this information, and knowledge of quaternions and quaternion algebra, a person of skill in the art would understand that the conversion of pitch and roll angles into quaternion form would be a simple matter of plugging Euler angle values into Equation 25 to calculate the quaternion. I explain this below.

58. For example, assume an initial orientation of 0° pitch angle (θ) and 0° roll angle (ψ), i.e., $(\theta, \psi) = (0^\circ, 0^\circ)$. Substituting those values into Equation 25 of Bassompierre, each of the pitch and roll angles $(0^\circ, 0^\circ)$ would be represented in quaternion form as $q_{\text{initial}} = 1 + 0i + 0j + 0k$, since there is no rotation ($u=0$) along any axis.

59. Now assume an applied pitch angle of 45° ($\pi/4$) and an applied roll angle of 22.5° ($\pi/8$) to the initial orientation. In Euler angle form, the new orientation would simply be $(45^\circ, 22.5^\circ)$ or $(\pi/4, \pi/8)$ because the original orientation was $(0^\circ, 0^\circ)$ and adding angle to zero yields the angle.

60. In quaternion form, the new orientation for the pitch angle would be determined by calculating the rotation quaternion, per Equation 25 above, as follows (letting $a = \pi/4$; and $u = [0, j, 0]$, i.e., a rotation around only the Y (j) axis):

$$\begin{cases} q_0 = \cos \frac{\pi/4}{2} \\ q_1 \\ q_2 = \sin \frac{\pi/4}{2} \\ q_3 \end{cases} \begin{matrix} 0 \\ 1 \\ 1 \\ 0 \end{matrix}$$

Thus, the rotation quaternion for the pitch angle can be represented as $q_\theta = [\cos(\pi/8), 0, \sin(\pi/8), 0]$.

61. In quaternion form, the new orientation for the roll angle would be determined by calculating the rotation quaternion, per Equation 25 above, as follows (letting $a = \pi/8$ and $u = [i, 0, 0]$, i.e., a rotation around the X (i) axis):

$$\begin{cases} q_0 = \cos \frac{\pi/8}{2} \\ q_1 \\ q_2 = \sin \frac{\pi/8}{2} \\ q_3 \end{cases} \begin{matrix} 1 \\ 0 \\ 0 \\ 0 \end{matrix}$$

Thus, the rotation quaternion for the roll angle can be represented as $q_\psi = [\cos(\pi/16), 0, \sin(\pi/16), 0]$.

62. To calculate the new quaternion representing the combined rotation (pitch then roll) applied to the original orientation, a person of ordinary skill in the art would know to multiply the individual quaternions in the order of application (from right to left):

$$q_{\text{new}} = q_\theta \otimes q_\psi \otimes q_{\text{initial}}$$

$$= (\cos(\pi/8) + j \sin(\pi/8)) \otimes (\cos(\pi/16) + i \sin(\pi/16)) \otimes (1+0i+0j+0k)$$

$$= \cos(\pi/8) \cos(\pi/16) + i \sin(\pi/16) \cos(\pi/8) + j \sin(\pi/8) \cos(\pi/16) - k$$

$$\sin(\pi/8) \sin(\pi/16).$$

$$= 92*.98 + i .2*.92 + j.38*.98 - k.38*.2i$$

$$= .90 + i.18 + j.37 - k.07$$

63. Thus, as we can see above, a person of ordinary can represent a state vector of Euler angles $(45^\circ, 22.5^\circ)$ or $(\pi/4, \pi/8)$ with a quaternion $.90 + i.18 + j.37 - k.07$.

64. Returning to equations 21-23, I now explain below how those equations would be represented in quaternion form.

65. We begin with equation 21

$$\hat{x}_k^- = \begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix} = \begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix} + T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$$

Equation 21 takes the previous pitch and roll angles $\begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix}$ and adds to that the

change in the pitch and roll angles represented by $T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$ using the

gyroscope readings $[\omega_x, \omega_y, \omega_z]$ multiplied by a time interval T_e .³ A person of

³ This is equivalent to taking the derivative of the pitch and roll angles with respect to $\begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$ as shown in the differential equation of Equation 16 of Bassompierre. (*Id.*, 18:4-5.)

ordinary skill in the art would understand $T_e \left(\frac{\alpha \sqrt{\omega_y^2 + \omega_z^2}}{\omega_x} \right)$ to be an angular rotation that is added to the previous pitch and roll angles $\begin{pmatrix} \hat{\Theta}_{k-1} \\ \hat{\Psi}_{k-1} \end{pmatrix}$. That summation will yield the current state vector $(\hat{x}_k^-)$, which is the current pitch and roll angles $\begin{pmatrix} \hat{\Theta}_k^- \\ \hat{\Psi}_k^- \end{pmatrix}$ in view of the rate of movement in the x, y, z axes of the pointer as reflected by the gyroscope readings. The derivation of $T_e \left(\frac{\alpha \sqrt{\omega_y^2 + \omega_z^2}}{\omega_x} \right)$ is described in equations 11 through 16 in Bassompierre. (*Id.*, 17:7-18:5.)

66. Equation 21 of Bassompierre can be expressed as the rate of change of an orientation quaternion based on the angular velocities from a gyroscope. A person of ordinary skill in the art would understand this to be a quaternion kinematic equation. Bassompierre's Equation 21

$$\hat{x}_k^- = \begin{pmatrix} \hat{\Theta}_k^- \\ \hat{\Psi}_k^- \end{pmatrix} = \begin{pmatrix} \hat{\Theta}_{k-1} \\ \hat{\Psi}_{k-1} \end{pmatrix} + T_s \left(\frac{(\alpha \sqrt{\omega_y^2 + \omega_z^2})}{\omega_x} \right)$$

is a discrete-time update equation for Euler angles (specifically pitch Θ and roll Ψ). In quaternion form, a person of skill in the art could approach this as differential equation for propagating quaternions using gyroscope readings. Let the quaternion

be $q = \begin{pmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{pmatrix}$, where q_0 is the scalar part and (q_1, q_2, q_3) is the vector part. Let the

angular velocity vector from the gyroscope readings be $\omega = \begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix}$. The quaternion

differential equation is given by: $\dot{q} = \frac{1}{2} q \otimes \omega_p$ where:

$\dot{q} = \begin{pmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{pmatrix}$ is the time derivative of the quaternion.

$q = \begin{pmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{pmatrix}$ is the current orientation quaternion.

$\omega_p = \begin{pmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{pmatrix}$ is a "pure" quaternion formed from the angular velocity vector.

$\otimes$ denotes quaternion multiplication, i.e., a rotation of the current orientation given an angular velocity. To express Equation 21 of Bassompierre in quaternion form, where the quaternion q (represented as q_0, q_1, q_2, q_3) multiplies the vector $(0, \omega_x, \omega_y, \omega_z)$, we can write the quaternion multiplication as a matrix-vector product. It will be fully explained below that this matrix-vector multiplication is equivalent to $\dot{q} = \frac{1}{2} q \otimes \omega_p$. The left quaternion q multiplication can be expressed as a matrix (4x4) by vector (4x1) multiplication:

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

67. Expand this multiplication to see each component of $\dot{q}$, we get:

$$\dot{q}_0 = \frac{1}{2} (q_0 \cdot 0 - q_1 \omega_x - q_2 \omega_y - q_3 \omega_z) = \frac{1}{2} (-q_1 \omega_x - q_2 \omega_y - q_3 \omega_z)$$

$$\dot{q}_1 = \frac{1}{2} (q_1 \cdot 0 + q_0 \omega_x - q_3 \omega_y + q_2 \omega_z) = \frac{1}{2} (q_0 \omega_x + q_2 \omega_z - q_3 \omega_y)$$

$$\dot{q}_2 = \frac{1}{2} (q_2 \cdot 0 + q_3 \omega_x + q_0 \omega_y - q_1 \omega_z) = \frac{1}{2} (q_0 \omega_y - q_1 \omega_z + q_3 \omega_x)$$

$$\dot{q}_3 = \frac{1}{2} (q_3 \cdot 0 - q_2 \omega_x + q_1 \omega_y + q_0 \omega_z) = \frac{1}{2} (q_0 \omega_z + q_1 \omega_y - q_2 \omega_x)$$

This set of four equations describes how the orientation quaternion changes over time given the gyroscope's angular velocity readings. To implement this, a person of ordinary skill in the art would integrate these differential equations over a time step Δt : $q_k \approx q_{k-1} + \dot{q}_{k-1} \Delta t$ followed by normalization of q_k to ensure it remains a unit quaternion.

68. The matrix-vector form of the differential equation described above and presented here again:

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

is equivalent to equation 26 in Bassompierre:

$$\dot{q} = \frac{1}{2} \begin{vmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{vmatrix} \otimes \begin{vmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{vmatrix} ;$$

69. A person of ordinary skill in the art would understand that the matrix-vector multiplication above is a way to represent the quaternion multiplication operation in a linear algebra format. Again, take Bassompierre's equation 26:

$$\dot{q} = \frac{1}{2} \begin{vmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{vmatrix} \otimes \begin{vmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{vmatrix}$$

let $q = \begin{pmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{pmatrix}$ (which can be written as $q_0 + q_1i + q_2j + q_3k$) and

$\omega_p = \begin{pmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{pmatrix}$ (which can be written as $0 + \omega_xi + \omega_yj + \omega_zk$).

70. As known by any person of ordinary skill in the art familiar with quaternion mathematics, the quaternion multiplication $p \otimes r$ for two quaternions $p = (p_0, p_1, p_2, p_3)$ and $r = (r_0, r_1, r_2, r_3)$ is defined as follows for its components:

Resulting scalar part (0^{th} component): $p_0r_0 - p_1r_1 - p_2r_2 - p_3r_3$

Resulting i part (1^{st} component): $p_0r_1 + p_1r_0 + p_2r_3 - p_3r_2$

Resulting j part (2^{nd} component): $p_0r_2 - p_1r_3 + p_2r_0 + p_3r_1$

Resulting k part (3^{rd} component): $p_0r_3 + p_1r_2 - p_2r_1 + p_3r_0$

Applying these rules to $q \otimes \omega_p$, where p is q and r is ω_p ,

we get $p_0 = q_0, p_1 = q_1, p_2 = q_2, p_3 = q_3$ and $r_0 = 0, r_1 = \omega_x, r_2 = \omega_y, r_3 = \omega_z$.

We now calculate each component of $q \otimes \omega_p$:

0th component (scalar part of the result):

$$q_0(0) - q_1\omega_x - q_2\omega_y - q_3\omega_z = -q_1\omega_x - q_2\omega_y - q_3\omega_z$$

1st component (i-part of the result):

$$q_0\omega_x + q_1(0) + q_2\omega_z - q_3\omega_y = q_0\omega_x - q_3\omega_y + q_2\omega_z$$

2nd component (j-part of the result):

$$q_0\omega_y - q_1\omega_z + q_2(0) + q_3\omega_x = q_0\omega_y + q_3\omega_x - q_1\omega_z$$

3rd component (k-part of the result):

$$q_0\omega_z + q_1\omega_y - q_2\omega_x + q_3(0) = q_0\omega_z - q_2\omega_x + q_1\omega_y$$

The right-hand side (excluding the $\frac{1}{2}$) is the vector:

$$q \otimes \omega_p = \begin{pmatrix} -q_1\omega_x - q_2\omega_y - q_3\omega_z \\ q_0\omega_x - q_3\omega_y + q_2\omega_z \\ q_0\omega_y + q_3\omega_x - q_1\omega_z \\ q_0\omega_z - q_2\omega_x + q_1\omega_y \end{pmatrix}$$

Now consider the right-hand side of the matrix-vector equation provided above

$$\text{(again, excluding the } \frac{1}{2}\text{): } \begin{bmatrix} q_0 & -q_1 & -q_2 & -q_3 \\ q_1 & q_0 & -q_3 & q_2 \\ q_2 & q_3 & q_0 & -q_1 \\ q_3 & -q_2 & q_1 & q_0 \end{bmatrix} \begin{pmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{pmatrix}$$

Perform this matrix-vector multiplication as follows:

Row 1 times the column vector:

$$(q_0 \cdot 0) + (-q_1 \cdot \omega_x) + (-q_2 \cdot \omega_y) + (-q_3 \cdot \omega_z) = -q_1\omega_x - q_2\omega_y - q_3\omega_z$$

Row 2 times the column vector:

$$(q_1 \cdot 0) + (q_0 \cdot \omega_x) + (-q_3 \cdot \omega_y) + (q_2 \cdot \omega_z) = q_0\omega_x - q_3\omega_y + q_2\omega_z$$

Row 3 times the column vector:

$$(q_2 \cdot 0) + (q_3 \cdot \omega_x) + (q_0 \cdot \omega_y) + (-q_1 \cdot \omega_z) = q_3\omega_x + q_0\omega_y - q_1\omega_z$$

Row 4 times the column vector:

$$(q_3 \cdot 0) + (-q_2 \cdot \omega_x) + (q_1 \cdot \omega_y) + (q_0 \cdot \omega_z) = -q_2\omega_x + q_1\omega_y + q_0\omega_z$$

Comparing the results from both methods:

Component 0:

$$-q_1\omega_x - q_2\omega_y - q_3\omega_z \text{ matches } -q_1\omega_x - q_2\omega_y - q_3\omega_z.$$

Component 1:

$$q_0\omega_x - q_3\omega_y + q_2\omega_z \text{ matches } q_0\omega_x - q_3\omega_y + q_2\omega_z.$$

Component 2:

$$q_0\omega_y + q_3\omega_x - q_1\omega_z \text{ matches } q_3\omega_x + q_0\omega_y - q_1\omega_z$$

(terms are just reordered).

Component 3:

$$q_0\omega_z - q_2\omega_x + q_1\omega_y \text{ matches } -q_2\omega_x + q_1\omega_y + q_0\omega_z$$

(terms are just reordered).

71. As one can see, the components derived from the direct quaternion multiplication $q \otimes \omega_p$ are identical to the components derived from the matrix-vector product. The matrix

$$\begin{bmatrix} q_0 & -q_1 & -q_2 & -q_3 \\ q_1 & q_0 & -q_3 & q_2 \\ q_2 & q_3 & q_0 & -q_1 \\ q_3 & -q_2 & q_1 & q_0 \end{bmatrix}$$

is thus simply a matrix representation of the left quaternion q when performing a quaternion multiplication $q \otimes \omega_p$ where ω_p is treated as a column vector. This is a standard way to express quaternion multiplication in linear algebra. Thus, the right-hand side of Bassompierre's equation 26 can be considered equivalent to the right-hand side of the matrix-vector multiplication equation above because the matrix formulation is a direct algebraic expansion of the quaternion multiplication rule.

72. Turning now to Equation 22 of Bassompierre, $\begin{bmatrix} -\sin \hat{\theta}_k^- \\ \cos \hat{\theta}_k^- \cdot \sin \hat{\psi}_k^- \\ \cos \hat{\theta}_k^- \cdot \cos \hat{\psi}_k^- \end{bmatrix}$,

a person of ordinary skill in the art would know how to derive the predicted acceleration of Bassompierre from quaternion form, i.e., from $\hat{x}_k^-$ in quaternion form. Bassompierre explains that Equation 22 is derived by multiplying a known rotation matrix for pitch and roll, $R(\theta, \psi)$, shown in Equation 17, by the gravity vector $G_0=[0 \ 0 \ 1]$ (i.e., $y=\text{measurement}_{\text{accelero}}=R(\theta, \psi).G_0$). (Ex. 1006, 18:6-11

(equation 17).) The result of this calculation is that the rotation matrix reduces to its last column

$$R(\theta, \Psi) = \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ \sin \theta \cdot \sin \psi & \cos \Psi & \cos \theta \cdot \sin \Psi \\ \sin \theta \cdot \cos \Psi & -\sin \Psi & \cos \theta \cdot \cos \Psi \end{bmatrix}$$

i.e.,

$$\begin{bmatrix} -\sin \hat{\theta}_k^- \\ \cos \hat{\theta}_k^- \cdot \sin \hat{\Psi}_k^- \\ \cos \hat{\theta}_k^- \cdot \cos \hat{\Psi}_k^- \end{bmatrix}$$

(Id. (emphasis added).)

73. To determine the equivalent set of equations in quaternion form, a person of ordinary skill in the art would know to take a known rotation matrix in quaternion form and perform the same calculation:

$$y = \text{measurement}_{\text{accelero}} = R(q) \cdot G_0.$$

Rotation matrices in quaternion form were known to persons of ordinary skill in the art. Kim shows such a rotation matrix in quaternion form

$$C_o^b = \begin{bmatrix} 2q_0^2 - 1 + 2q_j^2 & 2q_j q_2 + 2q_0 q_3 & 2q_1 q_3 - 2q_0 q_2 \\ 2q_1 q_2 - 2q_0 q_3 & 2q_0^2 - 1 + 2q_2^2 & 2q_3 q_2 + 2q_0 q_1 \\ 2q_1 q_3 + 2q_0 q_2 & 2q_3 q_2 - 2q_0 q_1 & 2q_0^2 - 1 + 2q_3^2 \end{bmatrix}$$

(Ex. 1007, 270 (equation 7) (emphasis added).) Performing the operation

$y = \text{measurement}_{\text{accelero}} = R(q) \cdot G_0$ described in Bassompierre on the quaternion form rotation matrix yields

$$\begin{aligned}
 &= \begin{bmatrix} 2q_0^2 - 1 + 2q_j^2 & 2q_jq_2 + 2q_0q_3 & 2q_1q_3 - 2q_0q_2 \\ 2q_1q_2 - 2q_0q_3 & 2q_0^2 - 1 + 2q_2^2 & 2q_3q_2 + 2q_0q_1 \\ 2q_1q_3 + 2q_0q_2 & 2q_3q_2 - 2q_0q_1 & 2q_0^2 - 1 + 2q_3^2 \end{bmatrix} * \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \\
 &= \begin{bmatrix} 2q_1q_3 - 2q_0q_2 \\ 2q_3q_2 + 2q_0q_1 \\ 2q_0^2 - 1 + q_3^2 \end{bmatrix}
 \end{aligned}$$

which is equivalent to

$$= \begin{bmatrix} 2(q_1q_3 - q_0q_2) \\ 2(q_2q_3 + q_0q_1) \\ q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$$

As with the Euler angle form of the calculation, the result is that the predicted acceleration reduces to the last column of the rotation matrix.

74. The equations for predicted acceleration are the same set of known equations for predicted acceleration presented in Equations 2 through 4 of the challenged '846 patent. (Ex. 1001, 17:20-26, Equations 2-4.) Patentee's expert has admitted that these equations were known:

Q. So Equation 2 is a calculation of a predicted acceleration along the x-axis?

A. Yes.

Q. And then Equation 3 is the predicted calculation acceleration along the y-axis?

A. Uh-huh.

Q. And then Equation 4 is a prediction of -- predicted acceleration along the 11 z-axis?

A. Yes.

Q. Is what we've been talking about, are those well-known concepts, or were they well-known concepts at the time of the invention of the '438 patent? MR. RAFILSON: Objection. Form.

A. The standard equations for -- the differential equation for the quaternion and the equations for computing these predicting accelerations are fairly well-known in the field.

(Ex. 1015, 58:3–22; *see generally id.*, 55:4–60:7 (testifying as to the related '438 patent).)

75. As further confirmation, the Kim paper itself determined the predicted acceleration from quaternions as part of the measurement model (predicted acceleration) of the EFK. (Ex. 1007, 270, Section III.B.) The predicted acceleration is found as part of the measurement vector f_{IMU} , which uses the “familiar direction cosine matrix” to secure the rotation matrix (C_o^b) from frame o to frame b, applied to gravity (g). (*Id.*) The accelerometer measurements are modeled to account only the gravitational force as well as a stochastic error vector ∇ :

$$f_{IMU} \cong C_o^b \begin{bmatrix} 0 \\ 0 \\ -||g||_2 \end{bmatrix} + \nabla$$

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$$= ||g||_2 \begin{bmatrix} -2q_1q_3 + 2q_0q_2 \\ -2q_0q_1 - 2q_2q_3 \\ -q_0^2 + q_1^2 + q_2^2 - q_3^2 \end{bmatrix} + \nabla \quad (13)$$

Where $||g||_2$ is the magnitude of gravity

(Ex. 1007, 270, equation 13 (emphasis added).) Kim's equation for the predicted acceleration from orientation in quaternion form is the same as the '846 patent's Equations 2 through 4 for predicted acceleration (Ax' , Ay' , Az') when removing the negative, which Kim accords for gravity facing upward:

$\begin{aligned} 2(q_1q_3 - q_0q_2) &= Ax' \\ 2(q_2q_3 - q_0q_1) &= Ay' \\ q_0^2 - q_1^2 - q_2^2 + q_3^2 &= Az' \end{aligned}$ (Ex. 1001, 17:20-26, Equations 2-4.)	$\begin{aligned} -2q_1q_3 + 2q_0q_2 \\ -2q_0q_1 - 2q_2q_3 \\ -q_0^2 + q_1^2 + q_2^2 - q_3^2 \end{aligned}$ (Ex. 1007 (Kim), 270, Equation 13.)
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76. We now arrive at Equation 23 of Bassompierre

$$\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$$

This equation provides an updated state vector of pitch and roll angles $\hat{x}_k$ as the *a priori* estimate of the state vector of the pitch and roll angles $\hat{x}_k^-$ added to a

correction $K_k \left(\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$. The correction is provided by multiplying the gain

K_k by the difference (comparison) in measured and predicted acceleration.

77. A person of ordinary skill in the art would understand that the above EKF equation for $\hat{x}_k$ would be presented in quaternion form as:

$$\hat{q}_k = \hat{q}_{\bar{k}} \otimes (K_k(z_k - h(\hat{q}_{\bar{k}})))$$

Here, $\hat{q}_k$ is the upated quaternion. $\hat{q}_{\bar{k}}$ is the current quaternion, which we described above as being the solution to the differential equation

$$\dot{q} = \frac{1}{2} \begin{vmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{vmatrix} \otimes \begin{vmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{vmatrix}.$$

Both $\hat{q}_k$ and $\hat{q}_{\bar{k}}$ are four-dimensional quaternion representing orientation. The

difference $z_k - h(\hat{q}_{\bar{k}})$ is the comparison between measured acceleration $z_k \begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix}$

and predicted acceleration in quaternion form (i.e., $h(\hat{q}_{\bar{k}})$), which, as described

above, is $\begin{bmatrix} 2(q_1 q_3 + q_0 q_2) \\ 2(q_2 q_3 - q_0 q_1) \\ q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$ in quaternion form.

78. The quaternion form EKF equation, like the Euler angle form Equation 23 of Bassompierre, determines the current quaternion by calculating a current orientation based on gyroscope readings ($\hat{q}_{\bar{k}}$), which, as explained above, is the solution to the differential equation

$$\dot{q} = \frac{1}{2} \begin{vmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{vmatrix} \otimes \begin{vmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{vmatrix} ;$$

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(*Id.*, 20:21 (equation 26); *see also id.*, 6:3-7.) Then, like in Equation 23 of Bassompierre, the current quaternion is rotated based on the correction provided by the K_k gain multiplied by the difference between measured and predicted acceleration ($z_k - h(\hat{q}_k^-)$). As one of ordinary skill in the art would readily appreciate, the addition of a rotation in quaternion space is a quaternion multiplication ($\otimes$) of current quaternion $\hat{q}_k^-$ with the correction ($z_k - h(\hat{q}_k^-)$), whereas in Euler angle form as in Equation 21 of Bassompierre, the rotation was an addition of $\hat{x}_k^-$ to the correction factor $K_k \left(\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$.

79. Any person of skill in the art would appreciate and understand that for the dimensions of $\hat{q}_k^-$ and $z_k - h(\hat{q}_k^-)$ to match in the quaternion EKF equation

$$\hat{q}_k = \hat{q}_k^- \otimes (K_k(z_k - h(\hat{q}_k^-)))$$

the Kalman gain K_k must be a 4×3 matrix. In that way, the three-dimensional comparison of measured to predicted acceleration can be mapped to the four-dimensional current quaternion $\hat{q}_k^-$. To this end, Bassompierre provides that the Kalman gain is multidimensional. (Ex. 1006, 16:13-15 (equations 5-10), referring to the Kalman gain as “G”.) Consequently, $K_k(z_k - h(\hat{q}_k^-))$ results in a four-dimensional vector that effectively represents a small rotation in quaternion space,

just as $K_k \left(\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$ represents a correction in Euler angle form. The

quaternion multiplication $\otimes$ of that error and the current quaternion $\hat{q}_k$, results in the updated quaternion $\hat{q}_k$.

5. Converting Quaternions Back to Euler Angles

80. As discussed above, a person of ordinary skill in the art would have been motivated to and would have been capable of using quaternions in equations 21-23 of Bassompierre. But equation 24, which I discuss in Section VIII.A.3 above, utilizes the pitch and roll angles from equation 23 in Euler angle format to derive the components ω_v and ω_w .

81. Thus, a person of ordinary skill has two choices. They can either convert equation 24 to use quaternions or they can convert the quaternion output of equation 23 into Euler angles, and use the Euler angles in equation 24. A POSA would have been capable of computing ω_v and ω_w under either choice.

82. A person of ordinary skill in the art would know how to convert the updated quaternion $\hat{x}_k$ of equation 23, when in quaternion form, to Euler angle form. As I noted earlier in my declaration at ¶26, patentee's expert has admitted as much. (Ex. 1016, 32:3-25.) A person of ordinary skill in the art would have been motivated to convert the quaternion output of equation 23 to Euler angles because Euler angles are more intuitive, i.e., it is easier to understand and perceive the effect of an orientation change of an object in terms of Euler angles than

quaternions. (Ex. 1007, 271 (“The quaternion states were also decomposed into the more intuitive representation of roll, pitch, and yaw in Fig. 5”).)

83. A person of ordinary skill in the art would know that rotation matrices could be used to perform the conversion from quaternion to Euler angles. A rotation matrix is a well-known mathematical tool for representing and performing rotations in space, e.g., Euler angle or quaternion space. A rotation matrix describes how to rotate an object to a new orientation from a starting orientation. In the case of quaternions, the rotation matrix defines how to rotate some given vector (e.g., described as a unit quaternion) to a new orientation. In the case of Euler angles, the rotation matrix defines how to rotate some give given orientation described in pitch, roll and/or yaw to a new orientation.

84. To convert a quaternion to a Euler angle form, a person of skill in the art would know to first convert the quaternion into a rotation matrix using some known quaternion-based rotation matrix. Kim, as noted earlier, presents one such quaternion “rotation matrix transforming from frame o to frame b ”, i.e., rotation of a unit quaternion from orientation o to b , as follows:

$$C_o^b = \begin{bmatrix} 2q_0^2 - 1 + 2q_j^2 & 2q_jq_2 + 2q_0q_3 & 2q_1q_3 - 2q_0q_2 \\ 2q_1q_2 - 2q_0q_3 & 2q_0^2 - 1 + 2q_2^2 & 2q_3q_2 + 2q_0q_1 \\ 2q_1q_3 + 2q_0q_2 & 2q_3q_2 - 2q_0q_1 & 2q_0^2 - 1 + 2q_3^2 \end{bmatrix}$$

(Ex. 1007, 270 (equation 7)). One would substitute the values of the quaternion $[q_0, q_1, q_2, q_3]$ into the above to arrive at the quaternion form rotation matrix for the specified quaternion.

85. Now the Euler angle (θ, ψ) must be extracted from the quaternion-defined rotation matrix. This is done by utilizing an Euler angle rotation matrix. Bassompierre presents a known rotation matrix for pitch and roll Euler angles, where the rotation matrix is defined as $R(\theta, \psi)$ meaning that the order of rotation is first pitch θ and then roll ψ :

$$R(\theta, \Psi) = \begin{bmatrix} \cos \theta & 0 & -\sin \theta \\ \sin \theta \cdot \sin \psi & \cos \Psi & \cos \theta \cdot \sin \Psi \\ \sin \theta \cdot \cos \psi & -\sin \Psi & \cos \theta \cdot \cos \Psi \end{bmatrix}$$

(Ex. 1006, 18:9). By comparing the elements of the quaternion rotation matrix with the elements of the Euler angle rotation matrix $R(\theta, \psi)$, one can solve for the Euler angles. Take a simple example where a person of skill in the art would need to focus only on the (1,1) position of each matrix, i.e., $q_0^2 - 1 + q_1^2$ and $\cos \theta$. Assume $q_0=1/2$ and $q_1=0$. Plugging those values into $q_0^2 - 1 + q_1^2$ of the quaternion rotation matrix and comparing that to $\cos \theta$ yields:

$$2(1/4) - 1 + 0 = 1/2, \text{ or}$$

$$\cos(\theta) = 1/2.$$

Because $\cos(\pi/3) = 1/2$, θ is 60 degrees or $\pi/3$.

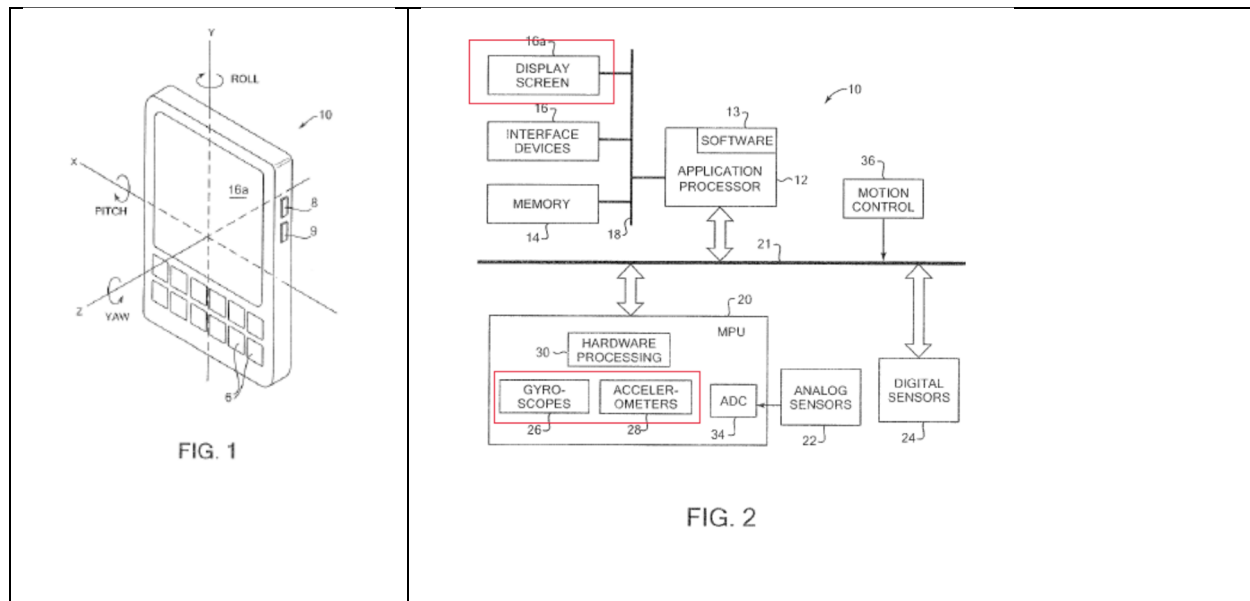
B. Bassompierre and Nasiri

86. As I explain below in the claim charts set forth in the attached Appendix, Bassompierre discloses an “electronic device” having a “display device” and a “motion sensor module,” as recited in claim 1 of the ’846 patent. It is my understanding that in the context of claim 1, the “display device” and a “motion sensor module” are not required to be in the same housing of the “electronic device.” I believe that this understanding is consistent with the ’846 patent. For example, Figure 5 illustrates an embodiment of the purported invention where an “electronic device 500” includes a first part 560 and a second part 570. (Ex. 1001, 11:44–46.) As shown in Figure 5, the first part 560 (which is a pointer device) and the second part 570 are not physically connected, and need not be in the same housing. (*Id.*, 11:46–60.)

87. To the extent Patent Owner argues the “electronic device” must include both a “display device” and a “motion sensor module” in the same housing (e.g., claim elements [1.pre], [1.a], [1.b]), it is my opinion that claim 1 would have been disclosed or suggested by Bassompierre in view of Nasiri.

88. Nasiri is analogous art to the ’846 patent because it teaches a mobile device with gyrometer and accelerometer motion sensors (Ex. 1008, 30:48-54, FIGS. 1, 2), running a sensor fusion algorithm (*id.*) to facilitate display of an image on a two dimensional screen. (*Id.*, 30:48–54; *see also id.*, 10:46-53, 14:49-57.)

Nasiri describes a mobile phone with a display screen, gyroscope, and accelerometer, all held in the same housing:



(Ex. 1008, 8:21-49, 9:47-10:37, FIG. 1, 2 (emphasis added).) Mobile phone 10 of Nasiri uses the output reading of its gyroscope and accelerometer in a sensor fusion algorithm (which, like the EKF of Bassompierre, predicts the acceleration) to provide handheld gaming on the phone. (*Id.*, 30:48-54, 10:46-53, 14:49-57 (“a driving, flying, skiing, or other game involving steering could be controlled **using gyroscopes and accelerometers**. The **sensor fusion algorithm** that **combines gyroscopes and accelerometer** can output a gravity vector that determines which way the direction ‘down’ is, relative to the device. By rotating the device relative to the gravity vector, **a steering motion can be used to control a game.**”).) (emphases added).)

89. Bassompierre also teaches the use of gyroscopes and accelerometers to facilitate movement on a display for use in gaming applications. (Ex. 1006, 1:3-26 (“The user normally holds the pointer in his hand, although other modes of carriage may easily be envisaged depending on the application, . . . They may have diverse functions, notably: . . . **electronic games interface** where, depending on the **game**, the pointer may be an object manipulated by the user (golf club, tennis racket, bowling ball, hand- gun, hip gun or rifle, etc.).” (emphasis added).) As already discussed, Bassompierre also uses a sensor fusion algorithm (EKF) to combine gyroscope and accelerometer readings. Having looked to Nasiri, a person of ordinary skill in the art would have recognized that an EKF, like that described in Bassompierre, could and should be implemented in Nasiri to allow playing games on a handheld device that included gyroscopes and accelerometers in addition to the display screen. In fact, Bassompierre calls out gaming applications as one particularly suited to the device of Figure 5 that can be addressed by using a three-axis gyroscope instead of a two-axis gyroscope. (*Id.*, 14:7-17 (“The invention makes it possible to compute the displacement of the mobile element in a plane surface on the basis of the movements of the pointer for small values of the angle of pitch (less than 30°). **This condition is fulfilled in most pointing applications, except perhaps in games where the amplitude of displacement is particularly important.** The choice of a gyrometer with two measurements axes is a solution

which is simpler and less expensive to implement than a solution based on a three-axis gyrometer. In this second solution, **the pointing device comprises**, for example, a three-axis MEMS accelerometer sensor 20 and a **three-axis gyrometer MEMS sensor 30** composed of three single-axis or of one single-axis and of one two-axes. The **third gyrometer axis makes it possible to circumvent the constraint on the value of the pitch angle.**” (emphases added).) Moreover, Bassompierre’s EKF sensor fusion algorithm has several advantages, including compensation of “tilt” or “torsion.” (*Id.*, 2:16-22, 10:10-14, 13:15-14:2.) Thus, Bassompierre motivates a person of ordinary skill in the art to use its EKF process in a mobile phone gaming solution such as that of Nasiri.

90. Configuring the Bassompierre-Nasiri combined system to allow an EKF sensor fusion operation on a mobile device with a screen, such as a mobile phone, would have been within ordinary skill and would not have required much (if any) change to the underlying system configuration. Since Bassompierre already teaches the translation of angles from the reference frames of the pointer and user to the display, it would have been within the knowledge of the person of skill in the art to do a fixed transformation between the reference frame of the pointer with that of the device to accomplish the movement of images to the display. In fact, the transformation would be simpler than that already described because the

sensors and display would be in a fixed relation, meaning that there would be fewer axes of rotation involved.

91. As shown in Figure 2 of Bassompierre, the device reference frame (X,Y,Z) can be transformed into display reference frame (x,y,z) , where $x=0$, using transformation matrices to represent the relationship between the two frames of reference. If the two frames of reference are connected to each other to force one to move with the other in some defined way, then instead of utilizing the (x,y,z) reference frame, a person of ordinary skill would know to utilize reference frame (X,Y,Z) and its fixed relation to the display to create a transformation matrix specific to that now fixed relationship.

92. Bassompierre describes exactly this scenario with respect to the device depicted in Figure 5. There “the sensors are positioned in the upper part of the device, whose orientation is different from the lower part, held by the wearer,” but the two positions are fixed by angle of pitch θ . (Ex. 1006, FIG. 5, 14:19-21.) As described by Bassompierre “the sensor axes are defined by the reference frame (X, Y, Z) . When the carrier of the device performs a rotation about the axis w , the gyrometer, located in the inclined part of the device, detects a rotation around the axes X and Z , dependent on the angle of pitch θ . The determination of the angle θ coupled with the knowledge of the measurements of angular rate around the axes X and Z then makes it possible to deduce therefrom the angular rate/velocity about

the axis w.” (*Id.*, 14:19:27.) Thus, a person of ordinary skill in the art could implement Bassompierre’s sensor fusion algorithm in a device where both the sensors and the display screen are fixed in the same housing.

93. Patentee’s expert testified that a person of ordinary skill in the art would be able to convert a three-dimensional orientation to a display screen of two dimensions even in the case where the display screen was part of the same handheld device:

Q. And does the mapping or the ability of a person of ordinary skill in the art to do the mapping, does that depend on whether it’s a built-in display or a display that is, say, somewhere across the room from the 3D pointing device?

A. It does make a difference as to where the quote, unquote, display reference frame is. If it’s coupled with the 3D -- by the handheld 3D pointing device versus some screen somewhere in some distance away, you have to understand the relationship between the two coordinate systems in order to properly perform the mapping.

Q. So, would your answer be different than specifically to the question, did a person of ordinary skill in the art in the 2009 or earlier time frame have the ability to do that transformation, if it’s a built-in display?

A. A person of ordinary skill in the art would be able to do that.

Q. Would it require a lot of experimentation?

A It's hard to say. I mean, there's various levels of skill in the art, so... I would say if that person was following proper procedure for how you do transformations from one coordinate system to another, then there wouldn't be a lot of experimentation needed.

(Ex. 1016, 49:22-50:23.)

IX. THE PROVISIONAL '558 APPLICATION

94. The provisional '558 application does not provide written support for several claim elements of the '846 patent.

95. The provisional '558 application makes no mention of, and presents no equations using, quaternions. All disclosure in the provisional '558 application is described with respect to only Euler angles. For example, the provisional '558 application discloses a “three-dimensional (3D) pointing device may refer to an input device applicable to be moved by a user in three or more dimensions in the space (e.g., air) in front of a screen (or monitor) to control a corresponding user interface by translating those motions done by the user with the 3D pointing device directly into commands acceptable by the user interface, for example, movement of a cursor on the screen.” (Ex. 1014, ¶0002.) To accomplish the translation of pointer movement to movement of a cursor on the screen, the provisional '558 application describes the 3D point device as including “an accelerometer (g-

sensor) and a gyroscope, wherein the accelerometer is used to detect/measure the acceleration of the 3D pointing device in a specific direction(s) (e.g., the three axis directions), and the gyroscope is used to measure the rotation (e.g., the rotation rate) of the 3D pointing device.” (Ex. 1014, ¶0003.) The provisional ’558 describes the rotations of the gyroscope as “tilt angles.” (*Id.*, ¶¶0010, 0011, 0028, 0029. The provisional ’558 application also refers to tilt angles as “rotation angles.” (Ex. 1014, ¶0029 (“Referring to FIG. 2A, rotation (tilt) angles θ_x and θ_y may be calculated by A_x and A_y signals”).) With respect to accelerometer data, the ’558 provisional application similarly describes “tilt angles calculated from measuring results of an accelerometer.” (Ex. 1014, ¶30.) The ’558 provisional application never converts, or suggests conversion or use of, quaternions to represent the orientation of the pointer.

96. Further, the ’558 provisional application does not describe or suggest the use of quaternions for the sensor fusion algorithms that combine the sensor measurements. For example, the sensor fusion algorithm, described in Figures 5A and 5B performs its calculations (represented in the boxes shown below) using Euler angles, not quaternions:

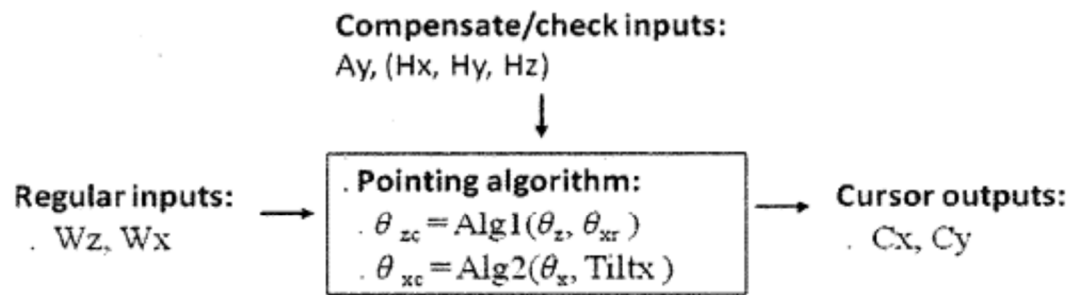


FIG. 5A

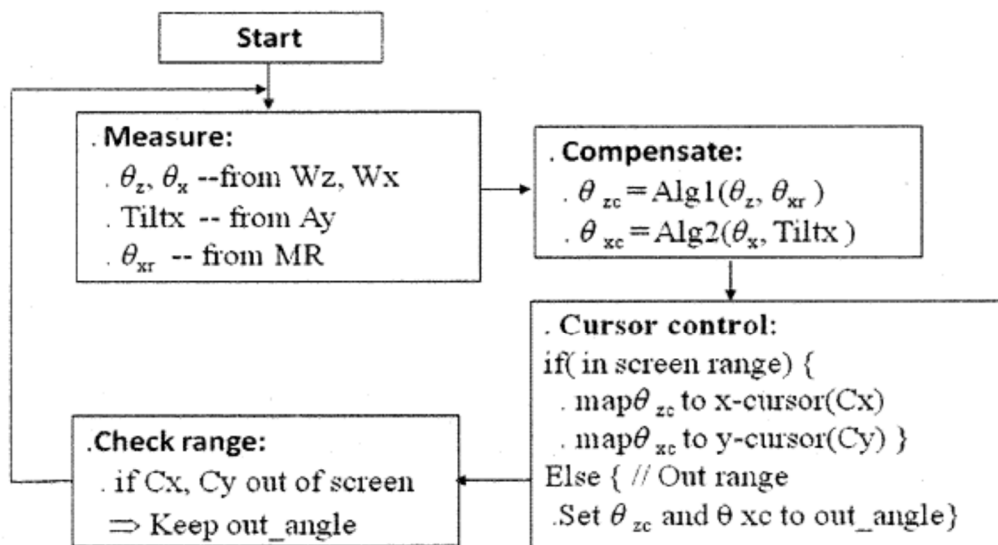


FIG. 5B

(Id., FIGS.5A, 5B, ¶0040.)

97. Further, the provisional '558 application does not describe a comparison of a predicted axial accelerations and measured axial accelerations. For example, the '558 provision application describes the algorithms of Figures 5A and 5B in only the most general terms as using “tilt measured by the accelerometer

to compensate x-gyro drift and monitor cursor vertical range.” (*Id.*, FIGS.5A, 5B, ¶0040.) Nowhere in the specification or drawings does the ’558 provisional application describe the details of that algorithm, let alone to the level that would indicate that predicted axial accelerations and measured axial accelerations should be compared.

X. CONCLUSION

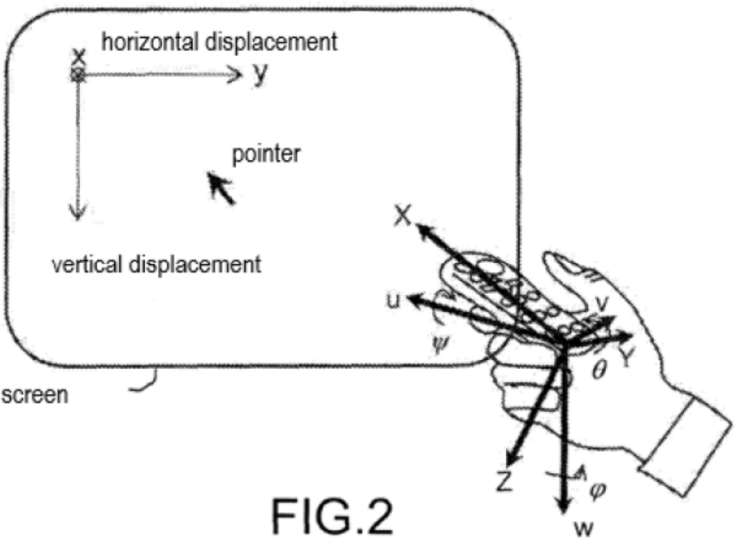
98. I declare that all statements made herein of my knowledge are true, and that all statements made on information and belief are believed to be true, and that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

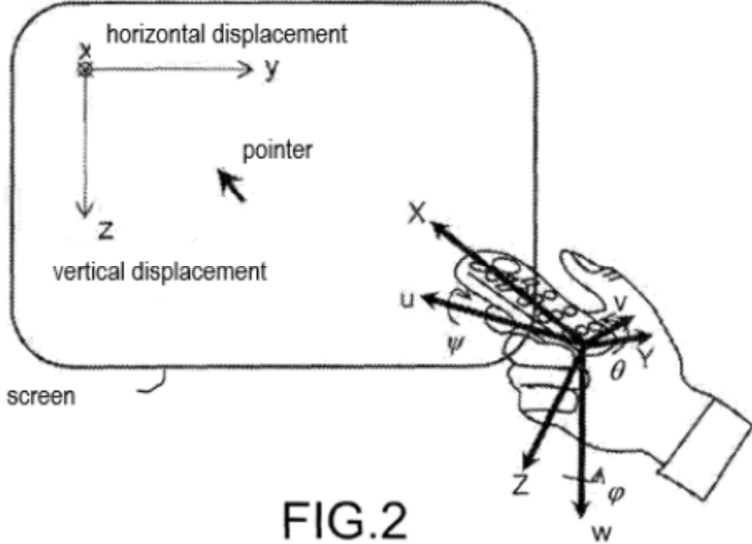
Dated: May 18, 2025

By:  _____

Majid Sarrafzadeh

APPENDIX

'846 Patent Claim Element	Prior Art Analysis
Claim 1 [1.pre] “1. An electronic device subject to movements and rotations in dynamic environments, comprising:”	Bassompierre discloses a device “for pointing by a user at a mobile element in a plane surface.” (Ex. 1006, 4:1-12, 8:24-25, FIGS. 1, 2.) For example, as shown in Figure 1, the pointer “has the shape and appearance of a television remote control, i.e., it is of elongate form, able to be held in the user’s hand.” (<i>Id.</i>, 8:25-27.) The pointer includes a gyroscope (20) and accelerometer (30). (<i>Id.</i>, FIG. 1.) Figure 2 shows the system (“<u>electronic device</u>”), which includes a pointer and a screen.  FIG.2 (<i>Id.</i>, FIG, 2.) The electronic device of Figure 1 and Figure 2 is “<u>subject to movements and rotations in dynamic environments</u>” because the hand holding the pointer is moving, and that movement is displayed on the screen. (<i>Id.</i>, 8:14-16 (“Figure 2 illustrates the definition of the various reference frames in which are computed the displacements of a pointer and of a cursor on a screen in an embodiment of the invention.”); <i>see also</i> my analysis below for [1.b] describing various sensors for sensing movement and rotation of the pointer).)

[1.a] “a display device associated with a display reference frame;”	Bassompierre discloses this limitation. For example, Figure 2 shows a screen (“display device”) upon which the three-dimensional movements of the pointer are displayed in two dimensions (y, z) on a screen (“associated with a display reference frame”). (<i>Id.</i>, 8:14-16.)  (<i>Id.</i>, FIG. 2.) Bassompierre states that “the pointer is associated with a mobile element able to move in a plane surface, for example, a screen or a writing surface. The displacements of this mobile element are controlled by the displacements of the pointer.” (<i>Id.</i>, 9:1-4.)
[1.b] “a motion sensor module comprising a rotation sensor and an accelerometer, the rotation sensor having sensor circuitry configured to generate measured angular velocities and the accelerometer	Bassompierre discloses this limitation. Bassompierre explains that the pointer has an angular velocity sensor 20 (“rotation sensor”) and a linear acceleration sensor 30 (“accelerometer”). (<i>Id.</i>, 9:24-25, 10:17-21, FIG. 1.)

having circuitry configured to generate measured axial accelerations, with both the rotation sensor and the accelerometer being associated with the movements and the rotations of the electronic device in a spatial reference frame; and:

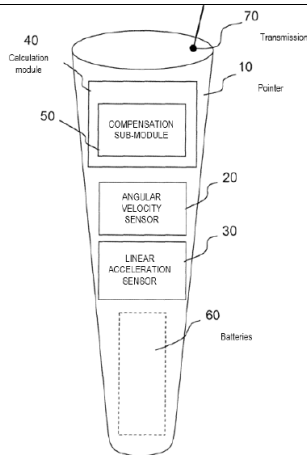


FIG. 1

(*Id.*, FIG. 1.)

The angular velocity sensor 20 (also referred to as a “gyrometer,” which a person of ordinary skill would also understand to refer to a gyroscope) (Ex. 1006, 9:25-29) has **“sensor circuitry configured to generate measured angular velocities.”** (*Id.*, 9:23-30 (“angular velocity sensors 20 have the function of measuring the rotations of the pointer in relation to two or three axes. These sensors will preferably be gyrometers. It may be a two-axis gyrometer or a three-axis gyrometer. . . . It is, for example, possible to use the gyrometers provided by Analog Devices with the reference ADXRS300. But any sensor capable of measuring angular rates or velocities is usable.”.) Linear acceleration sensor 30 has **“circuitry configured to generate measured axial accelerations.”** (*Id.*, 10:14-17 (“The compensation sub-module recovers as input the outputs from a second sensor 30 which measures the linear accelerations of the pointer ax, ay, az. Preferably, the sensor 30 is a three-axis accelerometer.”).)

The gyroscope and accelerometer described in Bassompierre are part of the same **“motion sensor module.”** (*Id.*, 10:17-21 (“the sensors 20 and 30 are both produced by MEMS (Micro Electro Mechanical Systems) technology, **optionally within one and the same circuit** (for example, reference accelerometer ADXL103 from Analog Devices, LIS302DL from Thomson, reference gyrometer MLX90609 from Melixis, ADXRS300 from Analog Devices).” (emphasis added).) Moreover, the “motion sensor module”

	is a MEMS sensor, a well-known sensor component to a person of ordinary skill in the art. (<i>Id.</i>, 10:17-21; Ex. 1007, 268.) Further, the rotation sensor 20 and the accelerometer 30 of Bassompierre are associated with the “<u>movements and the rotations of the electronic device in a spatial reference frame</u>,” i.e., the reference frame XYZ of the pointer 10. (<i>Id.</i>, 10:21-22 (“the MEMS module will be situated near the center of gravity of the pointing device.”); <i>see also, id.</i>, 12:14-15 “The accelerometric and gyrometric sensors respectively return measurements noted (a_x, a_y, a_z) and ($\omega_x \cdot \omega_y$) in the frame of reference (XYZ) of the pointing device.”) (emphasis added), <i>id.</i>, 27:4-8 “at least one second sensor (30) for measuring the linear movements of said device along said two axes (Y, Z) and a third orthogonal axis (X), a module (40) for calculating the displacements (y, z) to be imparted to the mobile element in the plane surface as a function of the displacements (X, Y, Z) of the pointer in space,”) (emphases added); FIG. 2 (illustrating the reference frame XYZ of the pointing device).) As I discussed earlier in section VII, above, “spatial reference frame” means “a reference frame associated with a 3D pointing device, which always has its origin at the same point in the device and in which the axes are always fixed with respect to the device.” As shown in Figure 2 of Bassompierre, the reference frame XYZ of the pointing device has a fixed point of origin where the X, Y, and Z axes meet. Moreover, the X, Y, and Z axes are fixed with respect to the pointer device, as evident from Figure 2. In fact, the axes move as the device moves. Further, Bassompierre states that the accelerometer and gyroscopes respectively return “measurements noted (a_x, a_y, a_z) and ($\omega_x \cdot \omega_y$) in the frame of reference (XYZ) of the pointing device.” (<i>Id.</i>, 12:14–15.) The “<u>movements and the rotations of the electronic device</u>” are therefore “<u>in a spatial reference frame</u>.”
[1.c] “a computing processor having	Bassompierre discloses this limitation. For example, as illustrated in FIG. 1, the pointer has a compensation sub-module 50, which is a microprocessor that is programmed to

processor circuitry configured to calculate a resulting deviation comprising resultant angles associated with the movements and the rotations of the electronic device in the spatial reference frame by:"	determine how the pointer orientation has changed, and is therefore a “<u>computing processor</u>.” Specifically, compensation sub-module 50 comprises a “microprocessor” that “compensate[es] for the torsion imparted to the pointer by the user.” (Ex. 1006, 9:15-20 (emphases added).) The “torsion compensation operation is performed in two steps, a step 1 of estimating the angles θ and ψ of pitch and of roll by an EKF and a step 2 of computing the angular rate components ω_v, ω_w, related to the displacement of the mobile element with respect to the frame of reference of the user.” (<i>Id.</i>, 15:3-7; <i>see also id.</i>, 4:11-21.) Thus, the compensation sub-module 50 calculates angles θ and ψ of pitch and of roll, respectively. I further note that the angles θ and ψ are “<u>a resulting deviation comprising resultant angles associated with the movements and the rotations of the electronic device in the spatial reference frame</u>” because they represent the deviation in angular terms of the pointing device’s reference frame (XYZ) from a reference frame (uvw) of the user’s limb, as the user moves and rotates the pointing device. (<i>Id.</i>, FIG. 2, FIG. 3, 10:30-11:6, 11:31-12:9.) For example, when the two reference frames are aligned, “the pitch and roll angles are zero.” (<i>Id.</i>, 11:21-24.) A non-zero “roll and/or pitch angle[.]” indicates that the “reference frames (uvw) and (XYZ) are not aligned.” (<i>Id.</i>, 11:31-12:9.) Calculating roll and pitch angles thus allows correlating angular velocities determined in the XYZ reference frame to the uvw reference frame, which allows calculating “the displacement of the mobile element on the screen (d_y and d_z).” (<i>Id.</i>, 11:25-12:9.)
[1.d] “providing a previous quaternion corresponding to time $T-1$ based on the measured axial accelerations corresponding to	Bassompierre discloses or suggests this limitation. A person of ordinary skill in the art would understand claim elements [1.d] through [1.h] to describe the calculations performed for one loop, i.e., the present loop at time T, of the EKF algorithm described in the ’846 patent. The output of the loop is a quaternion, and related angular deviations, that describe how the electronic device is oriented in three-dimensional space. The output of any given loop at time $T-1$

time T-1 and the measured angular velocities corresponding to time T-1;	becomes the input of the next loop, i.e., the present loop, at time T, as the previous quaternion. As will now be described, claim element [1.d] is the first step in the loop (at present time T), and begins by referencing the “previous quaternion,” i.e., the output of the previous loop’s operation (at time T-1), which provides the orientation of the electronic device at time T-1. Bassompierre discloses limitation [1.d]. To estimate the pitch angle θ and roll angle ψ by an EKF, Bassompierre defines the angles θ and ψ as a state vector. (Ex. 1006, 17:5-6 (“the state vector chosen to solve the problem is: $x=[\theta \ \psi]$. Where θ and ψ are respectively the pitch and roll angles.”).) In particular, Bassompierre discloses using the state vector $\hat{x}_{k-1}^-$ from the previous iteration k-1⁴ (represented by the pitch and roll angles from the previous iteration $\begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix}$) (“providing a previous quaternion corresponding to time T-1”) to calculate an estimate of the state vector in the current loop at time k, as seen in equation 21 (reproduced below). (Ex. 1006, 4:20-26, 19:1-3, 28:9-13 (emphasis added in text and figure).) $\hat{x}_k^- = \begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix} = \begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix} + T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$ (<i>Id.</i>, 19:1-3 (equation 21).) As shown in equation 21 above, the state vectors $\hat{x}_k^-$ and $\hat{x}_{k-1}^-$ include the pitch and roll angles in Euler angle form. But Bassompierre explains that the state vector calculation can instead be a quaternion. (<i>Id.</i>, claim 1 (“its state vector comprises at least one torsion representation chosen from the group Euler angles, quaternions”), 20:10-13 (“A first variant embodiment consists in replacing the angles of torsion θ and ψ by a quaternion formulation of the same torsion. This variant exhibits the advantage of avoiding the computations of the sines and cosines of the pitch and roll
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⁴ Bassompierre describes operations in the present loop with the time index “k,” rather than the time index of “T” or “t”, and describes operation in the preceding past loop as “k-1” instead of “T-1” or “t-1”. A POSA would understand k and T or t to be equivalent for purposes of the present analysis.

angles that are greedy in terms of computational power.”).) The benefits of using quaternions over Euler angles were well-known to a person of ordinary skill in the art. (See Ex. 1007 at 269-270 (“For modeling the rotational motion, quaternions are used rather than direction cosines and Euler angles because the quaternion representation does not have a problem with singularities; handles normalization better; and exchanges the bulky trigonometry of Euler angles with multiplication and addition . . .”).)

Thus, a POSA would have been motivated to modify equation 21 to include quaternions instead of Euler angles. In such a modification, the state vectors $\hat{x}_k^-$ and $\hat{x}_{k-1}^-$ would have been represented using quaternions. A POSA would have a reasonable expectation of success in using quaternions (as opposed to Euler angles) for reasons I discussed above in Section VIII.A.4 and VIII.A.5. Also, Patent Owner’s expert in IPR proceedings for the related ’438 patent and ’978 patent admitted that quaternions “would be known to someone of ordinary skill in the art.” (Ex. 1013, p. 44.) The PTAB consequently found that “knowledge of quaternion mathematics [was] within the level of ordinary skill.” (*Id.*, pp. 44–45.)

Bassompierre, in fact, uses a quaternion formulation to obtain a current quaternion based on a previous quaternion and the current angular velocities. Specifically, Bassompierre discloses utilizing a previous quaternion (q_0, q_1, q_2, q_3) in conjunction with the angular velocities from the current time to estimate a state vector at the current time, i.e., $\dot{q}$ (“**current quaternion**”). (Ex. 1006, 20:10-25 (equation 26), 30:1-5.)

$$\dot{q} = \frac{1}{2} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} \otimes \begin{bmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} ;$$

(Ex. 1006, 20:10–25 (equation 26).) A POSA would have understood that equation 26 is a quaternion form representation of equation 21. This is explained further below with reference to claim element [1.e] and earlier in my declaration in Section VIII.A.4.

[1.e] “converting the measured angular velocities corresponding to time T based on the previous quaternion into a current quaternion and predicted axial accelerations without using the measured axial accelerations corresponding to time T;”	Bassompierre discloses or suggests this limitation. For example, the <i>a priori</i> estimate of the state vector, $\hat{x}_k^-$ (“<u>current quaternion</u>”), is calculated by adding the pitch and roll angles from the previous iteration k-1, i.e., $\begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix}$ (“<u>based on the previous quaternion</u>”), to the gyroscope readings (ω_x, ω_y and ω_z) (“<u>converting the measured angular velocities corresponding to time T</u>”) multiplied by a sampling period T_e as follows: $\hat{x}_k^- = \begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix} = \begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix} + T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$ (<i>Id.</i>, 19:3 (equation 21), 28:13.) As the above equation shows, the conversion of measured angular velocities to a current quaternion does not require the use of measured acceleration at time k (“<u>without using the measured axial accelerations corresponding to time T</u>”). While equation 21 above utilizes Euler angles to represent the state vector, a person of ordinary skill would have been motivated to use quaternions in place of Euler angles, as discussed earlier in my declaration. One way of utilizing the current angular velocities and a previous quaternion (i.e., quaternion from the last loop) to estimate a current quaternion is set forth in Bassompierre in short-hand form in equation 26 (reproduced below). $\dot{q} = \frac{1}{2} \begin{vmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{vmatrix} \otimes \begin{vmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{vmatrix} ;$ (<i>Id.</i>, 20:20-23 (equation 26); <i>see also id.</i>, 6:3–7.) In the above equation, ω_x, ω_y and ω_z are the current angular angular velocities in three dimensions (X, Y, Z) in the sensor frame in the present loop of the EKF (“<u>measured angular velocities</u>”).
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corresponding to time T).⁵ The “**previous quaternion**” is represented by the vector $q = (q_0, q_1, q_2, q_3)$. The solution to the differential equation is to “**convert the measured angular velocities corresponding to time T based on the previous quaternion into a current quaternion.**” The solution thus yields the “**current quaternion.**” Equation 1 of the challenged ’846 patent is written in expanded form, but otherwise presents a similar equation for deriving the current quaternion from the previous quaternion using the measured angular velocities at time T:

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

(Ex. 1001, equation 1, 16:45-54.)

Bassompierre determines an “*a priori* estimation of the [acceleration] measurement” (“**predicted axial accelerations**”) based on the *a priori* estimation of the state vector (“**current quaternion**”). (Ex. 1006, 19:4–5; *see also id.*, 28:15–17.) This *a priori* estimation of the [acceleration] measurement is taken in time step k and calculated as follows:

$$\hat{y}_k^- = \begin{bmatrix} -\sin \hat{\theta}_k^- \\ \cos \hat{\theta}_k^- \cdot \sin \hat{\psi}_k^- \\ \cos \hat{\theta}_k^- \cdot \cos \hat{\psi}_k^- \end{bmatrix}$$

(*Id.*, 19:4–5 (equation 22); *see also id.*, 28:15–17.) In the above equation, $\hat{x}_k^-$ (“**current quaternion**”), which as explained above was “**converted**” from “**measured angular velocities corresponding to time T based on the previous quaternion,**” is used to determine the **predicted axial acceleration** $\hat{y}_k^-$. Readings from the current linear

⁵ Bassompierre also teaches the conversion of the gyroscope readings taken in only two directions (i.e., without ω_x). (*Id.*, 20:21–21:1.)

	acceleration sensor 30 are not used in this calculation (<u>“without using measured axial accelerations corresponding to time T”</u>). Further, as noted above, Bassompierre teaches a POSA to substitute quaternions for Euler angles, such that the <i>a priori</i> estimation of the [acceleration] measurement $\hat{y}_k^-$ (<u>“predicted axial accelerations”</u>) can be rendered from orientation in quaternion form as described by Bassompierre: A first variant embodiment consists in replacing the angles of torsion θ and ψ by a quaternion formulation of the same torsion. This variant exhibits the advantage of avoiding the computations of the sines and cosines of the pitch and roll angles that are greedy in terms of computational power. (<i>Id.</i> 20:10–19 (emphasis added).) To confirm that Bassompierre discloses the determination of predicted acceleration from quaternion form to a POSA, and that such a determination was well within the grasp of a POSA, Patent Owner admitted that the Equations 2 through 4 of the '846 patent, which show explicit quaternion-form calculations for determining predicted acceleration, were known in the art: Q. So Equation 2 is a calculation of a predicted acceleration along the x-axis? A. Yes. Q. And then Equation 3 is the predicted calculation acceleration along the y-axis? A. Uh-huh. Q. And then Equation 4 is a prediction of -- predicted acceleration along the 11 z-axis?
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	A. Yes. Q. Is what we've been talking about, are those well-known concepts, or were they well-known concepts at the time of the invention of the '438 patent? MR. RAFILSON: Objection. Form. A. The standard equations for – the differential equation for the quaternion and the equations for computing these predicting accelerations are fairly well-known in the field. (Ex. 1015, 58:3–22; <i>see generally id.</i>, 55:4–60:7 (testifying as to the related '438 patent).) A person of ordinary skill in the art would know how to derive the predicted acceleration of Bassompierre in quaternion form. As I explained in detail earlier in my declaration, that operation would yield the exact same formulas as Equations 2 through 4 in the challenged '846 patent: $\begin{bmatrix} 2(q_1q_3 + q_0q_2) \\ 2(q_2q_3 - q_0q_1) \\ q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$ (Ex. 1001, 17:20-26.) As I explained earlier in my declaration, this derivation of the predicted axial acceleration in quaternion form is done using known quaternion relations with a gravity frame of reference and known quaternion mathematics.
[1.f] “comparing the predicted axial accelerations, which are based on the measured axial	Bassompierre teaches the subtraction of $\hat{y}_k^-$ (“<u>predicted axial accelerations</u>”) from $\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix}$ at time k (“<u>measured axial accelerations corresponding to time <u>T</u></u>”), where the subtraction acts as a “<u>comparison</u>” of

accelerations corresponding to time T-1 and the measured angular velocities corresponding to time T, with the measured axial accelerations corresponding to time T to obtain a first comparison result;	predicted axial acceleration and measured axial accelerations at time T as part of the EKF process equation: $\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$ (Ex. 1006, 19:8-9 (equation 23) (emphasis added); <i>see also id.</i>, 5:4-6, 29:10-14 (claim 10).) Bassompierre describes the comparing process as “the correction of the state estimated <i>a priori</i> at sampling step k.” (<i>Id.</i>, 5:4-6, 19:8-9.) In Bassompierre, the difference between the predicted axial accelerations and measured axial accelerations (“<u>first comparison result</u>”) is multiplied by a gain (K_k), which is determined using equation 5, 6, 7, 8, and 9 of Bassompierre. (<i>Id.</i>, 19:6-9, 16:10-14.) The gain acts as a correction that takes into account covariances of the modeling and measurement noise to determine which of the predicted axial accelerations (which are derived from the measured angular velocities taken from the gyroscope reading) or the measured axial accelerations (which are read from the accelerometer) should be more trusted and to what degree. (<i>Id.</i>, 5:2-6, 13:21-32, 16:13-17:4, 19:6-9, 20:2-6, 28:18-29-1) This process of “comparison” is what the specification of the ’846 patent describes as “utilizing signals generated by motion sensors while reducing or eliminating noises associated with said motion sensors.” (Ex. 1001, 2:37-43.) The patentee has admitted (and I agree) that the EKF equations, like that disclosed in Bassompierre (e.g., Ex. 1006, 6:10-17:6) and those discussed in the ’846 patent (Ex. 1001, 17:52-18:33, Eq. 5-11) were “basic” and “standard” and known in the art: “And those -- that piece right there will give you data that is necessary to put into Equations 5 through 11, which are the basic equations of the extended Kalman filter. . . . So those pieces, then, can be put into the, quote/unquote, main equations of the extended Kalman Filter to get the comparison and to calculate the third quaternion, which essentially fuses all of these information together. Q. And that main equation is 5 through 11? A. Yeah. Standard - - Q. And that's just a framework? A. Yes.” (Ex. 1015, 62:6-
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	63:9, testifying as to the same equations in the related '438 patent.) In the deposition of patentee's expert (Dr. LaViola) in the IPR proceedings for the '438 and '978 patents, Dr. Laviola described equation 11 (the same equation as that in the '846 patent) as the "weighted vector norm" and described it as subtracting the predicted from the measured acceleration. He described the weighted vector norm as "the enhanced comparison method": A Well, the weighted vector norm is going to be represented as D sub T in equation 11. And that equation takes advantage -- what it does is it utilizes the covariance or the variability that's calculated between the measurements, which would be the sensor data [measured acceleration], and the prediction for the orientation given the angular velocities [predicted acceleration]. And what it does effectively is it subtracts those two numbers and then multiplies it by the --that's where there are variances in weight. It just gives you the weight. (Ex. 1016, 35:12-36:3 (emphasis added, "measured acceleration" and "predicted acceleration" notations added).) While equation 23 involves Euler angles, a POSA would have been motivated to utilize quaternions in place of Euler angles. This is explained further below in the analysis for claim element [1.g] and earlier in my declaration. Bassompierre states that $\hat{y}_k^-$ ("<u>predicted axial accelerations</u>") is calculated using pitch and roll angles $\begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix}$, which are derived using the previous quaternion $\begin{pmatrix} \hat{\theta}_{k-1}^- \\ \hat{\psi}_{k-1}^- \end{pmatrix}$ and the "<u>measured angular velocities corresponding to time T.</u>" (See analysis for claim element [1.e]; Ex. 1006, equations 21-22.) But pitch and roll angles $\begin{pmatrix} \hat{\theta}_{k-1}^- \\ \hat{\psi}_{k-1}^- \end{pmatrix}$ is the output of the prior loop (k-1). (See above
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	analysis for claim element [1.d] for “providing a previous quaternion corresponding to time T-1 based on the measured axial accelerations corresponding to time T-1.”) And the output of the previous loop, i.e., the output pitch and roll angles at time T-1, is calculated “based on the measured axial accelerations corresponding to time T-1.” (See below analysis of element 1.g explaining that equation 23 provides the output pitch and roll angles based on the measured accelerations during that loop).)
[1.g] “obtaining an updated quaternion associated with time T based on the current quaternion and the first comparison result, which is based on the measured axial accelerations corresponding to time T-1, measured axial accelerations corresponding to time T, and angular velocities corresponding to time T, and using the updated quaternion as a next occurrence of the previous quaternion; and	Returning again to the EKF equation of Bassompierre, $\hat{x}_k$ is the “updated quaternion” in Euler angle form: $\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$ (Ex. 1006, 19:8-9, 28:9-13 (emphasis added).) Bassompierre describes $\hat{x}_k$ (“updated quaternion”) as the “correction of the <i>a priori</i> estimated state” (<i>id.</i>, 19:8-9), which is calculated in time k as indicated by the subscript k (“associated with time T.”) (<i>Id.</i> at 29:2-5 (“correction of the state estimated a priori in the sampling step k of the Kalman filter.”).) Thus, solving the above equation gives the “updated quaternion associated with time T.” $\hat{x}_k$ (“updated quaternion”) is “based on the current quaternion,” $\hat{x}_k^-$, at least for the reason that the $\hat{x}_k^-$ (“current quaternion”) is an explicit part of the equation for calculating $\hat{x}_k$ (“current quaternion”): $\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$ (<i>Id.</i> 19:8–9 (equation 23) (emphasis added), 29:2-5.) $\hat{x}_k$ (the “updated quaternion”) is also “based on . . . the first comparison result,” (i.e., the difference between the measured axial acceleration $\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix}$ and the predicted acceleration $\hat{y}_k^-$) described in claim element [1.f] and shown in the EKF equations as highlighted below:

$$\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$$

(*Id.* 19:8–9 (equation 23), 29:2-5.)

A POSA would have been motivated to perform the calculations of equation 23 using quaternions instead of Euler angles. The '846 patent does not explain how quaternions would have been used to obtain an “updated quaternion.” But Patent Owner’s expert has testified that equations 5-11 in the '846 patent correspond to step 735 (which is the step that obtains the “updated” quaternion) and were “known in the art.” (Ex. 1012 at 11-12)

As I explained in earlier in my declaration above, following Bassompierre’s instruction to utilize quaternions instead of Euler angles, a person of ordinary skill in the art would have known that the above EKF equation for $\hat{x}_k$ (Ex. 1006, 29:2–5 (equation 23)) could be presented in quaternion form as:

$$\hat{q}_k = \hat{q}_k^- \otimes (K_k(z_k - h(\hat{q}_k^-)))$$

where $\hat{q}_k$ is the updated quaternion, $\hat{q}_k^-$ is the current quaternion, and $z_k - h(\hat{q}_k^-)$ represents the difference or

comparison between measured acceleration $z_k(\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix})$ and predicted acceleration in quaternion form

$\begin{bmatrix} 2(q_1q_3 + q_0q_2) \\ 2(q_2q_3 - q_0q_1) \\ q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$.) I explained earlier that this is the same

equation performing the same operation as Equation 23 of Bassompierre, except that it utilizes quaternions instead of Euler angles in the manner known by a person of ordinary skill in the art, just as Bassompierre recommends.

Also, as I explained earlier in my declaration, any person of skill in the art would appreciate and understand that for the dimensions of $\hat{q}_k^-$ and $z_k - h(\hat{q}_k^-)$ to match, the Kalman gain K_k must be a 4×3 matrix. In that way, the three-dimensional comparison of measured to predicted acceleration can be mapped to the four-dimensional current

quaternion $\hat{q}_k^-$. To this end, Bassompierre provides that the Kalman gain is multidimensional. (Ex. 1006, 16:13–15 (equations 5–10 (referring to the Kalman gain as “G”).) Consequently, $K_k(z_k - h(\hat{q}_k^-))$ results in a four-dimensional vector that effectively represents a small rotation in quaternion space, just as $K_k \begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix} - \hat{y}_k^-$ represented a correction in Euler angle form. The quaternion multiplication $\otimes$ of that error and the current quaternion $\hat{q}_k^-$ results in the updated quaternion $\hat{q}_k$.

The result of the comparison between the measured axial acceleration $\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix}$ and the predicted acceleration $\hat{y}_k^-$

uses the measured axial acceleration $\begin{bmatrix} a_{x,k} \\ a_{y,k} \\ a_{z,k} \end{bmatrix}$, which is the

“measured axial accelerations corresponding to time T.”

It also uses the predicted acceleration $\hat{y}_k^-$ that is calculated based on **“angular velocities corresponding to time T.”** (See above analysis of claim element [1.f].)

The predicted acceleration $\hat{y}_k^-$ is **“based on the measured axial accelerations corresponding to time T–1.”** Specifically, $\hat{y}_k^-$ is calculated using the pitch and roll angles represented by $\hat{x}_k^-$:

$$\hat{y}_k^- = \begin{bmatrix} -\sin \hat{\theta}_k^- \\ \cos \hat{\theta}_k^- \cdot \sin \hat{\psi}_k^- \\ \cos \hat{\theta}_k^- \cdot \cos \hat{\psi}_k^- \end{bmatrix}$$

(Ex. 1006, 19:4-5, 28:15-17.) But $\hat{x}_k^-$ is calculated with reference to the output of the previous loop (i.e., the **previous quaternion**) shown in yellow boxes as follows:

$$\dot{q} = \frac{1}{2} \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} \otimes \begin{bmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} ;$$

	(Id., 20:21 (emphasis added).) $\hat{x}_k^- = \begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix} = \begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix} + T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$ (Id., 19:3 (emphasis added).) The <u>previous quaternion</u> at time T (k) is the <u>updated quaternion</u> $\hat{x}_k$ from the previous loop (“<u>corresponding to time T-1</u>”), which is based on the measured acceleration at time T-1 in that loop. (Ex. 1006, equation 23.) Thus, $\hat{y}_k^-$ is “<u>based on the measured axial accelerations corresponding to time T-1.</u>” $\hat{x}_k$ (“<u>updated quaternion</u>”) becomes the “<u>previous quaternion</u>,” i.e., $\begin{matrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{matrix}$ or $\begin{matrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{matrix}$, in the “<u>next occurrence</u>” (next loop k) in the equations for determining the <u>current quaternion</u>: $\dot{q} = \frac{1}{2} \begin{vmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{vmatrix} \otimes \begin{vmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{vmatrix} ;$ (Id., 20:21 (emphasis added).) $\hat{x}_k^- = \begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix} = \begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix} + T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$ (Id., 19:3 (emphasis added).)
[1.h] “providing the resulting deviation based on the updated quaternion;”	Bassompierre discloses or suggests this limitation. Bassompierre teaches that after “step 1 of estimating the angles θ and ψ of pitch and of roll by an EKF . . . a step 2 of computing the angular rate components ω_v, ω_w, related to the displacement of the mobile element with respect to the

frame of reference of the user” is performed. (Ex. 1006, 15:3–7 (emphasis added).) “Step two” is performed by using the pitch and roll angles of (θ, Ψ) from equation 23 to derive ω_v and ω_w as follows:

$$\begin{cases} \omega_v = \cos\hat{\psi} \cdot \omega_y - \sin\hat{\psi} \cdot \omega_z \\ \omega_w = -\sin\hat{\theta} \cdot \omega_x + \cos\hat{\theta} \cdot \sin\hat{\psi} \cdot \omega_y + \cos\hat{\theta} \cdot \cos\hat{\psi} \cdot \omega_z \end{cases}$$

(Ex. 1006, 19:10–11 (equation 24); *see also id.*, 29:6–9.) This is further illustrated in FIG. 6, where Bassompierre shows ω_v and ω_w as the output of a “step 2” process, where the input to the step 2 process includes the pitch and roll angles (θ, ψ) and the output of the step 2 process is ω_v and ω_w calculated using Equation 24 above (using Euler angles).

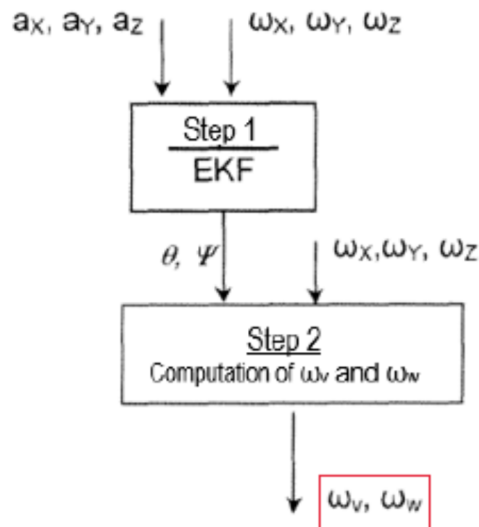


FIG.6

(*Id.*, 19:11)

Thus, a POSA would understand that if the output of Bassompierre’s equation 23 is a quaternion representing the pitch and roll angles, such a quaternion would then be translated into pitch and roll angles in Euler angle format. I explained this above in detail in Section VIII.A.5. For example, $\hat{x}_k$ (“**updated quaternion**”) would be transformed to provide the pitch and roll angles (“**resulting deviation**”) in

	Euler angle form.⁶ Indeed, $\hat{x}_k$ is merely a state vector in terms of pitch and roll angles. (Ex. 1006, 19:1-3, 19:8-9; <i>see also id.</i>, FIG. 6 (output of step 1), 17:5-6 (“In a first embodiment, the state vector chosen to solve the problem is: $\mathbf{x}=[\theta \ \psi]$. Where θ and ψ are respectively the pitch and roll angles.”) (emphasis added).) Thus, the providing of the pitch and roll angles as the output of the EKF is a “<u>providing [of] the resulting deviation based on the updated quaternion.</u>” The Board has previously determined in the proceedings for the related ’438 patent, that it would have been obvious to a person of ordinary skill in the art to convert a quaternion into yaw, pitch and roll resultant Euler angles in the spatial reference frame because the equations for such a transformation were widely known in the art. (Ex. 1011, p. 49.) I explained earlier in my declaration the straight-forward known way of using quaternion and Euler angle rotation matrices to render the conversion formulas to move from quaternion to Euler angles. Thus, to the extent the calculations for the Kalman filter process of Bassompierre is performed using quaternions, as opposed to Euler angles, it would have been straightforward for a person of ordinary skill in the art to convert the quaternion output $\hat{x}_k$ (“<u>updated quaternion</u>”) into pitch and roll angles in Euler angle format, which provides “<u>the resulting deviation based on the updated quaternion.</u>”
[1.i] “wherein the current quaternion and the predicted axial accelerations are converted from the measured	Bassompierre discloses the limitations therein assuming that equations 21-23 use quaternions instead of Euler angles as I described earlier in my declaration. As I already explained in the analysis for claim [1.g] above, $\hat{x}_k^-$ (“<u>current quaternion</u>”) is calculated from the reading of the gyroscope (ω_x, ω_y and ω_z) at time step k (“<u>converted from the measured angular velocities corresponding to time T</u>”):

⁶ As explained above with reference to limitation [1.c], the pitch and roll angles disclose the “**resulting deviation.**”

angular velocities corresponding to time T so that the first comparison result and the updated quaternion correspond to time T; and”	$\hat{x}_k^- = \begin{pmatrix} \hat{\theta}_k^- \\ \hat{\psi}_k^- \end{pmatrix} = \begin{pmatrix} \hat{\theta}_{k-1} \\ \hat{\psi}_{k-1} \end{pmatrix} + T_e \begin{pmatrix} \alpha \sqrt{\omega_y^2 + \omega_z^2} \\ \omega_x \end{pmatrix}$ (Ex. 1006, 19:1-3, 28:13.) Using quaternions, a similar calculation is performed by solving the differential equation for q using the same gyroscope readings (ω_x, ω_y and ω_z) at time step k (“converted from the measured angular velocities corresponding to time T”): $\dot{q} = \frac{1}{2} \begin{vmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{vmatrix} \otimes \begin{vmatrix} 0 \\ \omega_x \\ \omega_y \\ \omega_z \end{vmatrix};$ (<i>Id.</i>, 6:3-7, 19:1-3, and see 20:10-11 (“A first variant embodiment consists in replacing the angles of torsion θ and ψ by a quaternion formulation of the same torsion.”) (emphasis added).) As described in the analysis of claim element [1.e] above, $\hat{y}_k^-$ (“predicted axial accelerations”) is based on $\hat{x}_k^-$ (“current quaternion”): $\hat{y}_k^- = \begin{vmatrix} -\sin \hat{\theta}_k^- \\ \cos \hat{\theta}_k^- \cdot \sin \hat{\psi}_k^- \\ \cos \hat{\theta}_k^- \cdot \cos \hat{\psi}_k^- \end{vmatrix}$ (<i>Id.</i>, 19:4-5, 28:15-17.) Thus, $\hat{y}_k^-$ (“predicted axial accelerations”) is derived from the gyroscope readings of the measured angular velocity (ω_x, ω_y and ω_z) at time step k (T) (“converted from the measured angular velocities corresponding to time T”). Thus, “[t]he first comparison result and the updated quaternion” also “correspond to time T.” (<i>Id.</i>, equation 23.)
[1.j] “wherein the processor circuitry is further configured to translate the resultant angles	Bassompierre discloses this limitation. For example, the processor circuitry of Bassompierre (described above in the analysis for claim element [1.c]) is configured to translate the pitch and roll angles (θ ψ) (“resultant angles of the resulting deviation in the spatial reference frame”), which are output as the updated quaternion, $\hat{x}_k$, into a resultant deviation in the two-dimensional reference frame of the

of the resulting deviation in the spatial reference frame into a real-time movement pattern in the display reference frame.”	screen through use of the user reference frame (u, v, w). For example, the pitch and roll angles allow correlating angular velocities determined in the XYZ reference frame to the uvw reference frame, which allows calculating “the displacement of the mobile element on the screen (d_y and d_z)” (“real time movement patterns in the display reference frame”). (<i>Id.</i>, 11:25-12:9.) Specifically, “ω_v and ω_w . . . give direct information on the horizontal displacements (rotation about the axis ω represented by ω_w) and vertical displacements (rotation about the axis v represented by ω_v) and therefore the displacement of the mobile element on the screen (d_y and d_z).” (<i>Id.</i>) Equation 24 discloses the calculation of ω_w and ω_v using the roll and pitch angles of the updated quaternion. $\begin{cases} \omega_v = \cos\hat{\psi} \cdot \omega_y - \sin\hat{\psi} \cdot \omega_z \\ \omega_w = -\sin\hat{\theta} \cdot \omega_x + \cos\hat{\theta} \cdot \sin\hat{\psi} \cdot \omega_y + \cos\hat{\theta} \cdot \cos\hat{\psi} \cdot \omega_z \end{cases}$ (<i>Id.</i>, 19:10-11 (equation 24).)
Claim 3	
[3.pre] The electronic device of claim 1, wherein, in calculating the resulting deviation, the computing processor is further configured to:	The <u>computing processor</u> of the <u>electronic device</u> of Bassompierre (described above in the analysis for claim element [1.c]) is responsible for <u>calculating the resulting deviation</u>. My analysis for claim 3 assume that equations 21-23 of Bassompierre use quaternions instead of Euler angles.
[3.a] utilize a first data association model to determine whether compensation is needed to obtain the updated quaternion based on the measured	Bassompierre discloses the limitation. As described in [1.f] above, the EKF of Bassompierre includes “<u>a first data association model</u>” in the form of the comparison by subtraction of $\hat{y}_k^-$ (“<u>predicted axial acceleration</u>”) with $\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix}$ (“<u>measured axial accelerations</u>”) at time step k (“<u>corresponding to time T</u>”), which is then multiplied by the Kalman gain at time step k in the form of K_k:

axial accelerations corresponding to time T;	$\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$ (Ex. 1006, 5:4-6 (emphasis added), 19:8-9, 29:2-4 (claim 10).) The value of the Kalman gain determines the influence of the measured axial acceleration reading $\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix}$ (“<u>measured axial accelerations</u>”) on $\hat{x}_k^-$ (“<u>current quaternion</u>.”) In other words, the value of the compensation data association model (Kalman gain times the difference between the measured acceleration and predicted acceleration) determines that amount by which the $\hat{x}_k$ (“<u>current quaternion</u>”) must be changed (compensated) to arrive at $\hat{x}_k$ (“<u>updated quaternion</u>”). That calculation is “<u>based on the measured axial accelerations corresponding to time T</u>” because the measured accelerometer values $\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix}$ taken at time k (“<u>measured axial accelerations corresponding to time T</u>”) is part of the EKF equation that solves for $\hat{x}_k$ (“<u>updated quaternion</u>”).
[3.b] and obtain the updated quaternion in response to determining that the compensation is needed.	Bassompierre discloses this limitation. For example, as explained in the analysis of [3.a], “<u>determining that the compensation is needed</u>” is performed by the EKF equation based on the comparison by subtraction of $\hat{y}_k^-$ (“<u>predicted axial acceleration</u>”) with $\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix}$ (“<u>measured axial accelerations</u>”) multiplied by the Kalman gain: $\hat{x}_k = \hat{x}_k^- + K_k \left(\begin{bmatrix} \alpha_{x,k} \\ \alpha_{y,k} \\ \alpha_{z,k} \end{bmatrix} - \hat{y}_k^- \right)$ (<i>Id.</i>, 5:4-6 (emphasis added), 29:1-4 (claim 10).) If that calculated value is anything other than 0, then $\hat{x}_k^-$ (“<u>current quaternion</u>”) will be incremented or decremented

	(“ <u>compensation</u> ”) thus adjusting $\hat{x}_k$ (“ <u>obtain the updated quaternion</u> ”). A determination is thus made that “ <u>compensation is needed.</u> ”
Claim 7	
[7.pre] “A method for determining movements and rotations in dynamic environments, comprising:”	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.b] and [1.c].
[7.a] “generating, with a rotation sensor having sensor circuitry measured angular velocities;”	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitations [1.b].
[7.b] “generating, with an accelerometer having accelerometer circuitry measured axial accelerations;”	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.b].
[7.c] “calculating, with a computing processor having processor circuitry, a resulting deviation comprising resultant angles associated with the movements and the rotations	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.c].

in a spatial reference frame by:”	
[7.d] “providing a previous quaternion corresponding to time $T-1$ based on the measured axial accelerations corresponding to time $T-1$ and the measured angular velocities corresponding to time $T-1$;	Bassompierre discloses or suggests this limitation for the reasons I discuss above with reference to limitation [1.d].
[7.e] “converting the measured angular velocities corresponding to time T based on the previous quaternion into a current quaternion and predicted axial accelerations without using the measured axial accelerations corresponding to time T ;	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.e].
[7.f] “comparing the predicted axial accelerations, which are based on the measured	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.f].

axial accelerations corresponding to time T-1 and the measured angular velocities corresponding to time T, with the measured axial accelerations corresponding to time T to obtain a first comparison result;”	
[7.g] “obtaining an updated quaternion associated with time T based on the current quaternion and the comparison result, which is based on the measured axial accelerations corresponding to time T-1, measured axial accelerations corresponding to time T, and angular velocities corresponding to time T, and using the updated quaternion as a next occurrence	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.g].

of the previous quaternion; and”	
[7.h] “providing the resulting deviation based on the updated quaternion,	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.h].
[7.i] wherein the current quaternion and the predicted axial accelerations are converted from the measured angular velocities corresponding to time T so that the comparison result and the updated quaternion correspond to time T; and”	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.i].
[7.k] “translating the resultant angles of the resulting deviation in the spatial reference frame into a real-time movement pattern in a display reference frame associated with a display device.”	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.j].
Claim 9	
[9.pre] The method of claim	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [1.c] and [3.pre].

7, wherein calculating the resulting deviation further comprises:	
[9.a] utilizing a first data association model to determine whether compensation is needed to obtain the updated quaternion based on the measured axial accelerations corresponding to time T; and	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [3.a].
[9.b] obtaining the updated quaternion in response to determining that the compensation is needed.	Bassompierre discloses this limitation for the reasons I discuss above with reference to limitation [3.b].