

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

Google LLC

Petitioner

v.

Cywee Group Ltd.

(record) Patent Owner

Patent No. 8,441,438

DECLARATION OF PROF. MAJID SARRAFZADEH

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I. ENGAGEMENT AND COMPENSATION

1. My name is Majid Sarrafzadeh. I have been retained by Google LLC for the purpose of providing my opinion with respect to the unpatentability of U.S. Pat. No. 8,441,438 (“the ’438 patent”). I am being compensated for my time in preparing this declaration at the rate of \$650/hr, and my compensation is not dependent upon my opinions or the outcome of the proceedings.

II. QUALIFICATIONS

2. 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. I am the Co-Director of the Center for SMART Health, Co-Director for the BRITE Center on Minority Health Disparities, and a Co-Founder of the UCLA Wireless Health Institute.

3. 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. My current Curriculum Vitae is attached to the end of this declaration, and summarizes my qualifications.

4. 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.

5. 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.

6. I am an author or co-author on more than 500 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.

7. 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. I have performed data capture, data processing and analytics with these mobile systems. I have utilized the design in remote monitoring systems. In many of my projects 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.

III. SUMMARY OF OPINIONS

8. In my opinion, claims 1 and 3-5 of the '438 patent are obvious over the Zhang publication and Bachmann patent.

IV. MATERIALS REVIEWED

9. In forming my opinions, I have relied of my knowledge of the field and my experience, and have specifically reviewed the following exhibits:

Exhibit No.	Description
1001	U.S. Pat. No. 8,441,438 (“ the '438 patent ”).
1004	U.S. Pat. No. 7,089,148 (“ Bachmann ”)
1005	U.S. Pat. App. Pub. 2004/0095317 (“ Zhang ”)
1006	U.S. Pat. No. 7,158,118 (“ Liberty ”)
1009	File History of U.S. Pat. App. 12/943,934

V. UNDERSTANDING OF THE RELEVANT LAW

10. I have the following understanding of the applicable law:

A. Anticipation

11. I understand that a claim in an issued patent can be unpatentable if it is anticipated. In this case, “anticipation” means that there is a single prior art reference that discloses every element of the claim, arranged in the way required by the claim.

12. I understand that an anticipating prior art reference must disclose each of the claim elements expressly or inherently. I understand that “inherent” disclosure means that the claim element, although not expressly described by the

prior art reference, must necessarily be present based on the disclosure. I understand that a mere probability that the element is present is not sufficient to qualify as “inherent disclosure”.

B. Obviousness

13. I understand that a claim in an issued patent can be unpatentable if it is obvious. Unlike anticipation, obviousness does not require that every element of the claim be in a single prior art reference. Instead, it is possible for claim elements to be described in different prior art references, so long as there is motivation or sufficient reasoning to combine the references.

14. I understand that a claim is unpatentable for obviousness if the differences between the claimed subject matter and the prior art are such that the subject matter as a whole would have been obvious at the time the alleged invention was made to a person having ordinary skill in the art to which said subject matter pertains.

15. I understand, therefore, that when evaluating obviousness, one must consider obviousness of the claim “as a whole”. This consideration must be from the perspective of the person of ordinary skill in the relevant art, and that such perspective must be considered as of the “time the invention was made”.

16. The level of ordinary skill in the art is discussed in ¶23 below.

17. The relevant time frame for obviousness, the “time the invention was

made”, is discussed in ¶24, below.

18. I understand that in considering the obviousness of a claim, one must consider four things. These include the scope and content of the prior art, the level of ordinary skill in the art at the relevant time, the differences between the prior art and the claim, and any “secondary considerations”.

19. I understand that “secondary considerations” include real-world evidence that can tend to make a conclusion of obviousness either more probable or less probable. For example, the commercial success of a product embodying a claim of the patent could provide evidence tending to show that the claimed invention is not obvious. In order to understand the strength of the evidence, one would want to know whether the commercial success is traceable to a certain aspect of the claim not disclosed in a single prior art reference (i.e., whether there is a causal “nexus” to the claim language). One would also want to know how the market reacted to disclosure of the invention, and whether commercial success might be traceable to things other than innovation, for example the market power of the seller, an advertising campaign, or the existence of a complex system having many features beyond the claims that might be desirable to a consumer. One would also want to know how the product compared to similar products not embodying the claim. I understand that commercial success evidence should be reasonably commensurate with the scope of the claim, but that it is not necessary for a commercial product to

embody the full scope of the claim.

20. Other kinds of secondary considerations are possible. For example, evidence that the relevant field had a long-established, unsolved problem or need that was later provided by the claimed invention could be indicative of non-obviousness. Evidence that others had tried, but failed to make an aspect of the claim might indicate that the art lacked the requisite skill to do so. Evidence of copying of the patent owner's products before the patent was published might also indicate that its approach to solving a particular problem was not obvious. Evidence that the art recognized the value of products embodying a claim, for example, by praising the named inventors' work, might tend to show that the claim was non-obvious.

21. I further understand that prior art references can be combined where there is an express or implied rationale to do so. Such a rationale might include an expected advantage to be obtained, or might be implied under the circumstances. For example, a claim is likely obvious if design needs or market pressures existing in the prior art make it natural for one or more known components to be combined, where each component continues to function in the expected manner when combined (i.e., when there are no unpredictable results). A claim is also likely unpatentable where it is the combination of a known base system with a known technique that can be applied to the base system without an unpredictable result. In these cases, the

combination must be within the capabilities of a person of ordinary skill in the art.

22. I understand that when considering obviousness, one must not refer to teachings in the specification of the patent itself. One can, however, refer to portions of the specification admitted to being prior art, including the “BACKGROUND” section. Furthermore, a lack of discussion in the patent specification concerning how to implement a disclosed technique can support an inference that the ability to implement the technique was within the ordinary skill in the prior art.

VI. LEVEL OF ORDINARY SKILL IN THE ART

23. In my opinion, the relevant art was that of sensors and sensor data processing. In the relevant timeframe, a person of ordinary skill in the art had an undergraduate degree in computer science, electrical engineering, mechanical engineering, or other related technical field, and knowledge of sensor systems. I believe I would meet this definition, and would have met this definition in the relevant timeframe.

VII. RELEVANT TIMEFRAME FOR DETERMINING OBVIOUSNESS

24. I understand that obviousness must be evaluated “at the time of the invention”. From the cover page of the ’438 patent, I can see that the first provisional application for a patent was filed in the United States on January 6, 2010. For the purpose of this declaration, I will analyze obviousness in the time frame immediately prior to this date, although my testimony is applicable to a longer period of time (at

least a year) before January 6, 2010. My testimony is directed to this timeframe, even if I do not always use a past tense.

VIII. TECHNICAL INTRODUCTION

25. The '438 patent discloses 3D pointing devices and methods of sensing their movements and determining their orientations. (Ex. 1001, Title, Abstract). According to the '438 patent, a 3D pointing device enables a user to “perform control actions and movements utilizing the pointing device for certain purposes including entertainment such as playing a video game, on the display device ... through the aforementioned pointer on the screen”. (Ex. 1001, 1:48-51). Unlike computer mice, touchscreens, and other 2D input interfaces, a 3D pointing device can be translated and rotated in 3D, allowing a wider variety of movements and rotations to be translated into actions shown on a computer display. (Ex. 1001, 1:32-34). FIG. 1 of the '438 patent (reproduced below) shows an example 3D pointing device 110 and a corresponding display 120:

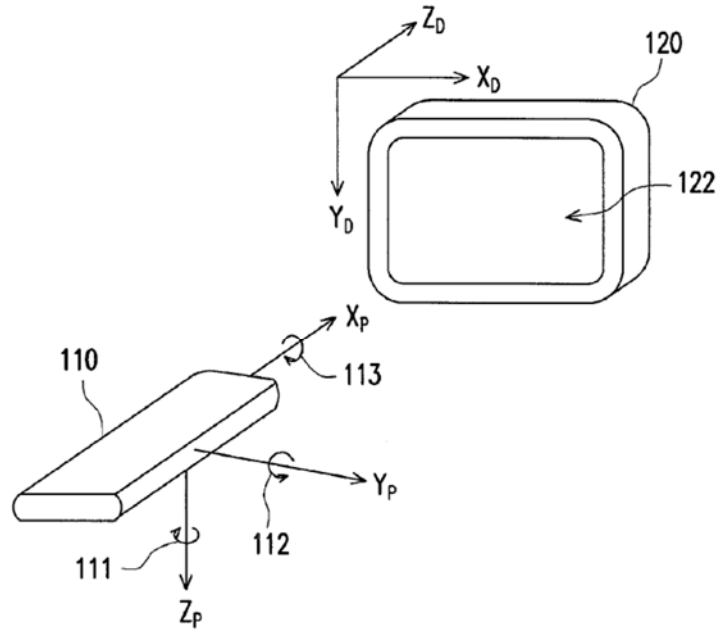


FIG. 1 (RELATED ART)

26. The '438 patent discloses tracking the 3D pointing device's orientation with rotation sensors and accelerometers. (Ex. 1001, Fig. 4). The rotation sensors detect angular velocity, and the accelerometers detect axial velocity (*i.e.* axial accelerations). The rotation sensors and accelerometers can be mounted in or on the 3D pointing device.

27. The '438 patent also discloses calculating the orientation of the 3D pointing device from the changes in angular and axial velocity detected by the rotation sensors and accelerometers. (Ex. 1001, 4:6-19). The 3D pointing device's orientation (also called the "attitude" or "tilt") represents the 3D pointing device's alignment with respect to a given coordinate system. (Ex. 1001, 1:58-2:2). For example, Fig. 2 of the '438 patent shows the 3D pointing device 110 of FIG. 1 in a different orientation, having been rotated about the X_p axis by 90 degrees:

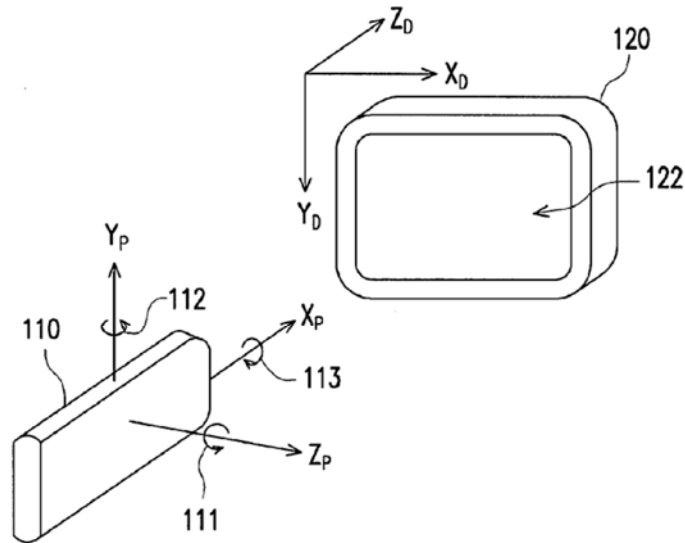


FIG. 2 (RELATED ART)

28. “Orientation” can be represented in a number of different ways. One way is to use a set of angles, known as “Euler angles”. The Euler angles, called “yaw”, “pitch” and “roll” represent rotation around three orthogonal axes. If the object whose orientation is being described is an airplane, the “yaw” could be thought of as the horizontal (compass) direction of the airplane, while the “pitch” is the inclination of the nose of the airplane, and the “roll” is the angle of wings. The Euler angles do not need to be defined relative to the axes that most naturally fit airplane flight, however, but can be with respect to any coordinate system with three orthogonal axes.

29. Orientation can also be represented by a quaternion. A quaternion is a four-valued vector (q_0 q_1 q_2 q_3) that can be thought of as a generalization of a complex number. Quaternions were first described in the 19th Century. The

elements of a quaternion are usually thought of as having one real value (q_0) and three values (q_1 q_2 q_3) parallel with three different imaginary axes, labeled i , j and k . For this reason, quaternions can also be represented with vector addition in the form $q = a + bi + cj + dk$, where $i^2=j^2=k^2=ijk=-1$, and where the following relations hold: $ij=k$, $ji=-k$, $jk=i$, $kj=-i$, $ki=j$, $ik=-j$.

30. Quaternions have special mathematical properties that allow them to describe rotations efficiently. For any rotation of angle Θ around a given axis defined by a vector (x,y,z) , a quaternion q representing the rotation can be defined such that $q = \cos(\Theta/2) + \sin(\Theta/2)(xi + yj + zk)$. Furthermore, multiplying two quaternions together using the distributive law and the relationships defined in 29, above results in an application of rotations described by both quaternions. Furthermore, and most usefully, any ordinary vector $v=(v_1 v_2 v_3)$ can be defined as a quaternion with real component $=0$, e.g. $v'=(0 v_1 v_2 v_3)$. Then, any rotation defined by a quaternion q can be applied to v' to get a rotated quaternion r , by using q and its conjugate (q^{-1}), in the following way $r=qv'q^{-1}$. In this equation, the application of the quaternion q is by quaternion multiplication using the distributive law and the relationships defined in 29. The conjugate of q , labeled q^{-1} , is simply q with the imaginary components negated.

31. The relationships described in ¶¶29-30 were well-known in the relevant timeframe, and are described in the prior art I reviewed. (e.g. Ex. 1004, 8:63-67)(Ex.

1006, 16:65-18:28). It was also well known that the Euler angles, described above in ¶28 could be equivalently represented by a quaternion. For example, the Liberty reference (Ex. 1006), states:

“Q is the normalized rotation quaternion that represents the rotation from the body frame to the user frame. Since the rotation quaternion to rotate from the user frame to the body frame is Q, we could replace Q with R* where R is the rotation from the user frame to the body frame. Note that **Q can be represented in a number of equivalent forms including Euler angles** and the direction cosine matrix (DCM), and the above equations may vary slightly in their equivalent forms based upon different representations of Q.” (Ex. 1006, 17:36-44).

32. The Background section of the '438 patent acknowledges prior-art 3D pointing devices but says that they cannot calculate orientation accurately. (Ex. 1001, 2:22-3:51). To address this problem, the '438 patent discloses using more sensors to measure the 3D pointing device's movement and “compensating” the sensors' outputs using quaternions to improve the accuracy of the orientation calculation. (Ex. 1001, 1:21-26, 10:42 *et seq.*)

33. FIG. 7 of the '438 patent (reproduced at right) shows a compensation process using quaternions. This process includes obtaining measured angular velocities from the rotation sensors at step 715 (Ex. 1001, 12:31-35) and measured axial accelerations from the accelerometers in step 725 (Ex. 1001, 12:64-13:1). A *predicted* set of axial accelerations is calculated from the 3D pointing device's current step at step 730. (Ex. 1001, 13:1-11).

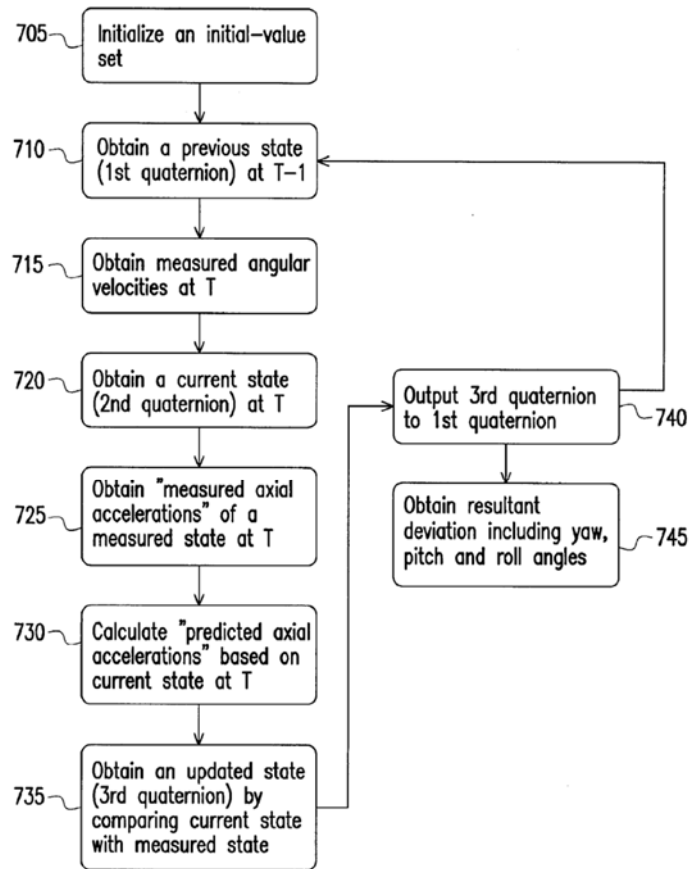


FIG. 7

34. The predicted and measured axial accelerations are compared in step 735 to yield a more accurate orientation estimate (the "updated state (3rd quaternion)" in box 735). (Ex. 1001, 13:25-49).

IX. CLAIM INTERPRETATION

35. I understand that it is sometimes necessary or useful for claim terms in a patent to be further explained or interpreted ("construed"). In the present proceeding, I understand generally that claims terms are construed according to their

broadest reasonable interpretation in light of the specification, looking at the ordinary meaning to a person of ordinary skill in the art in the relevant timeframe, and considering the specification of the patent and the file history of the patent.

36. I have reviewed the claim interpretations in the corresponding petition for *inter partes* review, and I am of the opinion that they would have been reasonable to a person of ordinary skill in the art in the relevant timeframe in the context of the '438 patent. These interpretations are set forth in the following paragraphs, and my testimony applies these interpretations:

A. “Comparison”—Claim 1

37. Claim 1 uses the term “comparison” in as follows (emphasis added):

“communicating with the six-axis motion sensor module to calculate a resulting deviation comprising resultant angles in said spatial pointer reference frame by utilizing a **comparison** to compare the first signal set with the second signal set whereby said resultant angles in the spatial pointer reference frame of the resulting deviation of the six-axis motion sensor module of the 3D pointing device are obtained under said dynamic environments, wherein the **comparison** utilized by the processing and transmitting module further comprises an update program....”

38. The '438 patent describes the term “comparison” as follows:

“The term of ‘**comparison**’ of the present invention may generally refer to the calculating and obtaining of the actual

deviation angles of the 3D pointing device 110 with respect to the first reference frame or spatial pointing frame $X_P Y_P Z_P$ utilizing signals generated by motion sensors while reducing or eliminating noises associated with said motion sensors.” (Ex. 1001, 2:26-32)(Emphasis added).

39. I take this to mean that a “comparison” is simply “calculating and obtaining” orientation using signals from different motion sensors, whether or not the values represented by those signals are actually compared to each other or to any other values. These calculations yield deviation angles with respect to the first reference frame or spatial pointing frame and use sensor signals in a way that reduces noise. I therefore construe the term “comparison” to mean the performance of calculations based on sensor signals to obtain the orientation of the device with respect to the spatial pointing frame in a way that reduces the effect of sensor noise.

A. Claim 1—“spatial pointer reference frame”

40. The term “spatial pointer reference frame” means “a reference frame associated with the 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. My interpretation of these terms is based on the claims and specification of the ’438 patent. The specification of the ’438 patent uses the term “spatial pointer reference frame” to refer to the frames of reference of pointing devices like those shown in FIGS. 1-3, 5, 6, 9, and 13–15 of the ’438 patent. The ’438 patent does not

define the term in great detail, but it does liken the spatial pointer reference frame to the reference frame associated with the 3D pointing device shown in FIGS. 1 and 2. For example, when describing the electronic device 300 shown in FIG. 3, the '438 patent states:

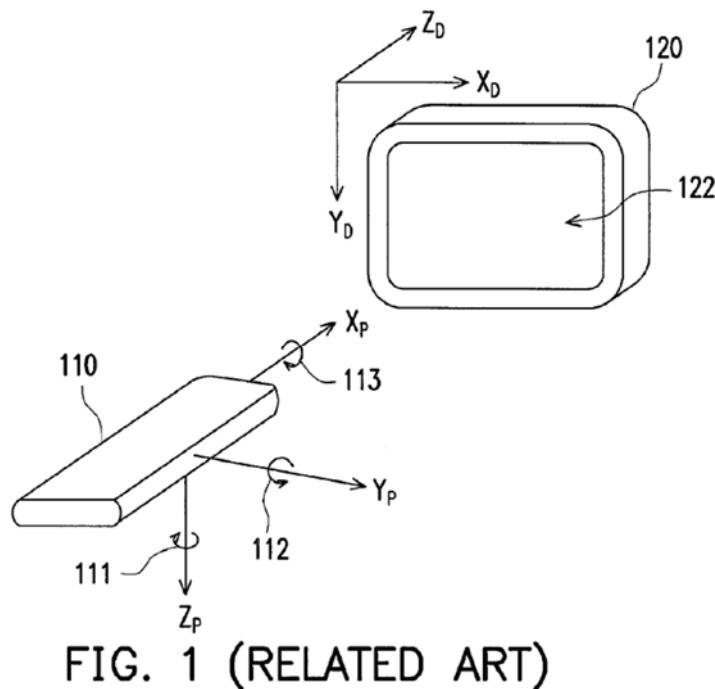
“The 3D pointing device 300 is subject to movements and rotations in dynamic environments in a 3D **spatial pointer reference frame**. The spatial pointer reference frame is **analogous to the reference frame $X_P Y_P Z_P$ in FIG. 1 and FIG. 2.**”

(Ex. 1001, 9:16-20)(Emphasis added). I take this to mean that the reference frame $X_P Y_P Z_P$ shown in FIGS. 1 and 2 is an example of a spatial pointer reference frame (associated with the 3D pointing device).

42. The reference frame $X_P Y_P Z_P$ shown in FIGS. 1 and 2 (reproduced below) is called the “spatial pointer reference frame.” (Ex. 1001, 1:38–1:42). The '438 patent states that the spatial pointer reference frame is “associated with the pointing device 110 [and] is defined by the coordinate axes X_P , Y_P and Z_P as shown in FIG. 1.” (Ex. 1001, 1:38-1:41). Because the pointing device 110 can be “a 3D pointing device” (Ex. 1001, 1:29), I interpret the spatial pointer reference frame to be “a reference frame associated with the 3D pointing device” per the first part of my interpretation of “spatial pointer reference frame.” This interpretation is consistent with the descriptions of spatial pointer reference frames elsewhere in the

specification of the '438 patent.

43. Next, I consider the second part of my interpretation, i.e., that the spatial reference frame “always has its **origin at the same point in the device** and in which the axes are always fixed with respect to the device.” This is based on FIGS. 1 and 2 of the '438 patent. These figures are reproduced below and show that the X_P , Y_P and Z_P coordinate axes intersect at a point within the electronic device 110. See, for example, FIG. 1 of the '438 patent:



44. FIG. 2 (reproduced below) also shows that the intersection of the X_P , Y_P , and Z_P coordinate axes is within the electronic device 110:

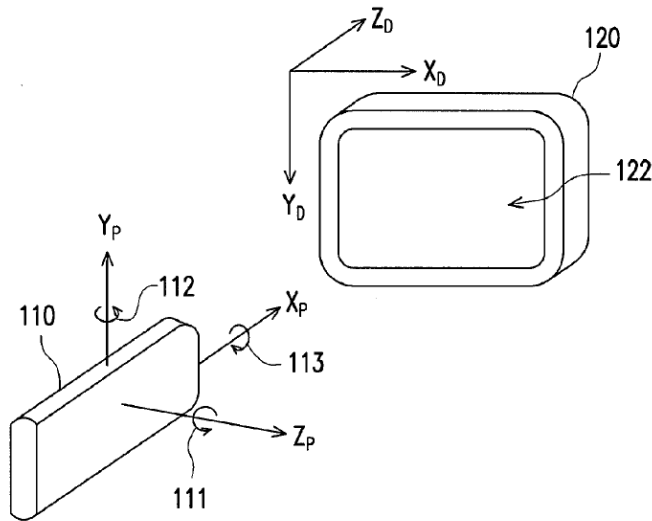


FIG. 2 (RELATED ART)

45. The intersection point of a set of coordinate axes is commonly called the “origin” of the reference frame, hence my interpretation that the spatial reference frame (associated with the 3D pointing device) has an **origin in the device**.

46. Not only is the origin in the device, it is always at the same point in the device, even if the device is rotated or translated. This is because the X_P , Y_P , and Z_P coordinate axes are always fixed with respect to the device. In other words, the coordinate frame does not move *relative to the device*, even if the device itself moves with respect to the display or the Earth.

47. FIG. 2 of the '438 patent shows that the X_P , Y_P , and Z_P coordinates do not move with respect to the device when the device is rotated. More specifically, rotating the device counterclockwise by 90 degrees with respect to the screen 120 (i.e., around the X_P axis) causes the X_P , Y_P , and Z_P coordinate axes to rotate

counterclockwise by 90 degrees. This means that the X_P , Y_P , and Z_P coordinate axes do not rotate *with respect to the device*. Similarly, it is my opinion that the X_P , Y_P , and Z_P coordinate axes do not translate *with respect to the device*. In other words, the X_P , Y_P , and Z_P coordinate axes are always fixed with respect to the device, hence my interpretation that the spatial reference frame has axes that “are always fixed with respect to the device.”

48. By definition, the coordinate axes are also fixed with each other. This means that their intersection point—the origin—is fixed with respect to the coordinate axes. And because the coordinate axes are fixed with respect to the device, the origin is also fixed with respect to the device. This means that the origin is always in the same point in the device.

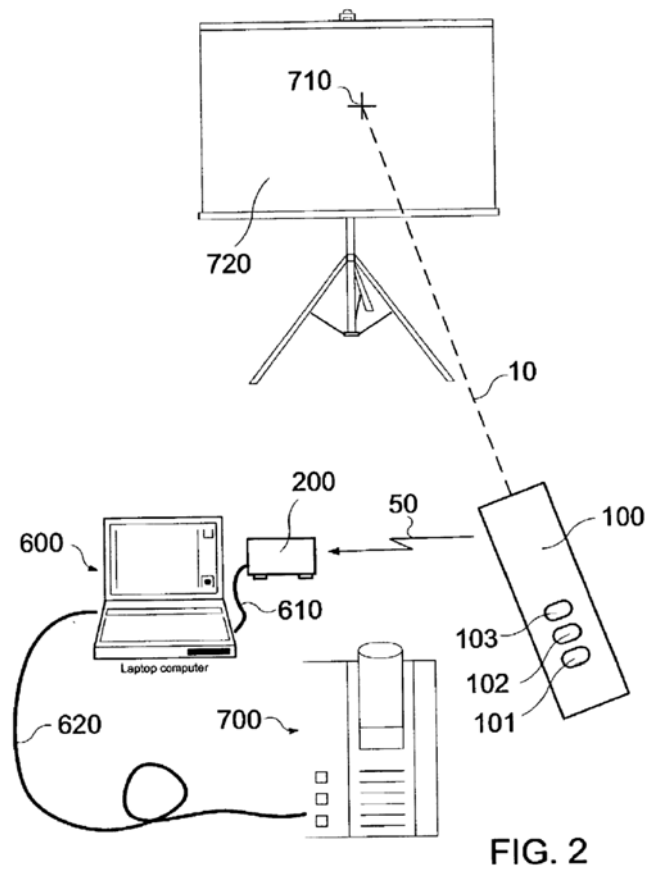
49. For these reasons, I interpret “spatial pointer reference frame” to mean “a reference frame associated with the 3D pointing device, which always has its origin at the same point in the device and in which the axes are always fixed with respect to the device.”

X. THE PRIOR ART (ZHANG AND BACHMANN)

A. Overview of Zhang

50. Zhang discloses a “handheld pointing device” for controlling a “computer pointing control system”. (Ex. 1005, Abstract). Zhang’s FIG. 2 (reproduced below) shows an example of this computer pointing control system with

a handheld pointing device 100:



51. Zhang’s device 100 includes several sensors that detect the device’s orientation. Zhang explains:

“A universal pointing control system for televisions and computer displays is disclosed. The system is comprised of a remote handheld device, a display control unit and a command delivery unit. The remote handheld device includes **a set of orientation sensors that detect the device’s current orientation.**” (Ex. 1005, ¶0008)(Emphasis added).

52. The set of orientation sensors “detects the device’s current orientation and generate[s] the pointing direction signal.” (Ex. 1005, ¶0021). This pointing

direction signal indicates which way the device 100 is pointing. (Ex. 1005, ¶0021).

53. Zhang discloses that these different orientation sensors include a two-axis magnetic field sensor and a two-axis accelerometer. Zhang's FIG. 3 (reproduced immediately below) shows an example two-axis magnetic field sensor 120 and an example two-axis accelerometer 130 on a circuit board 160 inside the device 100 along with a microcontroller 110:

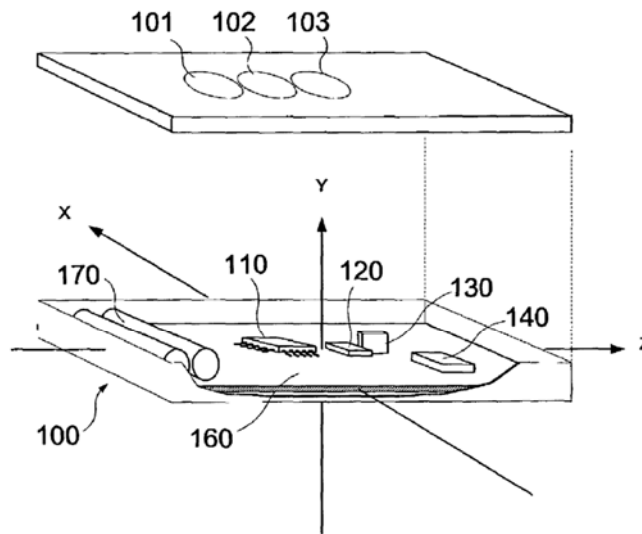


FIG. 3

54. FIG. 3 shows that the magnetic field sensor 120 and the accelerometer sensor 130 are mounted at right angles with respect to each other. (Ex. 1005, ¶0026). This is so that one sensor (here, the magnetic field sensor 120) detects the device's yaw (azimuth) angle and the other sensor (here, the accelerometer sensor 130) detects the device's pitch (inclination) angle. (Ex. 1005, ¶0025).

55. Zhang's FIG. 4a shows the magnetic field sensor 120, the yaw angle ϕ , and the orientation of the Earth's magnetic field 25. The magnetic field sensor 120 "detects the device's orientation relative to the direction of the earth's magnetic field 25." (Ex. 1005, ¶0026). Similarly, Zhang's FIG. 4b shows the accelerometer sensor 130 and the pitch angle ϵ . The accelerometer sensor 130 "sense[s] the device's heading change in the y-z plane." (Ex. 1005, ¶0027). Zhang's FIGS. 4a and 4b are reproduced immediately below:

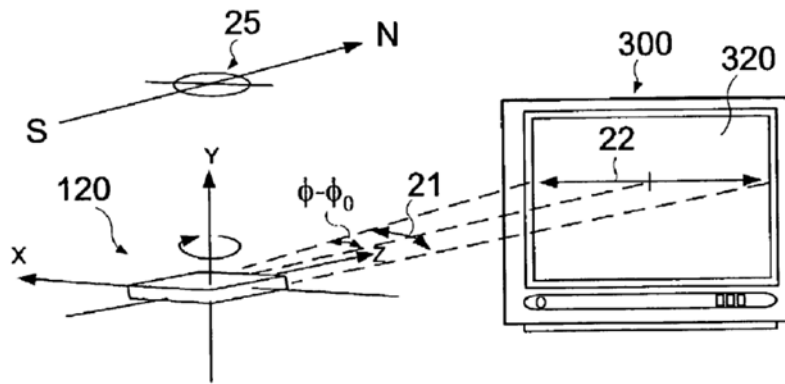


FIG. 4a

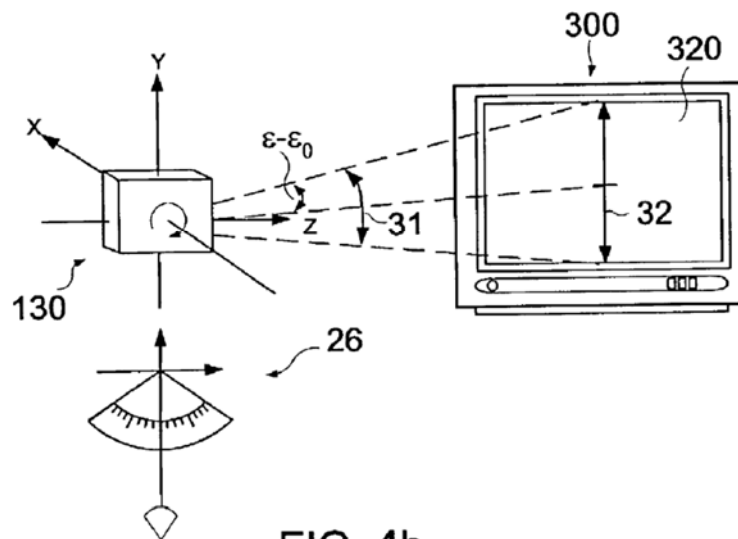


FIG. 4b

56. The microcontroller 110 determines the device's orientation from the signals generated by the magnetic field sensor 120 and the accelerometer sensor 130. (Ex. 1005, ¶¶0025 and 0029). These signals are filtered, amplified, digitized, and processed using the components shown in the system diagram in Zhang's FIG. 5, an annotated version of which is reproduced immediately below. (Ex. 1005, ¶0029).

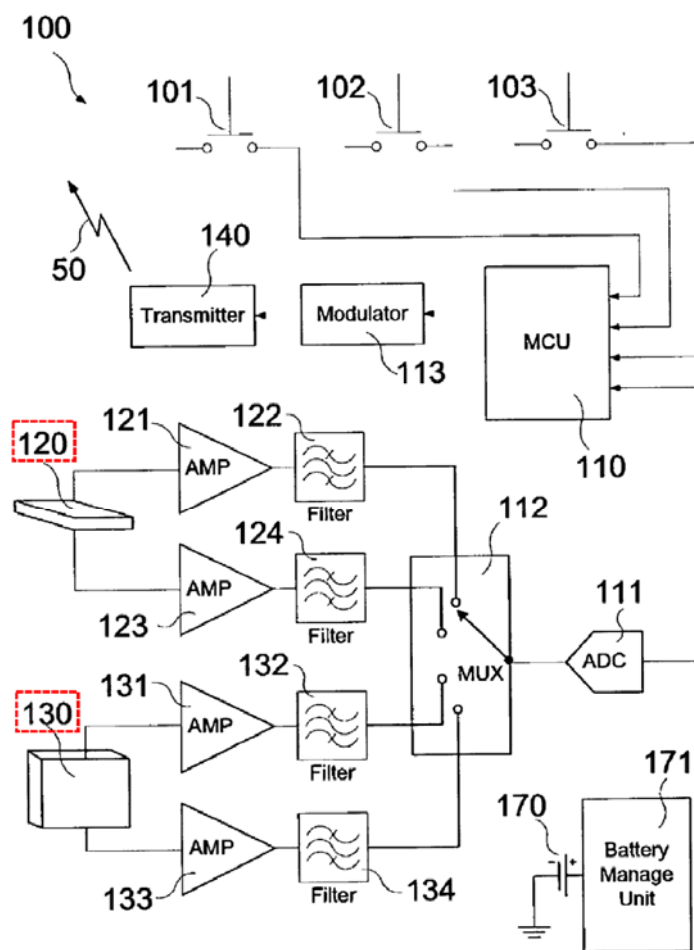


FIG. 5

57. The magnetic field sensor 120 and accelerometer sensor 130 appear in the lower left of FIG. 5 (numerals 120 and 130 are shown by red-dashed boxes).

These sensors output signals to amplifiers 121, 123, 131, and 133, which amplify the sensor outputs. (Ex. 1005, ¶0029). Low-pass filters 122, 124, 132, and 134 remove high-frequency components from the amplified signals, which are multiplexed by a multiplexer 112 and digitized by an analog-to-digital converter (ADC) 111 before being processed by the microcontroller (MCU) 110. (Ex. 1005, ¶0029). The MCU 110 determines the device's orientation, including its azimuth and inclination angles, from the digitized signals. (Ex. 1005, ¶0029). Zhang's system uses the device's orientation to "determine[] the new coordinates of the pointer on the screen." (Ex. 1005, ¶0024, 0030).

58. Although Zhang's FIGS. 3–5 show a handheld pointing device 110 with a four-axis sensor module (i.e., the two-axis magnetic field sensor 120 and the two-axis accelerometer sensor 130), Zhang states that other versions of the handheld pointing device can have more and different sensors. Referring to FIG. 3, for example, Zhang states that the handheld pointing device could include a roll sensor: "Additional sensors (not show[n] in the picture) could be used to detect [the] device's roll angle which may provide an additional dimension of control." (Ex. 1005, ¶0025). In addition, Zhang states that the handheld pointing device could include gyro sensors (angular velocity sensors):

"The orientation sensors' mechanisms are shown in FIGS. 4a and 4b. The orientation sensor demonstrated in FIG. 4a is a magnetic field sensor, whereas the one in FIG. 4b is an

accelerometer sensor. **However, the orientation detection may not be limited to these types of sensors. Other sensors, for example, a gyro sensor, can also be used** in the pointing control system.” (Ex. 1005, ¶¶0026; *see also id.* at ¶¶0006 and claim 2)(Emphasis added)

59. Moreover, Zhang contemplates that the handheld pointing device can include different types of multi-axis sensors operating in concert. Indeed, the handheld pointing device in Zhang’s FIGS. 1 and 3–5 includes both a two-axis magnetic field sensor and a two-axis accelerometer sensor. (Ex. 1005, ¶¶0025–0027). And Zhang says the handheld pointing device in Zhang’s FIGS. 1 and 3–5 can also include a roll sensor or a gyro. (Ex. 1005, ¶¶0025 and 0026). These statements indicate that Zhang’s handheld pointing device could accommodate a wide variety of sensors.

60. Zhang also contemplates digital sensors. If the sensors output digital signals instead of analog signals, it is possible to omit the ADC: “Some variations of the orientation sensor convert the analog signal internally to a digital or time period-based signal. In those cases, the can be directly sampled by the microcontroller without an ADC chip.” (Ex. 1005, ¶¶0026).

B. Overview of Bachmann

61. Bachmann discloses determining the orientation of a rigid body, such as a hand-held device, with magnetometers, accelerometers, and angular rate

detectors. (Ex. 1004, Abstract, 7:34-40, 13:43-48). The combination of magnetometers, accelerometers, and angular rate detectors is called a MARG sensor:

“In another sensor embodiment, the **magnetometers** and **accelerometers** are supplemented with **angular rate detectors** configured to detect the angular velocity of the sensor (comprising so-called Magnetic, Angular Rate, Gravity (MARG) sensors). **Each MARG sensor contains angular rate detectors, accelerometers, and magnetometers.**” (Ex. 1004, 7:34-40)(Emphasis added).

This combination of magnetometers, accelerometers, and angular rate detectors is the same combination suggested in ¶0025 of Zhang.

62. At least one of Bachmann’s MARG sensors is a nine-axis sensor because it includes three three-axis sensors: “a three-axis accelerometer (h_1, h_2, h_3) 31, a three-axis magnetometer (b_1, b_2, b_3) 32, and a three-axis angular rate sensor.” (Ex. 1004, 10:10-14). Miniaturized nine-axis MARG sensors were commercially available as of at least 2001 (Bachmann’s priority date)—about ten years before the earliest possible priority date of the ’438 patent. (Ex. 1004, 14:37-59).

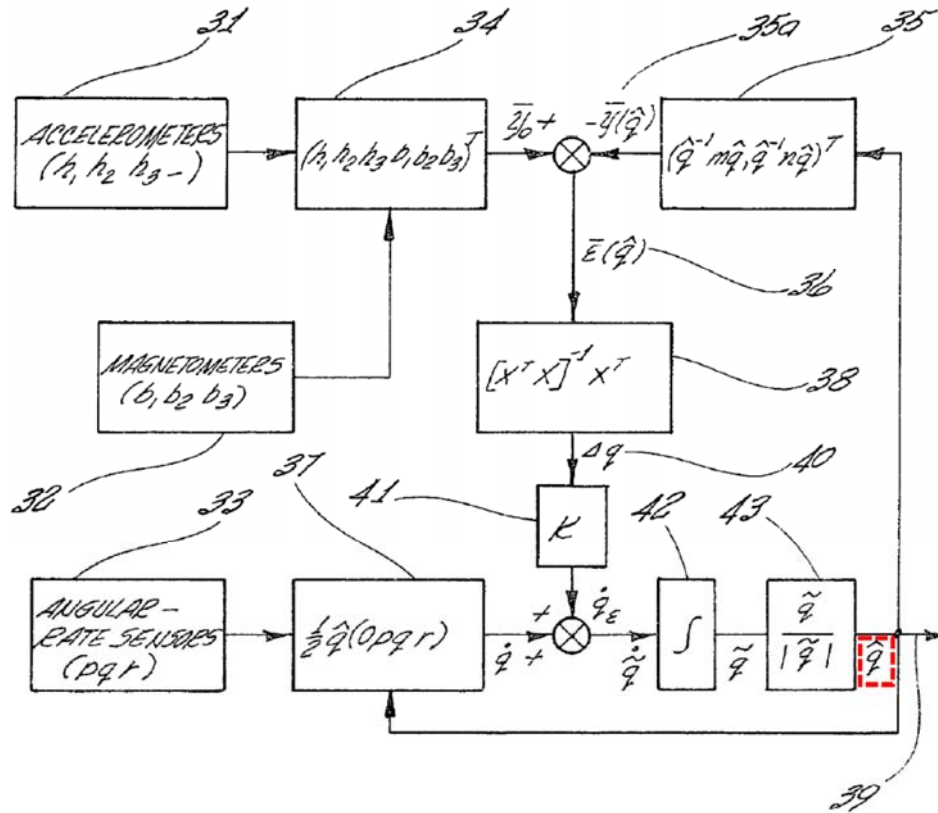
63. Bachmann uses a filter to generate a representation of the object’s orientation. This representation is a quaternion generated from the outputs of the accelerometer, magnetometer, and angular rate sensor in the MARG sensor. Bachmann states:

“[T]he filter inputs are from a **three-axis accelerometer** ($h_1 h_2$

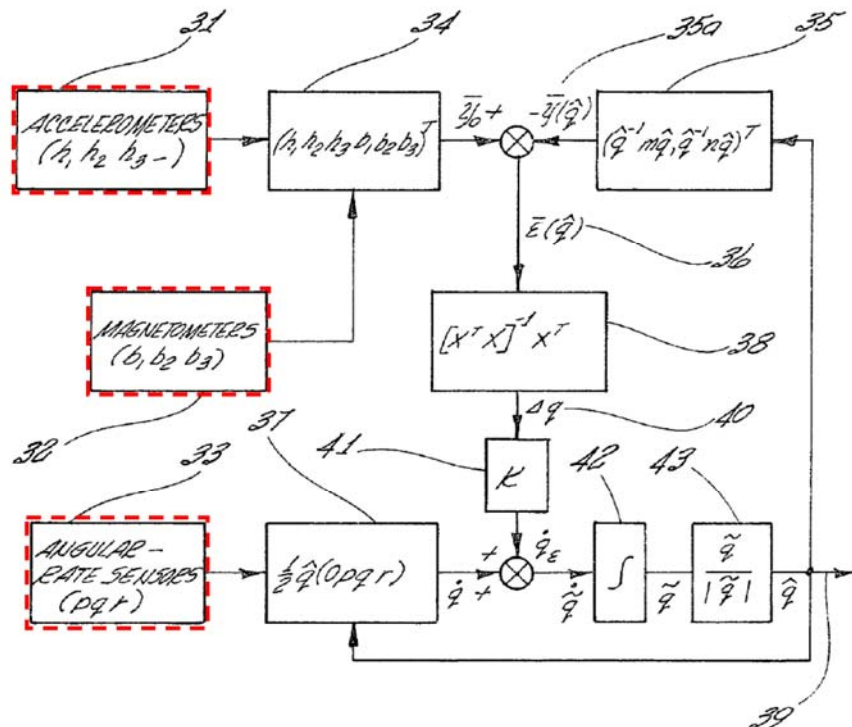
h_3) 31, a **three-axis magnetometer** (b_1 b_2 b_3) 32, and a **three-axis angular rate sensor** (p , q , r) 33. Its output is a quaternion representation of the **orientation of the tracked object** $\hat{q}$ 39.”
(Ex. 1004, 10:10-14)(Emphasis added).

64. In other words, Bachmann uses the nine outputs from a three-axis accelerometer, three-axis magnetometer, and three-axis angular rate sensor to calculate the orientation of a hand-held device or other object.

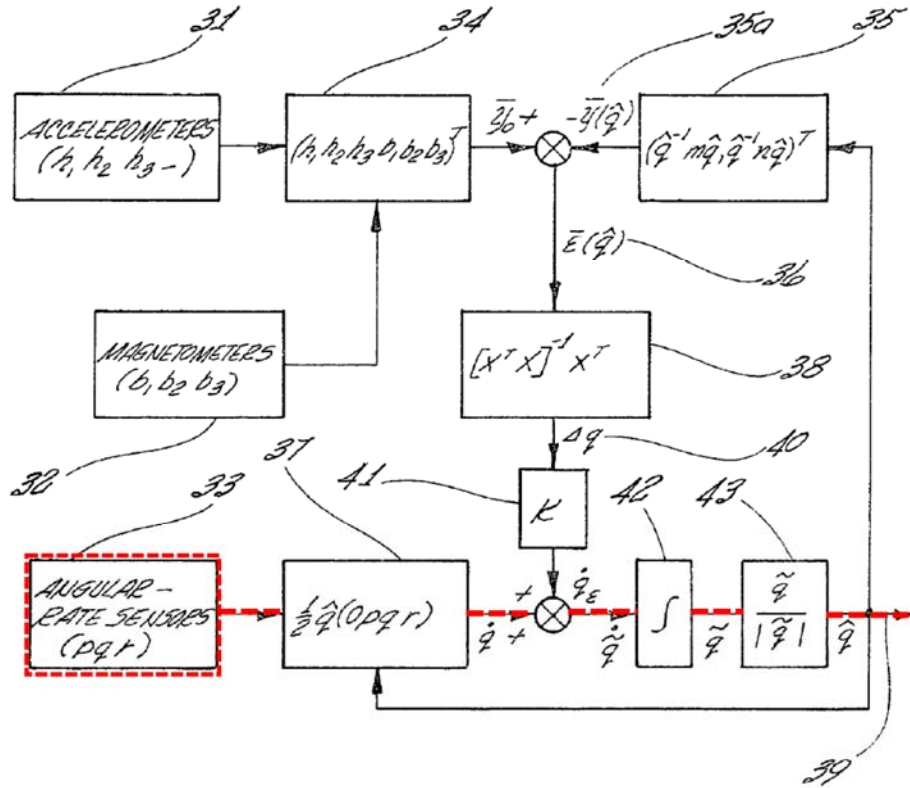
65. Bachmann’s FIG. 3 shows the filtering process used to calculate the device’s orientation from the nine sensor inputs. As I explain in the following sections, Bachmann’s filtering process corresponds to the calculations in claim 1 of the ’438 patent. The output of this filtering process is an estimated orientation quaternion, $\hat{q}$. (Ex. 1004, 7:59-61, 10:10-14). This output is outlined in a red-dashed box in the annotated version of Bachmann’s FIG. 3 reproduced immediately below:



66. The inputs to Bachmann's filtering process are the outputs from the accelerometers 31, magnetometers 32, and angular-rate sensors 33 on the left side of FIG. 3. (Ex. 1004, 10:10-14). These sensors are shown boxed in red below:



67. The filtering process in Bachmann's FIG. 3 involves calculating a rate quaternion $\dot{q}$ based on angular rate information 37 from the angular rate sensor 33 and correcting it using a correction factor $\dot{q}_e$, which is based on signals from the accelerometer 31 and magnetometers 32. (Ex. 1004, 10:15-17, 10:38-42). The angular rate information 37 represents the angular rotation rates about three axes in the sensor coordinate frame (i.e., a reference frame centered on the hand-held device). (Ex. 1004, 10:10-30). It is used to calculate the orientation quaternion $\hat{q}$ as shown by the boxes along the red line in the following annotated version of FIG. 3:



68. An ideal angular rate sensor 33 would produce noiseless, unbiased angular rate information 37 that could be used to find a perfectly precise rate quaternion. (Ex. 1004, 10:19-30). In real life, however, the angular rate information 37 from an angular rate sensor 33 may be imprecise and can drift over time. (Ex. 1004, 10:36-38). Fortunately, data from the accelerometers 31 and magnetometers 32 can be used to reduce this imprecision. (Ex. 1004, 10:38-45).

69. Boxes 34, 35, 35a, 36, 38, and 41 in Bachmann's FIG. 3 show how the accelerometer and magnetometer measurements are used to generate a correction factor, $\dot{q}_e$, that is applied to the rate quaternion. (Ex. 1004, 9:59-10:14). In box 34, the accelerometer and magnetometer measurements are combined to form a six-valued measurement vector $y_0 = [h_1 \ h_2 \ h_3 \ b_1 \ b_2 \ b_3]^T$, where h_1 , h_2 , and h_3 represent

acceleration along the accelerometer's X, Y and Z axes, respectively, and b_1 , b_2 , and b_3 represent magnetism measurements along the magnetometer's X, Y and Z axes, respectively. (Ex. 1004, 8:37-8:50). In boxes 35 and 35a, a predicted six-valued measurement vector $\bar{y}(\hat{q})$ is translated from a reference frame fixed with respect to the Earth to the sensors' reference frame. (Ex. 1004, 8:61-9:8). This predicted measurement vector is based on the angular rate information 37 from the angular rate sensor 33. (Ex. 1004, FIG. 3). Comparing the predicted measurement vector $\bar{y}(\hat{q})$ to the actual measurement vector y_0 yields a six-valued error vector $\bar{\epsilon}(\hat{q})$, numbered 36 in FIG. 3. (Ex. 1004, 9:9-17, 17:12-22).

70. The six-valued error vector $\bar{\epsilon}(\hat{q})$ represents the difference between the actual and predicted accelerometer and magnetometer measurements. (Ex. 1004, 9:21-48). It is based on the orientation quaternion $\hat{q}$ generated from the angular rate sensor measurements as shown by the line in FIG. 3 connecting the orientation quaternion and box 35. (Ex. 1004, FIG. 3). The error vector $\bar{\epsilon}(\hat{q})$ is corrected using a Gauss-Newton iteration 38 to yield a full correction Δq_{full} 40. (Ex. 1004, 10:42-55). The full correction is scaled by a filter gain value k in box 41 to yield a correction factor $\dot{q}_\epsilon$ that minimizes the error vector $\bar{\epsilon}(\hat{q})$ —and hence the difference between the actual and predicted measurement vectors—when fed back through boxes 35, 35a, and 36 in FIG. 3. (Ex. 1004, 10:66-11:12).

71. Adding the rate quaternion $\dot{q}$ to the correction factor $\dot{q}_\epsilon$ yields a

corrected rate quaternion $\hat{\tilde{q}}$, which is integrated (box 42 in FIG. 3) and normalized (box 43) to yield the orientation quaternion at the output, $\hat{q}$. (Ex. 1004, 9:43-48). This compensates drift in the angular rate sensor that would otherwise corrupt the orientation output of the filter, $\hat{q}$. (Ex. 1004, 10:36-15).

XI. GROUND 1: CLAIMS 1 AND 3-5 WOULD HAVE BEEN OBVIOUS OVER ZHANG AND BACHMANN

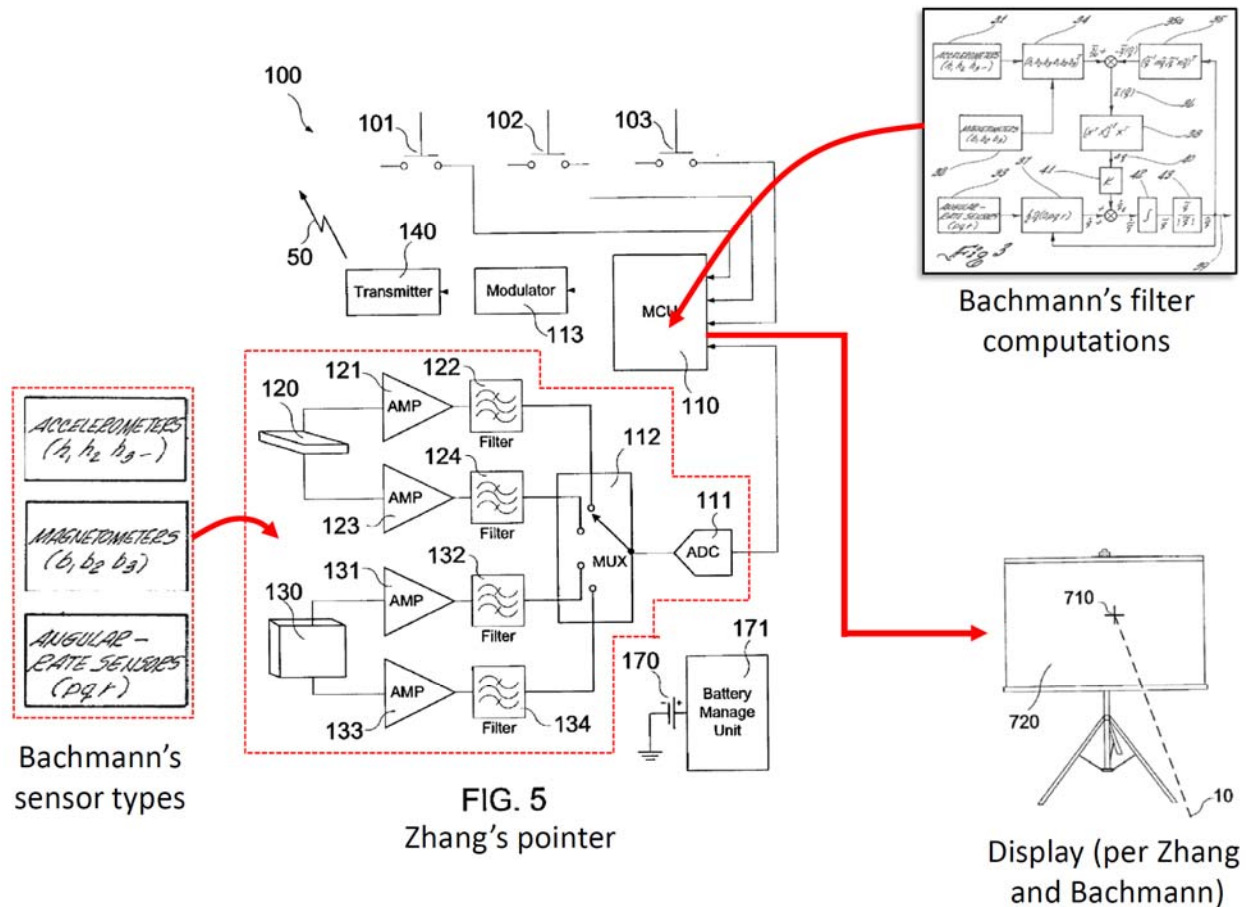
72. In my opinion, claims 1 and 3-5 would have been obvious over Zhang in view of Bachman.

A. Overview of the Combination

73. Independent claim 1 is directed to 3D pointing devices and methods for compensating rotations of a 3D pointing device. The combination of Zhang and Bachmann, broadly speaking, uses *Zhang's 3D pointing device* together with *Bachmann's extra sensors and method for compensating rotations*.

B. Combining Zhang and Bachmann

74. The proposed combination of Zhang and Bachmann is simple: use Bachmann's nine-axis sensor and filtering process to estimate the orientation of Zhang's 3D pointer. The orientation of Zhang's 3D pointer can be converted to the coordinate system of a display, as disclosed in both Zhang and Bachmann. (Ex. 1005, ¶0021; Ex. 1004, 14:20-29). The following figure shows how Zhang's 3D pointer can be modified to use Bachmann's sensors and filter processing:



C. Rationale for combining Zhang and Bachmann

75. In my opinion, it would have been obvious to a person of ordinary skill in the art during the relevant timeframe to use Zhang's 3D pointer with Bachmann's sensors and filter calculations as shown immediately above. As pointed out above in ¶59, Zhang says that the 3D pointer can include additional sensors, including angular rate sensors. (Ex. 1005, ¶¶0006, 0025, and 0026, claim 2). Including Bachmann's nine-axis sensor in Zhang's 3D pointer is therefore nothing more than following Zhang's suggestions.

76. In addition, a person of ordinary skill would have understood that

adding Bachmann's nine-axis sensor to Zhang's 3D pointer would have improved Zhang's 3D pointer in at least two ways. First, Bachmann's nine-axis sensor would have allowed Zhang's 3D pointer to detect different modes of movement, including roll angle, thus providing the user with "an additional dimension of control." (Ex. 1005, ¶0025). In other words, the 3D pointer would be able to detect a wider variety of movements, enabling a wider variety of user inputs. Second, Bachmann's nine-axis sensor would have provided more measurements, increasing measurement precision through overdetermination (the amount information beyond that necessary to determine orientation), which in turn would have enabled better error control.

77. Furthermore, Bachmann's nine-axis sensors were well-known in the art in the relevant timeframe. Bachmann, which has a filing date of 2001 and issued in 2006, states that magnetic, angular rate and gravitational (acceleration) (MARG) sensors were already commercially available and could be integrated in a known fashion. Bachmann states:

"One example of a suitable sensor device is an analog MARG sensor. In one embodiment such a sensor measures 10.1x5.5x2.5 cm. The analog output of the sensor is connected to a breakout header via a thin VGA monitor cable. Output range is 0-5 vdc. The power requirement of the sensors is 12 vdc at approximately 50 milliamperes. The primary sensing components are a triaxial accelerometer (e.g. a Model No. CXL04M3 manufactured by Crossbow, Inc.), a 3-axis

magnetometer (e.g., Model No. HMC2003 from Honeywell), and three miniature angular rate detectors mounted in an orthogonal configuration (e.g., Tokin CG-16D series sensors available from Tokin American, Inc.). The individual components can be integrated using a single integrated circuit board with the accelerometers mounted separately. Rate sensor output voltage is amplified by a factor of five and filtered to attenuate rate sensor oscillator noise. **Such MARG sensors can be obtained from McKinney Technology of Prunedale, Calif. Software or hardware biasing can be used to successfully integrate the signal from the angular rate detectors with the rest of the system.”** (Ex. 1004, 14:37-57)(Emphasis added).

78. Bachmann further states that its sensors and filter processing can be used in hand-held devices (like Zhang’s):

“By mounting a plurality of sensors on a body, the posture of the body can be determined and tracked. **Sensors constructed in accordance with the principles of the present invention can be used to track motion and orientation of simple rigid bodies** as long as they are made of non-magnetic materials. Examples include, but are not limited to **hand-held devices**, swords, pistols, or simulated weapons.” (Ex. 1004, 13:42-48)(Emphasis added).

79. In my opinion, a person of ordinary skill in the would have been motivated and able to use nine-axis MARG sensors like those in Bachmann to

improve Zhang's hand-held pointer, as suggested by Zhang and Bachmann.

80. Using Bachmann's quaternion-based filter processing (as illustrated, for example, in Fig. 3 of Bachmann) would have been a logical next step, in part because the quaternion-based filter processing was intended for use with nine-axis MARG sensors. (Ex. 1004, 7:18-45). In addition, a person of ordinary skill in the art would have understood that Bachmann's quaternion-based filter processing is computationally more efficient than processing that uses spatial (e.g., Euler) angle calculations. (Ex. 1004, 5:33-7:31). Bachmann's quaternion-based techniques also avoid singularities that might otherwise occur at certain sensor orientations. (Ex. 1004, 5:33-7:31). Bachmann explains:

“The principles of the present invention use magnetometer and accelerometer input subject to filtering to track body posture. In one implementation, Euler angles and their related coordinate transform matrices are used to calculate body orientation. Although computationally intensive, embodiments of the present invention can use Euler angle calculations to track body orientation. Additionally, angular velocity information can be used to correct for time lag errors. However, other embodiments of the present invention present a **particularly advantageous approach** for achieving body tracking using quaternion mathematics. **Such embodiments eliminate the Euler angle singularity problem, and reduce the computational complexity of the invention.**” (Ex. 1004,

7:4-17)(Emphasis added).

81. Thus, a person of ordinary skill would have been motivated to use Bachmann's quaternion-based filter processing with a nine-axis MARG sensor because (1) that was its intended use and (2) it performed better than the alternatives.

82. In my opinion, the combination of Zhang and Bachmann presented here is nothing more than the combination of known elements to achieve an expected improvement. Zhang's 3D pointer device has a housing, sensors, and a processor that estimates the device's orientation used the sensor outputs. Bachmann's device does the same thing, but with different sensors and different processing. Bachmann's sensors were available on the commercial market as of 2001, and Bachmann's calculations were known at least as early as 2004.¹ Bachmann's functional blocks (sensors and calculations) could have been substituted for the same functional blocks in Zhang using only ordinary skill as discussed below. The results would have been the *expected* improvement described in Bachmann.

83. Finally, it would have been obvious to translate the orientation estimated by Bachmann's filtering process into coordinates that can be used on a display. After all, this is what Zhang's system is used for—translating a 3D pointer's

¹ Bachmann is a divisional of U.S. Application No. 10/020,719, which was filed in 2001 and issued in 2004 as U.S. Pat. No. 6,820,025.

motion into cursor movements on a display. For example, Zhang states:

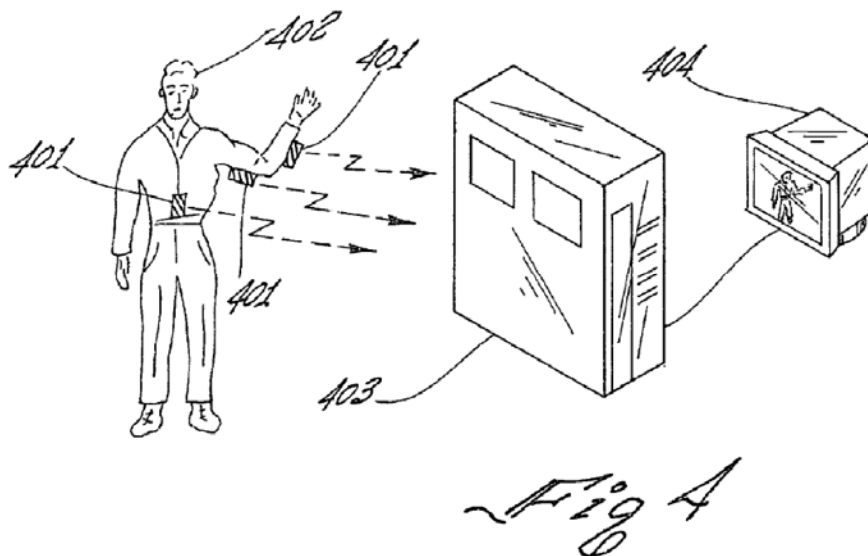
“The CPU in the display control unit interprets the direction information, sends the pointer move command to the computer’s peripheral port, and instructs the computer to move the pointer 710 on screen to the aimed place. This is analogous to moving the pointer by moving a regular computer mouse device, except that the moving information is in absolute coordinates instead of relative steps.” (Ex. 1005, ¶0024).

84. Zhang’s system instructs the computer to move the pointer by translating the device orientation from a device-centered reference frame to a reference frame fixed with respect to a display. Zhang explains:

“The CPU compares the **device’s azimuth and inclination angle data with the reference angles**, which are sampled and stored in the memory module 270 during the calibration procedure. The difference angles calculated are **translated into screen coordinates** and the target device is instructed to move the pointer to the new location.” (Ex. 1005, ¶0030)(Emphasis added).

85. Bachmann likewise discloses that its orientation output can be used with a display: “The system can further include a display for displaying the position and orientation of the body with respect to a synthetic environment.” (Ex. 1004, 4:26-28). This synthetic environment has a reference frame fixed with respect to the

display so that the pointer can be shown on the display, as shown in Bachmann's FIG. 4, reproduced below:



86. FIG. 4 shows sensors 401 on a person's arm and torso track the person's movement, allowing a display screen 404 to show an image of the person in display screen coordinates. (Ex. 1004, 13:64-14:29). For the display screen 404 to show the image correctly, the sensors' orientations must be translated from the sensors' frames of reference to the display's frame of reference.

D. Ability to Implement and Reasonable Expectation of Success

87. A person of skill in the art in the relevant timeframe could have implemented the proposed combination of Zhang and Bachmann with a reasonable expectation of success. As discussed above, nine-axis MARG sensors were widely available on the commercial market. And a person of ordinary skill would have been able to integrate these sensors into Zhang's 3D pointing device using standard

amplifiers, filters, samplers, and analog-to-digital converters, adjusting as necessary.

88. Similarly, Bachmann's filter processing could have been executed by programming a commercially available, off-the-shelf microcontroller or other processor using only ordinary skill. Both Zhang and Bachmann teach implementing orientation calculations on computer chips, including Zhang's MCU 110 (Ex. 1005, ¶10029) or Bachmann's CPU 403 (Ex. 1004, 13:64-14:29). In the relevant timeframe, microprocessors and microcontrollers with sufficient power to implement Bachmann's filter would have been readily available. Indeed, Bachmann shows that these components and programming skills were available about a decade before the relevant time frame.²

89. Similarly, a person of ordinary skill in the art would have expected success translating Bachmann's orientation from the sensor frame of reference into a display's frame of reference.

90. The '438 patent itself indicates that this component integration and programming was well within the level of ordinary skill in the art. I say this because the '438 patent does not say anything about any difficulties in constructing circuits for conditioning the sensor or programming the microcontroller to estimate the

² Bachmann's non-provisional priority date is October 30, 2001, about 9 years earlier than the earliest claimed priority date of the '438 patent.

orientation. In fact, the '438 patent does not explain how to implement sensor output conditioning circuits or program the microcontroller. This suggests that the inventors of the '438 patent considered this level of detail unnecessary given the relatively high level of ordinary skill in the art.

91. A person of ordinary skill therefore would have been able to implement the combination of Zhang and Bachmann with a reasonable expectation of success.

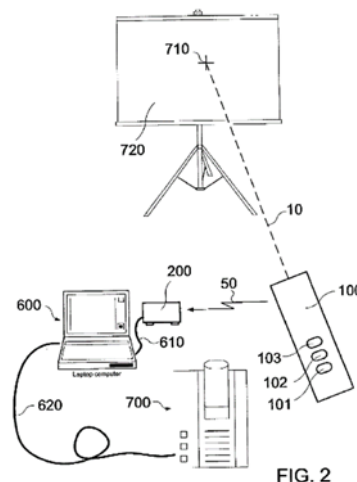
E. Claim Mapping

92. I map the elements of claims 1 and 3-5 to the combination of Zhang and Bachmann in the following paragraphs. Relevant claim language appears in bold-italic font with the mapping in the text following each claim element. I added lettering to each element of claim 1 (e.g., [1b]) for clarity. The claim mapping section supplements the discussion immediately above, and the two should be read together.

1. Claim 1

“1[a]. A three-dimensional (3D) pointing device subject to movements and rotations in dynamic environments, comprising:”

93. Zhang discloses a **3D pointing device**. (Ex. 1005, Title, Abstract)(¶50, *above*). Zhang’s FIG. 2 (reproduced at right) shows an example 3D pointing device 100.



94. Zhang states:

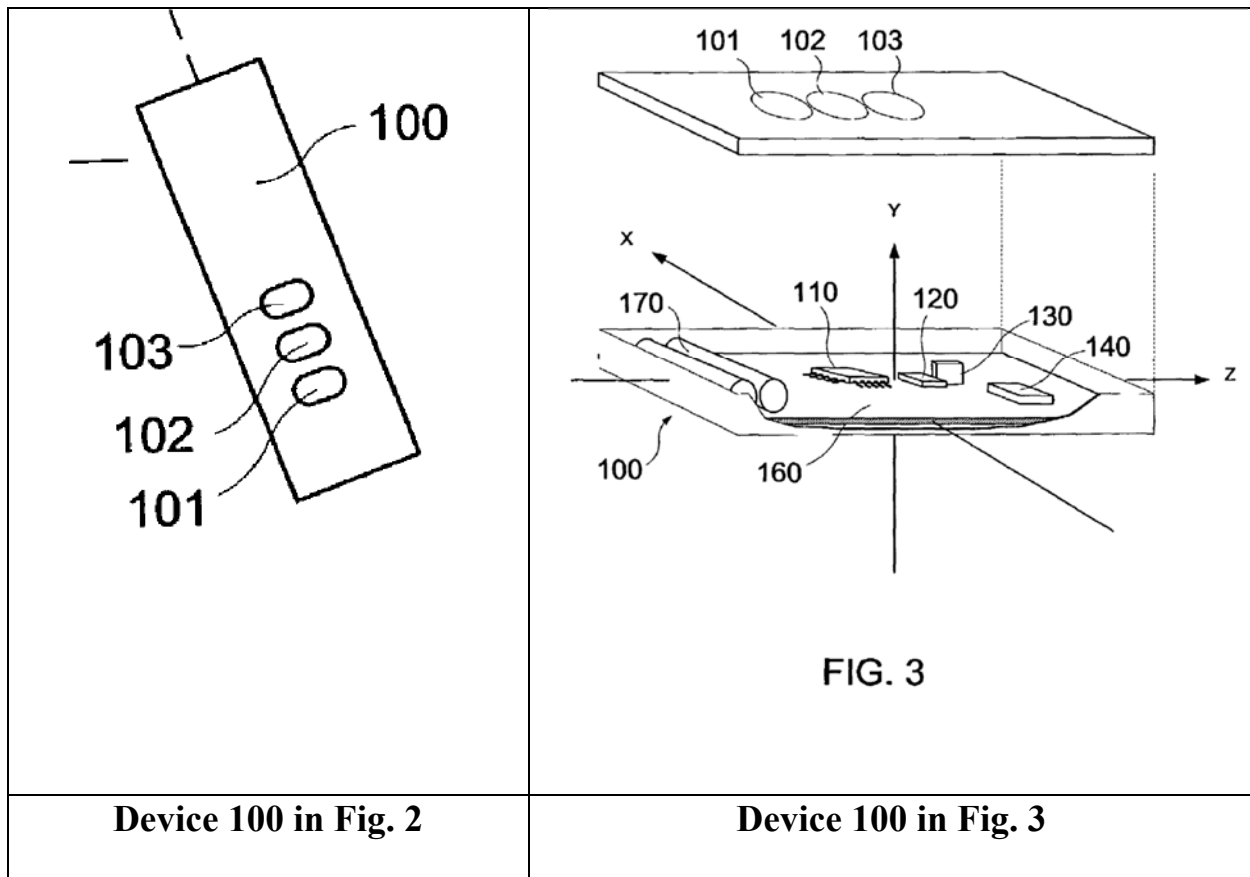
“The object of the present invention is to provide a low-cost, practical, **universal pointing device** to control home entertainment systems and computer systems using spatial orientation sensor technologies.” (Ex. 1005, ¶0007).

95. Zhang’s pointer is a “**3D pointing device**” because it can be moved in 3D: e.g., forward and backward, left and right, and up and down. As discussed above, it would have been obvious to use Zhang’s 3D pointing device with a three-axis rotation sensor, a three-axis accelerometer, and a three-axis magnetometer. This combination would have been motivated by the expected improvements in determining the 3D pointing device’s orientation.

96. Zhang’s 3D pointing device is **subject to movements and rotations in dynamic environments**. (Ex. 1005, ¶0026-0027). For example, Zhang discloses that a user can rotate Zhang’s 3D pointing device and move it horizontally and vertically. (*Id.*). And Zhang’s figures show that the 3D pointing device is not tethered or constrained, so a user could move it or rotate it in any direction.

“[1b] a housing associated with said movements and rotations of the 3D pointing device in a spatial pointer reference frame;”

97. Zhang’s FIGS. 1–3 show that the 3D pointing device 100 has a **housing**. Zhang’s FIGS. 2 and 3 are reproduced side-by-side below:



98. Each figure shows the housing as the external surface of the device 100, complete with buttons 101–103. FIG. 3 shows an exploded view of the device 100: “FIG. 3 exposes the components inside of the handheld pointing device.” (Ex. 1005, ¶¶0025 and 0012). In FIG. 3, the housing has been disassembled into an upper panel (not numbered, but comprising buttons 101, 102 and 103) and a lower container (also not numbered). (Ex. 1005, ¶¶0025). The lower container forms a recess that holds

the printed circuit board 160. (Ex. 1005, ¶0025). A person of skill would have readily understood that the upper panel and lower container are assembled to form the housing because they are shown as contiguous in FIGS. 1 and 2 and because the description of FIG. 3 states that other components are “inside of the handheld pointing device”. (Ex. 1005, ¶0025).

99. The housing is **associated with movements and rotations of the 3D pointing device in a spatial pointer reference frame**, because the user holds the 3D pointing device by its housing. (The 3D pointing device is handheld, after all. (Ex. 1005, ¶0025).) The user moves and rotates the 3D pointing device by its housing to issue commands to a computer or display device. The spatial pointer reference frame moves with the 3D pointing device. In fact, the spatial pointer reference frame’s origin is within the assembled housing as shown by the intersection of the X, Y and Z axes in Zhang’s FIG. 3.

“[1c] a printed circuit board (PCB) enclosed by the housing;”

100. Zhang discloses a **printed circuit board (PCB) enclosed by the housing**. Zhang’s FIG. 3 (reproduced above) shows that the housing encloses a PCB 160. (Ex. 1005, ¶0025). Zhang states:

“FIG. 3 exposes the components **inside of the handheld pointing device**. On the top face of the device are buttons 101, 102, and 103 for collecting user selection activities. A set of

orientation sensors 120 and 130 mounted on the **print circuit board 160** detect device's orientation changes. Note that the sensors are mounted orthogonally to each other.” (Ex. 1005, ¶0025)(Emphasis added).

101. A person of ordinary skill would have understood Zhang's print circuit board 160 to meet a plain-language interpretation of the “printed circuit board (PCB)” in claim 1.

“[1d] a six-axis motion sensor module attached to the PCB, comprising a rotation sensor for detecting and generating a first signal set comprising angular velocities Ω_x , Ω_y , Ω_z associated with said movements and rotations of the 3D pointing device in the spatial pointer reference frame,”

102. Zhang discloses a **motion-sensor module attached to the PCB** in the form of orientation sensors 120 and 140:

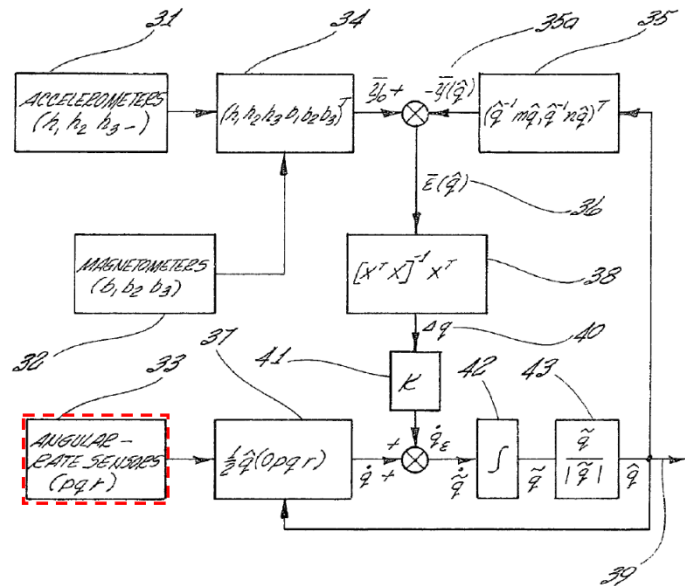
“A set of orientation sensors 120 and 130 mounted on the print circuit board 160 detect device's orientation changes. Note that the sensors are mounted orthogonally to each other.” (Ex. 1005, ¶0025).

103. Although Zhang's rotation sensor 120 detects angular velocities along the X, Y and Z axes shown in FIG. 3 and generates corresponding signals, Zhang does not explicitly disclose that the orientation sensors detect movement along six axes. Instead, the combination of Zhang and Bachmann uses Bachmann's three-axis angular rate sensor **to detect and generate a first signal set**. (Ex. 1004, 10:10-14).

Bachmann's three-axis angular rate sensor **detects and generates signals comprising angular velocities (angular rates) $\Omega_x, \Omega_y, \Omega_z$** . (Ex. 1004, 10:10-14).

Bachmann's three-axis accelerometer detects and generates axial accelerations A_x, A_y, A_z . And Bachmann's three-axis magnetometer measures magnetism b_1, b_2 and b_3 . (Ex. 1004, 10:10-14). Thus, the combination includes a six-axis sensor module with two sets of X, Y and Z axes: one set for Bachmann's three-axis rotation sensor and one set for Bachmann's three-axis accelerometer.

104. Bachmann's angular rate sensors generate signals (p, q, r) that represent the **angular velocities $\Omega_x, \Omega_y, \Omega_z$** . (Ex. 1004, 10:10-14). Specifically, Bachmann uses angular velocity (rate) detectors 33 to **generate a first set**



of signals (p, q, r) corresponding to the roll, pitch, and yaw of the 3D pointing device. These signals are shown in box 33 of Bachmann's Fig. 3 (outlined in a red-dashed box, at right).

105. The roll, pitch, and yaw signals are **associated with said movements and rotations of the 3D pointing device in the spatial pointer reference frame.** They are measured with respect to the angular rate sensor's frame of reference.

Because the angular rate sensor is mounted to the 3D pointing device, its frame of reference (including its origin and axes) is fixed with respect to the 3D pointing device. If the angular rate sensor is mounted properly, its reference frame is the same as **the spatial reference frame of the pointer**. (Improper mounting may introduce a static offset with respect to the spatial reference frame of the pointer.) As a result, if the 3D pointing device moves with respect to the Earth, the angular rate sensors move as well in the exact same way. This means that the angular velocities sensed by the angular rate sensors are “measured in the sensor reference frame.” (Ex. 1004, 10:17-30). Put differently, Bachmann’s “sensor reference frame” is the same as the “spatial pointer reference frame” in the ’438 patent.

106. The **spatial reference frame of the pointer** can be represented using **three axes**, such as Cartesian axes centered at a point on or within the 3D pointing device. Bachmann acknowledges this by calling the angular rate sensor a “**three-axis angular rate sensor**”. (Ex. 1004, 10:12)(Emphasis added). The axes are the three **coordinate axes of the spatial reference frame of the pointer**, e.g., as shown in Zhang’s FIG. 3.

107. It would have been **obvious to mount Bachmann’s sensors on Zhang’s PCB**. This is exactly what PCBs are for—to hold components like Bachmann’s sensors. After all, Zhang’s sensors are mounted on the printed circuit board 160. (Ex. 1005, ¶0025). As shown in Fig. 3 of Zhang, the PCB 160 takes up

the entire inner area of pointing device, and thus Bachmann's sensors would obviously need to be placed on the PCB 160. They are mounted orthogonally with respect to each other, so they sense motion along different axes, providing a model for mounting Bachmann's sensors, which also sense motion along orthogonal axes (X, Y, and Z). Given Zhang's disclosure of mounting sensors orthogonally on a PCB (Ex. 1005, ¶0025), the similar mounting of Bachmann's sensors, and the fact that components were commonly mounted to printed circuit boards in the relevant time frame, a person of ordinary skill would have found it obvious to mount **Bachmann's sensors on Zhang's PCB.**

“[1e] an accelerometer for detecting and generating a second signal set comprising axial accelerations A_x , A_y , A_z associated with said movements and rotations of the 3D pointing device in the spatial pointer reference frame;”

108. The combination of Zhang and Bachmann has a three-axis accelerometer that **detects and generates a second signal set comprising axial accelerations A_x , A_y , A_z .** (Ex. 1004, 10:10-14). Bachmann explains as follows:

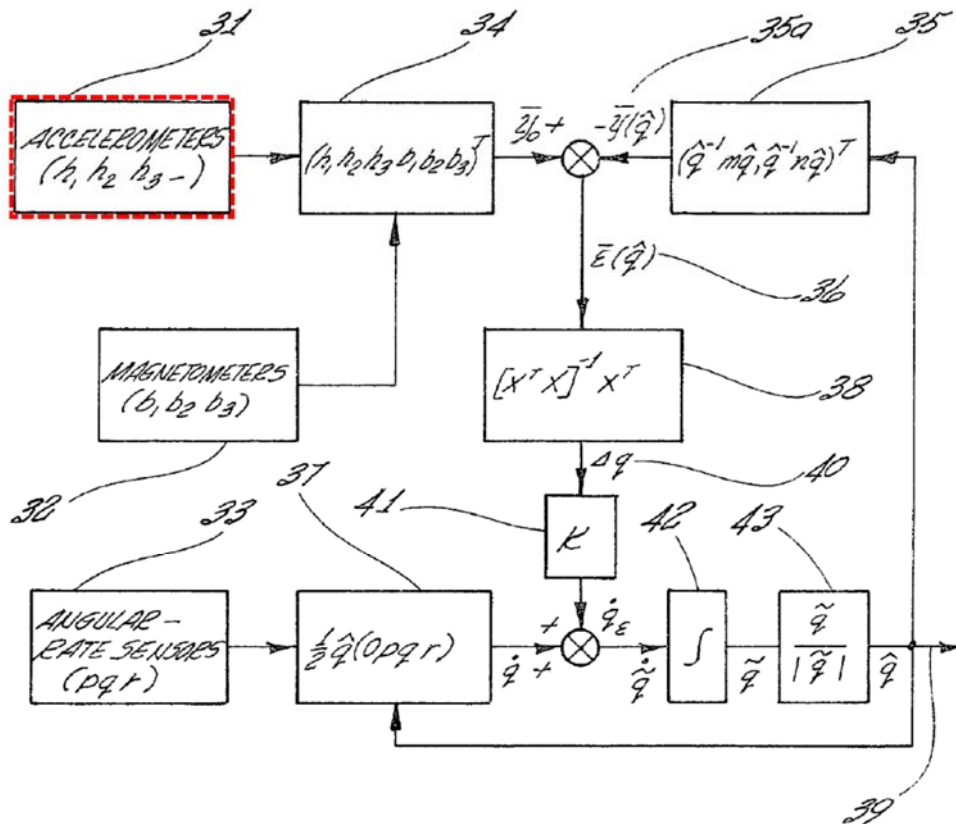
“In one embodiment, a **three-axis accelerometer** can be used to measure total acceleration (forced linear acceleration and gravitational reaction force) $\vec{a}_{measured}$ as over a fixed time period.” (Ex. 1004, 8:12-16)(Emphasis added)

109. Bachmann gives the measured acceleration as the sum of the forced

linear acceleration and the gravitational reaction force as:

$$\vec{a}_{measured} = \vec{a} + \vec{g} \quad (1)$$

110. The measured acceleration is low-pass filtered to remove fast accelerations, yielding a vector (h_1, h_2, h_3) , which shown in FIG. 3 of Bachmann. (Ex. 1004, 8:13-42). Figure 3 is reproduced below with a red box around the three-axis accelerometer and the filtered accelerometer vector (h_1, h_2, h_3) :



111. The measured accelerometer signals are **associated with said movements and rotations of the 3D pointing device in the spatial pointer reference frame**, because (as shown in the block quote above) they include a forced linear acceleration term. (Ex. 1004, 8:12-16). This forced linear acceleration term

represents accelerations that the **3D pointing device** experiences as it is moved and rotated by the user. The measured accelerometer signals also include a gravitational reaction term. These are also associated with movements and rotations, as rotation of the device will alter the linear acceleration along each axis, A_x , A_y , A_z .

112. Because the accelerometer is mounted to the 3D pointing device, it measures these accelerations **in the spatial pointer reference frame**, just like the angular rate sensor and magnetometer. (See ¶¶104 and 105, *above*). If this were not the case, then Bachmann would not have to transform the device's orientation from an Earth-fixed frame to the spatial pointer reference frame before combining it with the accelerometer measurements. (Ex. 1004, Equation (7)). That is, Bachmann's Equation (7) transforms the vector m , which represents gravity in flat-Earth coordinates, to an estimated measured acceleration vector, which is the spatial pointer frame of reference, so that it can be subtracted from the measured acceleration vector. (Ex. 1004, 8:63-67). This transformation is required because the filtered accelerometer output h is in the **spatial pointer reference frame** required by the claim. (Ex. 1001, 5:60-64, 6:10-13).

“[1f] and a processing and transmitting module, comprising a data transmitting unit electrically connected to the six-axis motion sensor module for transmitting said first and second signal sets thereof and a computing processor for receiving and calculating said first and second signal sets from the data transmitting unit,”

113. The combination of Zhang and Bachmann includes Zhang's **processing**

and transmitting module. This processing and transmitting module is shown in Zhang's FIG. 5, which is reproduced below with a red-dashed boundary drawn around the components in the processing and transmitting module. (Ex. 1005, ¶0029).

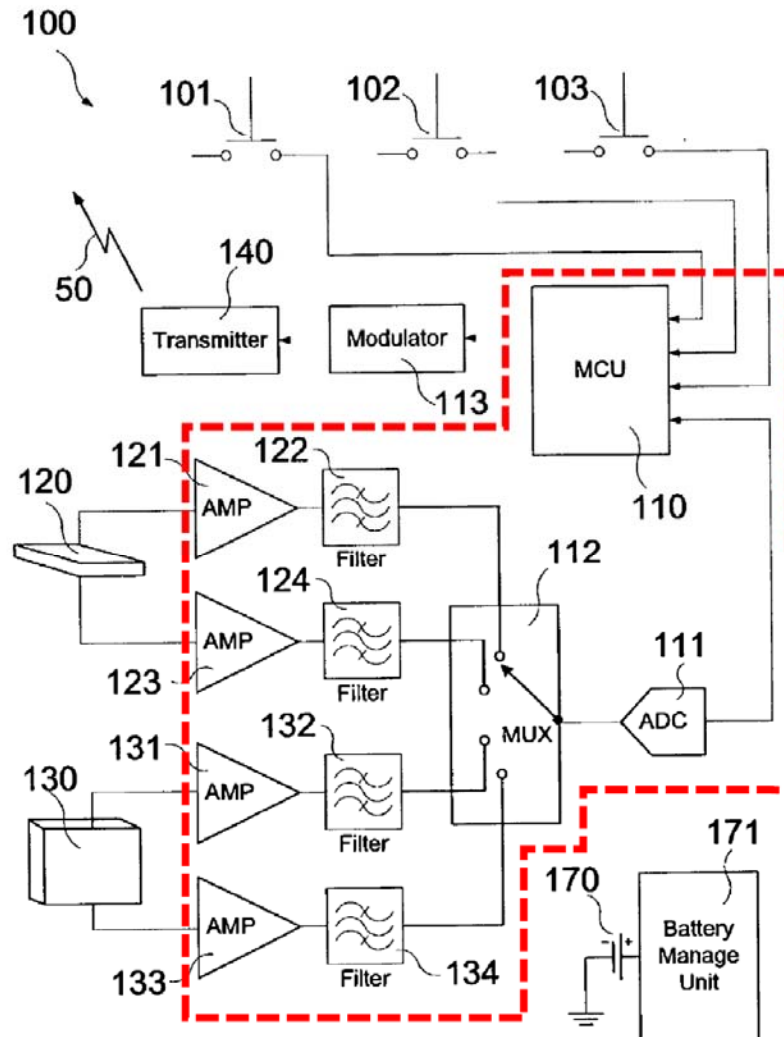


FIG. 5

114. The processing and transmitting module includes **a data transmitting unit electrically connected to the six-axis motion sensor module for transmitting said first and second signal sets thereof.** The data transmitting unit is shown in

the blue-dashed outline in Fig. 5, reproduced again below (Ex. 1005, ¶0029).

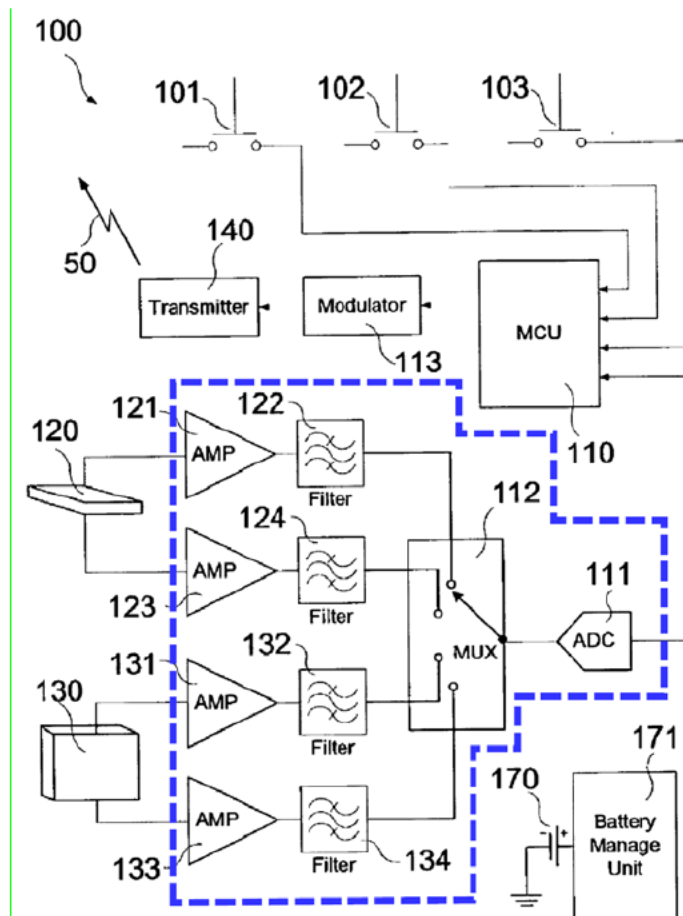


FIG. 5

115. FIG. 5 shows that the data transmitting unit includes amplifiers 121, 123, 131, and 133; filters 122, 124, 132, and 134; a multiplexer 112; and an analog-to-digital converter (ADC) 111. (Ex. 1005, ¶0029). The solid lines connecting the sensors 120 and 130 and the amplifiers 121, 123, 131, and 133 indicate electrical connections. In the combination, the six-motion sensor module would take the place of the angular rate sensor 120 and accelerometer 130 in Zhang's FIG. 5, so the data transmitting unit would be **electrically connected to the six-axis motion sensor**

module. (Ex. 1005, ¶0029). In operation, the data transmitting unit would condition and **transmit said first and second signal sets thereof** to the microcontroller (MCU) 110 via these electrical connections. (Ex. 1005, ¶0029).

116. If the six-motion sensor module has six outputs (one for each axis), the data transmitting unit could easily be modified to include an additional pair of amplifiers and filters for the extra outputs, and the 1×4 multiplexer could be replaced with a 1×6 multiplexer. These would be straightforward modifications given the relatively high level of skill in the art. Similarly, if Bachmann's entire nine-axis sensor module replaced the sensors 120 and 130, the data transmitting unit could be modified accordingly (e.g., to have nine input paths).

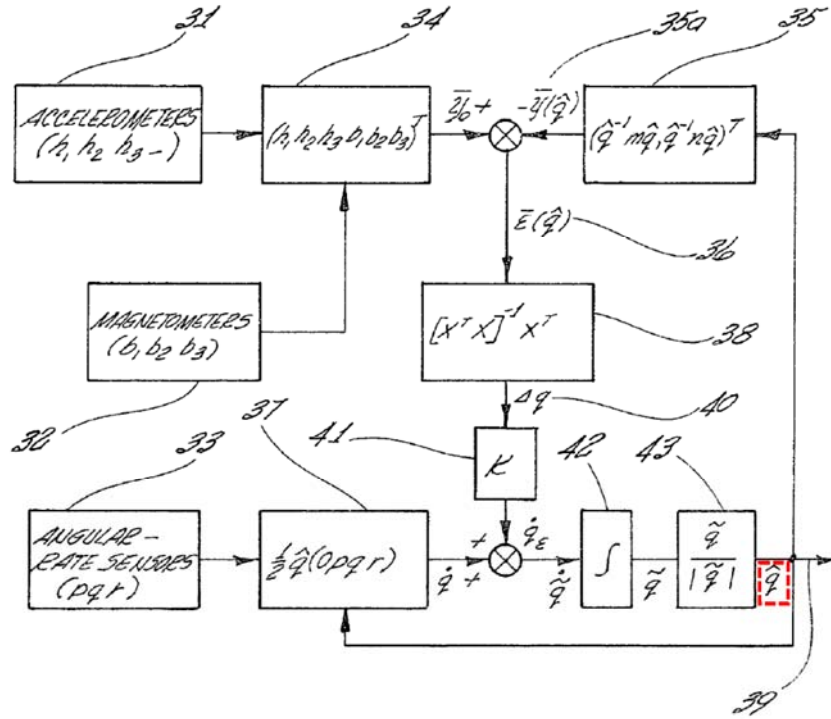
117. The microcontroller (MCU) 110 in FIG. 5 provides the **computing processor** of claim 1. Alternatively, the processor 403 in Bachmann's FIG. 4 could provide the computing processor of claim 1.

118. In either case, the MCU 110 or processor 403 **receives and calculates said first and second signal sets from the data transmitting unit.** (Ex. 1005, ¶0029). More specifically, the MCU 110 or processor 403 receives the sensor measurements and uses them to calculate the 3D pointing device's orientation. (Ex. 1005, ¶0029). In the combination, the MCU 110 or processor 403 would generate the orientation using Bachmann's quaternion-based filter processing.

“[1g] communicating with the six-axis motion sensor module to calculate a resulting deviation comprising resultant angles in said spatial pointer reference frame”

119. As discussed immediately above, in the combination of Zhang and Bachmann, the Zhang’s MCU 110 would **communicate with the six-axis motion sensor module**, by obtaining data from the sensors. (Ex. 1005, ¶0025).

120. In the combination, the processor (e.g. MCU 110 of Zhang or the processor 403 of Bachmann) also **calculates a resulting deviation comprising resultant angles in said spatial pointer reference frame**. Specifically, as described above in paragraphs 65-71, Bachmann discloses a filtering process that yields an “orientation of the tracked object.” (Ex. 1004, 10:10-14). Bachmann expresses the orientation output as an orientation quaternion, $\hat{q}$, but it can be expressed in other forms (e.g., a set of Euler angles) as well. Bachmann’s FIG. 3 shows the filtering process with the orientation output $\hat{q}$ at lower-right. An annotated version of FIG. 3 is reproduced below with a red-dashed box around it:



121. As mentioned above in paragraphs 28-31, a quaternion represents orientation (rotation angles) using a four-valued vector. It can be used to translate an orientation measurement from one reference frame to another. Here, the orientation output $\hat{q}$ is a quaternion that represents a rotation from the sensor-based coordinate system (the **spatial reference frame** of claim 1) to a flat-Earth coordinate system. (Ex. 1001, 5:60-64, 6:10-13). In fact, Bachmann's Equation (7) uses the orientation output $\hat{q}$ to transform a magnetism vector m from the sensor frame to the earth-fixed frame. (Ex. 1001, 5:60-64, 6:10-13). This transformation is expressed as $(h = \hat{q}^{-1} m \hat{q})$, where h is in the sensor frame and m is in the earth-fixed frame. (Rotations in quaternion mathematics are expressed as conjugations, where h is equal to the conjugation of m by $\hat{q}$ in Equation (7).) Equation (7) shows that $\hat{q}$

represents a rotation between the sensor frame and the earth-fixed frame.

122. The combination renders obvious **calculating a resulting deviation comprising resultant angles** in two ways. First, the orientation output $\hat{q}$ is a **deviation** because it represents the same information as the standard Euler angles, as discussed above in ¶¶28-31. Second, it would have been obvious to calculate **a resultant deviation including a plurality of deviation angles** from the orientation output $\hat{q}$ of Bachmann. It would have been obvious to convert the orientation output from a quaternion representation to Euler angles because Euler angles are conventional. Bachmann expressly states that:

“A **conventional** way of describing the orientation of a rigid body uses ‘**Euler angles**’ to describe the orientation of a rigid body in three dimensions. Euler angles describe the orientation of a rigid body using three rotations about specified axes.”

(Ex. 1004, 5:50-55)(Emphasis added).

123. Converting the orientation output quaternion, $\hat{q}$, into the “conventional” form of Euler angles (roll, pitch and yaw) would have made the underlying orientation information easier to interpret by a human user. The equations for such a transformation were widely known in the art.

124. Such a transformation would also have been obvious because Zhang uses Euler angles. Specifically, Zhang uses the rotation sensor 120 to determine yaw and pitch and expressly suggests determining the roll angle:

“The sensor 120 detects the device’s **yaw** (azimuth) angle and sensor 130 detects device’s **pitch** (inclination) angle.

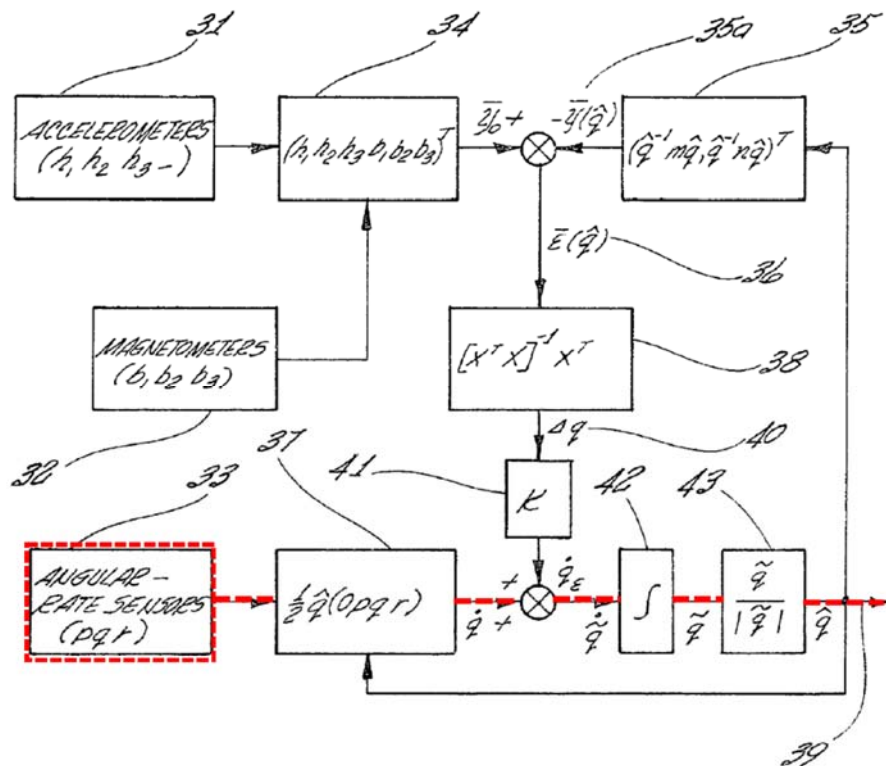
Additional sensors (not show in the picture) could be used to detect device’s **roll** angle which may provide an additional dimension of control. A microcontroller 110 provides computation power for calculating and encoding the orientation signal output from the orientation sensors.” (Ex. 1005, ¶0025)(Emphasis added).

125. Because Zhang’s output is in Euler angles, and because Bachmann outputs a quaternion equivalent to Euler angles, it would have been obvious to calculate Euler angles from Bachmann’s orientation output $\hat{q}$ to meet Zhang’s output requirements. Again, this would have the added benefit of making the orientation output easier to grasp by human users. Thus, these Euler angles represent **a resultant deviation including a plurality of deviation angles**.

126. As explained above, the orientation output quaternion $\hat{q}$ represents a rotation *from* the spatial pointer reference frame *to* the earth-fixed frame. It therefore represents angles between the spatial pointer reference frame and the earth-fixed frame. Converting the orientation output quaternion $\hat{q}$ into equivalent Euler angles makes that representation more explicit. And because the orientation output quaternion $\hat{q}$ goes from the spatial pointer reference frame to the earth-fixed frame, it can be converted into equivalent Euler angles that are **in said spatial pointer reference frame**.

“[1h] by utilizing a comparison to compare the first signal set with the second signal set whereby said resultant angles in the spatial pointer reference frame of the resulting deviation of the six-axis motion sensor module of the 3D pointing device are obtained under said dynamic environments, wherein the comparison utilized by the processing and transmitting module further comprises an update program to obtain an updated state based on a previous state associated with said first signal set and a measured state associated with said second signal set;”

127. Bachmann utilizes a comparison to compare the first signal set with the second signal set to obtain the resulting deviation. As explained above in paragraphs 63-71, Bachmann’s filter calculates the orientation output quaternion $\hat{q}$ by integrating and normalizing the angular rate quaternion $\dot{q}$. The red dashed line in the following annotated version of FIG. 3 shows the corresponding pathway:



128. The angular rate sensors 33 in FIG. 3 output measured angular rates of

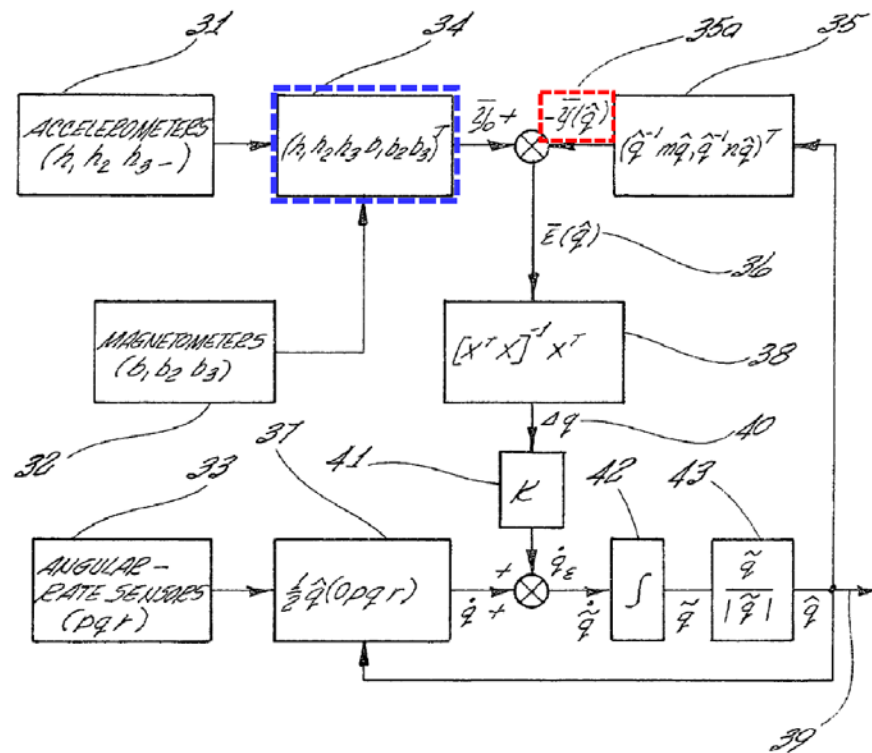
rotation (p, q, r) about X, Y and Z axes centered on the device. (Ex. 1004, 10:10-14). These rates (*i.e.* the first signal set) are converted, in box 31, to a rate quaternion $\dot{q}$. (Ex. 1004, 10:15-36). Adding a correction factor $\dot{q}_\varepsilon$ based on the accelerometer and magnetometer measurements to the rate quaternion $\dot{q}$ yields a corrected rate quaternion $\tilde{\dot{q}}$. (Ex. 1004, 10:38-65). Integrating the corrected rate quaternion $\tilde{\dot{q}}$ in box 42 and normalizing it in box 43 yields the orientation quaternion, $\hat{q}$. (Ex. 1004, 10:15-65).

129. The claimed **comparison** happens in forming the correction factor, $\dot{q}_\varepsilon$. As explained above, I take the term “comparison” to mean the performance of calculations based on sensor signals to obtain the orientation of the device with respect to the spatial pointing frame in a way that reduces the effect of sensor noise. (¶¶37-39, *above*). Bachmann performs these calculations in determining the correction factor $\dot{q}_\varepsilon$ in steps 34-41 of FIG. 3.

130. Bachmann forms a six-valued measurement vector (h_1 h_2 h_3 b_1 b_2 b_3), shown in box 34, from the *actual* accelerometer measurements³ and magnetometer measurements. (Ex. 1004, 10:10-14, 3:13-17, 8:47-51). This vector includes acceleration measurements along the X, Y and Z axes (*i.e.* the second signal set) and

³ The accelerometer measurements are low-pass filtered to remove high-frequency measurements representing sudden accelerations. (Ex. 1004, 8:12-20).

magnetic field measurements along the X, Y and Z axes. (*Id.*). This **measurement vector is compared to a predicted measurement** vector $\bar{y}(\hat{q})$ by subtracting the predicted measurement vector from the actual measurement vector. (Ex. 1004, 9:9-17, 17:12-22). In the following annotated version of Fig. 3, the actual measurement vector is in a blue-dashed box and the predicted measurement vector $\bar{y}(\hat{q})$ is in a red-dashed box: dashed box:



131. The difference between the predicted measurement vector and the actual measurement vector is a six-valued error vector $\bar{e}(\hat{q})$, numbered 36 in Fig. 3. (Ex. 1004, 9:9-17, 17:12-22). The subtraction that forms this vector is the claimed **comparison**, and happens in Fig. 3, above, directly between the blue and red-dashed

boxes, at the junction $\vec{y}_b + \vec{y}(\hat{q})$. The error vector $\vec{\varepsilon}(\hat{q})$ is used in boxes 38 and 41 to select a correction factor $\dot{q}_\varepsilon$ that minimizes $\vec{\varepsilon}(\hat{q})$. (Ex. 1004, 9:9-35). That is, adding correction factor $\dot{q}_\varepsilon$ to $\dot{q}$ minimizes the difference between the actual and predicted measurement vectors. (Ex. 1004, 9:9-35). Minimizing this difference compensates the orientation output of the filter, $\hat{q}$.

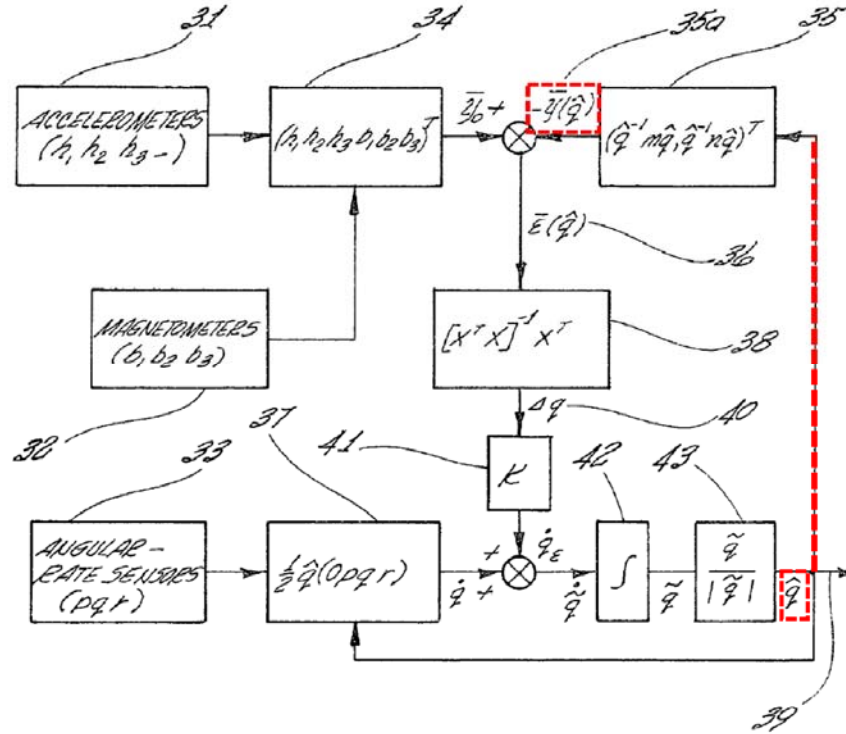
132. The process described above is a “**comparison**” as construed above (see ¶¶37-39, *above*) because it is used while **calculating and obtaining** the orientation output quaternion $\hat{q}$, which is in turn used to calculate **the deviation angles with respect to the spatial pointer frame**. (¶¶119–125, *above*). The calculation also **utilizes signals generated by motion sensors while reducing or eliminating noises associated with said motion sensors**. Calculating the correction factor $\dot{q}_\varepsilon$ involves signals from the magnetometer, accelerometer, and angular rate sensors to reduce error associated with the sensors. As Bachmann explains:

“[I]n normal operating environment, **the output 33 of angular rate detectors tends to drift over time**. Thus, rate detector data 33 can be used to determine orientation only for relatively short periods of time unless this **orientation is continuously corrected using ‘complementary’ data from additional sensors** (here, accelerometer 31 and magnetometer 32). Thus, as previously explained with respect to Eqns. (9) and (10) a

Gauss-Newton iteration 38 is performed **to correct a measured rate quaternion** (See FIG. 3, 36).” (Ex. 1004, 10:36-45)(Emphasis added)(*see also* Ex. 1004, 9:1-48).

133. In the combination, Bachmann’s filter processing would be performed by a processor (e.g., Zhang’s MCU 110 or Bachmann’s processor 403) and would thus constitute an **update program**. The processor and thus the update program are part of the **processing and transmitting module**, as explained above in paragraphs 113-118. The **updated state** is a new value of the orientation output quaternion $\hat{q}$. (Ex. 1004, 10:10-14).

134. The updated state is **based on a previous state** because the correction factor $\dot{q}_\varepsilon$ is calculated using the predicted measurement vector based on the most recent orientation output (*i.e.*, **the previous state**). This is shown by the red-dashed line added to Fig. 3, below:



135. Box 35 in Bachmann's Fig. 3 and Bachmann's Equation (7) show that the prior orientation output quaternion $\hat{q}$ is used to calculate predicted measurements $\bar{y}(\hat{q})$.

136. The **previous state** (i.e., the prior orientation output quaternion $\hat{q}$) is **associated with said first signal set**. The first signal set, as explained above in paragraphs 102-107, includes yaw, pitch, and roll signals (p, q, r) equivalent to the angular velocities $\Omega_x, \Omega_y, \Omega_z$. These first signals are used to calculate each output $\hat{q}$ (as explained above) and are therefore embedded in each orientation output quaternion $\hat{q}$.

137. The measured state is **associated with said second signal set**. The claimed **measured state** includes both actual and predicted measurement vectors.

The second signal set, as explained above in paragraphs 108-112, comprises axial accelerations A_x , A_y , A_z . The **measured state is associated with said second signal set** because the actual and predicted measurement vectors contain actual and predicted accelerations, respectively. Bachmann's Equation (8) shows that the composition of the *predicted* measurement vector, including the predicted accelerations (h_1 , h_2 , h_3). (Ex. 1004, 8:63-9:48). Bachmann's Equation (8) is reproduced below:

$$y(\hat{q}) = [h_1 \ h_2 \ h_3 \ b_1 \ b_2 \ b_3]^T \quad (8)$$

“[1i] wherein the measured state includes a measurement of said second signal set and a predicted measurement obtained based on the first signal set without using any derivatives of the first signal set.”

138. As explained immediately above, the measured state includes actual **measurements of the second signal set** (*i.e.* measured accelerations). The measured state also includes **predicted measurements of the second signal set** (*i.e.* predicted accelerations) in the vector $\bar{y}(\hat{q})$. (Ex. 1004, 8:63-9:48).

139. The predicted measurements of the second signal set are **obtained based on the first signal set without using any derivatives of the first signal set**. Specifically, the predicted measurement vector $\bar{y}(\hat{q})$ is obtained by transforming the magnetic field vector n and the gravity vector m from an Earth-fixed frame to the sensor frame using the prior orientation output quaternion $\hat{q}$. Bachmann's Equation

(7) shows this transformation:

$$h = \hat{q}^{-1} m \hat{q} \quad b = \hat{q}^{-1} n \hat{q} \quad (7)$$

140. (Ex. 1004, 8:52-67). Combining the resulting magnetic field and gravity vectors h and b yields the predicted measurement vector $\bar{y}(\hat{q})$. (Ex. 1004, 9:1-8).

141. Equation (7) and the predicted measurement vector are therefore **based on the first signal set** (i.e. angular velocities) because they are generated using the prior orientation output quaternion $\hat{q}$. The orientation output quaternion $\hat{q}$, in turn, is generated from the angular velocities (i.e. the first signal set) measured by the angular rate sensors 33. (§§127-137, *above*).

142. The **predicted measurements do not use any derivatives of the first signal set**. Specifically, Equation (7) does not use any derivatives of the first signal set (i.e. derivatives of angular velocities). The gravity and magnetism vectors represent linear accelerations and magnetic field orientations, not derivatives of the angular velocities. (Ex. 1004, 8:52-62). And the prior orientation output quaternion $\hat{q}$ is a normalized *integral* (the opposite of a derivative) of the corrected rate quaternion $\tilde{\hat{q}}$. (Ex. 1004, 10:15-65). The corrected rate quaternion $\tilde{\hat{q}}$ itself is formed by adding the rate quaternion $\dot{q}$ and the correction factor $\dot{q}_e$. (Ex. 1004, Fig. 3, 10:46-11:26). The rate quaternion $\dot{q}$ is simply a quaternion representation of the angular velocities, not a derivative of the angular velocities. (Ex. 1004, Fig. 3,

10:46-11:26). That is the rate quaternion $\dot{q}$ represents the angular velocities, not the angular accelerations.

143. The correction factor $\dot{q}_\varepsilon$ is formed using a matrix X , which uses derivatives. (Ex. 1004, 10:46-65). These derivatives are the partial derivatives of the acceleration and magnetism with respect to changes in orientation, not derivatives of the first signal set (angular acceleration). (Ex. 1004, 10:46-65). And the prior orientation output $\hat{q}$ is an integrated value of the rate quaternion (equivalent to the angular velocities), meaning that, if differentiated, it would simply yield the rate quaternion again, not a derivative of the angular velocities.

2. Claim 3

“3. The 3D pointing device of claim 1, wherein the PCB enclosed by the housing comprises at least one substrate having a first longitudinal side configured to be substantially parallel to a longitudinal surface of the housing.”

144. Per paragraphs 97-101 above, Zhang’s PCB is enclosed by the housing. And Zhang’s FIG. 3 shows that the PCB has a **substrate having a first longitudinal side configured to be substantially parallel to a longitudinal surface of the housing**. The following annotated version of FIG. 3 has red dashed lines along two edges of the PCB substrate that are parallel to the longitudinal surface of the housing (e.g., the upper housing panel with buttons 101–103). The red dashed line parallel to the z axis indicates a “longitudinal side” of the PCB substrate.

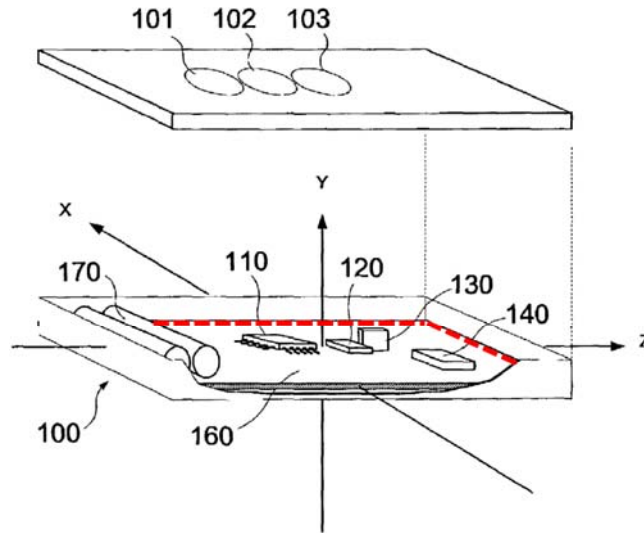


FIG. 3

145. In addition, a person of ordinary skill would have readily appreciated that fitting the PCB to the interior of the housing would have maximized the area of the PCB available for mounting components. And making the PCB substrate's longitudinal side(s) parallel to the housing's longitudinal side(s) would have made it easier to mount the sensors parallel and/or at right angles to the housing. By keeping the sensors parallel and/or at right angles to the housing, the sensors' frames of reference are aligned with the housing's surfaces, thus reducing the complexity of calibrating the sensors with respect to sensor reference frame.

3. Claim 4

“4. The 3D pointing device of claim 1, wherein the spatial pointer reference frame is a reference frame in three dimensions; and wherein said resultant angles of the resulting deviation includes yaw, pitch and roll angles about each of three orthogonal coordinate axes of the spatial pointer reference frame.”

146. Zhang and Bachmann each show the spatial pointer reference frame as a three-dimensional reference frame. For example, Zhang's FIG. 3 (reproduced below) shows a 3D pointing device in a reference frame with x, y, and z axes:

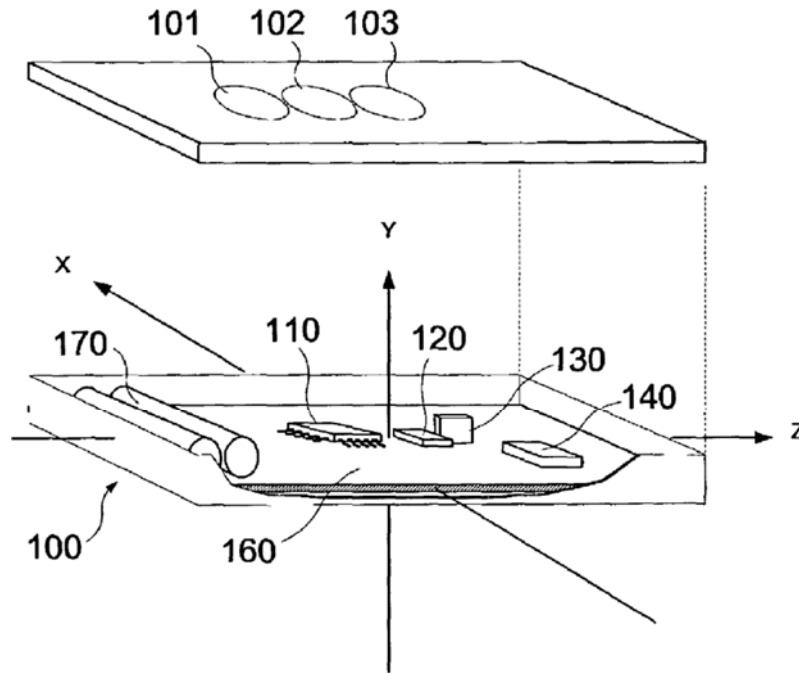
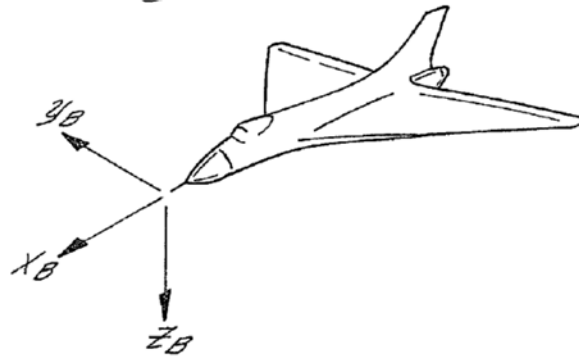


FIG. 3

147. Similarly, Bachmann's FIG. 2(b) (reproduced below) shows a tracked object (here, a plane, but alternatively a handheld device) in a "body coordinate system" equivalent to the claimed **spatial pointer reference frame**. (Ex. 1004, 5:49-6:10). This body coordinate system has three axes:



148. Bachmann states:

“[I]t is important to specify a **body coordinate system** which is attached to the body being tracked. FIG. 2(b) depicts such a system. This is also an X-Y-Z system with X pointing ‘out of the nose’ in a positive direction, Y out the right side, and Z down. The subscript ‘E’ designates earth reference coordinates (X_E , Y_E , Z_E) and the subscript ‘B’ designates body reference coordinates (X_B , Y_B , Z_B).” (Ex. 1004, 5:61-67)(Emphasis added).

149. Zhang discloses calculating the 3D pointing device’s yaw and pitch and suggests calculating the roll. (Ex. 1005, ¶0025). Likewise, Bachmann discloses a three-axis angular rate sensor that measures (p, q, r), which a person of ordinary skill in the art would readily understand represent yaw, pitch, and roll in the spatial reference frame. (Ex. 1004, 10:10-14)(Emphasis added). And as discussed above in paragraphs 119–125, the **resultant angles would be yaw, pitch and roll angles.**

4. Claim 5

“5. The 3D pointing device of claim 1, wherein the data transmitting unit of the processing and transmitting module is attached to the PCB enclosed by the housing and transmits said first and second signal of the six-axis motion sensor module to the computing processor via electronic connections on the PCB.”

150. It would have been obvious to **attach the data transmitting unit of the processing and transmitting module to the PCB and transmit the first and second signal sets to the processor via electronic connections on the PCB.** The amplifiers, filters, and multiplexer in the data transmitting unit can be implemented as electronic components that are suitable for mounting on a PCB. (See ¶¶113-118, *above*). Once mounted on the PCB, they could be connected via conductive traces on the PCB as readily understood by those of ordinary skill in the art.

151. Zhang’s FIG. 3 shows that the sensors and processor are mounted to the PCB 160. And as explained above in paragraphs 113-118, the data transmitting unit is electrically connected to the sensors and the processor (e.g., MCU 110). This leaves the PCB as the logical place to mount the data transmitting unit.

152. In addition, the PCB takes up the just about all of the device’s internal volume. (Ex. 1005, Fig. 3). This leaves little to no space to mount components anywhere but the PCB. This reinforces the logic of mounting the **data transmitting unit** to the PCB and using the PCB traces (electronic connections on the PCB) in a known fashion to form the desired connections between the sensors, data

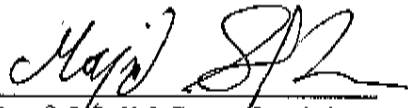
transmitting unit, and computing processor.

153. This would have been considered superior to adding a second PCB, for which the person of skill would have needed to find additional space and create longer board-to-board connections.

XII. OATH

154. This declaration and my opinions herein are made to the best of my knowledge and understanding, and based on the material available to me, at the time of signing this declaration. I declare under penalty of perjury under the laws of the United States of America that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true. I understand that willful false statements and the like are punishable by fine or imprisonment, or both (18 U.S.C. 1001) and may jeopardize the validity of the application or any patent issuing thereon.

Date: June 13, 2018

Signed: 

Prof. Majid Sarrafzadeh