THALES

Meta Platforms, Inc. v. Thales Visionix, Inc.

IPR2022-01304
IPR2022-01305
IPR2022-01308

December 7, 2023

Grounds and Challenged Claims

Welch & Horton: Sensor & estimation subsystems, sensor module, configuration data, etc.

Welch 2001 & Welch 1997	1304 Ground I	’632 patent, cls. 1-9, 11-22 & 24-29
	1305 Ground I	’632 patent, cls. 30-32, 44-45, 47-49, 51-53 & 59-61
	1308 Ground I	’253 patent, cls. 1-2
Welch 2001, Welch 1997 & Welch Thesis	1304 Ground II	’632 patent, cl. 23
	1305 Ground II	’632 patent, cl. 50
Horton	1304 Ground III	’632 patent, cls. 1-9, 11-19, 22-24 & 28-29
	1305 Ground IV	’632 patent, cls. 30-32, 47, 50-53 & 59-61
	1308 Ground IV	’253 patent, cls. 1-5
Horton & Welch 1997	1304 Ground IV	’632 patent, cls. 25-27

Grounds and Challenged Claims

Welch & Horton: Enumerating, selecting pairs, and expected utility

Welch 2001 & Welch 1997	1305 Ground I	’632 patent, cls. 33-36
	1308 Ground I	’253 patent, cls. 6-9
Horton	1304 Ground III	’632 patent, cls. 20-21
	1305 Ground IV	’632 patent, cl. 33
	1308 Ground IV	’253 patent, cls. 6-9
Horton & Welch 1997	1305 Ground V	’632 patent, cls. 34-36
	1308 Ground V	’253 patent, cls. 7-9

Other prior art references

Kramer & Chen	1304 Ground V	’632 patent, cls. 66-68
Kramer, Chen & Welch 2001	1304 Ground VI	’632 patent, cl. 69
Welch 2001, Welch 1997 & Harris	1305 Ground III	’632 patent, cls. 54-55 & 57-58
	1308 Ground II	’253 patent, cls. 3-5
Welch 2001, Welch 1997 & Reitmayr	1308 Ground III	’253 patent, cls. 3-4
Horton & Harris	1305 Ground VI	’632 patent, cls. 54-55 & 57-58

Patents and References

U.S. Patent Nos. 6,922,632 and 7,725,253

US006922632B2

(12) **United States Patent**
Foxlin

(10) **Patent No.: US 6,922,632 B2**
(45) **Date of Patent: Jul. 26, 2005**

(54) **TRACKING, AUTO-CALIBRATION, AND MAP-BUILDING SYSTEM**

(75) Inventor: **Eric Foxlin**, Arlington, MA (US)

(73) Assignee: **InterSense, Inc.**, Bedford, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/639,242**

(22) Filed: **Aug. 11, 2003**

(65) **Prior Publication Data**

US 2004/0073360 A1 Apr. 15, 2004

Related U.S. Application Data

(60) Provisional application No. 60/402,178, filed on Aug. 9, 2002.

(51) **Int. Cl.**^{7} **G01C 21/26**
(52) **U.S. Cl.** **701/207**; 701/36; 701/220; 701/300; 342/357.07
(58) **Field of Search** 701/33, 36, 207, 701/220, 222, 225, 300; 342/357.01, 357.07, 357.08, 424

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,176,837	B1		1/2001	Foxlin	600/595
6,288,785	B1	*	9/2001	Frantz et al.	356/614
6,611,141	B1	*	8/2003	Schulz et al.	324/226
2002/0052674	A1	*	5/2002	Chang et al.	700/300

FOREIGN PATENT DOCUMENTS

WO WO 01/80736 11/2001

OTHER PUBLICATIONS

"IEEE Standard for a Smart Transducer Interface for Sensors and Actuators—Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Format". Institute of Electrical and Electronics Engineers, Inc., New York, NY. Sep. 25, 1998.

Neal A. Carlson. "Federated Filter for Fault–Tolerant Integrated Navigation". NATO Advisory Group for Aerospace Research and Development (AGARD) book "Aerospace Navigation Systems", AGARD–AG–331, published Jun., 1995, pp. 265–280.

V. A. Tupysev. "A Generalized Approach to the Problem of Distributed Kalman Filtering". AIAA–98–4309, pp. 1097–1116, Aug., 1998.

Donald T. Knight. "Rapid Development of Tightly–Coupled GPS/INS Systems". IEEE, 1977.

Gudrun Klinker et al. "Distributed User Tracking Concepts for Augmented Reality Applications". IEEE, pp. 37–44, 2000.

* cited by examiner

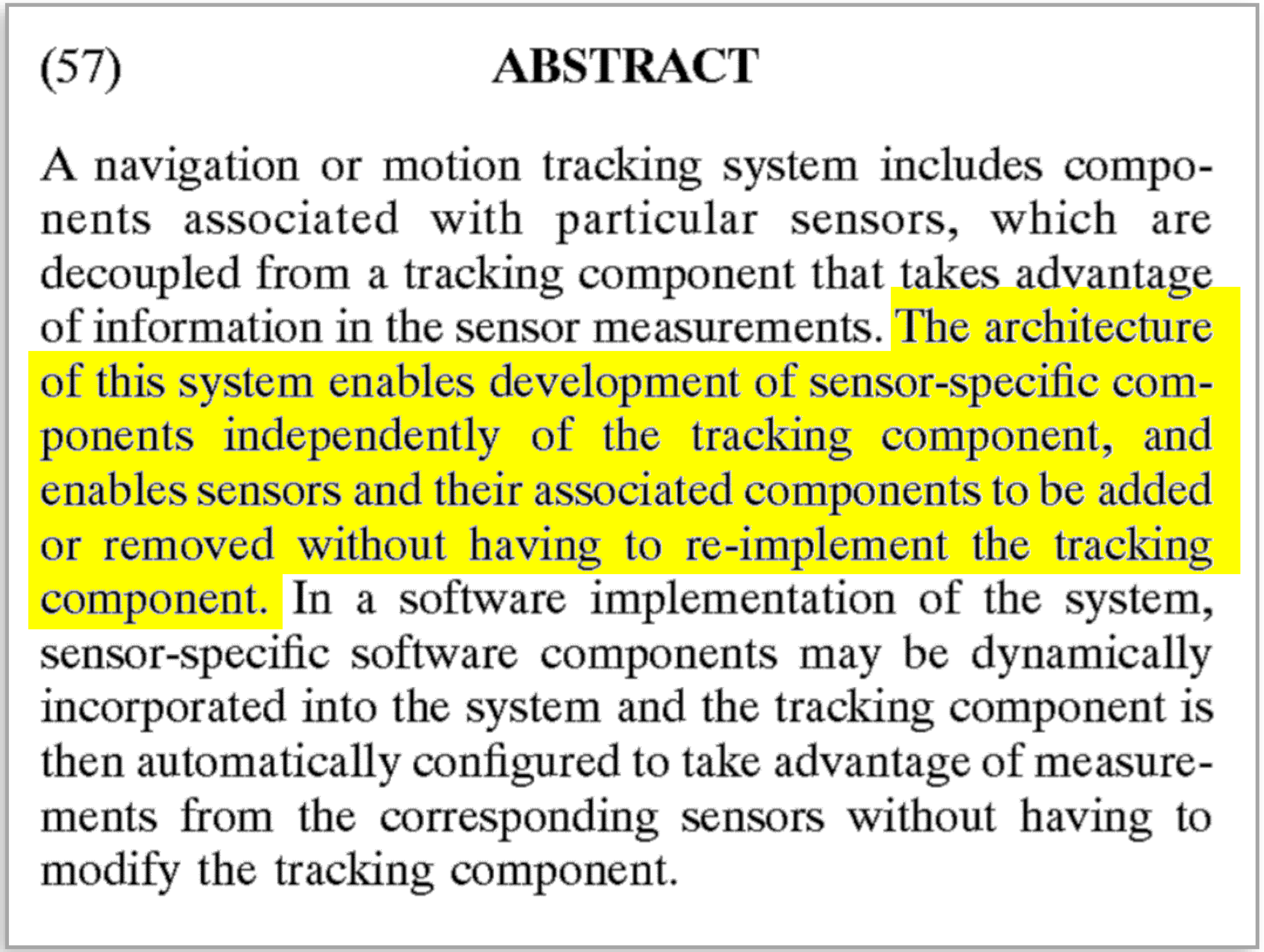
Primary Examiner—Gertrude A. Jeanglaude
(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

A navigation or motion tracking system includes components associated with particular sensors, which are decoupled from a tracking component that takes advantage of information in the sensor measurements. The architecture of this system enables development of sensor-specific components independently of the tracking component, and enables sensors and their associated components to be added or removed without having to re-implement the tracking component. In a software implementation of the system, sensor-specific software components may be dynamically incorporated into the system and the tracking component is then automatically configured to take advantage of measurements from the corresponding sensors without having to modify the tracking component.

69 Claims, 12 Drawing Sheets

META 1001
META V. THALES

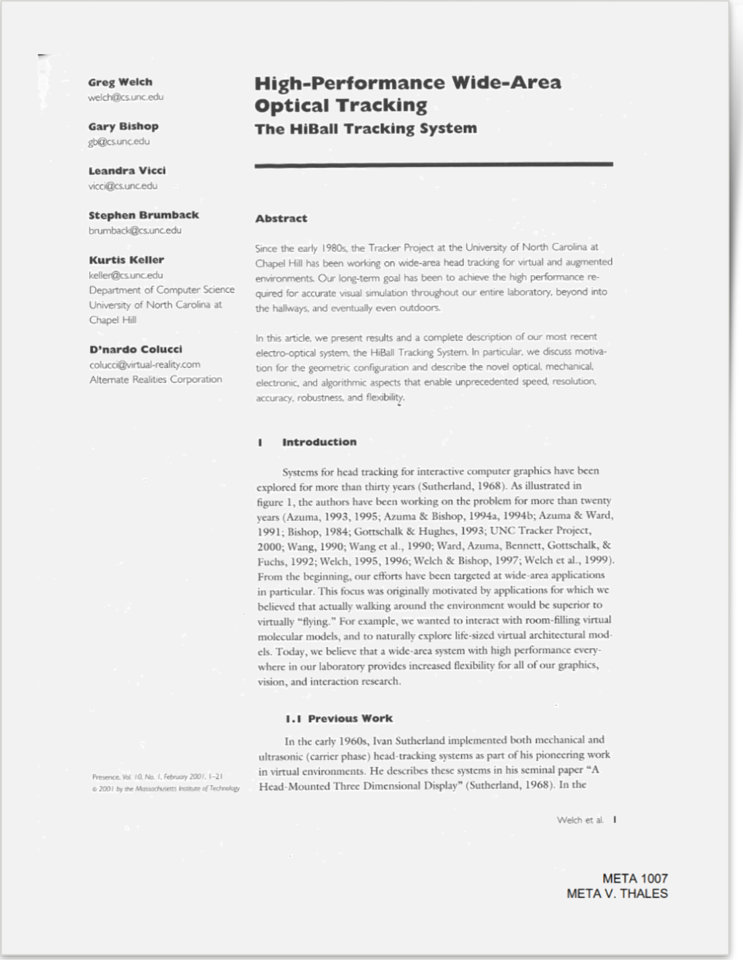


(57) **ABSTRACT**

A navigation or motion tracking system includes components associated with particular sensors, which are decoupled from a tracking component that takes advantage of information in the sensor measurements. The architecture of this system enables development of sensor-specific components independently of the tracking component, and enables sensors and their associated components to be added or removed without having to re-implement the tracking component. In a software implementation of the system, sensor-specific software components may be dynamically incorporated into the system and the tracking component is then automatically configured to take advantage of measurements from the corresponding sensors without having to modify the tracking component.

Ex. 1001, Abstract; *e.g.*, 1304 POR 1

Welch HiBall System



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High-Performance Wide-Area Optical Tracking

The HiBall Tracking System

Abstract

Since the early 1980s, the Tracker Project at the University of North Carolina at Chapel Hill has been working on wide-area head tracking for virtual and augmented environments. Our long-term goal has been to achieve the high performance required for accurate visual simulation throughout our entire laboratory, beyond into the hallways, and eventually even outdoors.

In this article, we present results and a complete description of our most recent electro-optical system, the HiBall Tracking System. In particular, we discuss motivation for the geometric configuration and describe the novel optical, mechanical, electronic, and algorithmic aspects that enable unprecedented speed, resolution, accuracy, robustness, and flexibility.

1 Introduction

Systems for head tracking for interactive computer graphics have been explored for more than thirty years (Sutherland, 1968). As illustrated in figure 1, the authors have been working on the problem for more than twenty years (Azuma, 1993, 1995; Azuma & Bishop, 1994a, 1994b; Azuma & Ward, 1991; Bishop, 1984; Gottschalk & Hughes, 1993; UNC Tracker Project, 2000; Wang, 1990; Wang et al., 1990; Ward, Azuma, Bennett, Gottschalk, & Fuchs, 1992; Welch, 1995, 1996; Welch & Bishop, 1997; Welch et al., 1999). From the beginning, our efforts have been targeted at wide-area applications in particular. This focus was originally motivated by applications for which we believed that actually walking around the environment would be superior to virtually "flying." For example, we wanted to interact with room-filling virtual molecular models, and to naturally explore life-sized virtual architectural models. Today, we believe that a wide-area system with high performance everywhere in our laboratory provides increased flexibility for all of our graphics, vision, and interaction research.

1.1 Previous Work

In the early 1960s, Ivan Sutherland implemented both mechanical and ultrasonic (carrier phase) head-tracking systems as part of his pioneering work in virtual environments. He describes these systems in his seminal paper "A Head-Mounted Three Dimensional Display" (Sutherland, 1968). In the

Presence, Vol. 10, No. 1, February 2001, 1–21

META 1007
META V. THALES

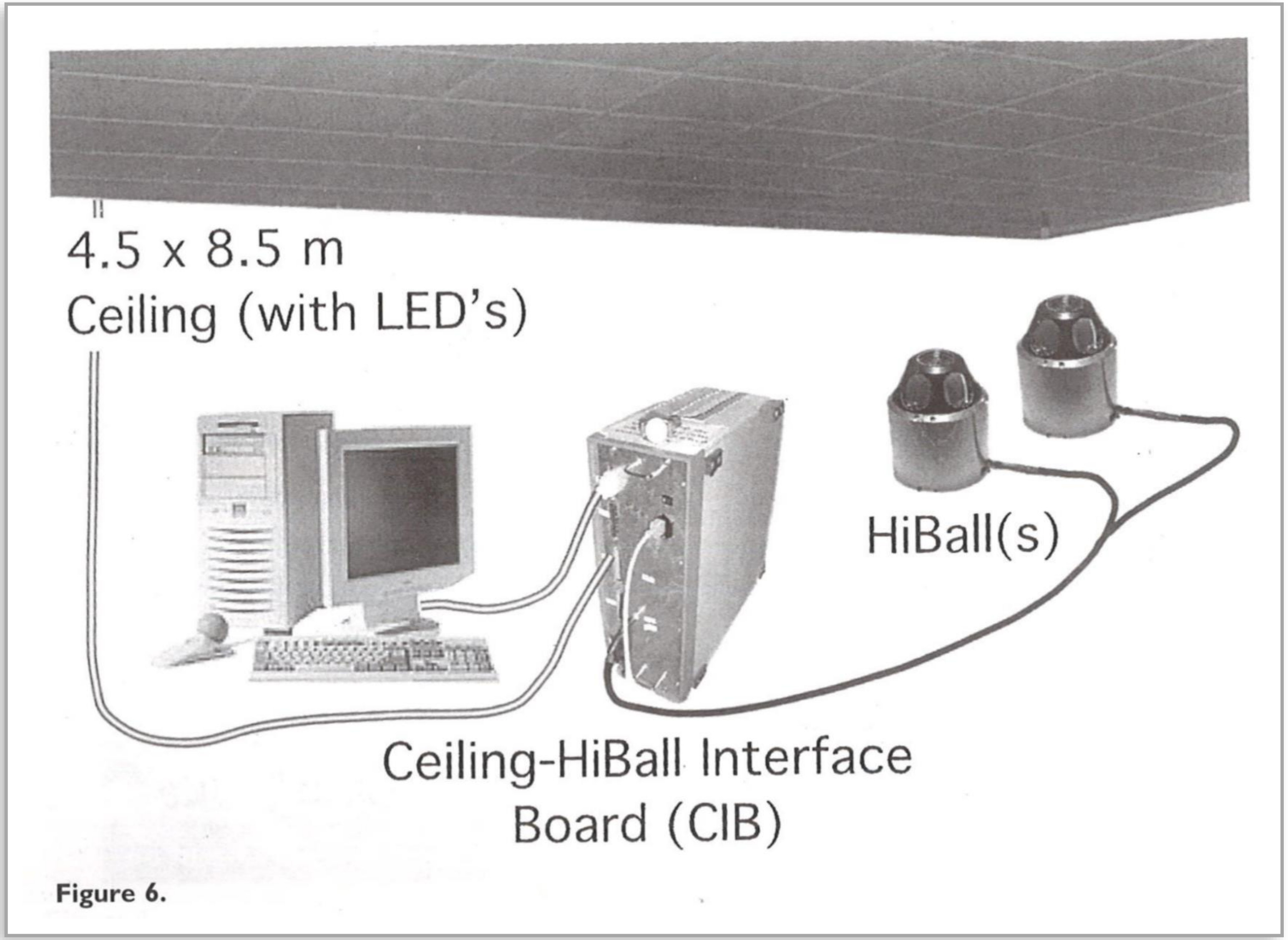
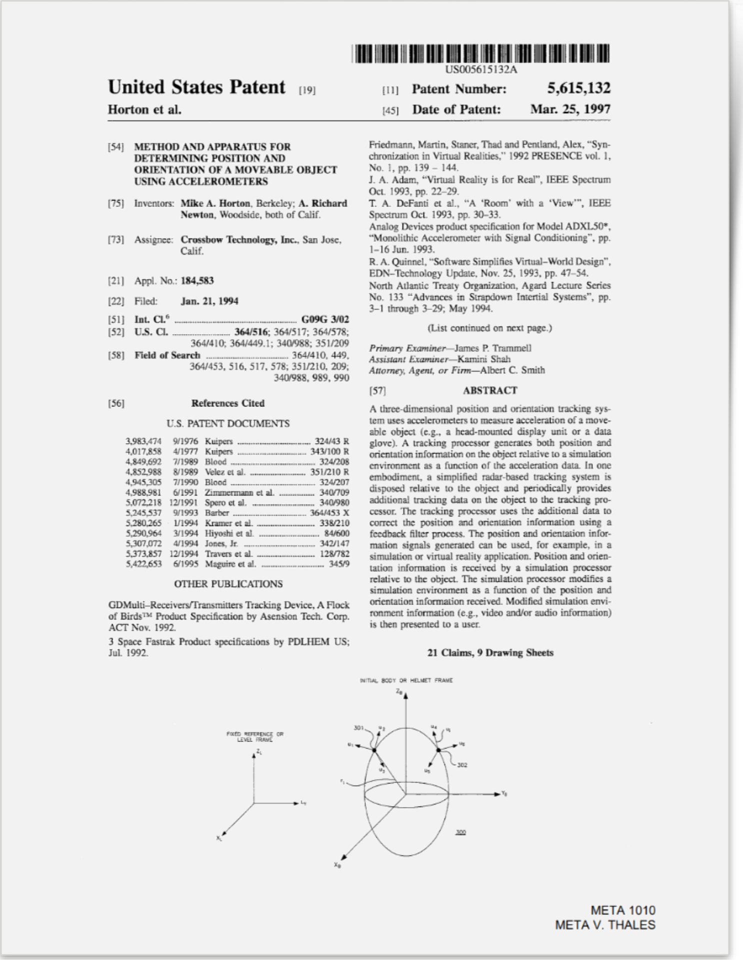


Figure 6.

Ex. 1007, Fig.6; *e.g.*, 1304 Petition 14; 1304 POR 7

Horton Accelerometer System



US005615132A

United States Patent [19]
Horton et al.

[11] **Patent Number: 5,615,132**
[45] **Date of Patent: Mar. 25, 1997**

[54] **METHOD AND APPARATUS FOR DETERMINING POSITION AND ORIENTATION OF A MOVEABLE OBJECT USING ACCELEROMETERS**

[75] Inventors: **Mike A. Horton**, Berkeley; **A. Richard Newton**, Woodside, both of Calif.

[73] Assignee: **Crossbow Technology, Inc.**, San Jose, Calif.

[21] Appl. No.: **184,583**

[22] Filed: **Jan. 21, 1994**

[51] **Int. Cl.**^{6} **G09G 3/02**
[52] **U.S. Cl.** **364/516**; 364/517; 364/578; 364/410; 364/449.1; 340/988; 351/209
[58] **Field of Search** 364/410, 449, 364/453, 516, 517, 578; 351/210, 209; 340/988, 989, 990

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,983,474	9/1976	Kuipers	324/43 R
4,017,858	4/1977	Kuipers	343/100 R
4,849,692	7/1989	Blood	324/208
4,852,988	8/1989	Velez et al.	351/210 R
4,945,305	7/1990	Blood	324/207
4,988,981	6/1991	Zimmermann et al.	340/709
5,072,218	12/1991	Spero et al.	340/980
5,245,537	9/1993	Barber	364/453 X
5,280,265	1/1994	Kramer et al.	338/210
5,290,964	3/1994	Hiyoshi et al.	84/600
5,307,072	4/1994	Jones, Jr.	342/147
5,373,857	12/1994	Travers et al.	128/782
5,422,653	6/1995	Maguire et al.	345/9

OTHER PUBLICATIONS

GDMulti–Receivers/Transmitters Tracking Device, A Flock of Birds™ Product Specification by Asension Tech. Corp. ACT Nov. 1992.

3 Space Fastrak Product specifications by PDLHEM US; Jul. 1992.

Friedmann, Martin, Staner, Thad and Pentland, Alex, "Synchronization in Virtual Realities," 1992 PRESENCE vol. 1, No. 1, pp. 139 – 144.

J. A. Adam, "Virtual Reality is for Real", IEEE Spectrum Oct. 1993, pp. 22–29.

T. A. DeFanti et al., "A 'Room' with a 'View'", IEEE Spectrum Oct. 1993, pp. 30–33.

Analog Devices product specification for Model ADXL50*, "Monolithic Accelerometer with Signal Conditioning", pp. 1–16 Jun. 1993.

R. A. Quinnel, "Software Simplifies Virtual–World Design", EDN–Technology Update, Nov. 25, 1993, pp. 47–54.

North Atlantic Treaty Organization, Agard Lecture Series No. 133 "Advances in Strapdown Intertial Systems", pp. 3–1 through 3–29; May 1994.

(List continued on next page.)

Primary Examiner—James P. Trammell
Assistant Examiner—Kamini Shah
Attorney, Agent, or Firm—Albert C. Smith

[57] **ABSTRACT**

A three-dimensional position and orientation tracking system uses accelerometers to measure acceleration of a moveable object (e.g., a head-mounted display unit or a data glove). A tracking processor generates both position and orientation information on the object relative to a simulation environment as a function of the acceleration data. In one embodiment, a simplified radar-based tracking system is disposed relative to the object and periodically provides additional tracking data on the object to the tracking processor. The tracking processor uses the additional data to correct the position and orientation information using a feedback filter process. The position and orientation information signals generated can be used, for example, in a simulation or virtual reality application. Position and orientation information is received by a simulation processor relative to the object. The simulation processor modifies a simulation environment as a function of the position and orientation information received. Modified simulation environment information (e.g., video and/or audio information) is then presented to a user.

21 Claims, 9 Drawing Sheets

META 1010
META V. THALES

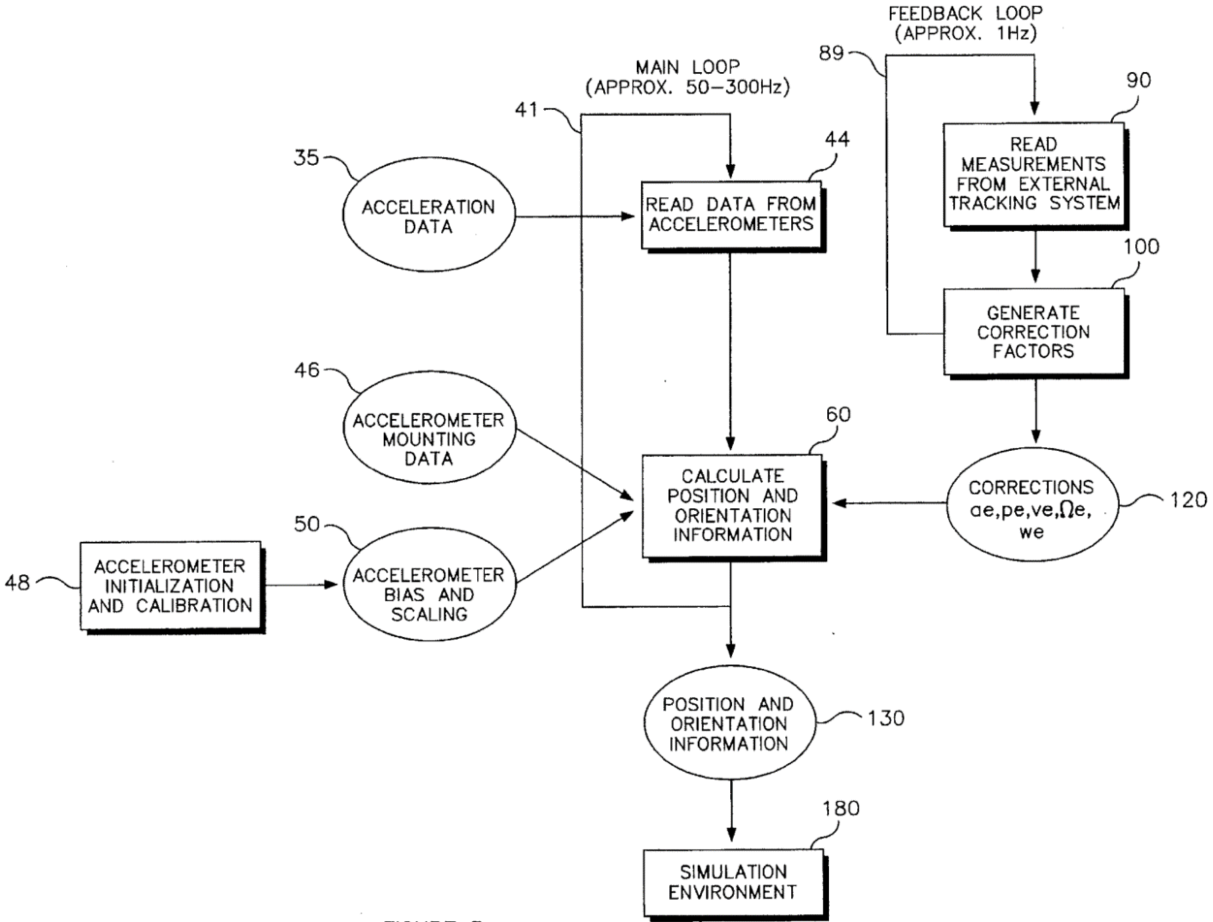


FIGURE 3

Ex. 1010, Fig.3; *e.g.*, 1304 Petition 40; 1304 POR 9

Claim Construction

“Estimation Subsystem/Module” & “Sensor Subsystem”

Patent Owner’s Construction	Petitioner’s Construction
Estimation Subsystem/Module: the tracking component of a motion tracking system, which is separate from but connected to the sensor subsystem **Sensor Subsystem:** a component or group of components of a motion tracking system associated with particular sensors, which is separate from but connected to the estimation subsystem	No Construction Subsystems need not be “entirely separate” and may “partially overlap”
E.g., 1304 POR 12-18	*E.g.*, 1304 Reply 1-5

Estimation Subsystem / Sensor Subsystem

The sensor and estimation subsystems are distinct elements of the claims.

US006922632B2

(12) **United States Patent**
Foxlin

(10) **Patent No.:** **US 6,922,632 B2**
(45) **Date of Patent:** **Jul. 26, 2005**

(54) **TRACKING, AUTO-CALIBRATION, AND MAP-BUILDING SYSTEM**

(75) Inventor: **Eric Foxlin**, Arlington, MA (US)

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(21) Appl. No.: **10/639,242**

(22) Filed: **Aug. 11, 2003**

(65) **Prior Publication Data**

US 2004/0073360 A1 Apr. 15, 2004

Related U.S. Application Data

(60) Provisional application No. 60/402,178, filed on Aug. 9, 2002.

(51) **Int. Cl.**^{7} **G01C 21/26**
(52) **U.S. Cl.** **701/207**; 701/36; 701/220; 701/300; 342/357.07
(58) **Field of Search** 701/33, 36, 207, 701/220, 222, 225, 300; 342/357.01, 357.07, 357.08, 424

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,176,837 B1 1/2001 Foxlin 600/595
6,288,785 B1 * 9/2001 Frantz et al. 356/614
6,611,141 B1 * 8/2003 Schulz et al. 324/226
2002/0052674 A1 * 5/2002 Chang et al. 700/300

FOREIGN PATENT DOCUMENTS

WO WO 01/80736 11/2001

OTHER PUBLICATIONS

"IEEE Standard for a Smart Transducer Interface for Sensors and Actuators—Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Format". Institute of Electrical and Electronics Engineers, Inc., New York, NY. Sep. 25, 1998.

Neal A. Carlson. "Federated Filter for Fault–Tolerant Integrated Navigation". NATO Advisory Group for Aerospace Research and Development (AGARD) book "Aerospace Navigation Systems", AGARD–AG–331, published Jun., 1995, pp. 265–280.

V. A. Tupysev. "A Generalized Approach to the Problem of Distributed Kalman Filtering". AIAA–98–4309, pp. 1097–1116, Aug., 1998.

Donald T. Knight. "Rapid Development of Tightly–Coupled GPS/INS Systems". IEEE, 1977.

Gudrun Klinker et al. "Distributed User Tracking Concepts for Augmented Reality Applications". IEEE, pp. 37–44, 2000.

* cited by examiner

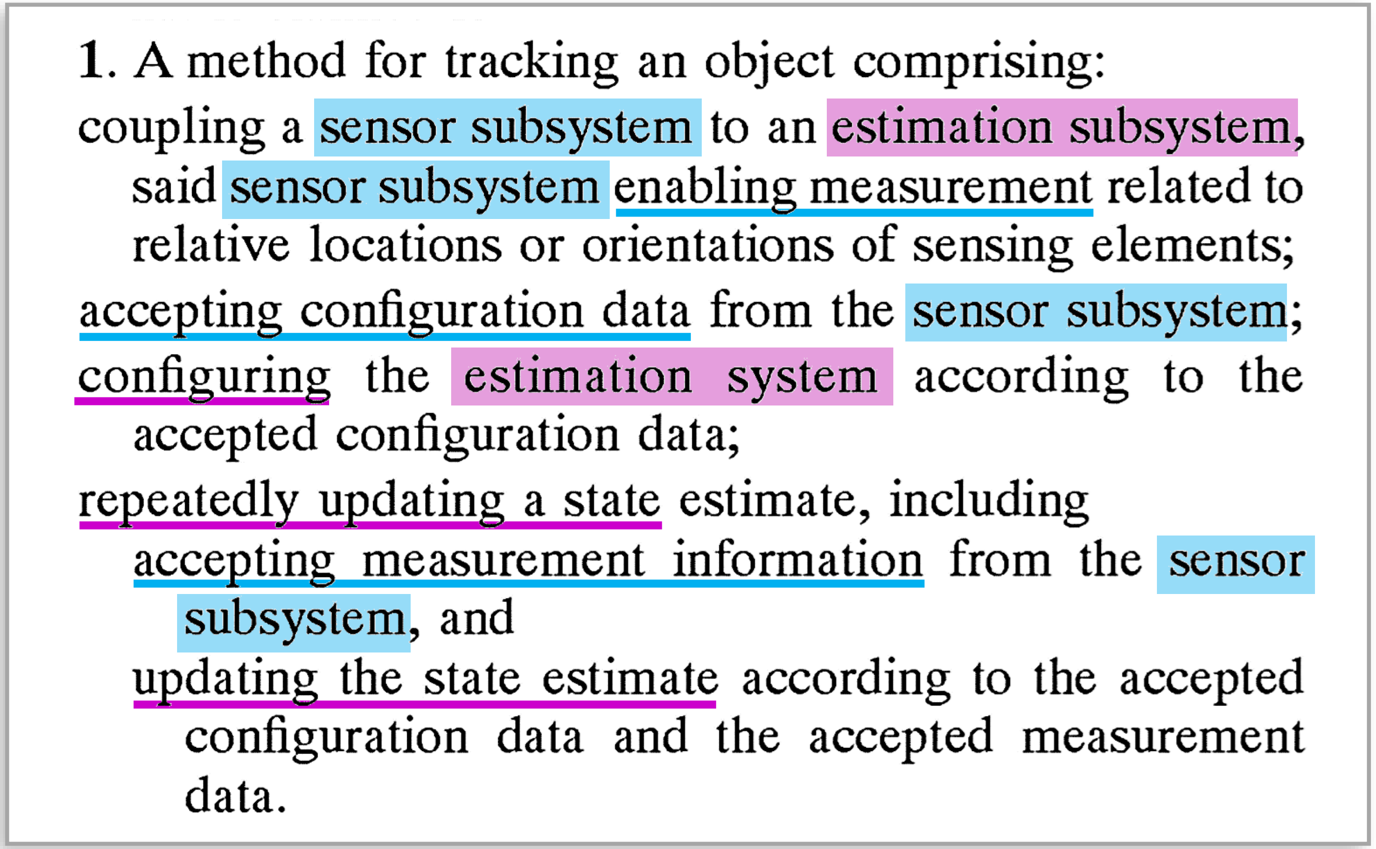
Primary Examiner—Gertrude A. Jeanglaude
(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

A navigation or motion tracking system includes components associated with particular sensors, which are decoupled from a tracking component that takes advantage of information in the sensor measurements. The architecture of this system enables development of sensor-specific components independently of the tracking component, and enables sensors and their associated components to be added or removed without having to re-implement the tracking component. In a software implementation of the system, sensor-specific software components may be dynamically incorporated into the system and the tracking component is then automatically configured to take advantage of measurements from the corresponding sensors without having to modify the tracking component.

69 Claims, 12 Drawing Sheets

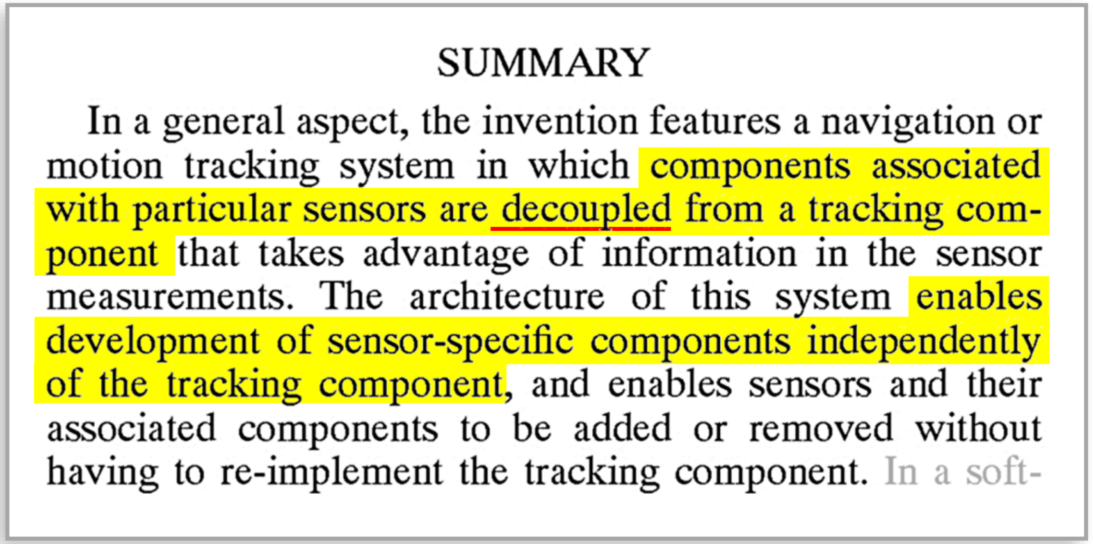
META 1001
META V. THALES



1. A method for tracking an object comprising:
coupling a sensor subsystem to an estimation subsystem, said sensor subsystem enabling measurement related to relative locations or orientations of sensing elements;
accepting configuration data from the sensor subsystem;
configuring the estimation system according to the accepted configuration data;
repeatedly updating a state estimate, including
accepting measurement information from the sensor subsystem, and
updating the state estimate according to the accepted configuration data and the accepted measurement data.

Ex. 1001, cl.1; *e.g.*, 1304 POR 6, 14-15

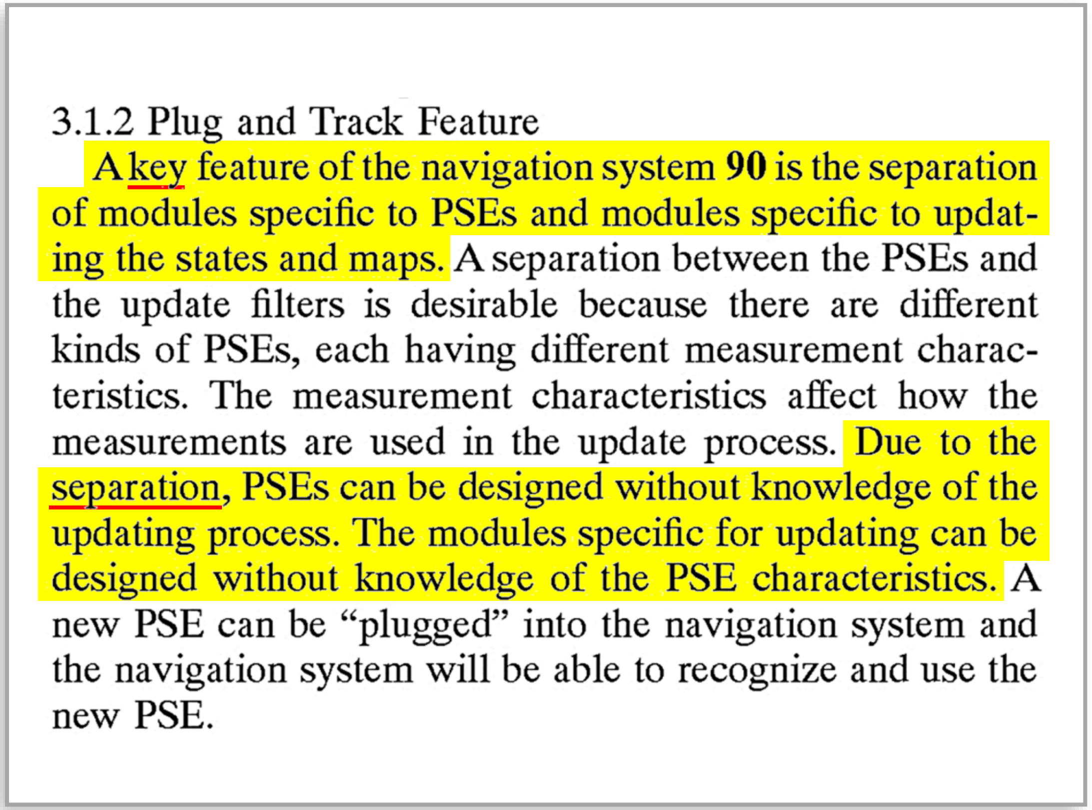
Estimation Subsystem / Sensor Subsystem



SUMMARY

In a general aspect, the invention features a navigation or motion tracking system in which components associated with particular sensors are decoupled from a tracking component that takes advantage of information in the sensor measurements. The architecture of this system enables development of sensor-specific components independently of the tracking component, and enables sensors and their associated components to be added or removed without having to re-implement the tracking component. In a soft-

Ex. 1001, 2:20-28; *e.g.*, 1304 POR 16-17



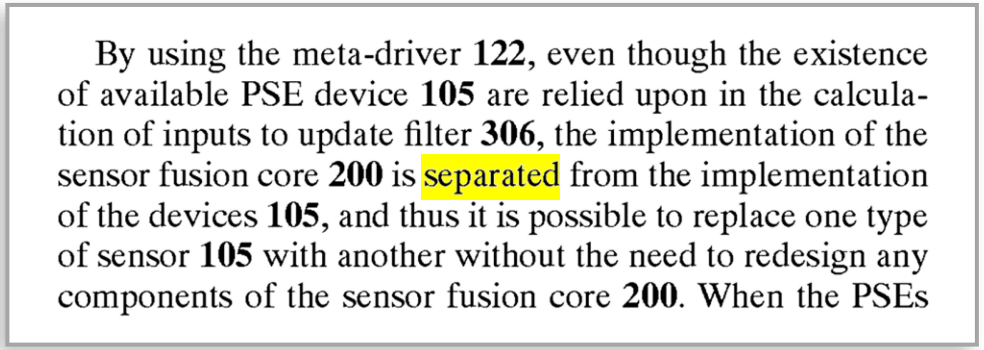
3.1.2 Plug and Track Feature

A key feature of the navigation system **90** is the separation of modules specific to PSEs and modules specific to updating the states and maps. A separation between the PSEs and the update filters is desirable because there are different kinds of PSEs, each having different measurement characteristics. The measurement characteristics affect how the measurements are used in the update process. Due to the separation, PSEs can be designed without knowledge of the updating process. The modules specific for updating can be designed without knowledge of the PSE characteristics. A new PSE can be “plugged” into the navigation system and the navigation system will be able to recognize and use the new PSE.

Ex. 1001, 22:37-50; *e.g.*, 1304 POR 5-6, 17

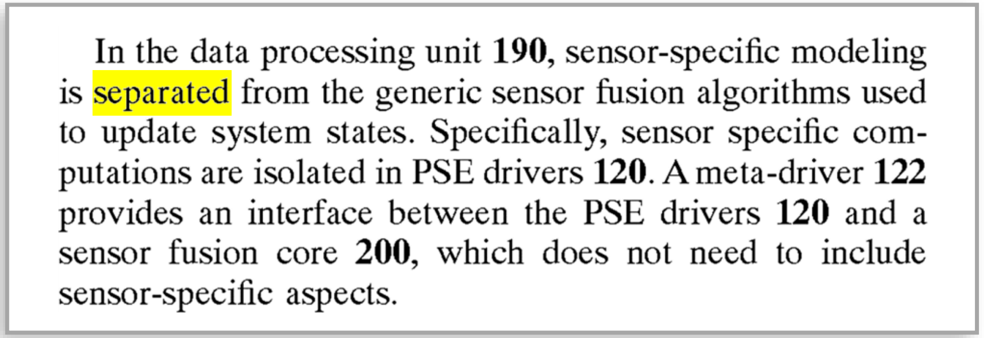
Estimation Subsystem / Sensor Subsystem

The meaning of the claim terms cannot be divorced from the patent's context.



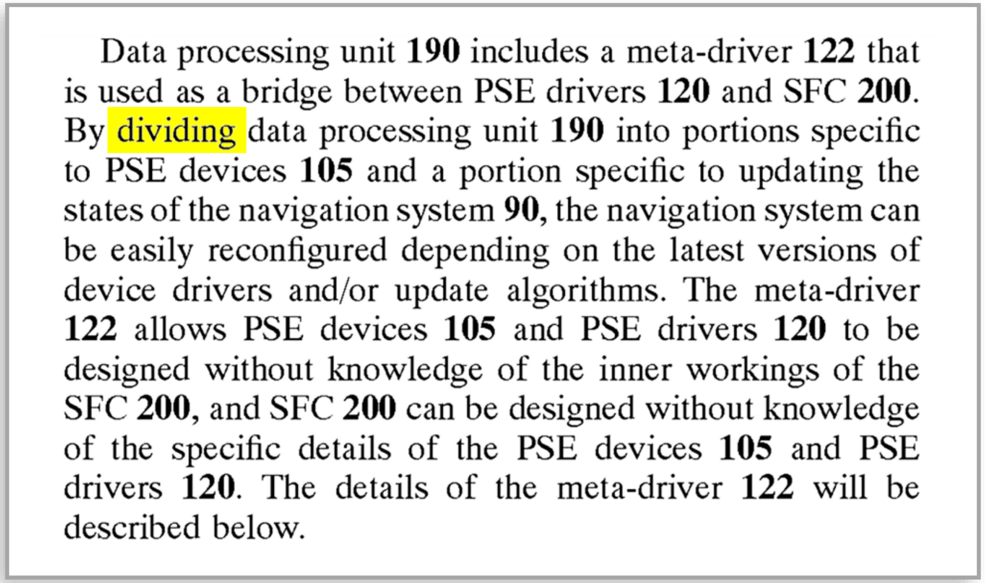
By using the meta-driver **122**, even though the existence of available PSE device **105** are relied upon in the calculation of inputs to update filter **306**, the implementation of the sensor fusion core **200** is separated from the implementation of the devices **105**, and thus it is possible to replace one type of sensor **105** with another without the need to redesign any components of the sensor fusion core **200**. When the PSEs

Ex. 1001, 19:14-20; *e.g.*, 1304 POR 16-17



In the data processing unit **190**, sensor-specific modeling is separated from the generic sensor fusion algorithms used to update system states. Specifically, sensor specific computations are isolated in PSE drivers **120**. A meta-driver **122** provides an interface between the PSE drivers **120** and a sensor fusion core **200**, which does not need to include sensor-specific aspects.

Ex. 1001, 16:38-44; *e.g.*, 1304 POR 16-17



Data processing unit **190** includes a meta-driver **122** that is used as a bridge between PSE drivers **120** and SFC **200**. By dividing data processing unit **190** into portions specific to PSE devices **105** and a portion specific to updating the states of the navigation system **90**, the navigation system can be easily reconfigured depending on the latest versions of device drivers and/or update algorithms. The meta-driver **122** allows PSE devices **105** and PSE drivers **120** to be designed without knowledge of the inner workings of the SFC **200**, and SFC **200** can be designed without knowledge of the specific details of the PSE devices **105** and PSE drivers **120**. The details of the meta-driver **122** will be described below.

Ex. 1001, 17:27-39; *e.g.*, 1304 POR 16-17

> "[A] patent's express purpose of the invention informs the proper construction of claim terms."

Sequoia Tech., LLC v. Dell, Inc., 66 F.4th 1317, 1326 (Fed. Cir. 2023) (internal quotation marks omitted); *e.g.*, 1304 Sur-Reply 3-4

Estimation Subsystem / Sensor Subsystem

Patent Owner’s construction is supported by expert evidence.

Yohan Baillot
CEO and Founder, ARCortex INC

The POSITA would have understood:

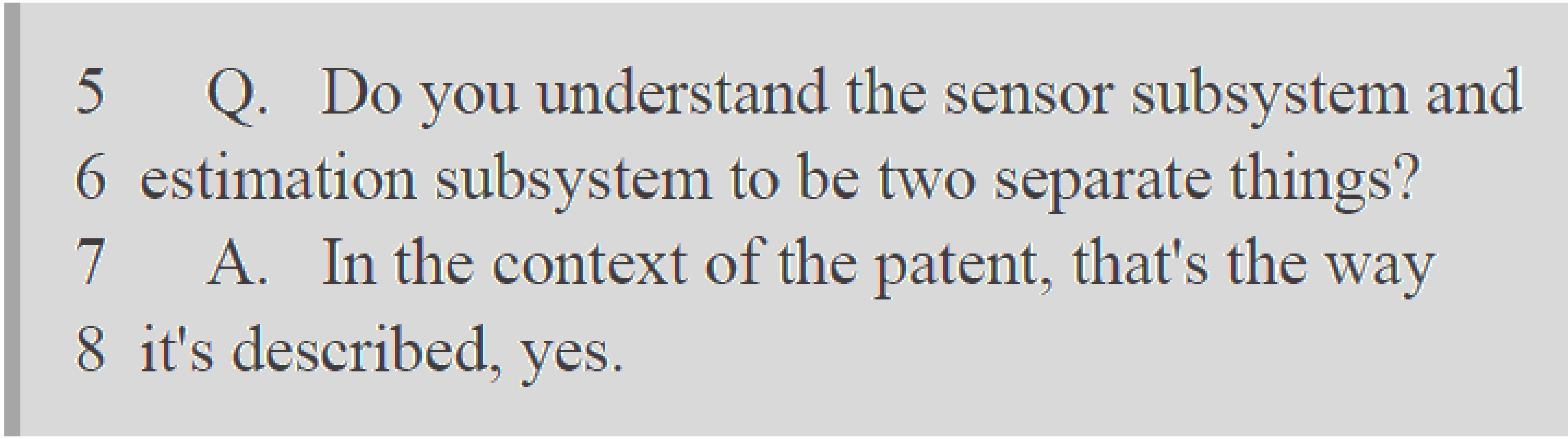
- “[T]he estimation and sensor portions of the system do not overlap and are not intertwined in a way that would result in any claimed processes being part of both segments.” ¶ 43
- “[T]his separation reflects a central innovation of the patents . . . allow[ing] for the use of different types of sensors.” ¶ 45
- “[O]verlapping or intertwined subsystems would defeat a key goal of the ’632 patent, because the potential for ‘plug and track’ functionality, or updating sensor components without updating the tracking component (or vice versa), would not be realized.” ¶ 46

Ex. 2007; *e.g.*, 1304 POR 16-18

Estimation Subsystem / Sensor Subsystem

Petitioner's expert *agrees* the sensor and estimation subsystems are separate.

Dr. Ulrich Neumann
University of Southern California



Q. Do you understand the sensor subsystem and estimation subsystem to be two separate things?
A. In the context of the patent, that's the way it's described, yes.

Ex. 2009, 43:5-8; *e.g.*, 1304 POR 14-15

Estimation Subsystem / Sensor Subsystem

Petitioner has no support for its position that the two subsystems can overlap.

No examples in the patent referring to overlapping components or processes that are part of both subsystems.

No expert evidence supporting overlap.

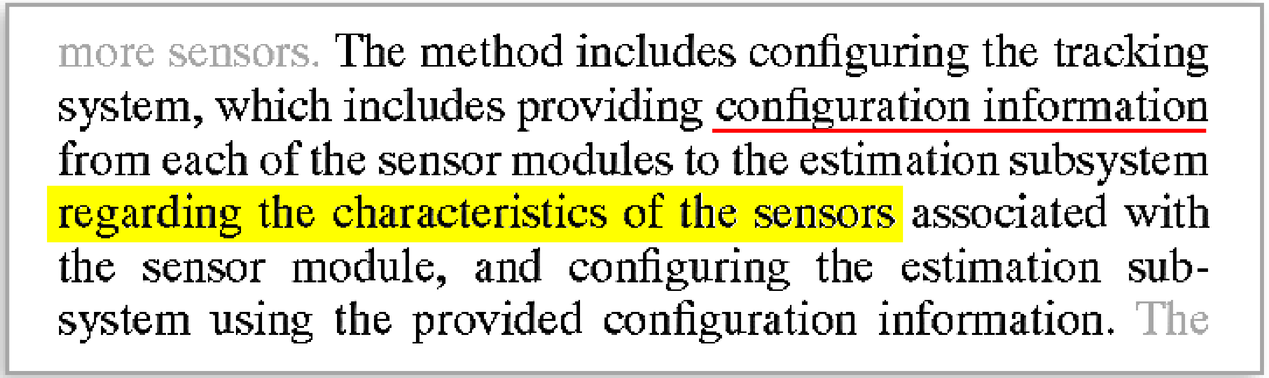
E.g., 1304 Sur-Reply 3-4

Configuration Data / Information

Patent Owner’s Construction	Petitioner’s Construction
Data describing characteristics or attributes of a sensor or set of sensors	Data that is used for configuration
E.g., 1304 POR 18-21	*E.g.*, 1304 Reply 6-7

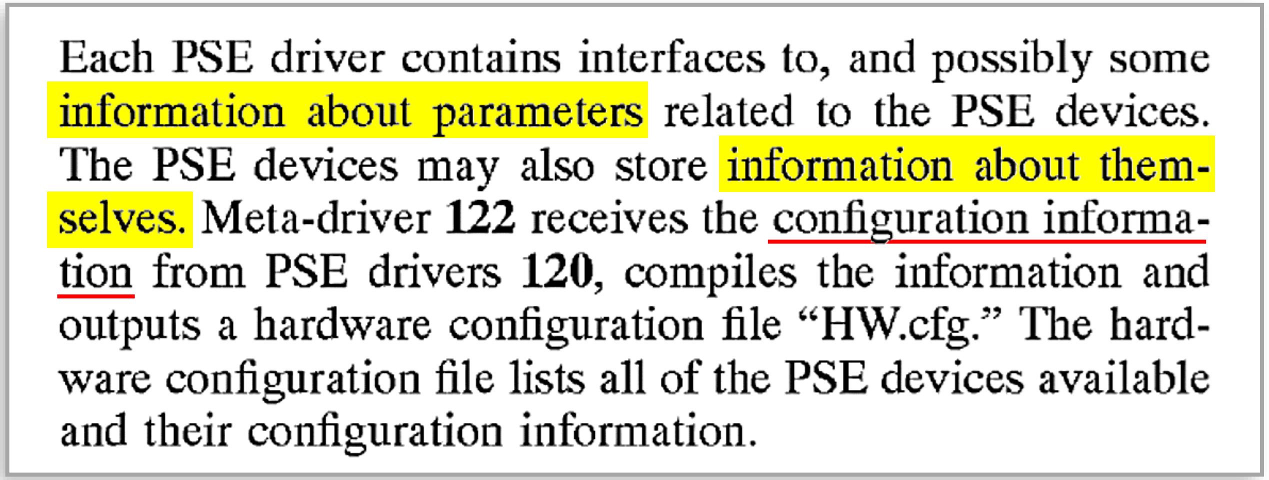
Configuration Data / Information

The estimation subsystem is configured according to characteristics, attributes, or parameters of the sensing elements, not according to raw sensor measurement inputs.



more sensors. The method includes configuring the tracking system, which includes providing configuration information from each of the sensor modules to the estimation subsystem regarding the characteristics of the sensors associated with the sensor module, and configuring the estimation subsystem using the provided configuration information. The

Ex. 1001, 6:27-32; *e.g.*, 1304 POR 20-21



Each PSE driver contains interfaces to, and possibly some information about parameters related to the PSE devices. The PSE devices may also store information about themselves. Meta-driver **122** receives the configuration information from PSE drivers **120**, compiles the information and outputs a hardware configuration file "HW.cfg." The hardware configuration file lists all of the PSE devices available and their configuration information.

Ex. 1001, 18:56-63; *e.g.*, 1304 POR 21

Configuration Data / Information

The patent's examples are not raw sensor measurements.

"uncertainty or noise characteristics of the measurement values" Ex. 1001, 1:30-35;

"operational parameters" *id.,* 3:1-3;

"a map of the locations of the sensing elements" *id.,* 3:7-9;

"parameters that identify a basic type of sensor, such a 2-D bearing, 1-D bearing, range" *id.,* 10:7-9;

"parameters that identify a specific type of sensor, such as make and model" *id.,* 10:10-11;

"measurement related parameters" *id.,* 10:14-15;

"white noise and random walk amplitudes, root-mean square initial uncertainty estimates for gyro and acceleration biases, ramps, misalignments, scale factors, nonlinearities" *id.,* 30:1-7;

"Pose [of the sensor]" *id.,* 30:31-32;

"Pose uncertainty" *id.,* 30:33;

"Bias parameters vector k" *id.,* 30:34-35;

"k-vector uncertainty" *id.,* 30:36;

"Basic type" *id.,* 30:37-49;

"Specific type" *id.,* 30:50-56;

"Unique identifier" *id.,* 30:57-58;

"Color" *id.,* 30:59;

"Size" *id.,* 30:60-65;

"Driver number" *id.,* 30:66-67;

"Device handle" *id.,* 31:1-3;

"Status (ready, busy, etc.)" *id.,* 31:4;

"Membership" *id.,* 31:5-6.

Ex. 1001; Ex. 2007 ¶ 60; *e.g.,* 1304 POR 20

Configuration Data / Information

Patent Owner’s position is supported by expert evidence.

Yohan Baillot
CEO and Founder, ARCortex INC

The POSITA would have understood:

- “‘[C]onfiguration data’ or ‘configuration information’ [are] ‘data describing characteristics or attributes of a sensor or set of sensors ....” ¶ 56
- “[R]aw measurements do not themselves constitute configuration data or information.” ¶ 57
- “[M]easurements may be processed in order to compute or estimate certain sensor parameters or characteristics (*e.g.*, noise or uncertainty) that then can be used for configuration purposes, but those parameters or characteristics are the configuration data, and the raw measurements that are used as inputs are not themselves configuration data.” ¶ 58

Ex. 2007; *e.g.*, 1304 POR 18-19

Configuration Data / Information

Petitioner has no support that the raw measurements it relies on are "configuration data."

No examples in the patent of configuration data that consist solely of raw, unprocessed sensor measurements.

No expert evidence that raw measurements are configuration data.

E.g., 1304 Sur-Reply 6-7

Configuration Data / Information

Measurements used to create calibration tables are not “information characterizing a calibration parameter.”

Yohan Baillot
CEO and Founder, ARCortex INC

The POSITA would have understood:

- Information characterizing a calibration parameter is “a calibration parameter itself, or some other description of the parameter, such as a range the parameter may fall within.”
- It does not include “a measurement input used in the process of creating a calibration table.”
- “The use of measurements to subsequently create calibration parameters does not mean that those inputs (measurements) either constitute or characterize the outputs.”

Ex. 2007 ¶ 61; *e.g.*, 1308 POR 22

Undisputed Constructions

Sensor Module	“a component or part of a sensor subsystem that provides an interface for communicating with an associated sensing element and an interface for communicating with an estimation subsystem”

E.g., 1305 POR 16-17; 1305 Reply 3

Configuring	“arranging or setting up the system so that it is able to operate in a particular way”

E.g., 1304 POR 21-24; 1304 Reply 7

Welch

Welch HiBall System

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High-Performance Wide-Area Optical Tracking

The HiBall Tracking System

Abstract

Since the early 1980s, the Tracker Project at the University of North Carolina at Chapel Hill has been working on wide-area head tracking for virtual and augmented environments. Our long-term goal has been to achieve the high performance required for accurate visual simulation throughout our entire laboratory, beyond into the hallways, and eventually even outdoors.

In this article, we present results and a complete description of our most recent electro-optical system, the HiBall Tracking System. In particular, we discuss motivation for the geometric configuration and describe the novel optical, mechanical, electronic, and algorithmic aspects that enable unprecedented speed, resolution, accuracy, robustness, and flexibility.

1 Introduction

Systems for head tracking for interactive computer graphics have been explored for more than thirty years (Sutherland, 1968). As illustrated in figure 1, the authors have been working on the problem for more than twenty years (Azuma, 1993, 1995; Azuma & Bishop, 1994a, 1994b; Azuma & Ward, 1991; Bishop, 1984; Gottschalk & Hughes, 1993; UNC Tracker Project, 2000; Wang, 1990; Wang et al., 1990; Ward, Azuma, Bennett, Gottschalk, & Fuchs, 1992; Welch, 1995, 1996; Welch & Bishop, 1997; Welch et al., 1999). From the beginning, our efforts have been targeted at wide-area applications in particular. This focus was originally motivated by applications for which we believed that actually walking around the environment would be superior to virtually "flying." For example, we wanted to interact with room-filling virtual molecular models, and to naturally explore life-sized virtual architectural models. Today, we believe that a wide-area system with high performance everywhere in our laboratory provides increased flexibility for all of our graphics, vision, and interaction research.

1.1 Previous Work

In the early 1960s, Ivan Sutherland implemented both mechanical and ultrasonic (carrier phase) head-tracking systems as part of his pioneering work in virtual environments. He describes these systems in his seminal paper "A Head-Mounted Three Dimensional Display" (Sutherland, 1968). In the

Presence, Vol. 10, No. 1, February 2001, 1–21

META 1007
META V. THALES

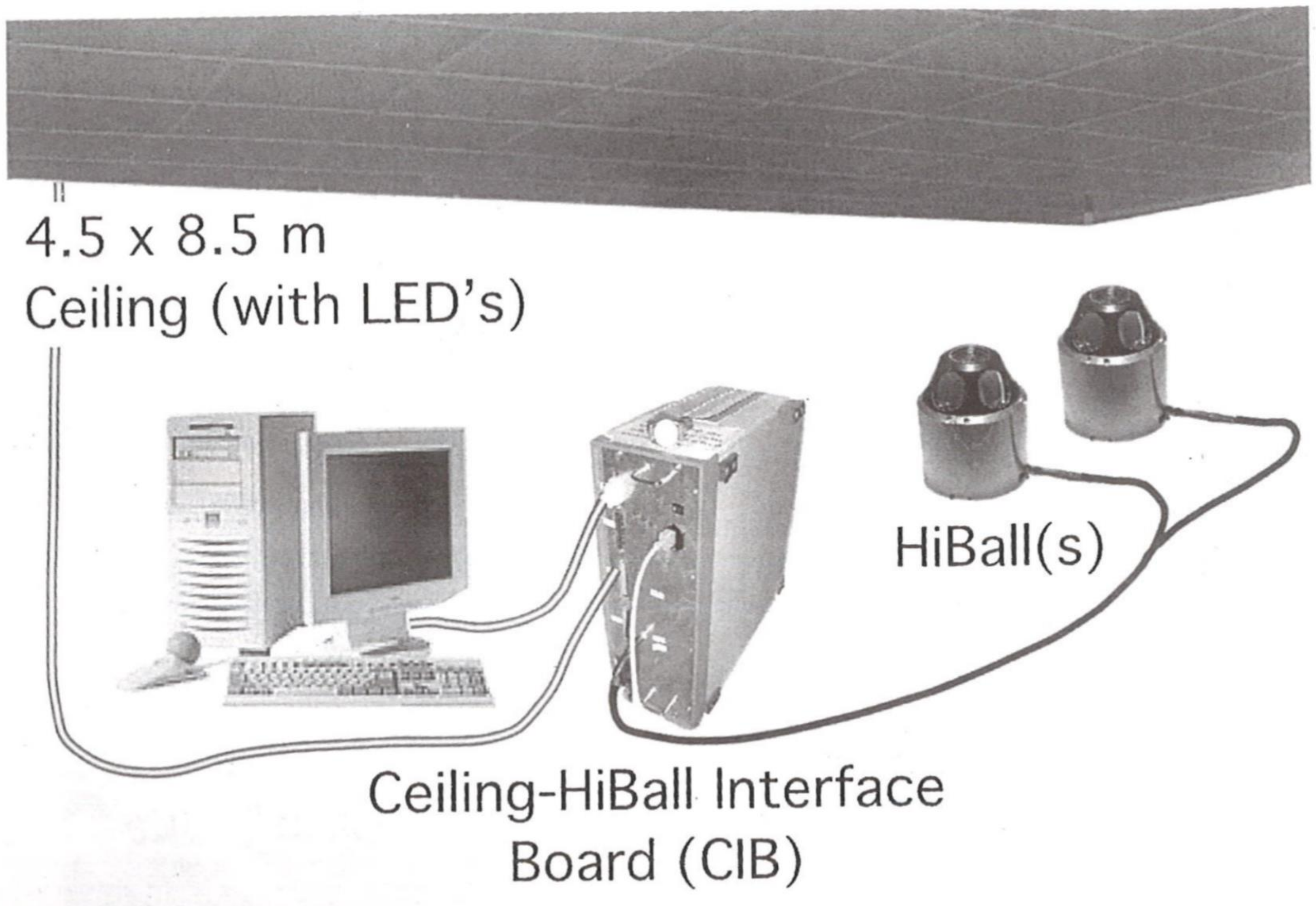


Figure 6.

Ex. 1007, Fig.6; *e.g.*, 1304 Petition 14; 1304 POR 7

Welch HiBall System

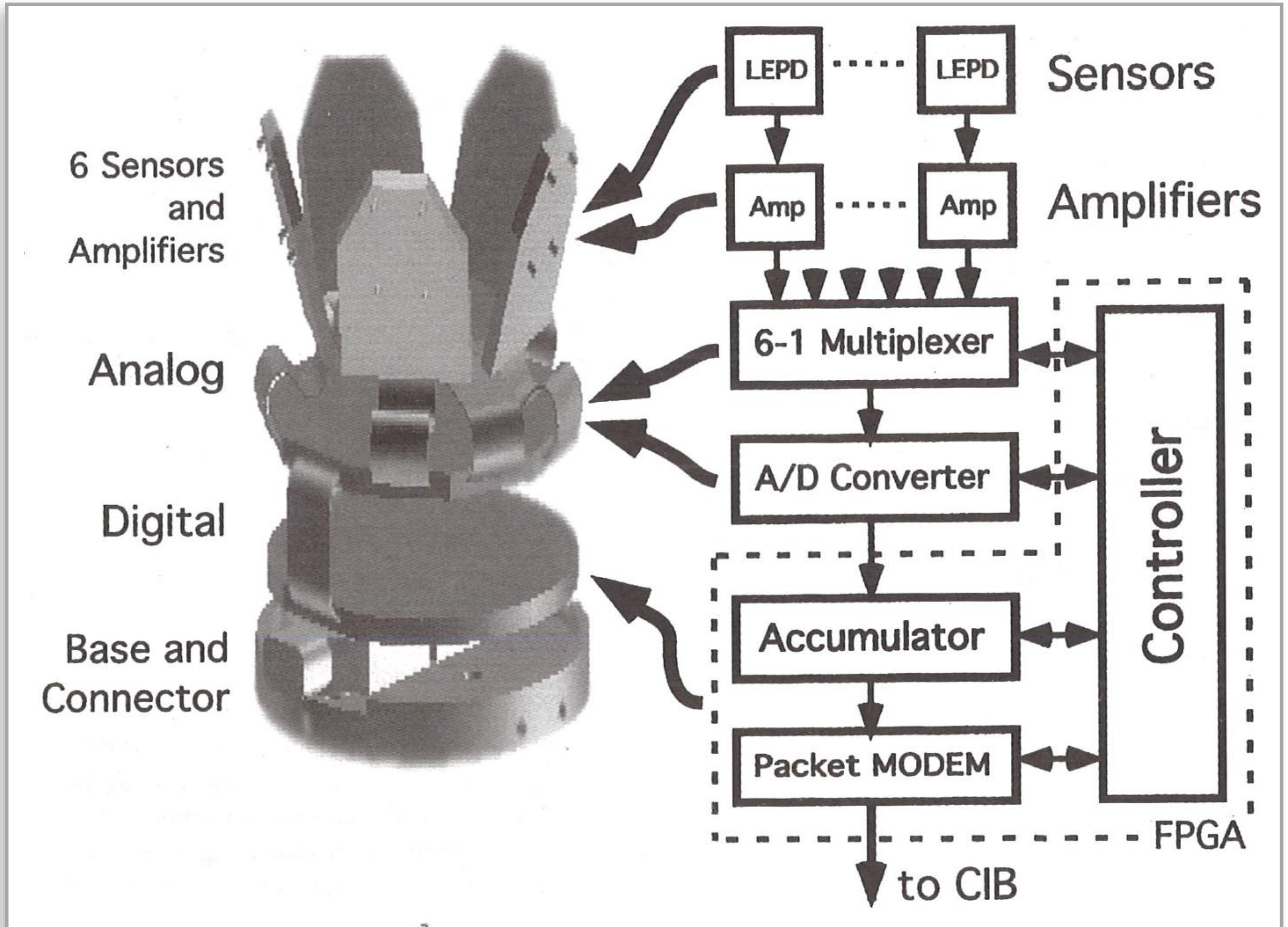
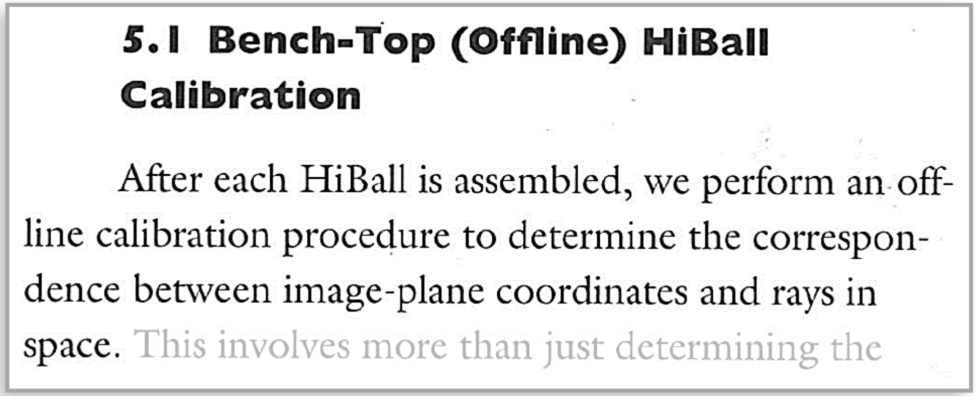


Figure 9.

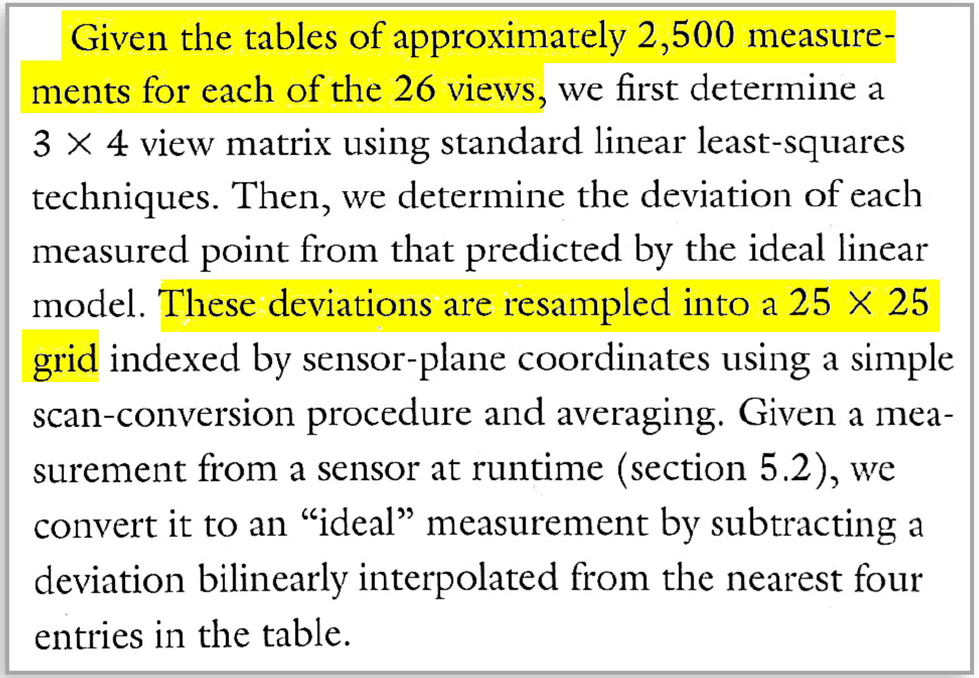
Ex. 1007, Fig.9; *e.g.*, 1305 Reply 6

Welch HiBall System



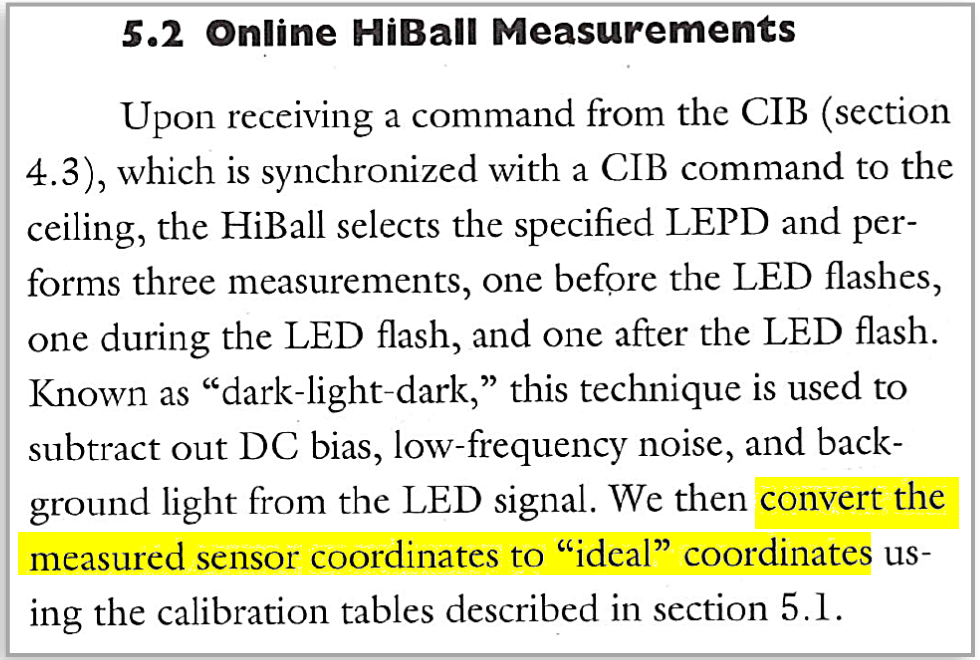
5.1 Bench-Top (Offline) HiBall Calibration

After each HiBall is assembled, we perform an offline calibration procedure to determine the correspondence between image-plane coordinates and rays in space. This involves more than just determining the



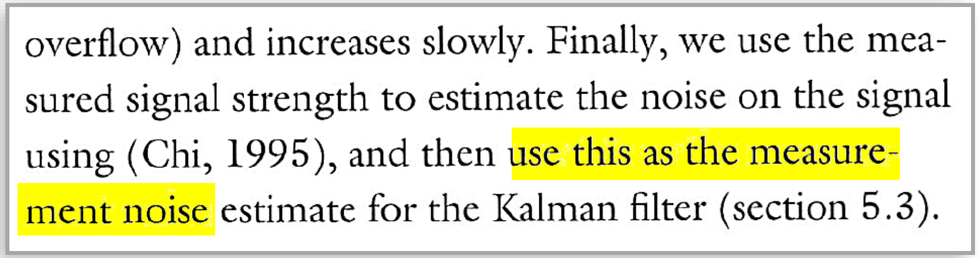
Given the tables of approximately 2,500 measurements for each of the 26 views, we first determine a 3 × 4 view matrix using standard linear least-squares techniques. Then, we determine the deviation of each measured point from that predicted by the ideal linear model. These deviations are resampled into a 25 × 25 grid indexed by sensor-plane coordinates using a simple scan-conversion procedure and averaging. Given a measurement from a sensor at runtime (section 5.2), we convert it to an "ideal" measurement by subtracting a deviation bilinearly interpolated from the nearest four entries in the table.

Ex. 1007, 9-10; *e.g.*, 1305 Petition 23; 1305 Reply 11



5.2 Online HiBall Measurements

Upon receiving a command from the CIB (section 4.3), which is synchronized with a CIB command to the ceiling, the HiBall selects the specified LEPD and performs three measurements, one before the LED flashes, one during the LED flash, and one after the LED flash. Known as "dark-light-dark," this technique is used to subtract out DC bias, low-frequency noise, and background light from the LED signal. We then convert the measured sensor coordinates to "ideal" coordinates using the calibration tables described in section 5.1.



overflow) and increases slowly. Finally, we use the measured signal strength to estimate the noise on the signal using (Chi, 1995), and then use this as the measurement noise estimate for the Kalman filter (section 5.3).

Ex. 1007, 10; *e.g.*, 1305 Petition 23; 1305 Reply 11

Welch's Sensor Subsystem Does Not Provide Configuration Data

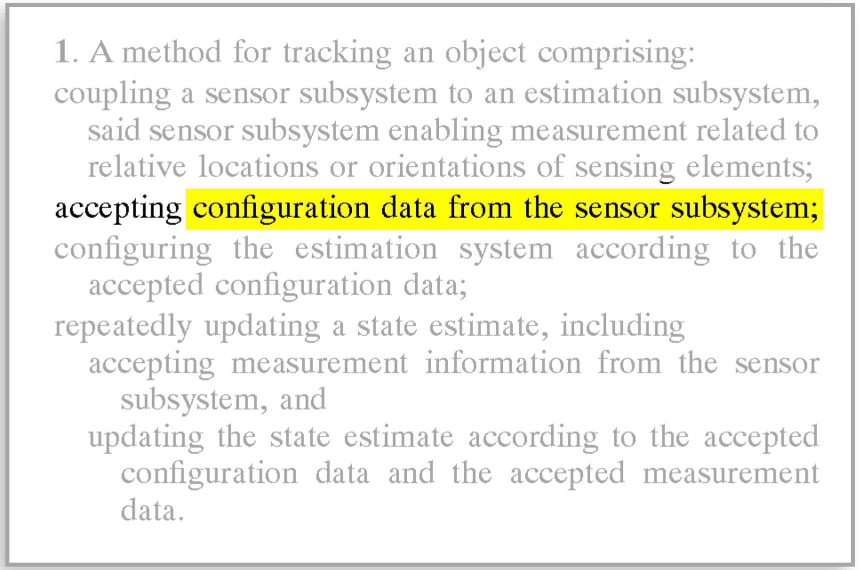
'632 cls. 1, 47 & dependent claims; '253 cl. 1 & dependent claims

Claims require:

1) Configuration data/information

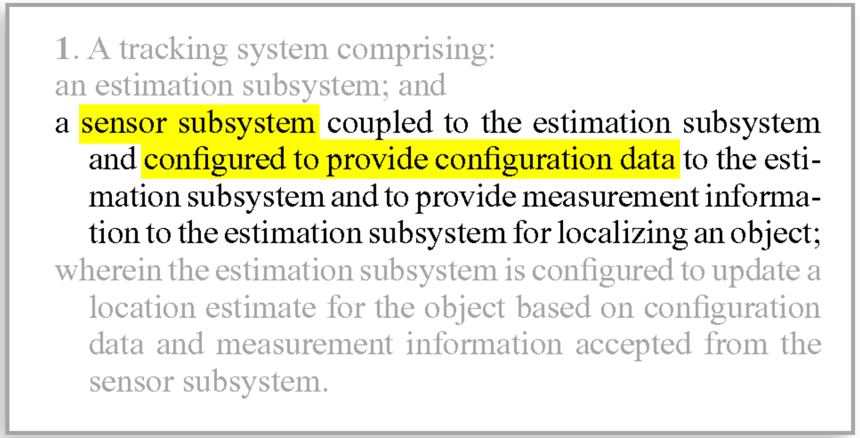
AND

2) Provided or accepted from the sensor subsystem or sensor module



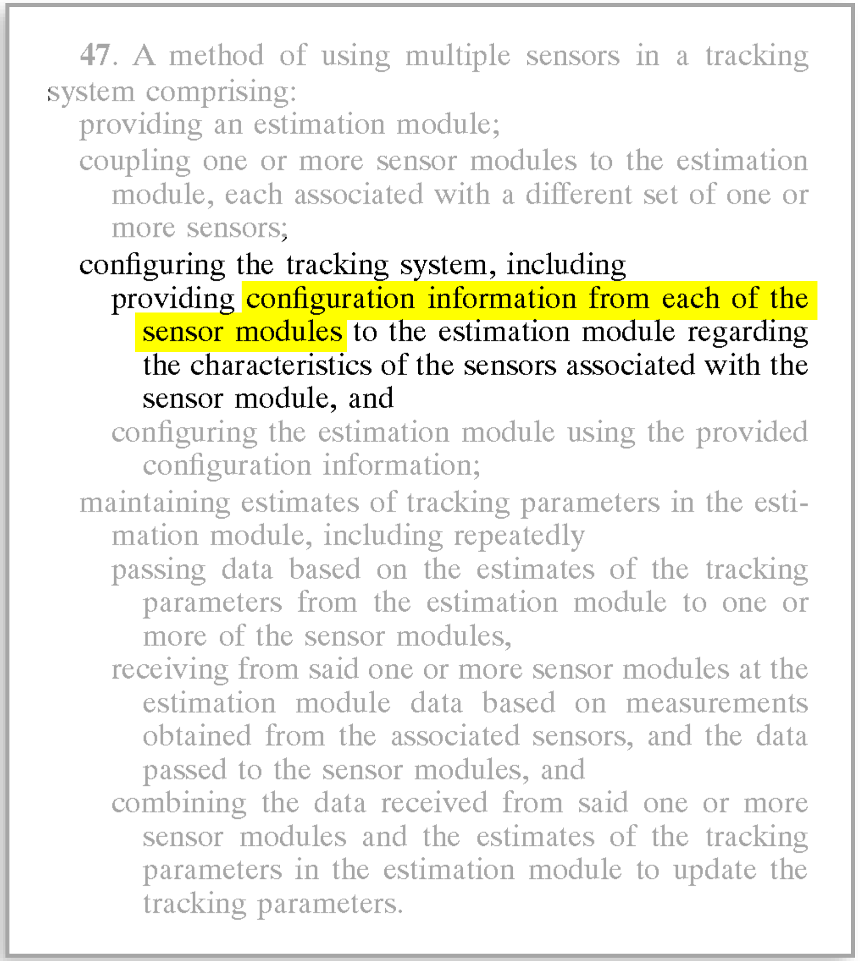
1. A method for tracking an object comprising:
coupling a sensor subsystem to an estimation subsystem, said sensor subsystem enabling measurement related to relative locations or orientations of sensing elements;
accepting configuration data from the sensor subsystem;
configuring the estimation system according to the accepted configuration data;
repeatedly updating a state estimate, including
accepting measurement information from the sensor subsystem, and
updating the state estimate according to the accepted configuration data and the accepted measurement data.

Ex. 1001, cl.1



1. A tracking system comprising:
an estimation subsystem; and
a sensor subsystem coupled to the estimation subsystem and configured to provide configuration data to the estimation subsystem and to provide measurement information to the estimation subsystem for localizing an object;
wherein the estimation subsystem is configured to update a location estimate for the object based on configuration data and measurement information accepted from the sensor subsystem.

Ex. 1003, cl.1



47. A method of using multiple sensors in a tracking system comprising:
providing an estimation module;
coupling one or more sensor modules to the estimation module, each associated with a different set of one or more sensors;
configuring the tracking system, including
providing configuration information from each of the sensor modules to the estimation module regarding the characteristics of the sensors associated with the sensor module, and
configuring the estimation module using the provided configuration information;
maintaining estimates of tracking parameters in the estimation module, including repeatedly
passing data based on the estimates of the tracking parameters from the estimation module to one or more of the sensor modules,
receiving from said one or more sensor modules at the estimation module data based on measurements obtained from the associated sensors, and the data passed to the sensor modules, and
combining the data received from said one or more sensor modules and the estimates of the tracking parameters in the estimation module to update the tracking parameters.

Ex. 1001, cl.47

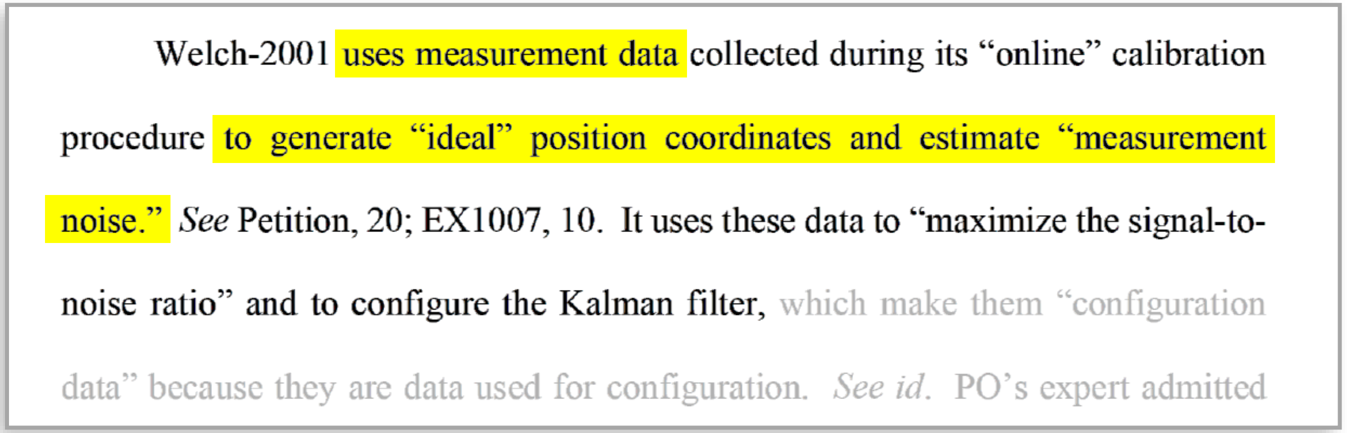
The Measurements on Which Petitioner Relies Are Not Configuration Data

’632 cls. 1, 47 & dependent claims; ’253 cl. 1 & dependent claims

Petitioner’s Construction: Data used for configuration

Petitioner	“Measurement data collected during [Welch-2001’s] ‘online’ calibration procedure”
Rebuttal	Petitioner acknowledges the sensor measurements are processed into ***different*** data on the PC The processed data, not the raw HiBall measurements, are used to configure the Kalman filter

Ex. 2007 ¶ 58; *e.g.*, 1304 POR 19; 1304 Reply 8; 1304 Sur-Reply 9-10



Welch-2001 uses measurement data collected during its “online” calibration procedure to generate “ideal” position coordinates and estimate “measurement noise.” *See* Petition, 20; EX1007, 10. It uses these data to “maximize the signal-to-noise ratio” and to configure the Kalman filter, which make them “configuration data” because they are data used for configuration. *See id.* PO’s expert admitted

1304 Reply 8

The Measurements on Which Petitioner Relies Are Not Configuration Data

’632 cls. 1, 47 & dependent claims; ’253 cl. 1 & dependent claims

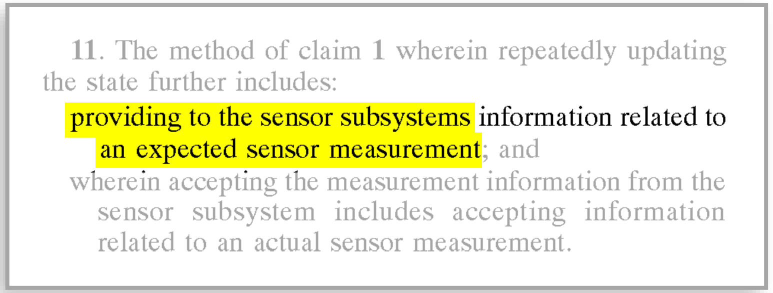
Patent Owner’s Construction: Data describing the characteristics or attributes of a sensor or set of sensors

Petitioner	“Amount of light impinging on different locations of the HiBall unit” describes HiBall pose	“Measurement type” metadata
Rebuttal	Describes where light hits on a HiBall sensor, not where in the environment that sensor is located or how the sensor is oriented	Programmed by a system designer, not provided by a sensor subsystem or module

E.g., 1304 Reply 9-10; 1304 Sur-Reply 10-11

Welch’s Estimation Subsystem Does Not Pass Information Back to a Sensor Subsystem or Modules

’632 cls. 11, 30, 47 & dependent claims

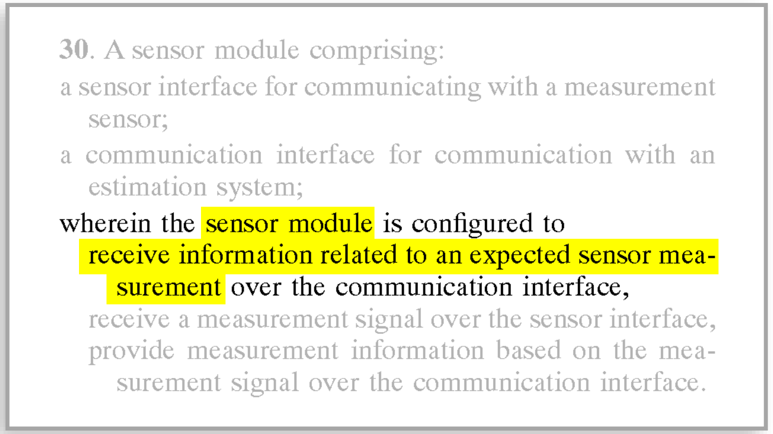


11. The method of claim 1 wherein repeatedly updating the state further includes:

providing to the sensor subsystems information related to an expected sensor measurement; and

wherein accepting the measurement information from the sensor subsystem includes accepting information related to an actual sensor measurement.

Ex. 1001, cl.11



30. A sensor module comprising:

a sensor interface for communicating with a measurement sensor;

a communication interface for communication with an estimation system;

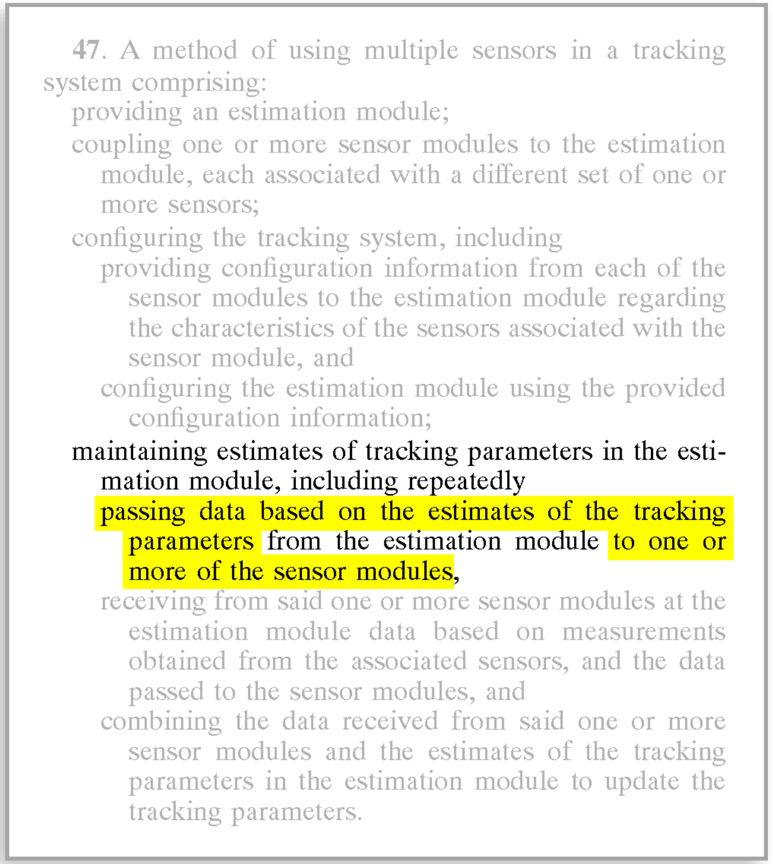
wherein the sensor module is configured to

receive information related to an expected sensor measurement over the communication interface,

receive a measurement signal over the sensor interface,

provide measurement information based on the measurement signal over the communication interface.

Ex. 1001, cl.30



47. A method of using multiple sensors in a tracking system comprising:

providing an estimation module;

coupling one or more sensor modules to the estimation module, each associated with a different set of one or more sensors;

configuring the tracking system, including

providing configuration information from each of the sensor modules to the estimation module regarding the characteristics of the sensors associated with the sensor module, and

configuring the estimation module using the provided configuration information;

maintaining estimates of tracking parameters in the estimation module, including repeatedly

passing data based on the estimates of the tracking parameters from the estimation module to one or more of the sensor modules,

receiving from said one or more sensor modules at the estimation module data based on measurements obtained from the associated sensors, and the data passed to the sensor modules, and

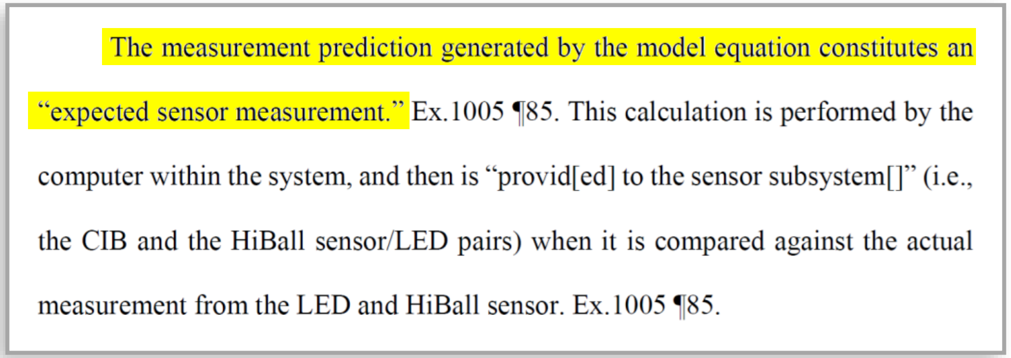
combining the data received from said one or more sensor modules and the estimates of the tracking parameters in the estimation module to update the tracking parameters.

Ex. 1001, cl.47

Petitioner's New Arguments Are Improper and Unsupported

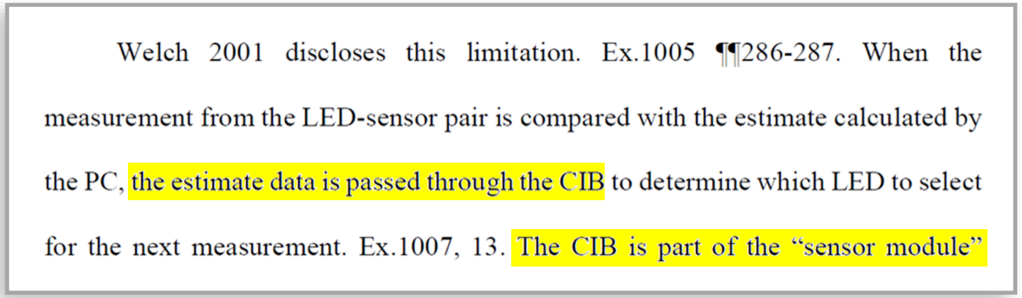
'632 cls. 11, 47 & dependent claims

Petition



The measurement prediction generated by the model equation constitutes an "expected sensor measurement." Ex.1005 ¶85. This calculation is performed by the computer within the system, and then is "provid[ed] to the sensor subsystem[]" (i.e., the CIB and the HiBall sensor/LED pairs) when it is compared against the actual measurement from the LED and HiBall sensor. Ex.1005 ¶85.

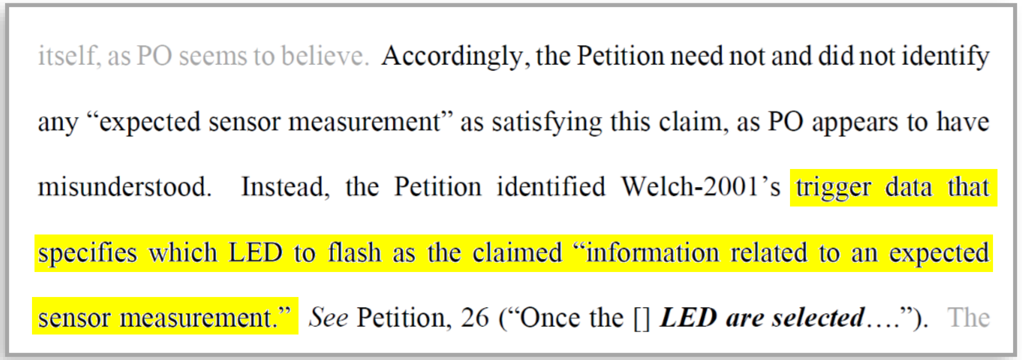
1304 Petition 26



Welch 2001 discloses this limitation. Ex.1005 ¶¶286-287. When the measurement from the LED-sensor pair is compared with the estimate calculated by the PC, the estimate data is passed through the CIB to determine which LED to select for the next measurement. Ex.1007, 13. The CIB is part of the "sensor module"

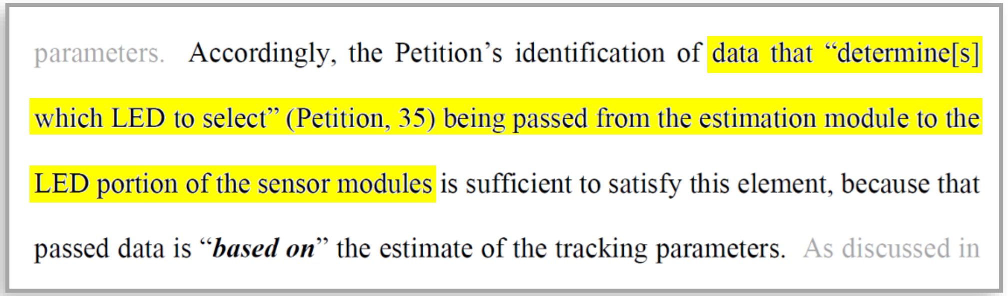
1305 Petition 35

Reply



itself, as PO seems to believe. Accordingly, the Petition need not and did not identify any "expected sensor measurement" as satisfying this claim, as PO appears to have misunderstood. Instead, the Petition identified Welch-2001's trigger data that specifies which LED to flash as the claimed "information related to an expected sensor measurement." *See* Petition, 26 ("Once the [] ***LED are selected***…."). The

1304 Reply 13



parameters. Accordingly, the Petition's identification of data that "determine[s] which LED to select" (Petition, 35) being passed from the estimation module to the LED portion of the sensor modules is sufficient to satisfy this element, because that passed data is "***based on***" the estimate of the tracking parameters. As discussed in

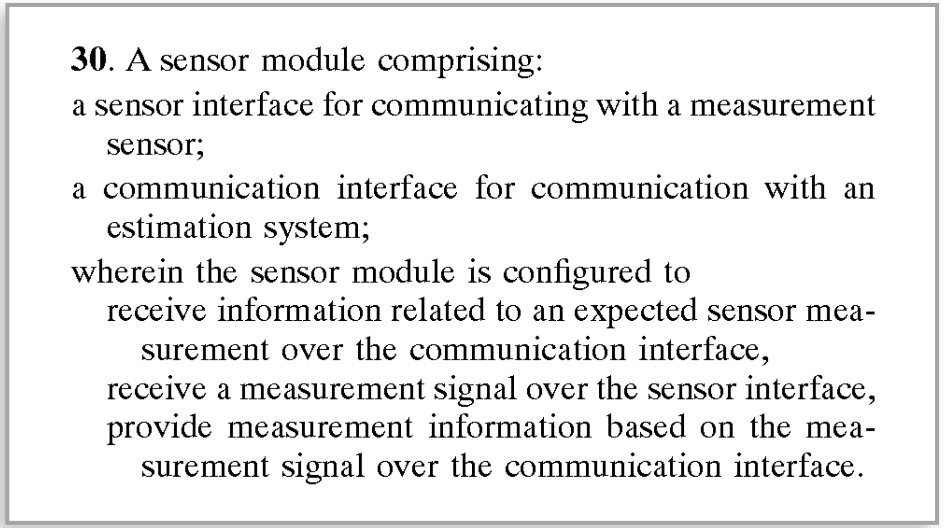
1305 Reply 14

> "[A]n IPR petitioner may not raise in reply an entirely new rationale for why a claim would have been obvious."

Henny Penny Corp. v. Frymaster LLC, 938 F.3d 1324, 1330-31 (Fed. Cir. 2019) (internal quotation marks omitted); e.g., 1305 Sur-Reply 17

Welch’s Sensor Module Does Not Receive Information Over the Asserted Communication Interface

’632 cl. 30 & dependent claims



30. A sensor module comprising:

a sensor interface for communicating with a measurement sensor;

a communication interface for communication with an estimation system;

wherein the sensor module is configured to
receive information related to an expected sensor measurement over the communication interface,
receive a measurement signal over the sensor interface,
provide measurement information based on the measurement signal over the communication interface.

Ex. 1001, cl.30

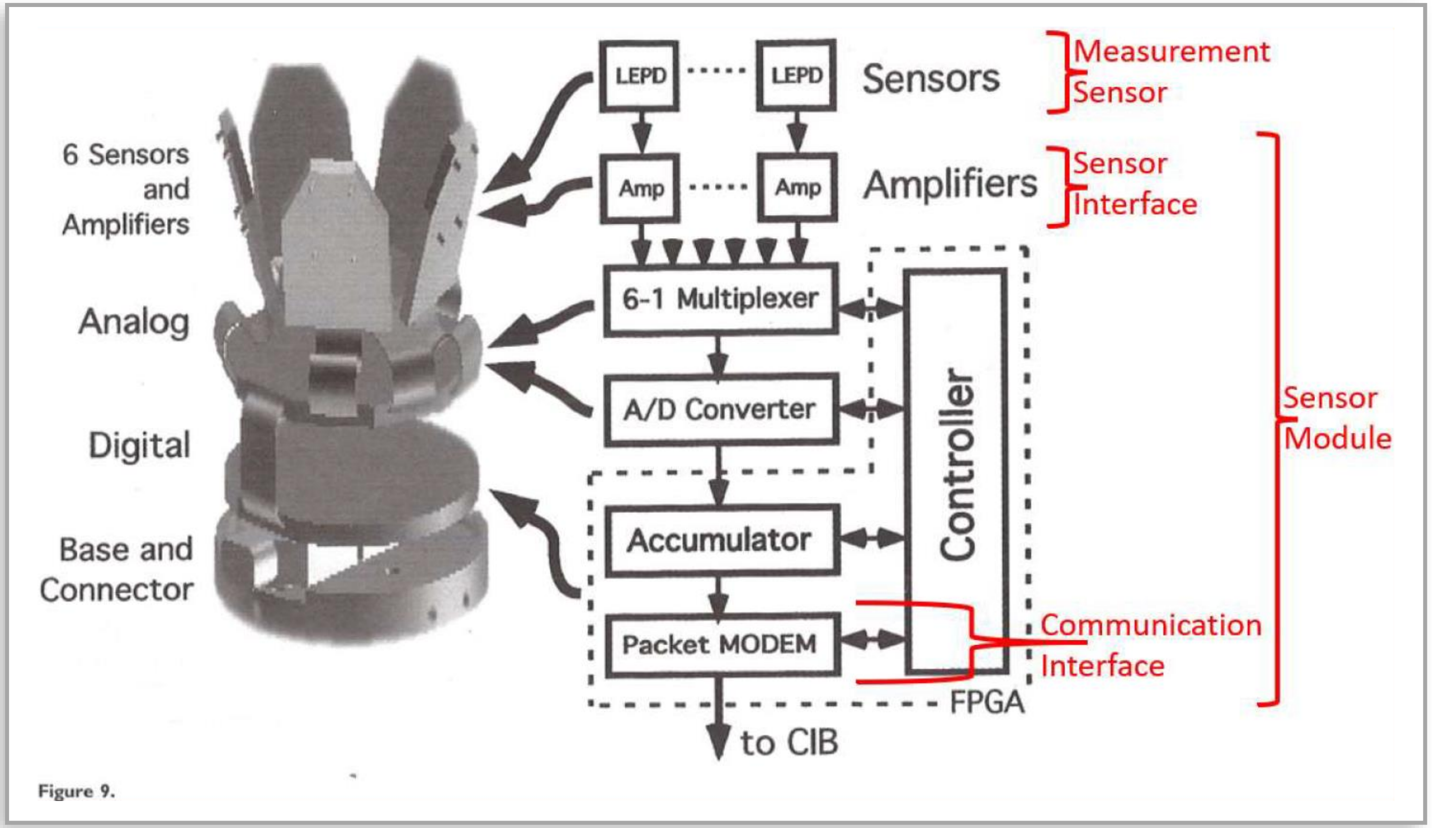


Figure 9.

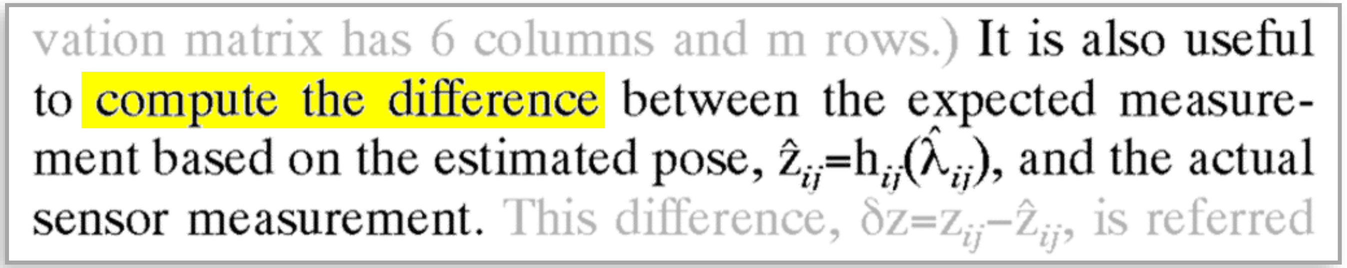
Ex. 1007, Fig.9 (annotated by Petitioner); 1305 Reply 6

Welch’s Sensor Module and Subsystem Do Not Receive Information Related to an Expected Sensor Measurement

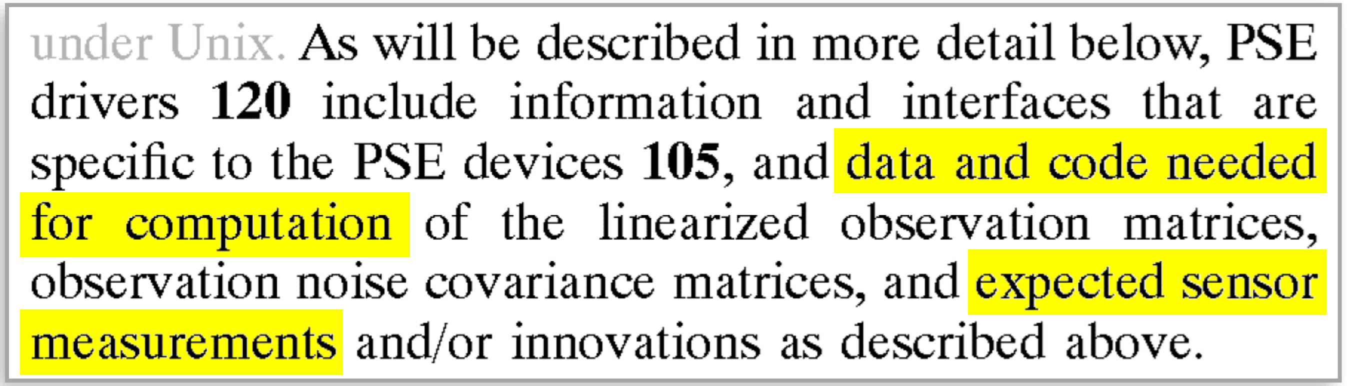
’632 cls. 3, 11 & dependent claims

Petitioner	Relies on anticipation that a measurement will occur
Rebuttal	Patent describes “expected sensor measurement” as a calculated numerical value

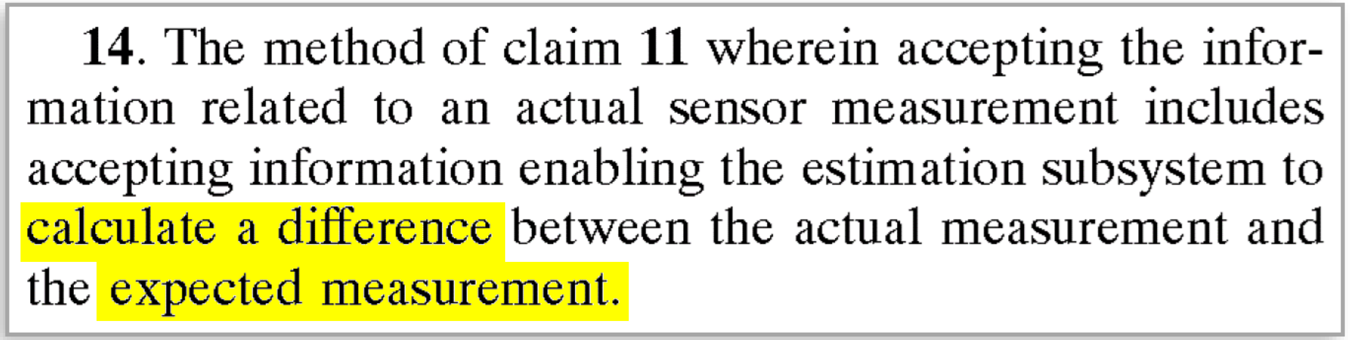
E.g., 1304 Reply 13; 1304 Sur-Reply 14



vation matrix has 6 columns and m rows.) It is also useful to compute the difference between the expected measurement based on the estimated pose, $\hat{z}_{ij}=h_{ij}(\hat{\lambda}_{ij})$, and the actual sensor measurement. This difference, $\delta z=z_{ij}-\hat{z}_{ij}$, is referred



under Unix. As will be described in more detail below, PSE drivers **120** include information and interfaces that are specific to the PSE devices **105**, and data and code needed for computation of the linearized observation matrices, observation noise covariance matrices, and expected sensor measurements and/or innovations as described above.



14. The method of claim **11** wherein accepting the information related to an actual sensor measurement includes accepting information enabling the estimation subsystem to calculate a difference between the actual measurement and the expected measurement.

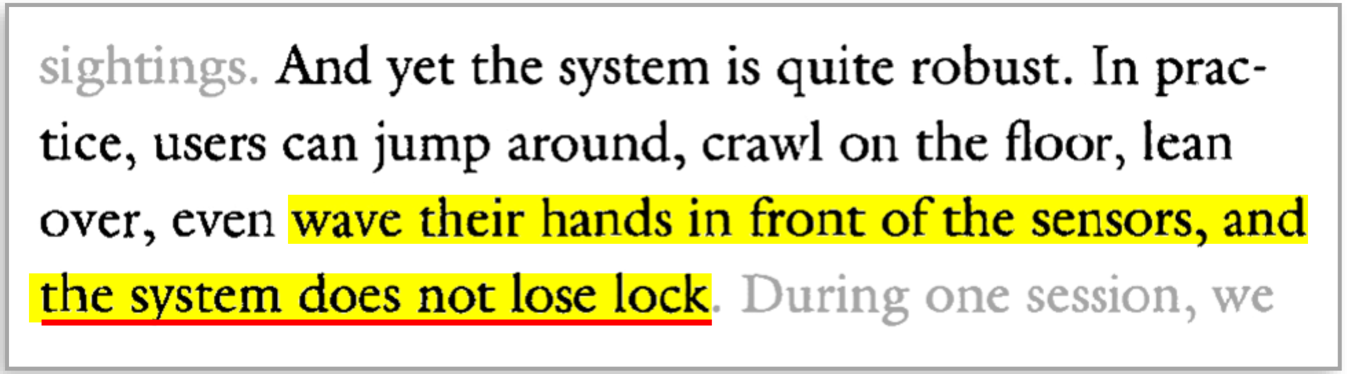
Ex. 1001, 15:47-50, 16:51-56, cl.14; *e.g.*, 1304 Sur-Reply 14

Petitioner Does Not Establish Any Motivation To Add Inertial Trackers to Welch’s HiBalls

’632 cl. 23

Petitioner	Points to purported “occlusions”
Rebuttal	Welch 2001 teaches that occlusions rarely cause problems in practice

1304 Reply 14; 1304 Sur-Reply 16



sightings. And yet the system is quite robust. In practice, users can jump around, crawl on the floor, lean over, even wave their hands in front of the sensors, and the system does not lose lock. During one session, we

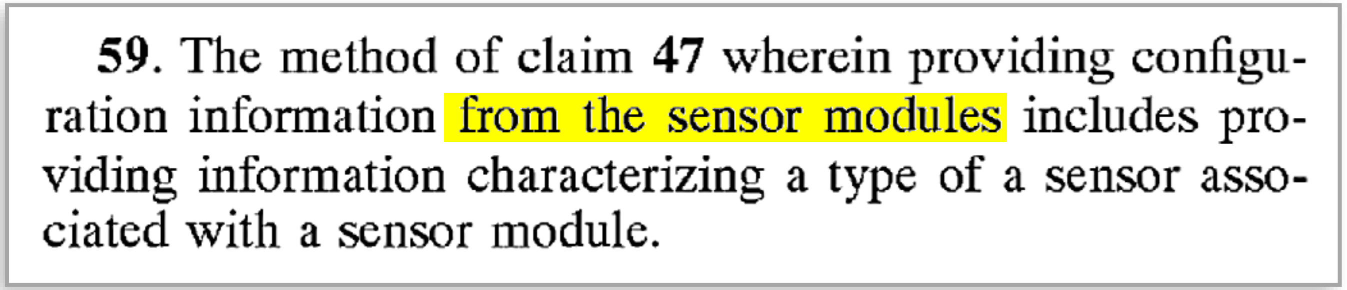
Ex. 1007, 14; 1304 Sur-Reply 16

Welch's Sensor Module Does Not Provide Information Characterizing Sensor Type

'632 cl. 59

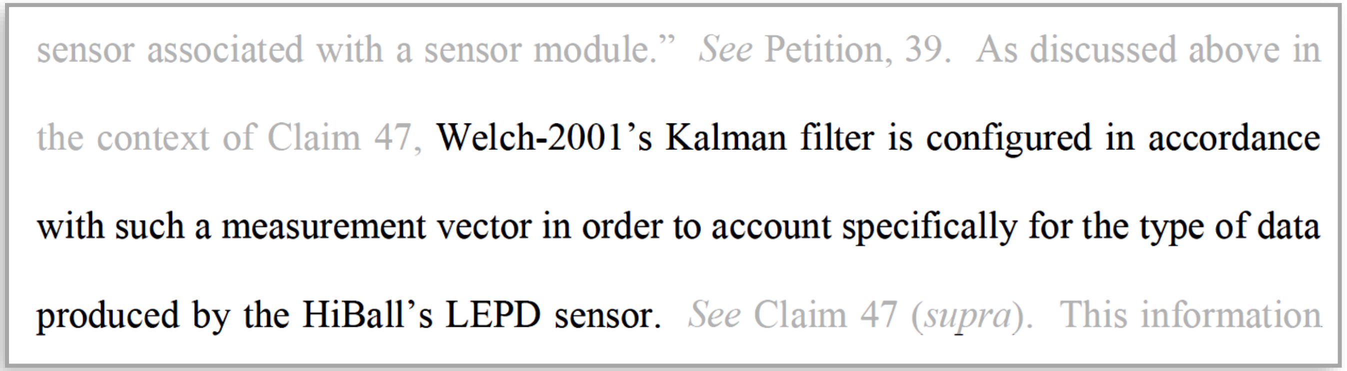
Petitioner	KF configured to account for type of data produced by HiBall LEPD sensor
Rebuttal	This configuration of Welch's Kalman filter is done by the system designer, not provided by a sensor module

E.g., 1305 Reply 16; 1305 Sur-Reply 17



59. The method of claim **47** wherein providing configuration information from the sensor modules includes providing information characterizing a type of a sensor associated with a sensor module.

Ex. 1001, cl.59; *e.g.*, 1305 Sur-Reply 17



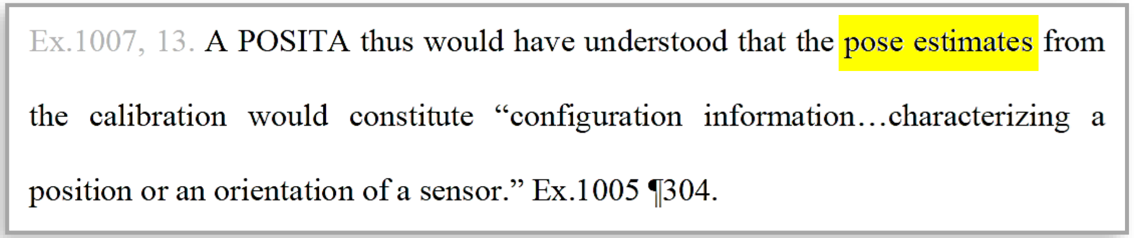
sensor associated with a sensor module." *See* Petition, 39. As discussed above in the context of Claim 47, Welch-2001's Kalman filter is configured in accordance with such a measurement vector in order to account specifically for the type of data produced by the HiBall's LEPD sensor. *See* Claim 47 (*supra*). This information

1305 Reply 16

Welch’s Sensor Module Does Not Provide Information Characterizing Sensor Position or Orientation

’632 cl. 60

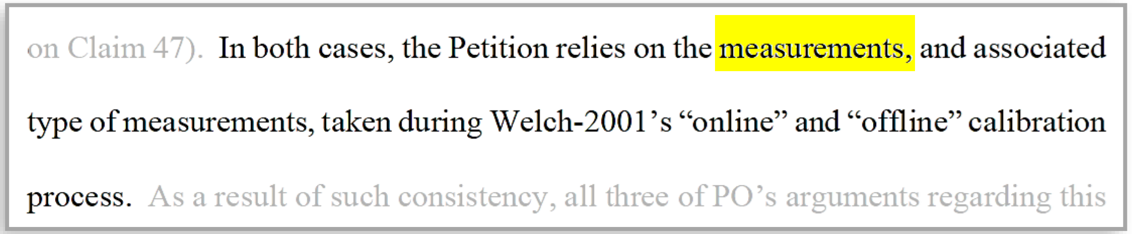
Petition



Ex.1007, 13. A POSITA thus would have understood that the pose estimates from the calibration would constitute “configuration information…characterizing a position or an orientation of a sensor.” Ex.1005 ¶304.

1305 Petition 40

Reply

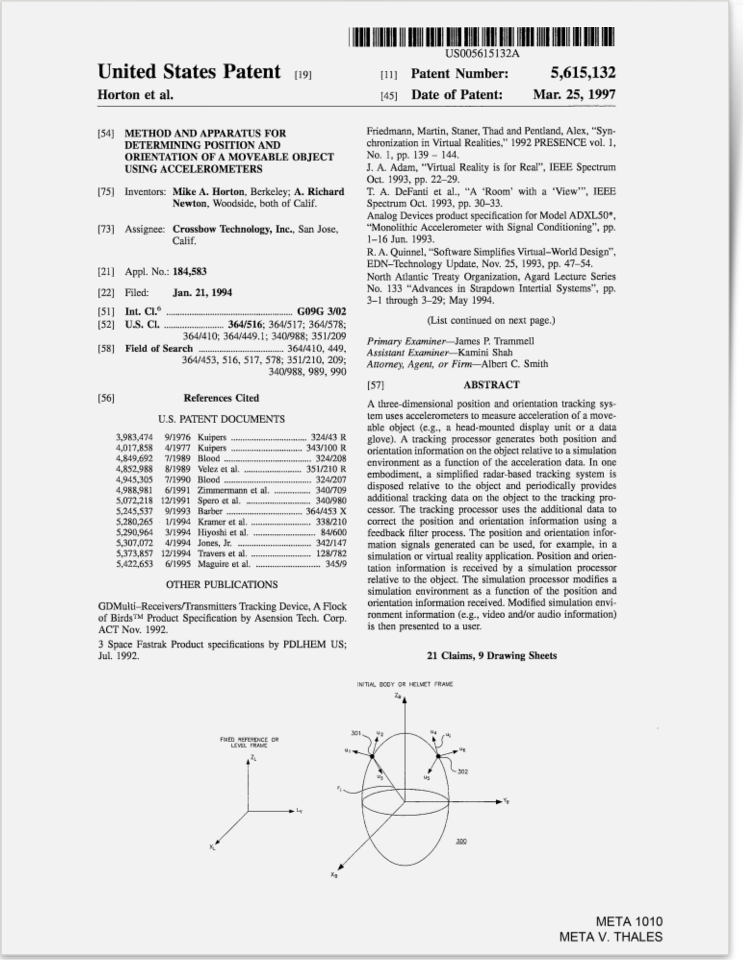


on Claim 47). In both cases, the Petition relies on the measurements, and associated type of measurements, taken during Welch-2001’s “online” and “offline” calibration process. As a result of such consistency, all three of PO’s arguments regarding this

1305 Reply 17

Horton

Horton Accelerometer System



US005615132A

United States Patent [19]

Horton et al.

[11] **Patent Number: 5,615,132**

[45] **Date of Patent: Mar. 25, 1997**

[54] **METHOD AND APPARATUS FOR DETERMINING POSITION AND ORIENTATION OF A MOVEABLE OBJECT USING ACCELEROMETERS**

[75] Inventors: **Mike A. Horton**, Berkeley; **A. Richard Newton**, Woodside, both of Calif.

[73] Assignee: **Crossbow Technology, Inc.**, San Jose, Calif.

[21] Appl. No.: **184,583**

[22] Filed: **Jan. 21, 1994**

[51] **Int. Cl.**^{6} **G09G 3/02**

[52] **U.S. Cl.** **364/516**; 364/517; 364/578; 364/410; 364/449.1; 340/988; 351/209

[58] **Field of Search** 364/410, 449, 364/453, 516, 517, 578; 351/210, 209; 340/988, 989, 990

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,983,474	9/1976	Kuipers	324/43 R
4,017,858	4/1977	Kuipers	343/100 R
4,849,692	7/1989	Blood	324/208
4,852,988	8/1989	Velez et al.	351/210 R
4,945,305	7/1990	Blood	324/207
4,988,981	6/1991	Zimmermann et al.	340/709
5,072,218	12/1991	Spero et al.	340/980
5,245,537	9/1993	Barber	364/453 X
5,280,265	1/1994	Kramer et al.	338/210
5,290,964	3/1994	Hiyoshi et al.	84/600
5,307,072	4/1994	Jones, Jr.	342/147
5,373,857	12/1994	Travers et al.	128/782
5,422,653	6/1995	Maguire et al.	345/9

OTHER PUBLICATIONS

GDMulti–Receivers/Transmitters Tracking Device, A Flock of Birds™ Product Specification by Asension Tech. Corp. ACT Nov. 1992.

3 Space Fastrak Product specifications by PDLHEM US; Jul. 1992.

Friedmann, Martin, Staner, Thad and Pentland, Alex, "Synchronization in Virtual Realities," 1992 PRESENCE vol. 1, No. 1, pp. 139 – 144.

J. A. Adam, "Virtual Reality is for Real", IEEE Spectrum Oct. 1993, pp. 22–29.

T. A. DeFanti et al., "A 'Room' with a 'View'", IEEE Spectrum Oct. 1993, pp. 30–33.

Analog Devices product specification for Model ADXL50*, "Monolithic Accelerometer with Signal Conditioning", pp. 1–16 Jun. 1993.

R. A. Quinnel, "Software Simplifies Virtual–World Design", EDN–Technology Update, Nov. 25, 1993, pp. 47–54.

North Atlantic Treaty Organization, Agard Lecture Series No. 133 "Advances in Strapdown Intertial Systems", pp. 3–1 through 3–29; May 1994.

(List continued on next page.)

Primary Examiner—James P. Trammell
Assistant Examiner—Kamini Shah
Attorney, Agent, or Firm—Albert C. Smith

[57] **ABSTRACT**

A three-dimensional position and orientation tracking system uses accelerometers to measure acceleration of a moveable object (e.g., a head-mounted display unit or a data glove). A tracking processor generates both position and orientation information on the object relative to a simulation environment as a function of the acceleration data. In one embodiment, a simplified radar-based tracking system is disposed relative to the object and periodically provides additional tracking data on the object to the tracking processor. The tracking processor uses the additional data to correct the position and orientation information using a feedback filter process. The position and orientation information signals generated can be used, for example, in a simulation or virtual reality application. Position and orientation information is received by a simulation processor relative to the object. The simulation processor modifies a simulation environment as a function of the position and orientation information received. Modified simulation environment information (e.g., video and/or audio information) is then presented to a user.

21 Claims, 9 Drawing Sheets

META 1010
META V. THALES

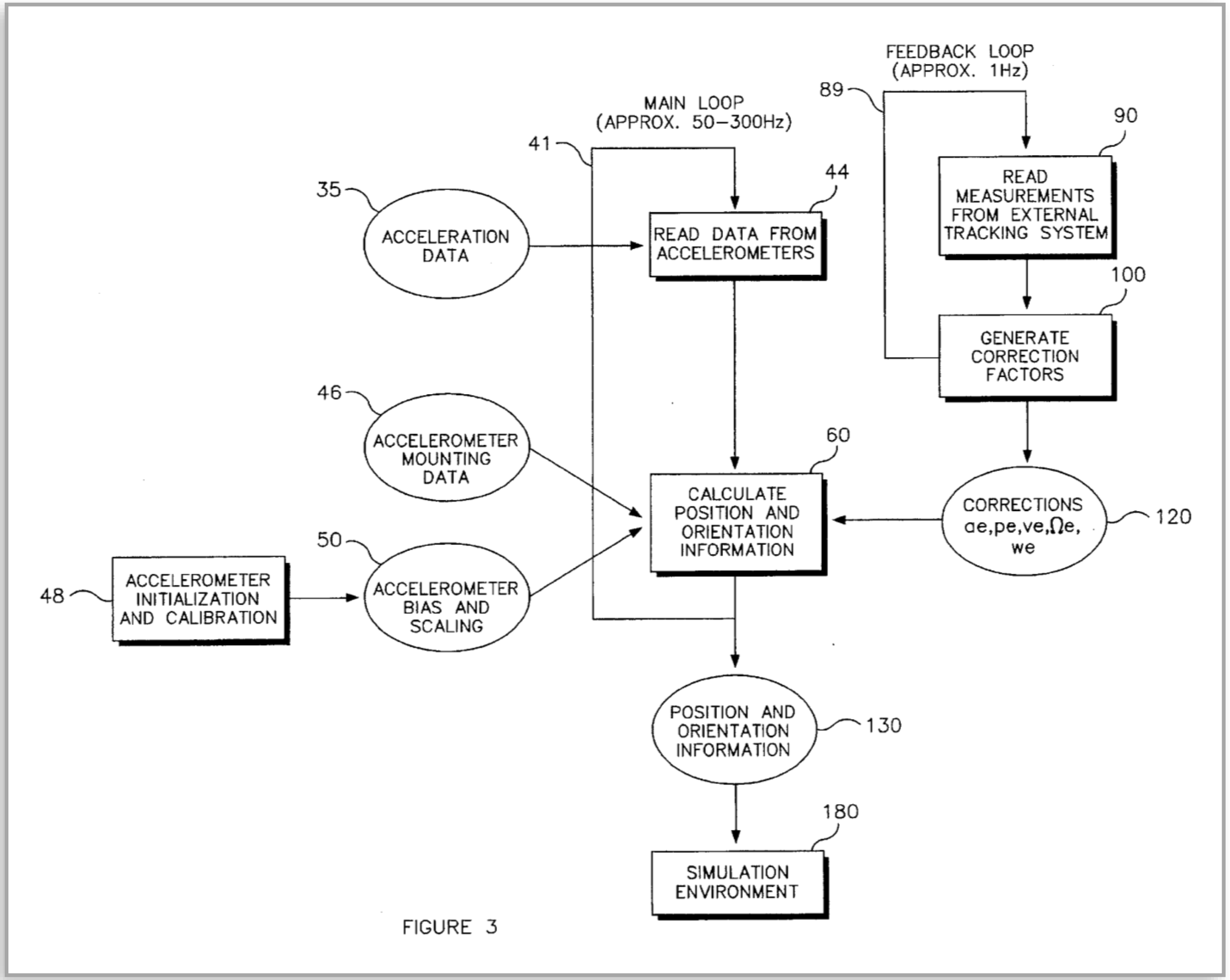


FIGURE 3

Ex. 1010, Fig.3; *e.g.*, 1304 Petition 40; 1304 POR 9

Horton Accelerometer System

Initialization and calibration routine 48

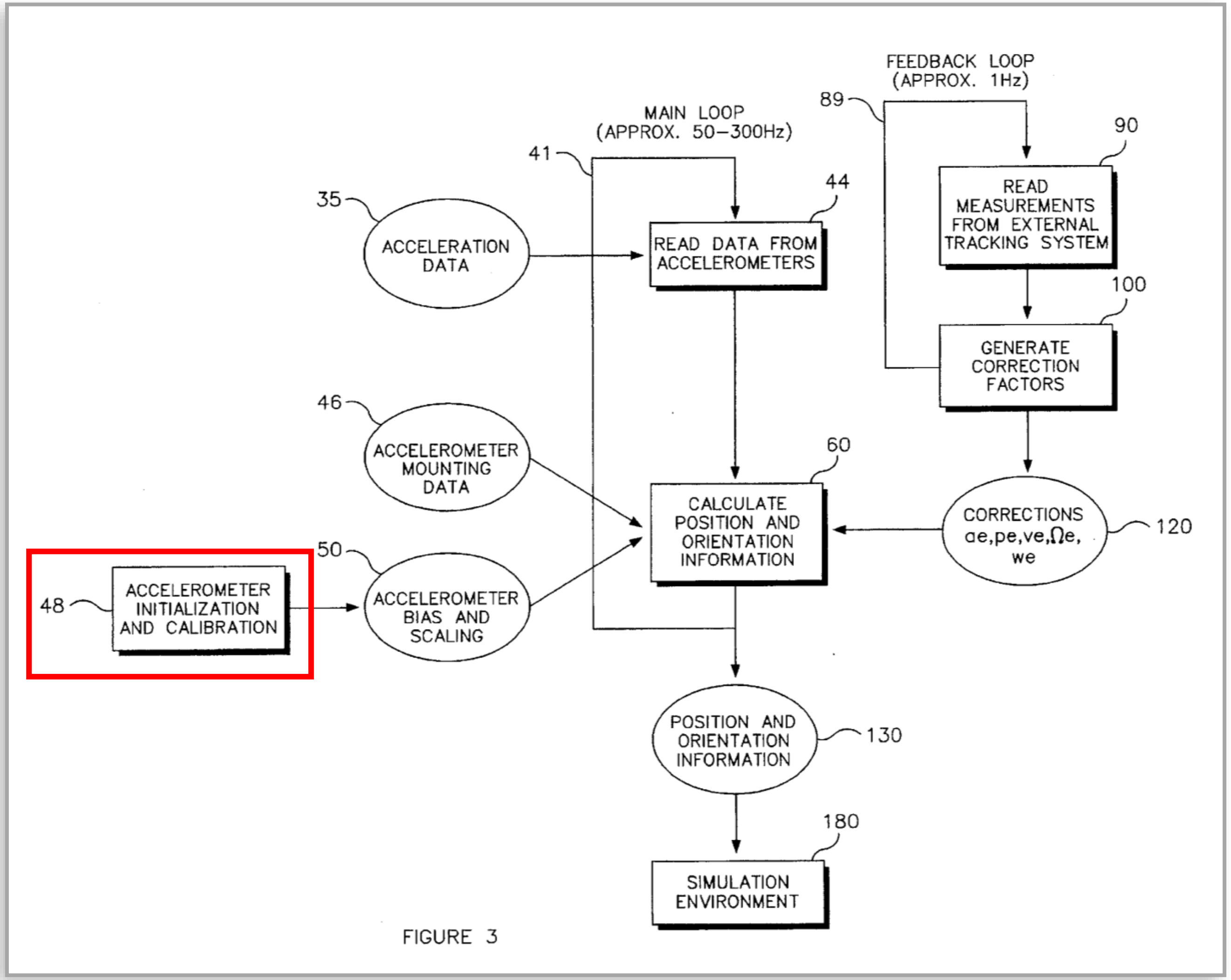
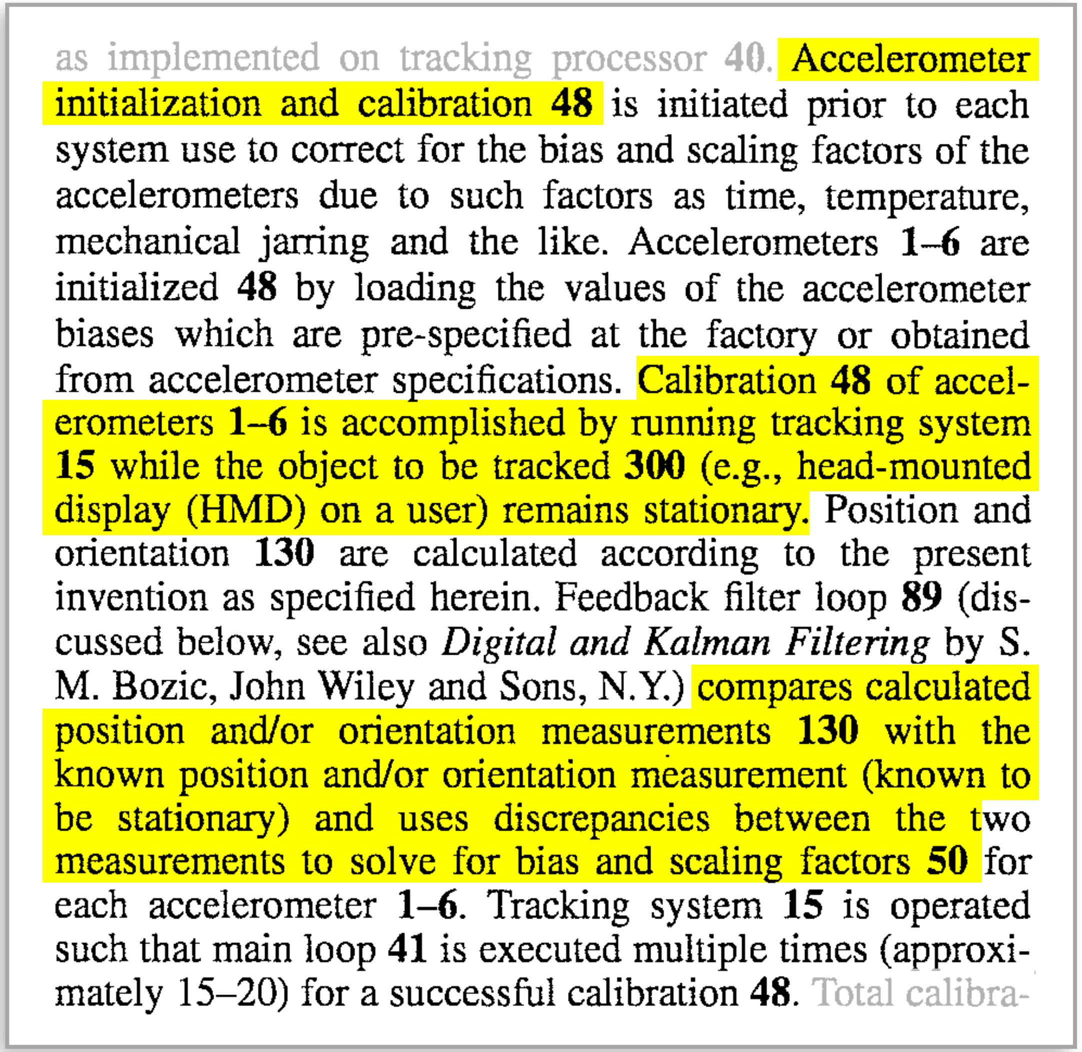


FIGURE 3

Ex. 1010, Fig.3; *e.g.*, 1304 POR 9



as implemented on tracking processor **40**. Accelerometer initialization and calibration **48** is initiated prior to each system use to correct for the bias and scaling factors of the accelerometers due to such factors as time, temperature, mechanical jarring and the like. Accelerometers **1–6** are initialized **48** by loading the values of the accelerometer biases which are pre-specified at the factory or obtained from accelerometer specifications. Calibration **48** of accelerometers **1–6** is accomplished by running tracking system **15** while the object to be tracked **300** (e.g., head-mounted display (HMD) on a user) remains stationary. Position and orientation **130** are calculated according to the present invention as specified herein. Feedback filter loop **89** (discussed below, see also *Digital and Kalman Filtering* by S. M. Bozic, John Wiley and Sons, N.Y.) compares calculated position and/or orientation measurements **130** with the known position and/or orientation measurement (known to be stationary) and uses discrepancies between the two measurements to solve for bias and scaling factors **50** for each accelerometer **1–6**. Tracking system **15** is operated such that main loop **41** is executed multiple times (approximately 15–20) for a successful calibration **48**. Total calibra-

Ex. 1010, 5:60-6:14; *e.g.*, 1304 POR 9; 1304 Sur-Reply 19

Horton Accelerometer System

External tracking system 170

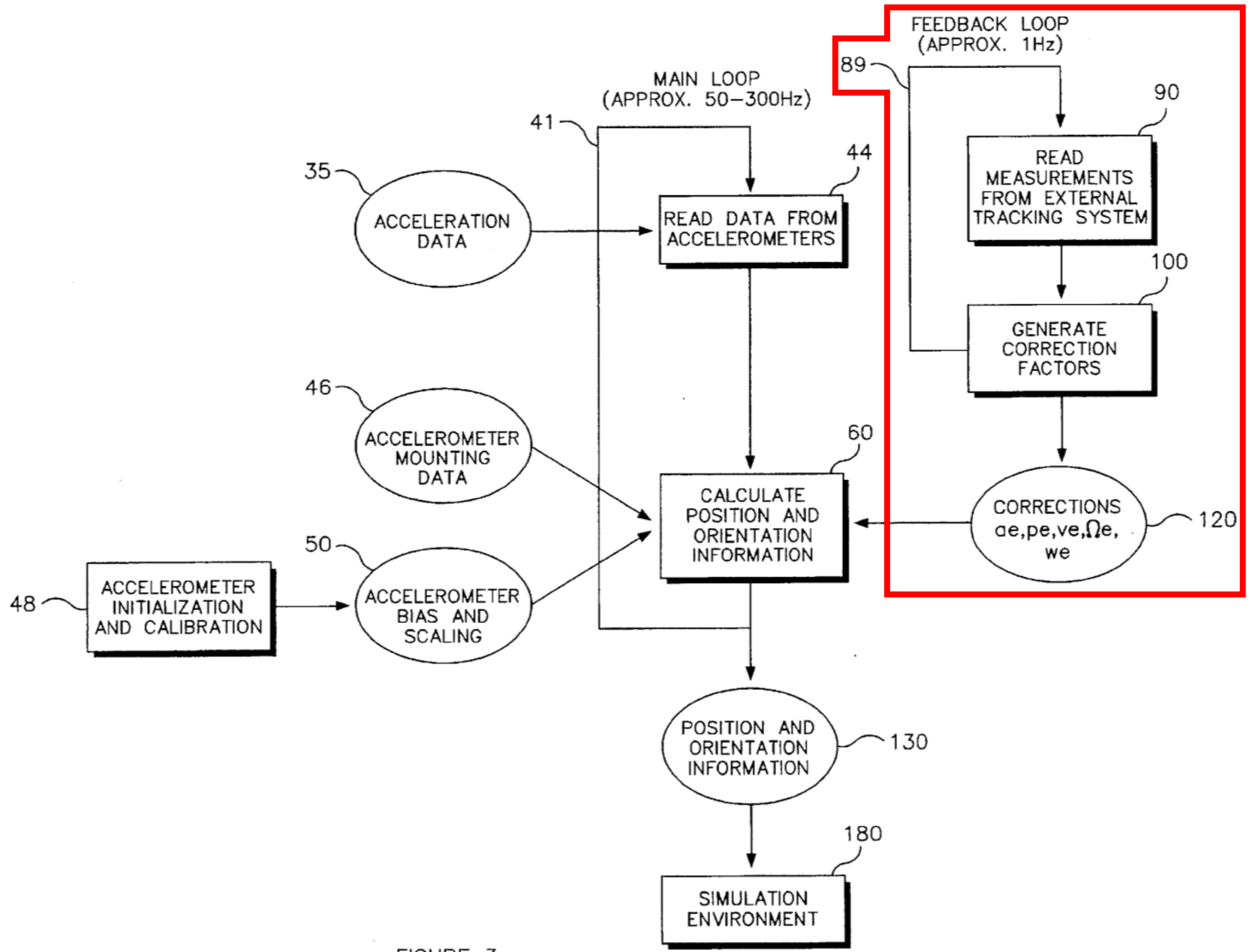
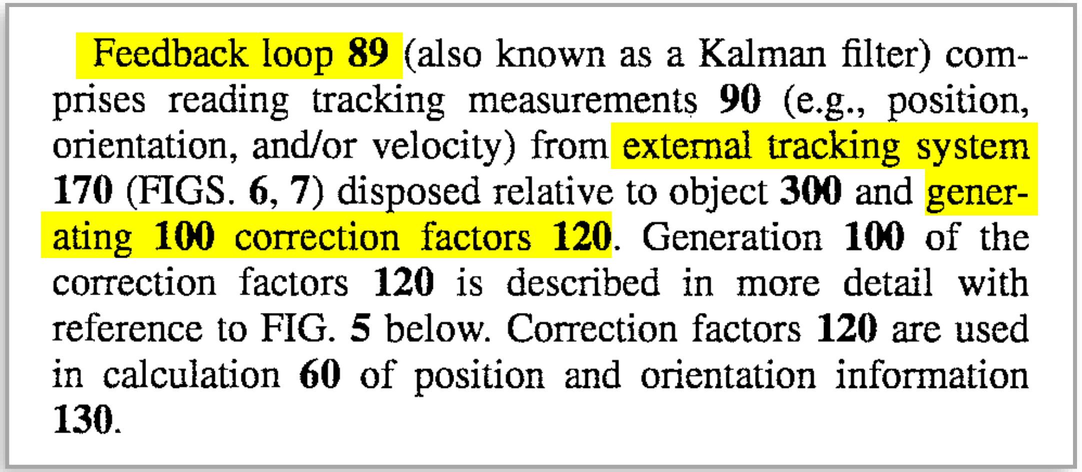


FIGURE 3

Ex. 1010, Fig.3; *e.g.*, 1304 POR 9



Feedback loop **89** (also known as a Kalman filter) comprises reading tracking measurements **90** (e.g., position, orientation, and/or velocity) from external tracking system **170** (FIGS. **6**, **7**) disposed relative to object **300** and generating **100** correction factors **120**. Generation **100** of the correction factors **120** is described in more detail with reference to FIG. **5** below. Correction factors **120** are used in calculation **60** of position and orientation information **130**.

Ex. 1010, 6:34-42; *e.g.*, 1304 POR 9

Horton Accelerometer System

Main loop 41

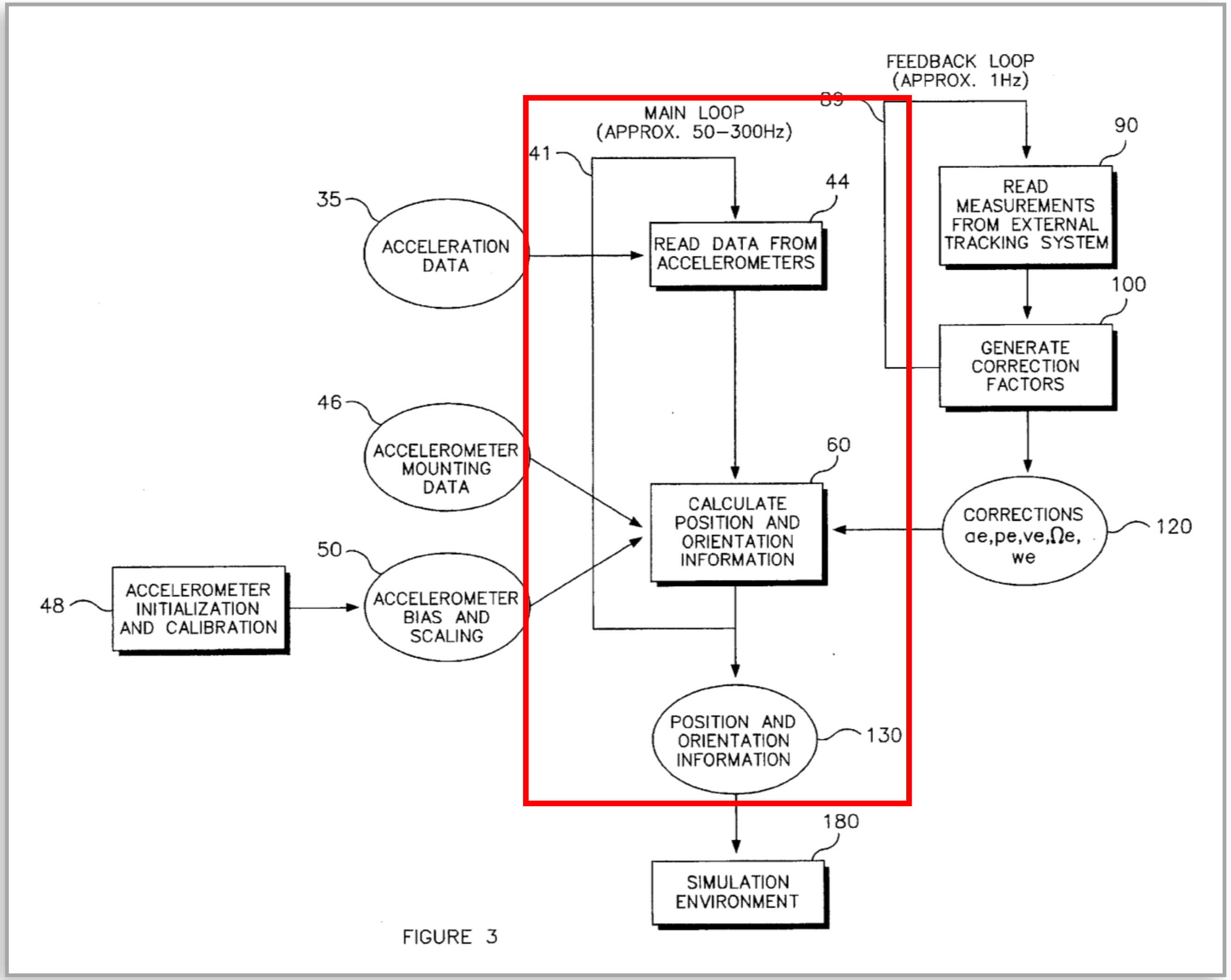
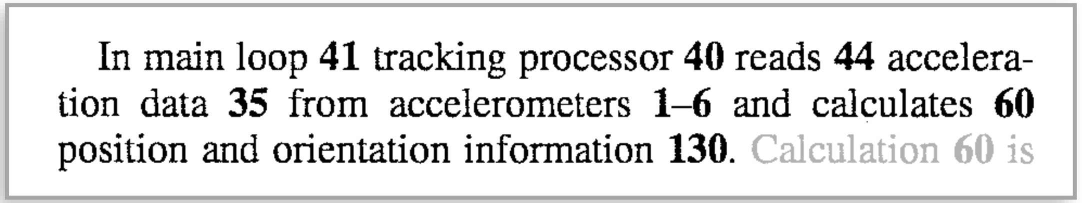


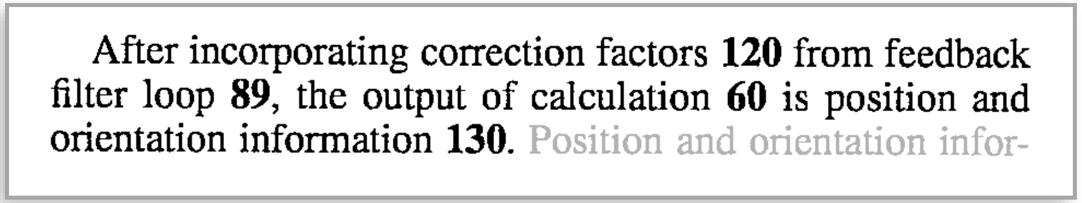
FIGURE 3

Ex. 1010, Fig.3; *e.g.*, 1304 POR 9



In main loop **41** tracking processor **40** reads **44** acceleration data **35** from accelerometers **1–6** and calculates **60** position and orientation information **130**. Calculation **60** is

Ex. 1010, 6:25-27; *e.g.*, 1304 POR 9, 43, 54



After incorporating correction factors **120** from feedback filter loop **89**, the output of calculation **60** is position and orientation information **130**. Position and orientation infor-

Ex. 1010, 7:1-3; *e.g.*, 1304 POR 9, 43, 54

Horton Accelerometer System

Calculation 60 of position and orientation information 130

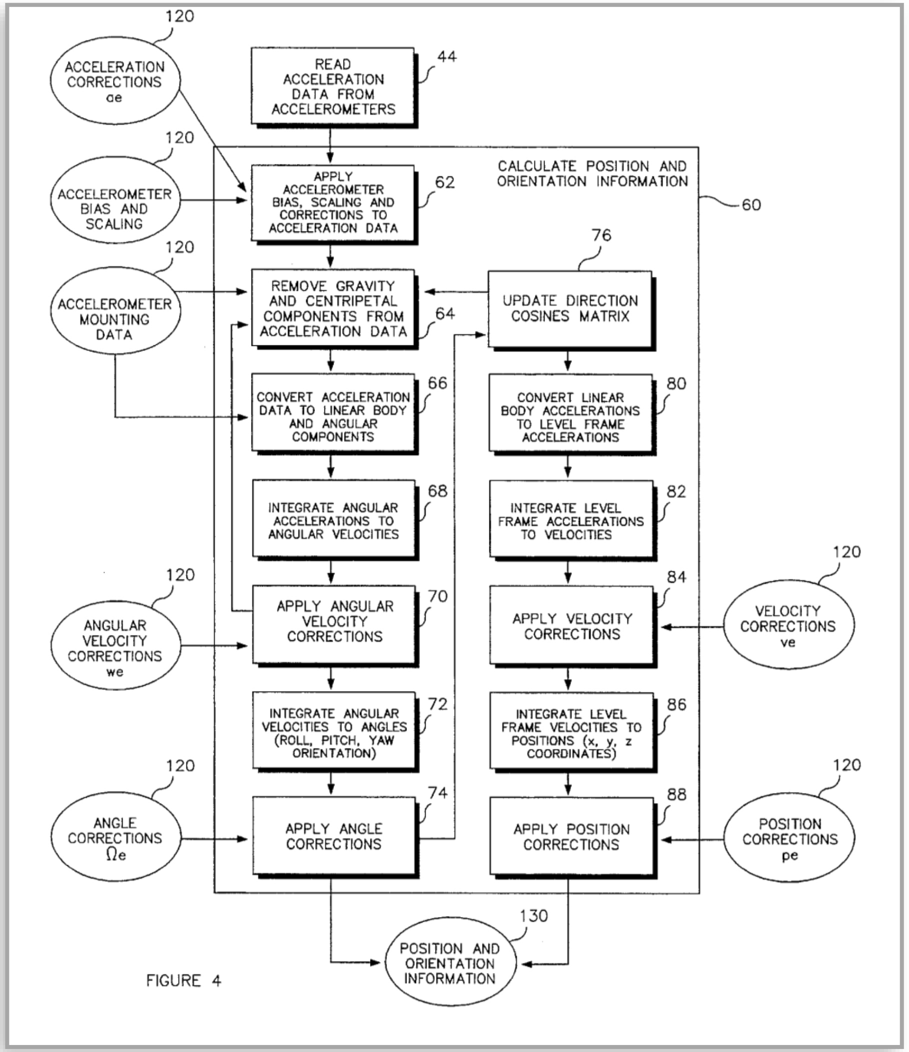


FIGURE 4

Ex. 1010, Fig.4; *e.g.*, 1304 POR 43, 54

Petitioner’s Sensor Subsystem and Estimation Subsystem Overlap

’632 cl. 1 & dependent claims; ’253 cl. 1 & dependent claims

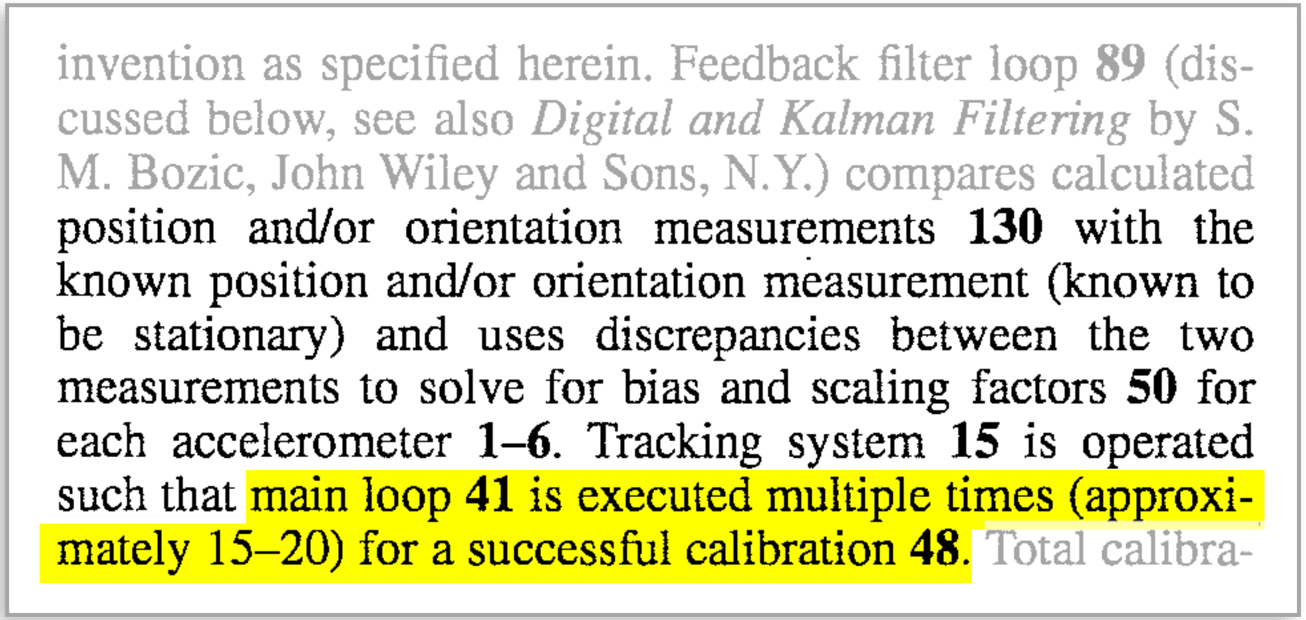
	Estimation Subsystem	**Sensor Subsystem**
Petitioner	“main loop 41 and the Kalman filter (i.e., feedback loop 89) executed by tracking processor 40”	“initialization routine 48 and related data”

E.g., 1304 Reply 15-16

Petitioner’s Sensor Subsystem and Estimation Subsystem Overlap

’632 cl. 1 & dependent claims; ’253 cl. 1 & dependent claims

- Main loop 41 (part of the asserted estimation subsystem) is used within initialization and calibration routine 48 (the asserted sensor subsystem).



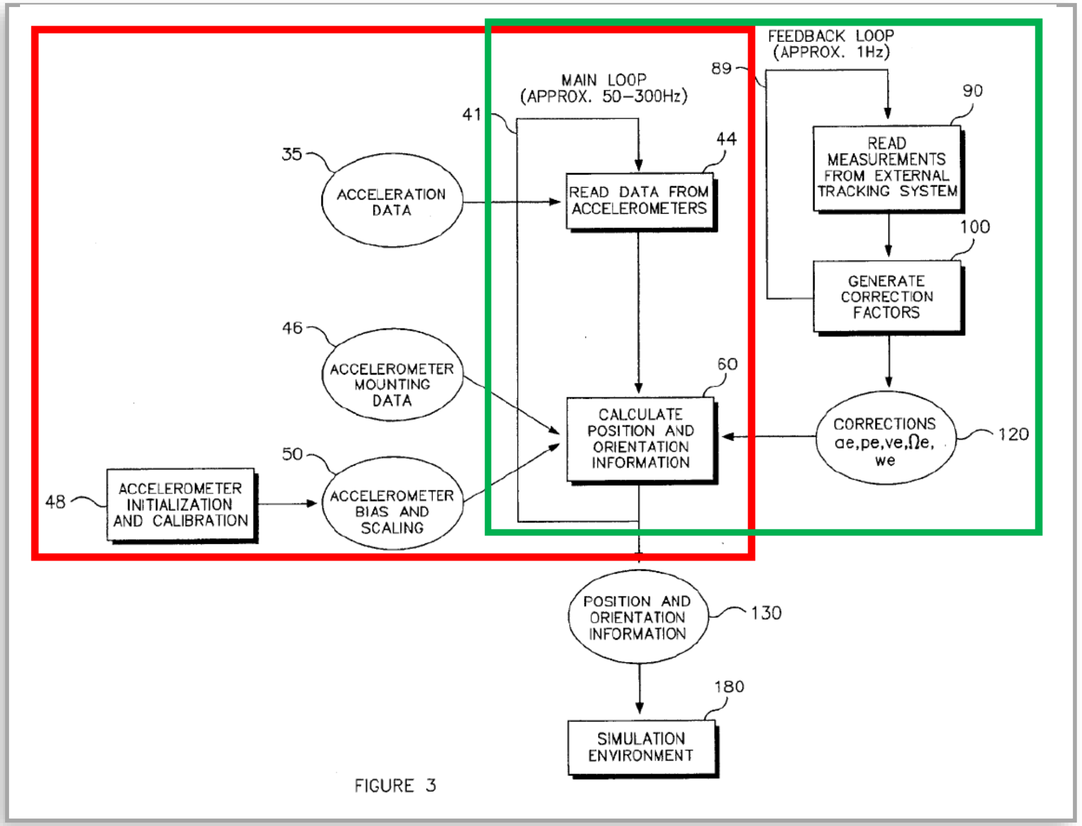
invention as specified herein. Feedback filter loop **89** (discussed below, see also *Digital and Kalman Filtering* by S. M. Bozic, John Wiley and Sons, N.Y.) compares calculated position and/or orientation measurements **130** with the known position and/or orientation measurement (known to be stationary) and uses discrepancies between the two measurements to solve for bias and scaling factors **50** for each accelerometer **1–6**. Tracking system **15** is operated such that main loop **41** is executed multiple times (approximately 15–20) for a successful calibration **48**. Total calibra-

Ex. 1010, 6:4-14; *e.g.*, 1304 POR 9, 43

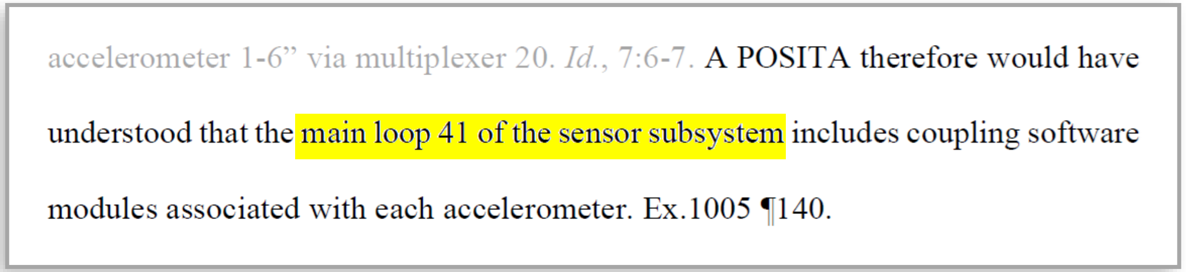
Petitioner’s Sensor Subsystem and Estimation Subsystem Overlap

’632 cl. 1 & ’253 cl. 1

Petitioner and its expert acknowledged this overlap.

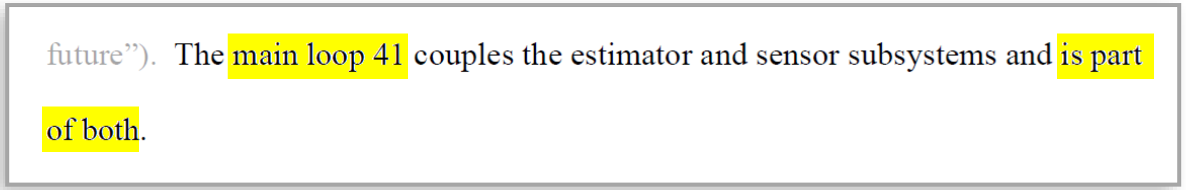


E.g., 1304 Petition 40 (annotating Ex. 1010, Fig.3)



accelerometer 1-6” via multiplexer 20. *Id.*, 7:6-7. A POSITA therefore would have understood that the main loop 41 of the sensor subsystem includes coupling software modules associated with each accelerometer. Ex.1005 ¶140.

E.g., 1304 Petition 43



future”). The main loop 41 couples the estimator and sensor subsystems and is part of both.

Ex. 1005 ¶ 129 (cited in 1304 Petition 40); 1304 POR 43; 1304 Sur-Reply 17

Petitioner’s Sensor Subsystem and Estimation Subsystem Overlap

’632 cl. 1 & ’253 cl. 1

- Horton uses the same pose calculation process for sensor calibrating and for object tracking.
- There is no way to update or change one without the other.
  - A change to pose calculation affects calibration.
  - A change to sensors affects the object tracking process.

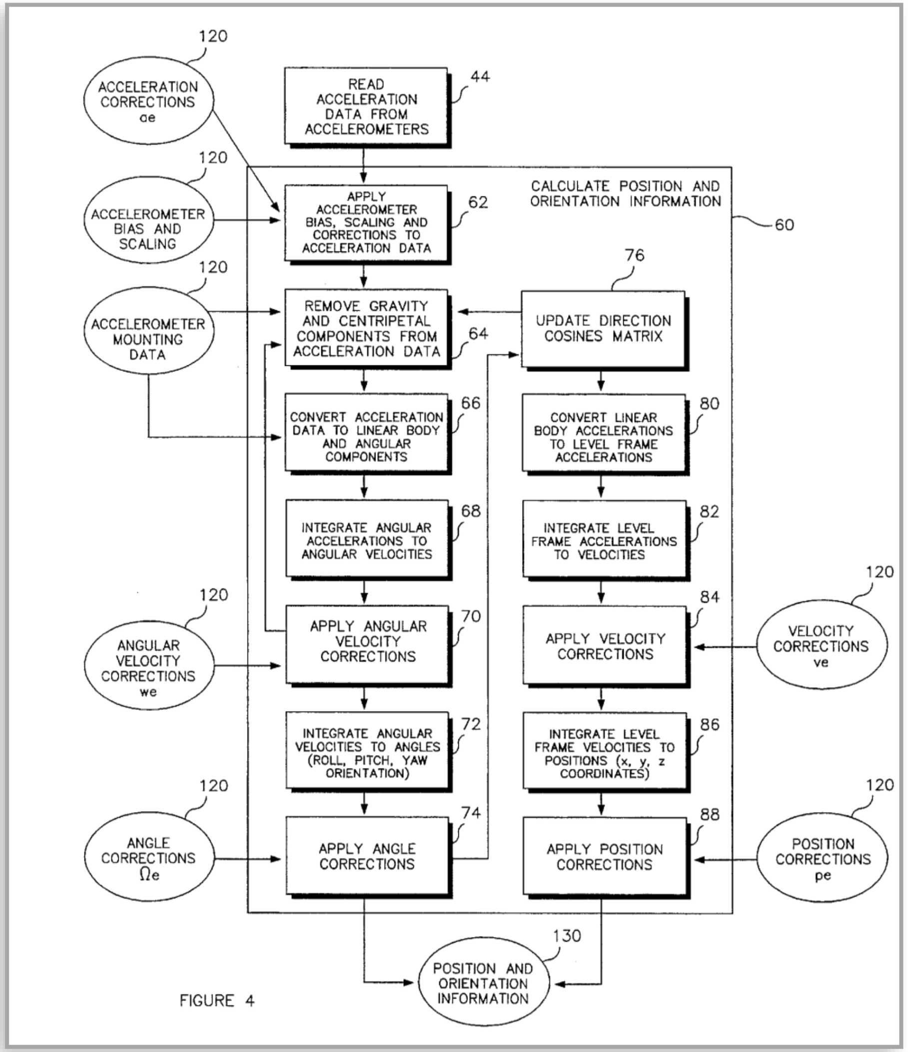
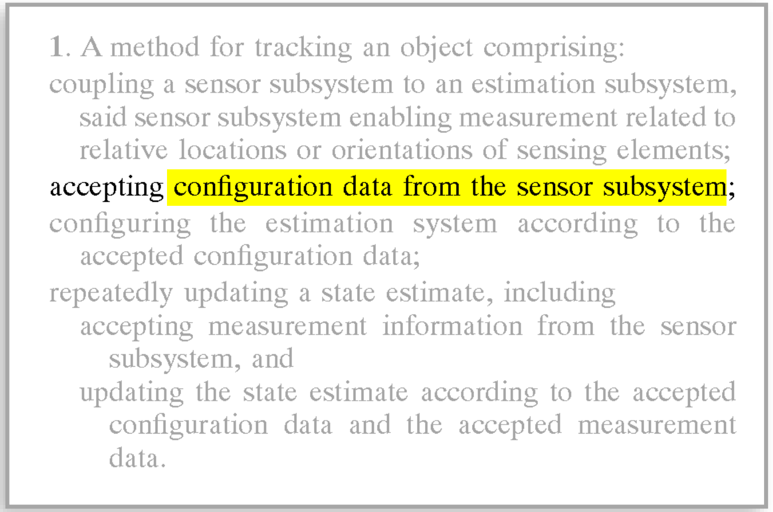


FIGURE 4

Ex. 1010, Fig.4; *e.g.*, 1304 POR 43

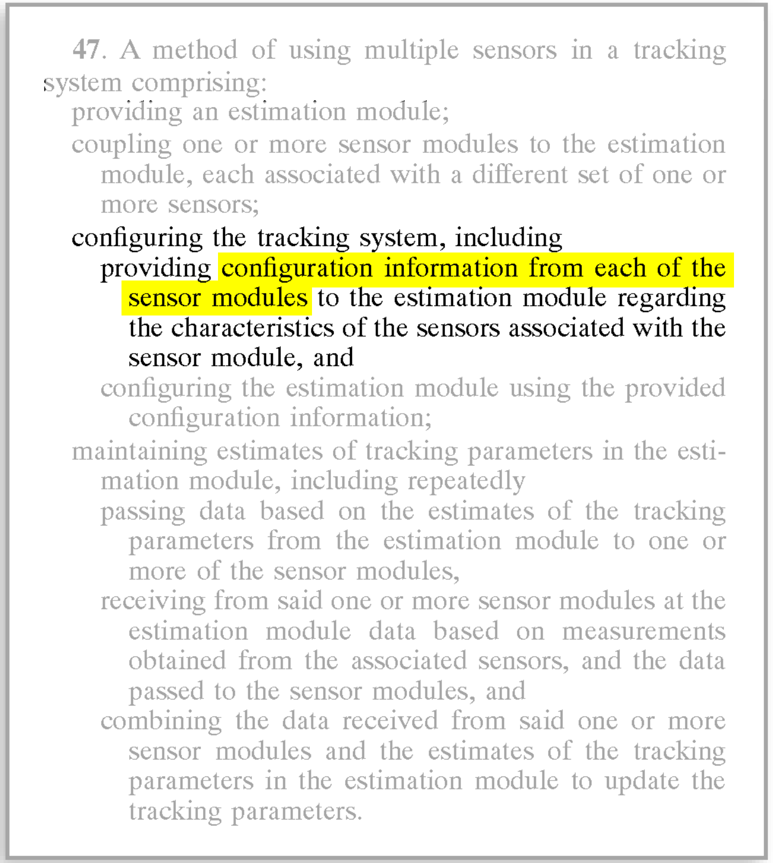
Horton’s Sensor Subsystem Does Not Provide Configuration Data

’632 cls. 1, 47 & dependent claims; ’253 cl. 1 & dependent claims



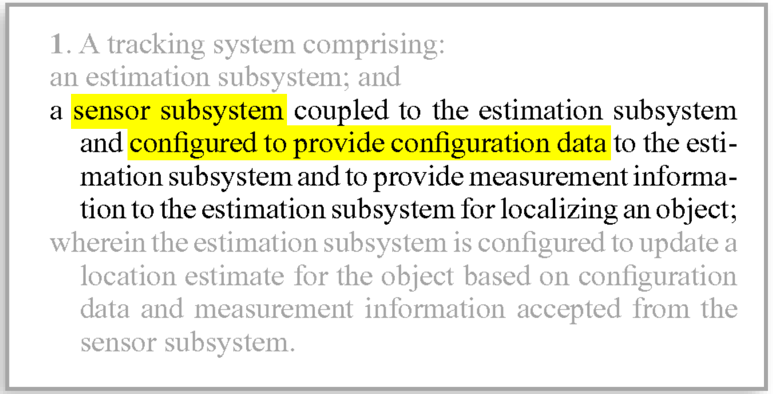
1. A method for tracking an object comprising:
coupling a sensor subsystem to an estimation subsystem, said sensor subsystem enabling measurement related to relative locations or orientations of sensing elements;
accepting configuration data from the sensor subsystem;
configuring the estimation system according to the accepted configuration data;
repeatedly updating a state estimate, including
accepting measurement information from the sensor subsystem, and
updating the state estimate according to the accepted configuration data and the accepted measurement data.

Ex. 1001, cl.1



47. A method of using multiple sensors in a tracking system comprising:
providing an estimation module;
coupling one or more sensor modules to the estimation module, each associated with a different set of one or more sensors;
configuring the tracking system, including
providing configuration information from each of the sensor modules to the estimation module regarding the characteristics of the sensors associated with the sensor module, and
configuring the estimation module using the provided configuration information;
maintaining estimates of tracking parameters in the estimation module, including repeatedly
passing data based on the estimates of the tracking parameters from the estimation module to one or more of the sensor modules,
receiving from said one or more sensor modules at the estimation module data based on measurements obtained from the associated sensors, and the data passed to the sensor modules, and
combining the data received from said one or more sensor modules and the estimates of the tracking parameters in the estimation module to update the tracking parameters.

Ex. 1001, cl.47



1. A tracking system comprising:
an estimation subsystem; and
a sensor subsystem coupled to the estimation subsystem and configured to provide configuration data to the estimation subsystem and to provide measurement information to the estimation subsystem for localizing an object;
wherein the estimation subsystem is configured to update a location estimate for the object based on configuration data and measurement information accepted from the sensor subsystem.

Ex. 1003, cl.1

None of the Data on Which Petitioner Relies Is Configuration Data Provided by the Sensor Subsystem or Module

’632 cls. 1, 47 & dependent claims; ’253 cl. 1 & dependent claims

Petitioner identifies:

- Position and orientation measurements taken during calibration
- Pre-specified accelerometer biases
- Accelerometer mounting data

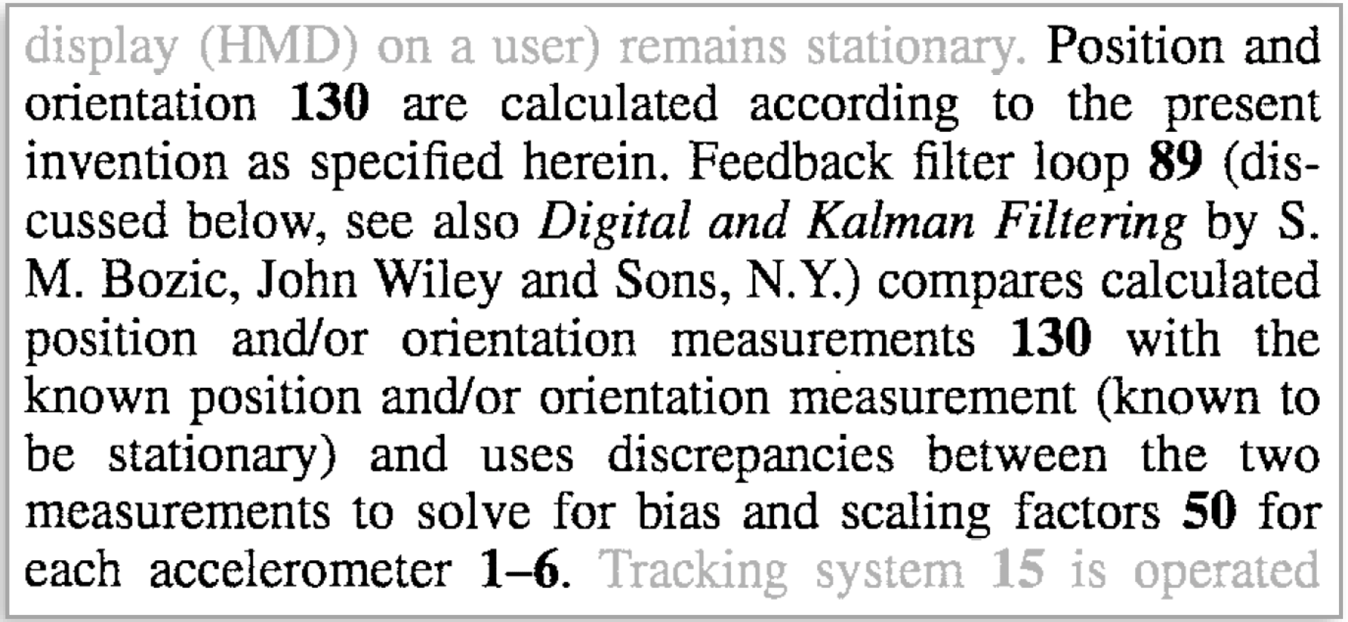
E.g., 1304 Reply 18-22; 1304 Sur-Reply 18-20

None of the Data on Which Petitioner Relies Is Configuration Data Provided by the Sensor Subsystem or Module

’632 cls. 1, 47 & dependent claims; ’253 cl. 1 & dependent claims

Petitioner	Measurements taken during calibration
Rebuttal	Not used to configure Used only ***within*** the sensor subsystem (initialization and calibration routine 48); not provided ***from*** the sensor subsystem No expert support

E.g., 1304 POR 44-45; 1304 Reply 22-23; 1304 Sur-Reply 18-20



display (HMD) on a user) remains stationary. Position and orientation **130** are calculated according to the present invention as specified herein. Feedback filter loop **89** (discussed below, see also *Digital and Kalman Filtering* by S. M. Bozic, John Wiley and Sons, N.Y.) compares calculated position and/or orientation measurements **130** with the known position and/or orientation measurement (known to be stationary) and uses discrepancies between the two measurements to solve for bias and scaling factors **50** for each accelerometer **1–6**. Tracking system **15** is operated

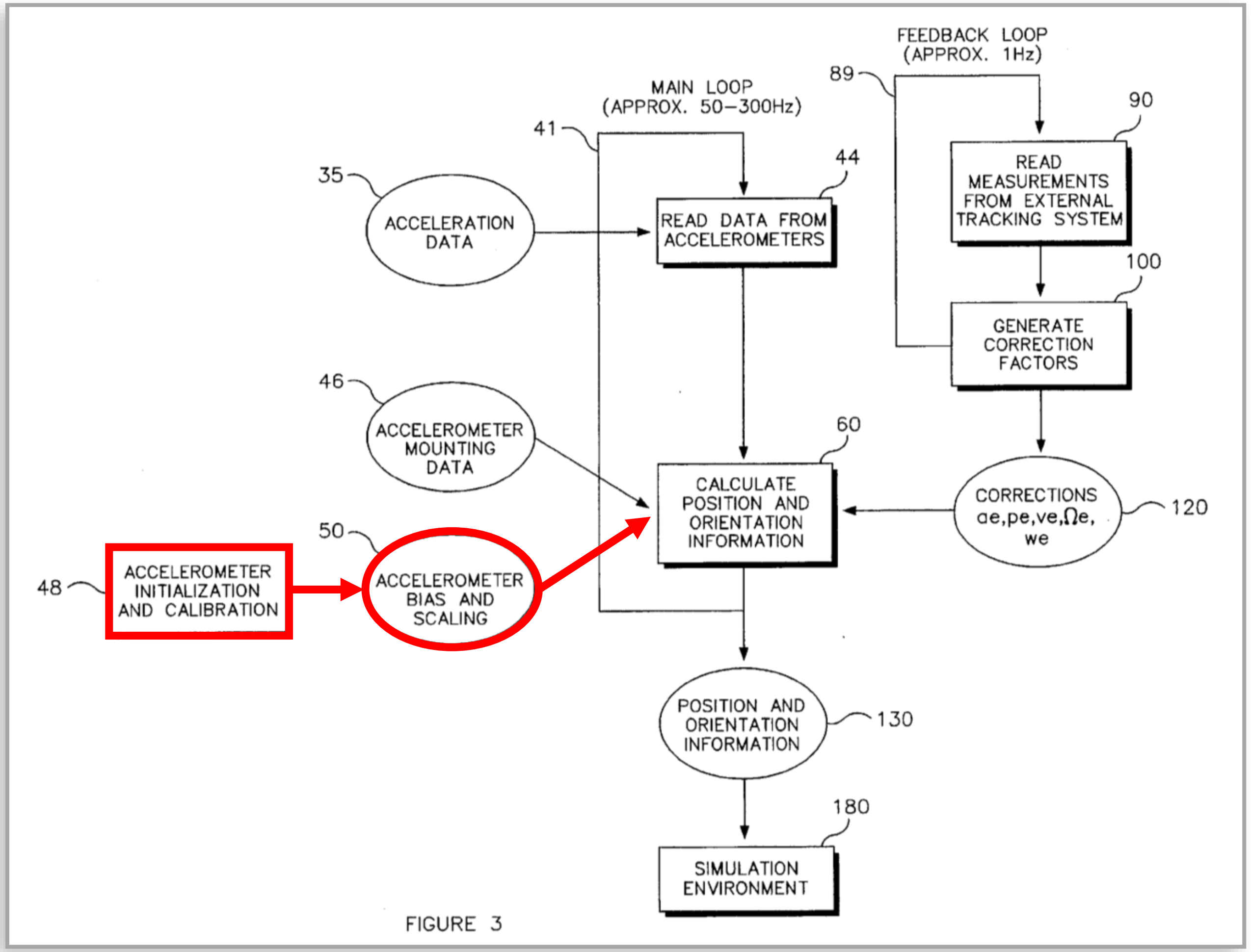
Ex. 1010, 6:3-12; *e.g.*, 1304 Sur-Reply 19

None of the Data on Which Petitioner Relies Is Configuration Data Provided by the Sensor Subsystem or Module

’632 cls. 1, 47 & dependent claims; ’253 cl. 1 & dependent claims

Petitioner	Pre-specified biases
Rebuttal	Used only ***within*** the sensor subsystem (initialization and calibration routine 48); not provided ***from*** the sensor subsystem or module No expert support

E.g., 1304 Sur-Reply 19-20; 1305 Sur-Reply 24

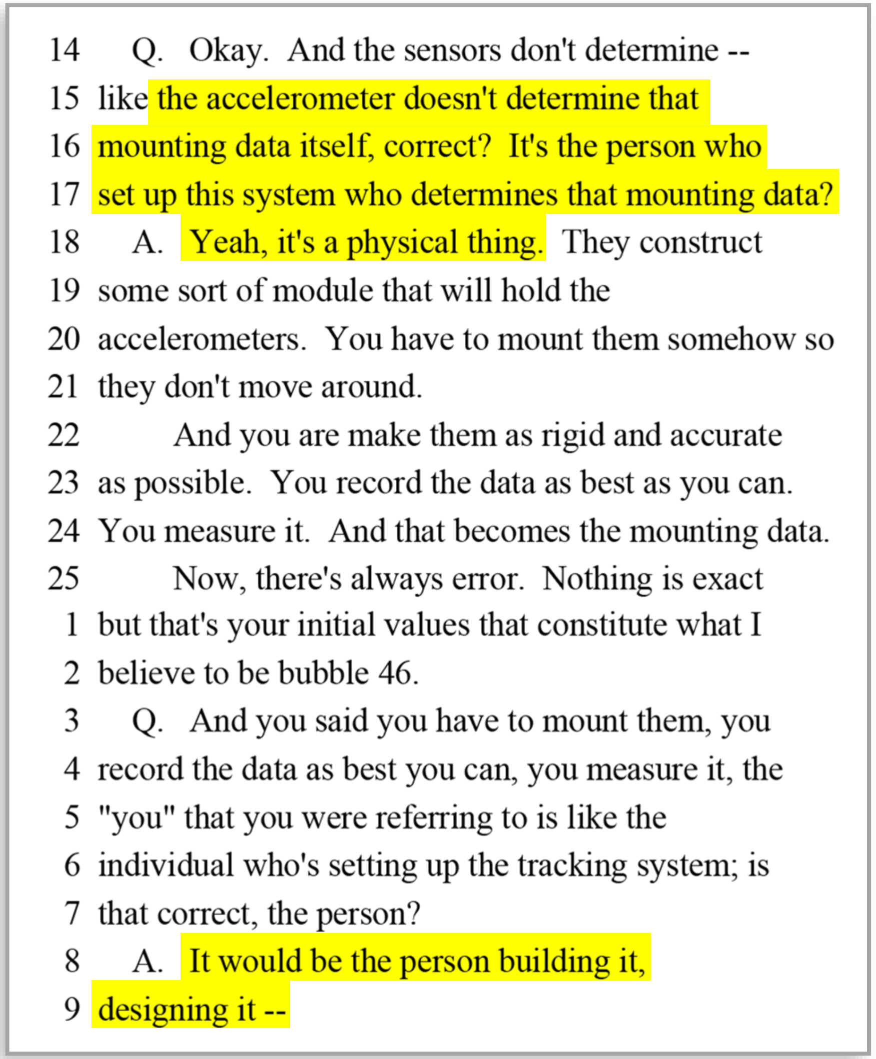


Ex. 1010, 5:64-6:12, Fig.4 (annotated by Petitioner); *e.g.*, 1305 Reply 26; 1305 Sur-Reply 24

None of the Data on Which Petitioner Relies Is Configuration Data Provided by the Sensor Subsystem or Module

Petitioner	Accelerometer mounting data
Rebuttal	Constants programmed into the main loop by the system designer Not accepted or provided from sensor subsystem or module

E.g., 1304 POR 45 n.11; 1304 Sur-Reply 20



Q. Okay. And the sensors don't determine -- like the accelerometer doesn't determine that mounting data itself, correct? It's the person who set up this system who determines that mounting data?

A. Yeah, it's a physical thing. They construct some sort of module that will hold the accelerometers. You have to mount them somehow so they don't move around.

And you are make them as rigid and accurate as possible. You record the data as best as you can. You measure it. And that becomes the mounting data.

Now, there's always error. Nothing is exact but that's your initial values that constitute what I believe to be bubble 46.

Q. And you said you have to mount them, you record the data as best you can, you measure it, the "you" that you were referring to is like the individual who's setting up the tracking system; is that correct, the person?

A. It would be the person building it, designing it --

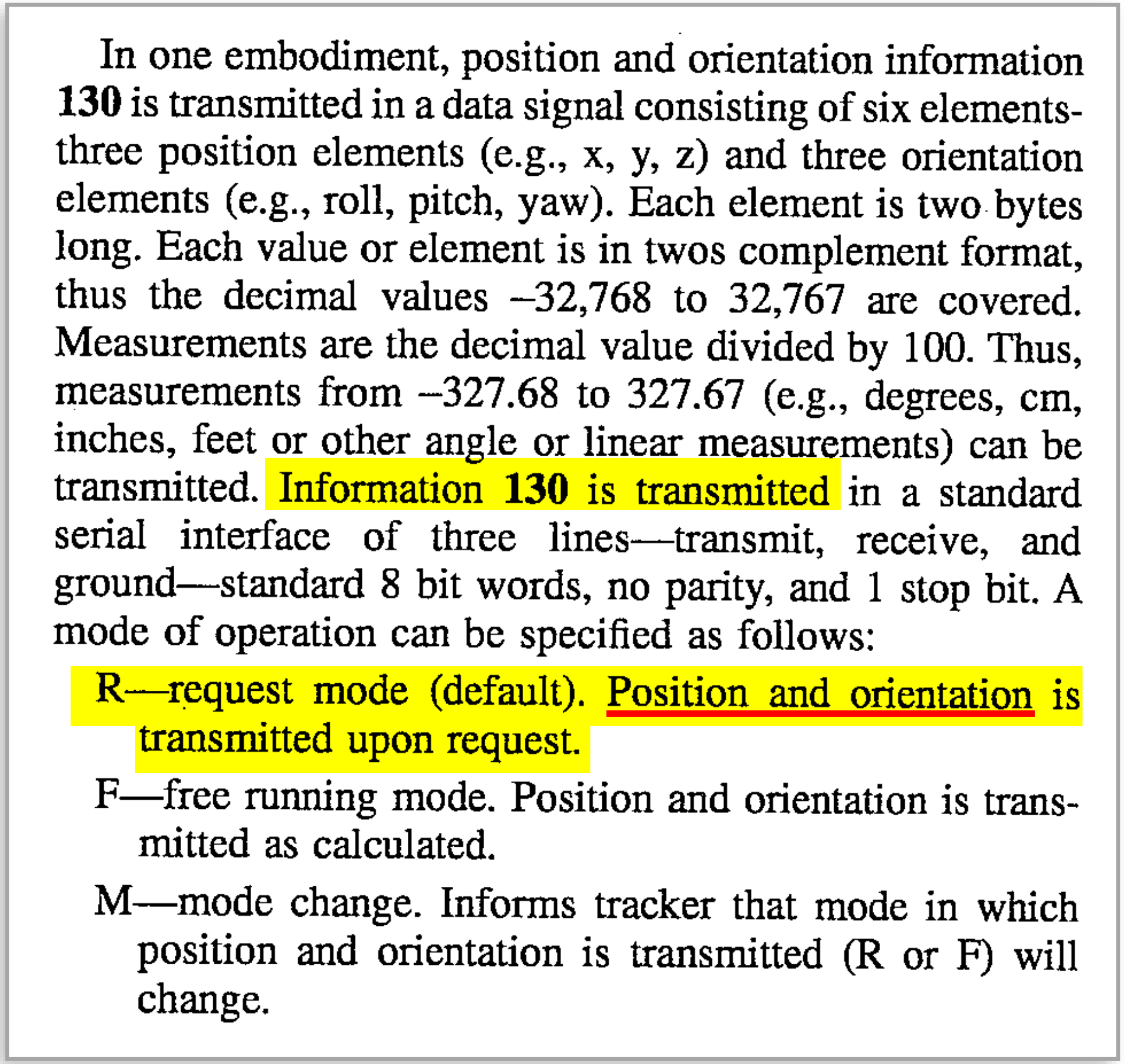
Ex. 2009, 155:14-156:9; *e.g.*, 1304 Sur-Reply 20

Horton's Estimation Subsystem Does Not Pass Information Back to a Sensor Subsystem or Modules

'632 cls. 30, 47 & dependent claims

Petitioner	Relies on purported "request mode" to "trigger a sensor measurement"
Rebuttal	Horton's "request mode" is a request to the ***tracking system*** for the calculated pose, not a request to the ***accelerometer*** to take a measurement No expert support

E.g., 1305 Reply 20, 27-28; 1305 Sur-Reply 20-21, 25



In one embodiment, position and orientation information **130** is transmitted in a data signal consisting of six elements-three position elements (e.g., x, y, z) and three orientation elements (e.g., roll, pitch, yaw). Each element is two bytes long. Each value or element is in twos complement format, thus the decimal values –32,768 to 32,767 are covered. Measurements are the decimal value divided by 100. Thus, measurements from –327.68 to 327.67 (e.g., degrees, cm, inches, feet or other angle or linear measurements) can be transmitted. Information **130** is transmitted in a standard serial interface of three lines—transmit, receive, and ground—standard 8 bit words, no parity, and 1 stop bit. A mode of operation can be specified as follows:

R—request mode (default). Position and orientation is transmitted upon request.

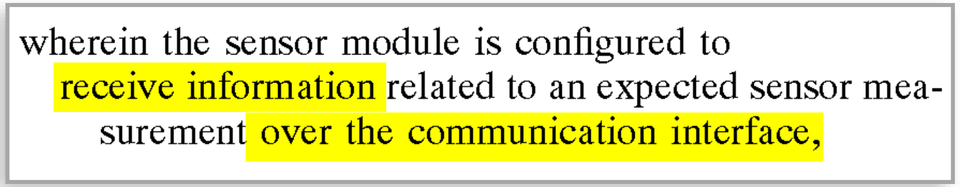
F—free running mode. Position and orientation is transmitted as calculated.

M—mode change. Informs tracker that mode in which position and orientation is transmitted (R or F) will change.

Ex. 1010, 4:47-67; *e.g.*, 1305 Sur-Reply 20

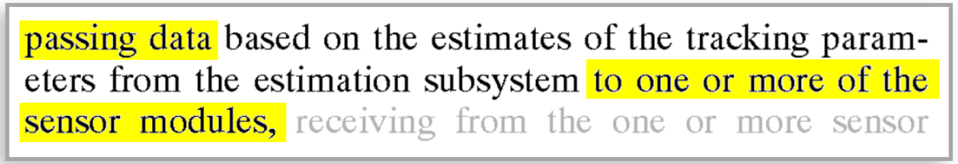
Horton's Estimation Subsystem Does Not Pass Information Back to a Sensor Subsystem or Modules

'632 cls. 30, 47 & dependent claims



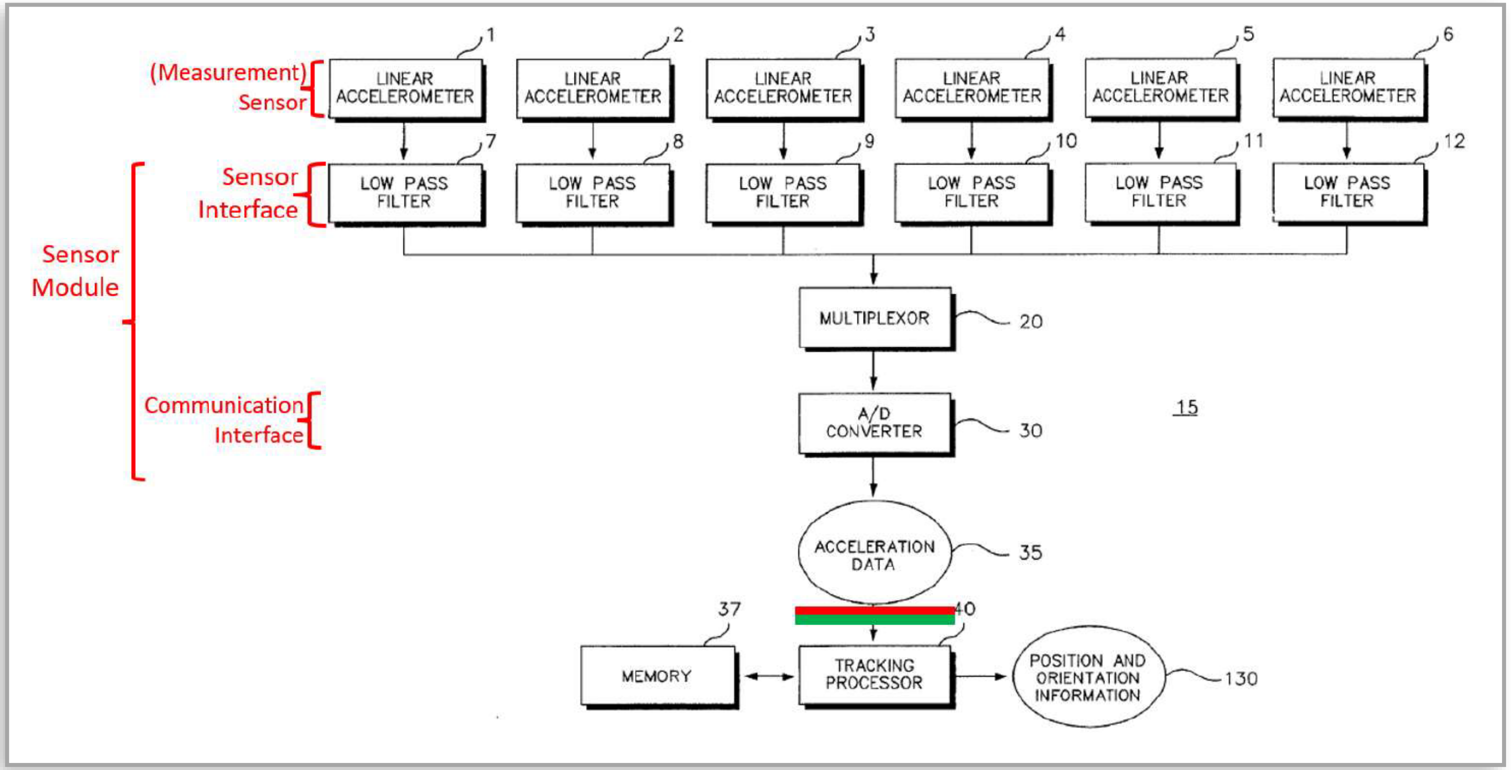
wherein the sensor module is configured to receive information related to an expected sensor measurement over the communication interface,

Ex. 1001, cl.30



passing data based on the estimates of the tracking parameters from the estimation subsystem to one or more of the sensor modules, receiving from the one or more sensor

Ex. 1001, cl.47



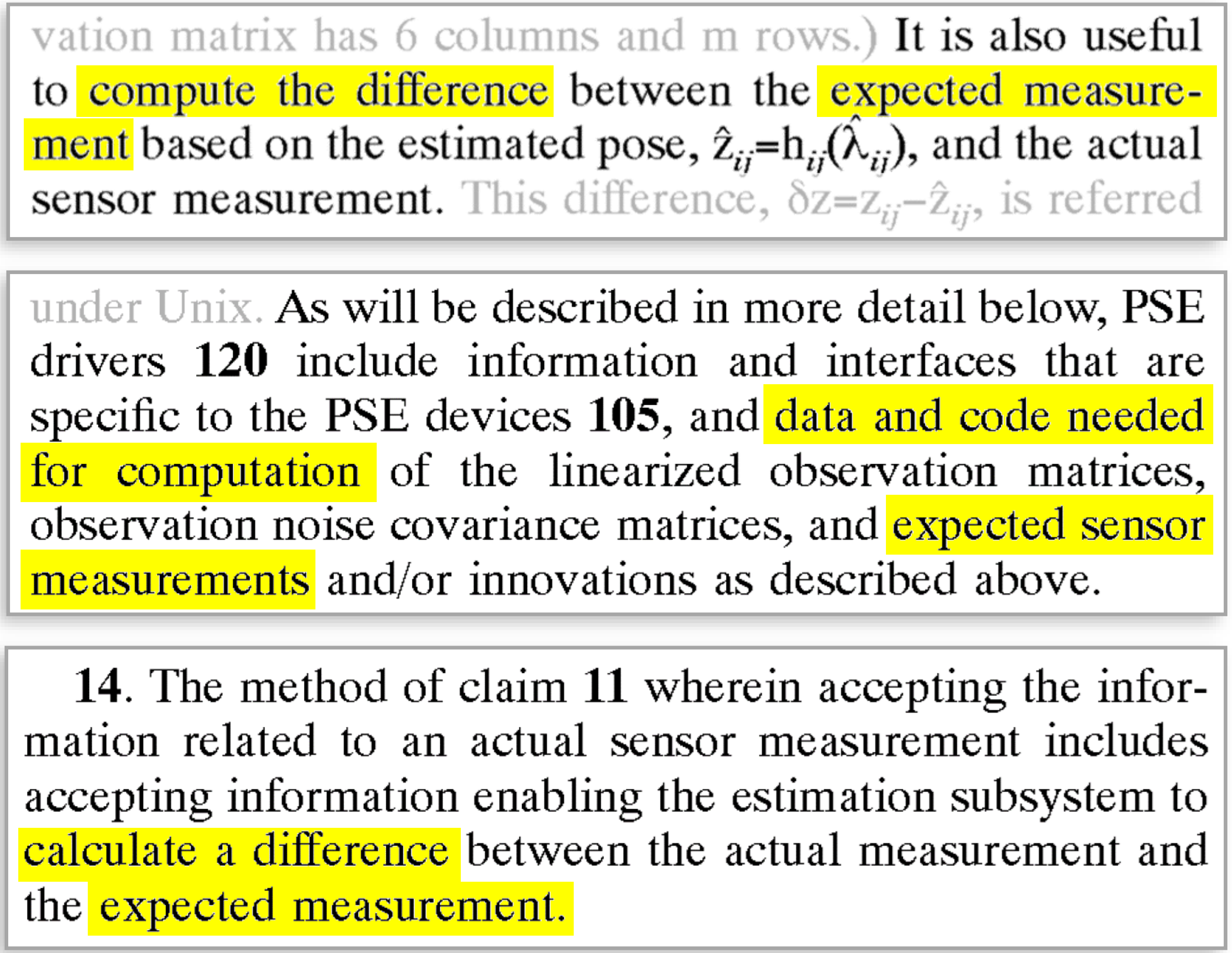
Ex. 1010, Fig.1 (annotated by Petitioner); 1305 Reply 19, 24; 1305 Sur-Reply 19, 23

Horton's Sensor Module and Subsystem Do Not Receive Information Related to an Expected Sensor Measurement

'632 cl. 30 & dependent claims

Petitioner	Relies on anticipation that a measurement will occur
Rebuttal	Patent describes "expected sensor measurement" as a calculated numerical value

E.g., 1305 Reply 20; 1305 Sur-Reply 20



vation matrix has 6 columns and m rows.) It is also useful to compute the difference between the expected measurement based on the estimated pose, $\hat{z}_{ij}=h_{ij}(\hat{\lambda}_{ij})$, and the actual sensor measurement. This difference, $\delta z=z_{ij}-\hat{z}_{ij}$, is referred

under Unix. As will be described in more detail below, PSE drivers **120** include information and interfaces that are specific to the PSE devices **105**, and data and code needed for computation of the linearized observation matrices, observation noise covariance matrices, and expected sensor measurements and/or innovations as described above.

14. The method of claim **11** wherein accepting the information related to an actual sensor measurement includes accepting information enabling the estimation subsystem to calculate a difference between the actual measurement and the expected measurement.

Ex. 1001, 15:47-50, 16:50-56, cl.14; *e.g.*, 1305 Sur-Reply 20

Petitioner Does Not Identify Multiple "Sensor Modules" in Horton.

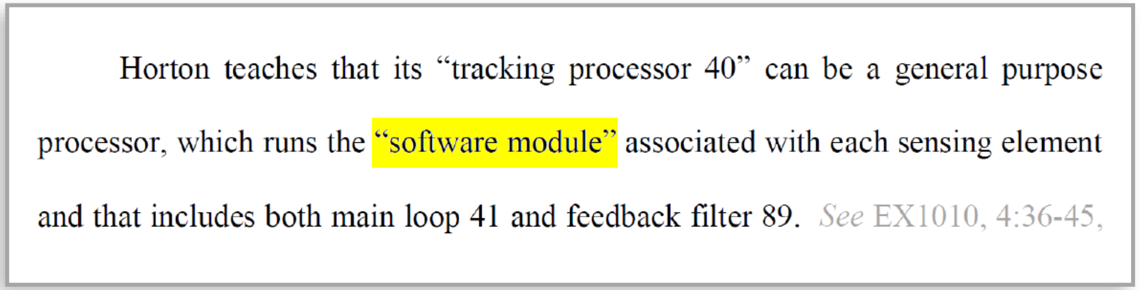
'632 cl. 2 & dependent claims

- Claim 2 recites "software modules," plural.
- Petitioner identifies only one purported "software module."

Ex. 1001, cl.2; 1304 Sur-Reply 21-22

> In accordance with common English usage, we presume a plural term refers to two or more items.

Apple Inc. v. MPH Techs. Oy, 28 F.4th 254, 261 (Fed. Cir. 2022);
1304 Sur-Reply 22)

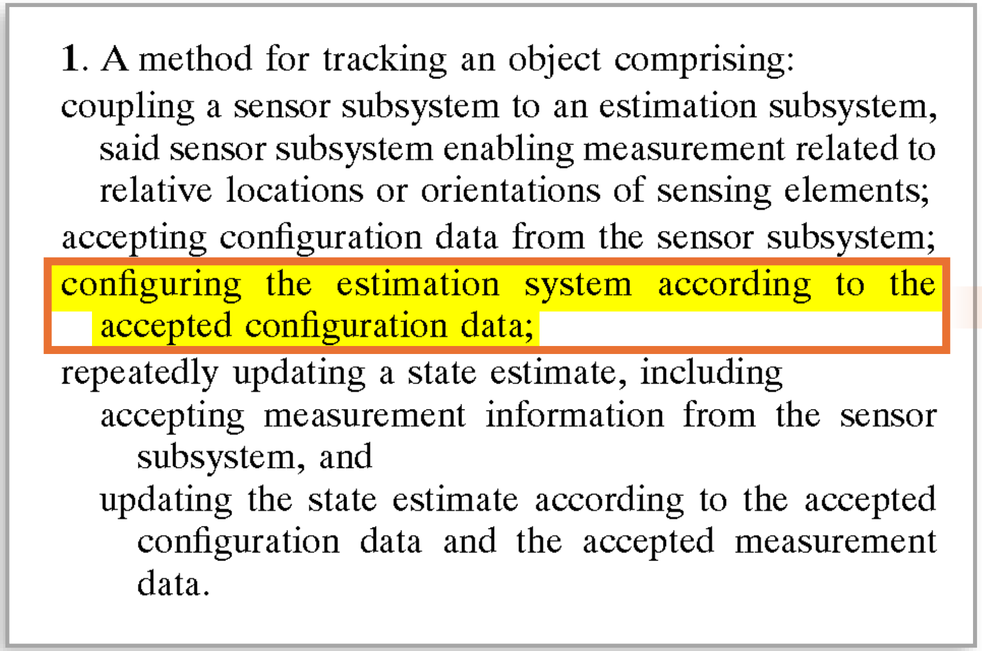


Horton teaches that its "tracking processor 40" can be a general purpose processor, which runs the "software module" associated with each sensing element and that includes both main loop 41 and feedback filter 89. *See* EX1010, 4:36-45,

1304 Reply 23

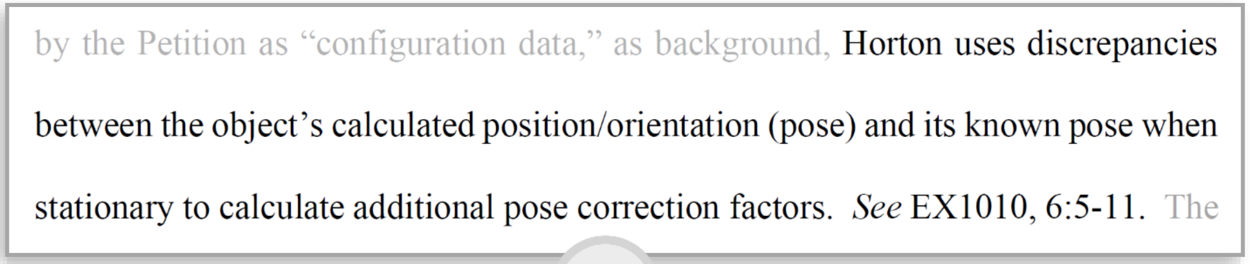
The Result of Horton’s Calibration Process Cannot Be Both an Input to and Output of the State Estimation Update Process Within the Same Claim

’632 cls. 6, 9, 11 & dependent claims



1. A method for tracking an object comprising:
coupling a sensor subsystem to an estimation subsystem, said sensor subsystem enabling measurement related to relative locations or orientations of sensing elements;
accepting configuration data from the sensor subsystem;
configuring the estimation system according to the accepted configuration data;
repeatedly updating a state estimate, including
accepting measurement information from the sensor subsystem, and
updating the state estimate according to the accepted configuration data and the accepted measurement data.

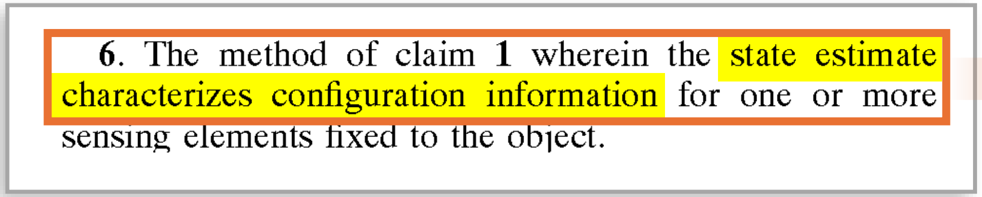
Ex. 1001, cl.1



by the Petition as “configuration data,” as background, Horton uses discrepancies between the object’s calculated position/orientation (pose) and its known pose when stationary to calculate additional pose correction factors. *See* EX1010, 6:5-11. The

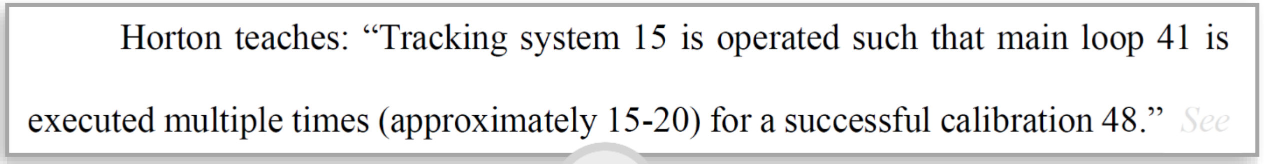
INPUT: Bias and scaling factors 50

1304 Reply 22; *see* 1304 Sur-Reply 23-24



6. The method of claim 1 wherein the state estimate characterizes configuration information for one or more sensing elements fixed to the object.

Ex. 1001, cl.6



Horton teaches: “Tracking system 15 is operated such that main loop 41 is executed multiple times (approximately 15-20) for a successful calibration 48.” *See*

OUTPUT: Bias and scaling factors 50

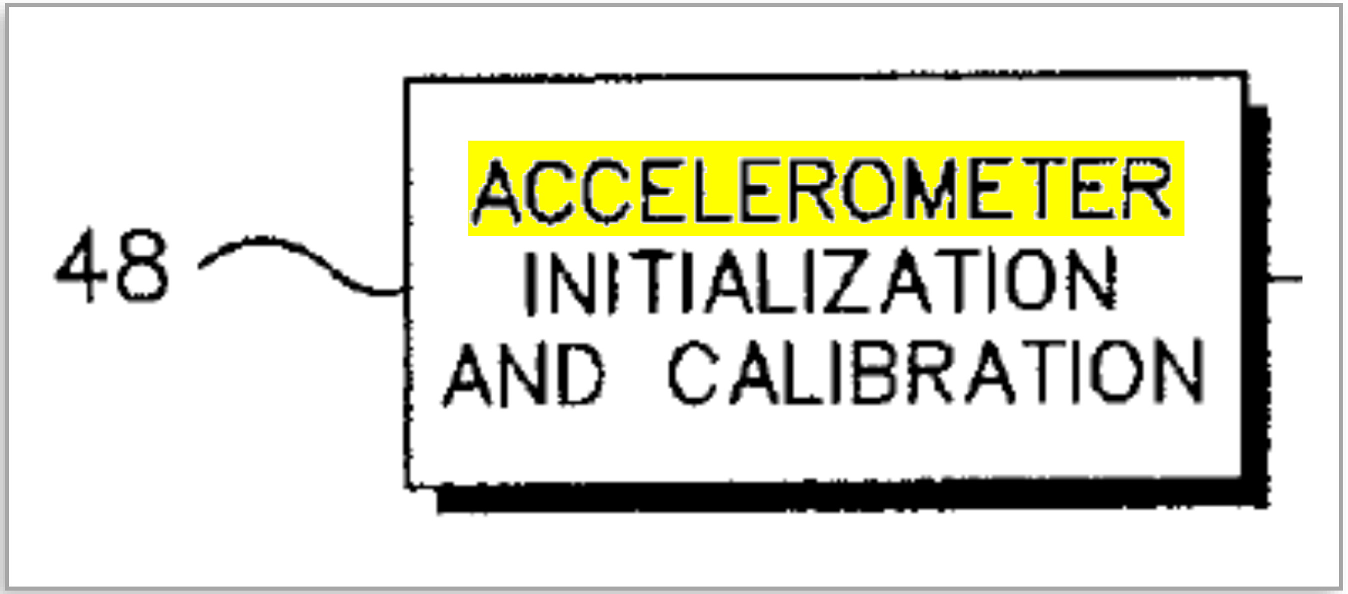
1304 Reply 24; *see* 1304 Sur-Reply 23-24

Horton’s External Tracking Sensors Are Not Part of the Sensor Subsystem

’632 cl. 25

Petitioner	Relies on external tracking system sensors
Rebuttal	Claim 25’s sensing elements must be part of the sensor subsystem, which Petitioner asserts is “initialization routine 48 and related data” Sensors in the external tracking system are not part of “initialization routine 48”

E.g.,1304 POR 61; 1304 Reply 25-26; 1304 Sur-Reply 25



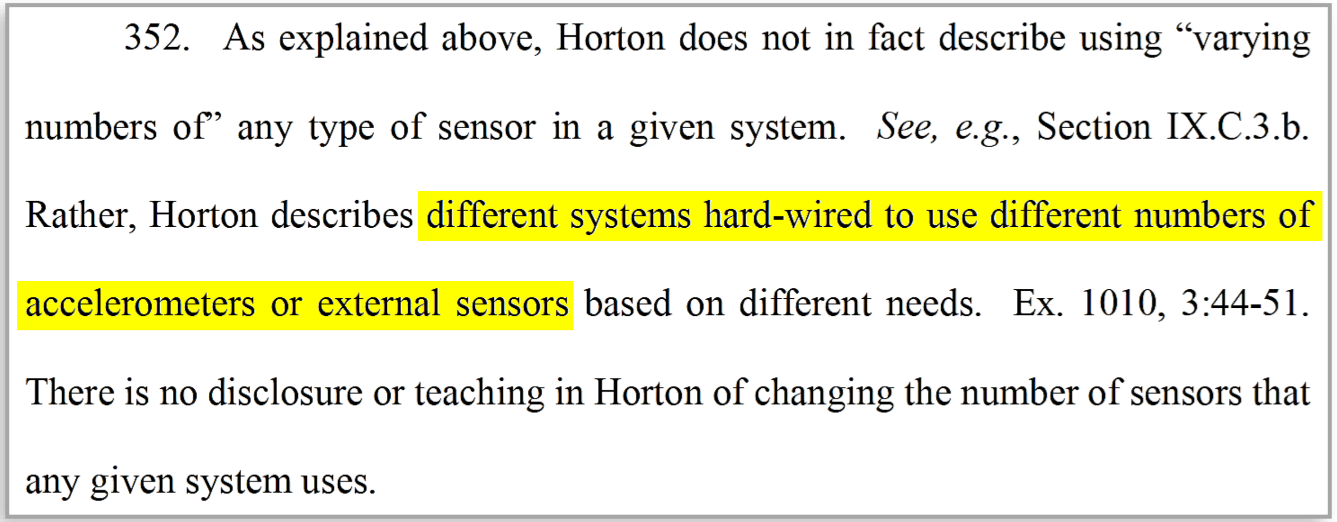
Ex. 1010, Fig.3; *e.g.*,1304 POR 61; 1304 Sur-Reply 25

Horton’s Estimation Module Is Not Configurable To Use Different Sensors

’632 cl. 50

Petitioner	Horton teaches using varying numbers of accelerometers and different external tracking systems
Rebuttal	The possibility of building ***different systems*** does not meet the claim requirement that a particular estimation module is “configurable” to use different sensors

E.g., 1305 Reply 29; 1305 Sur-Reply 26-27



352. As explained above, Horton does not in fact describe using “varying numbers of” any type of sensor in a given system. *See, e.g.*, Section IX.C.3.b. Rather, Horton describes different systems hard-wired to use different numbers of accelerometers or external sensors based on different needs. Ex. 1010, 3:44-51. There is no disclosure or teaching in Horton of changing the number of sensors that any given system uses.

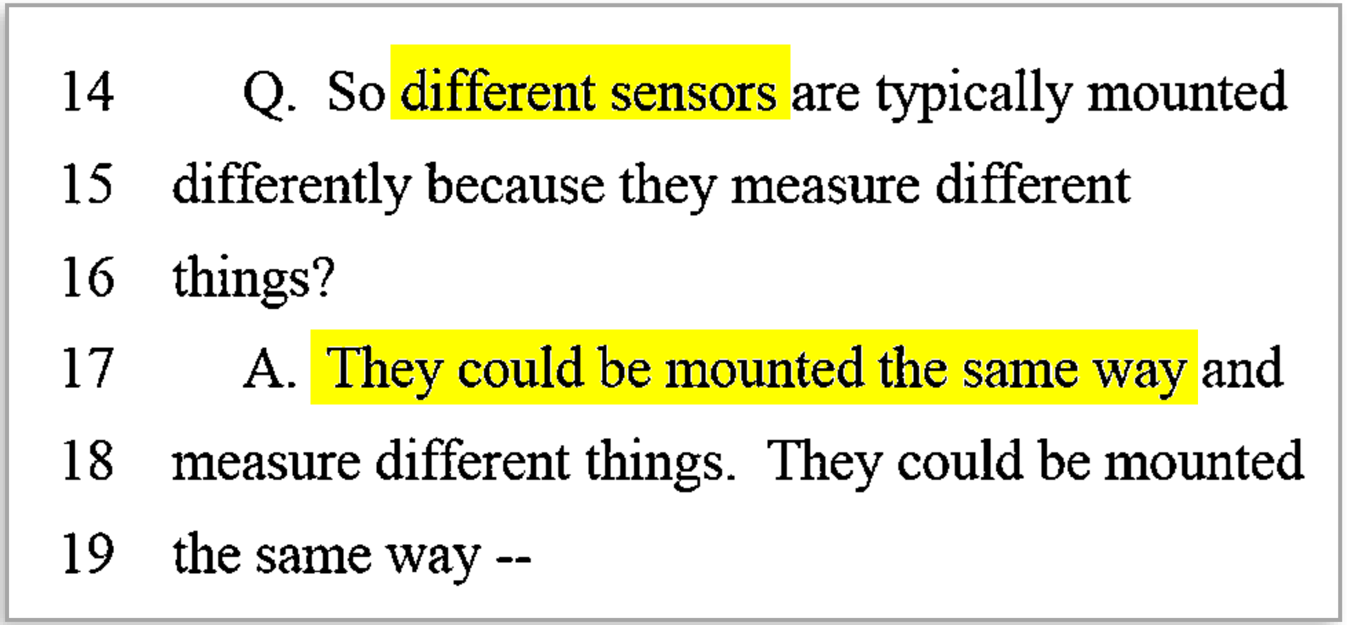
Ex. 2007 ¶ 352; *e.g.*, 1305 POR 63; 1305 Sur-Reply 26-27

Horton’s Accelerometer Mounting Data Does Not Characterize Sensor Type

’632 cl. 59

Petitioner	Relies on mounting data, because accelerometers are purportedly mounted differently
Rebuttal	Mounting data is not and does not describe sensor type Different types of sensors may be mounted in the same way

E.g., 1305 Reply 30; 1305 Sur-Reply 27



Q. So different sensors are typically mounted differently because they measure different things?

A. They could be mounted the same way and measure different things. They could be mounted the same way --

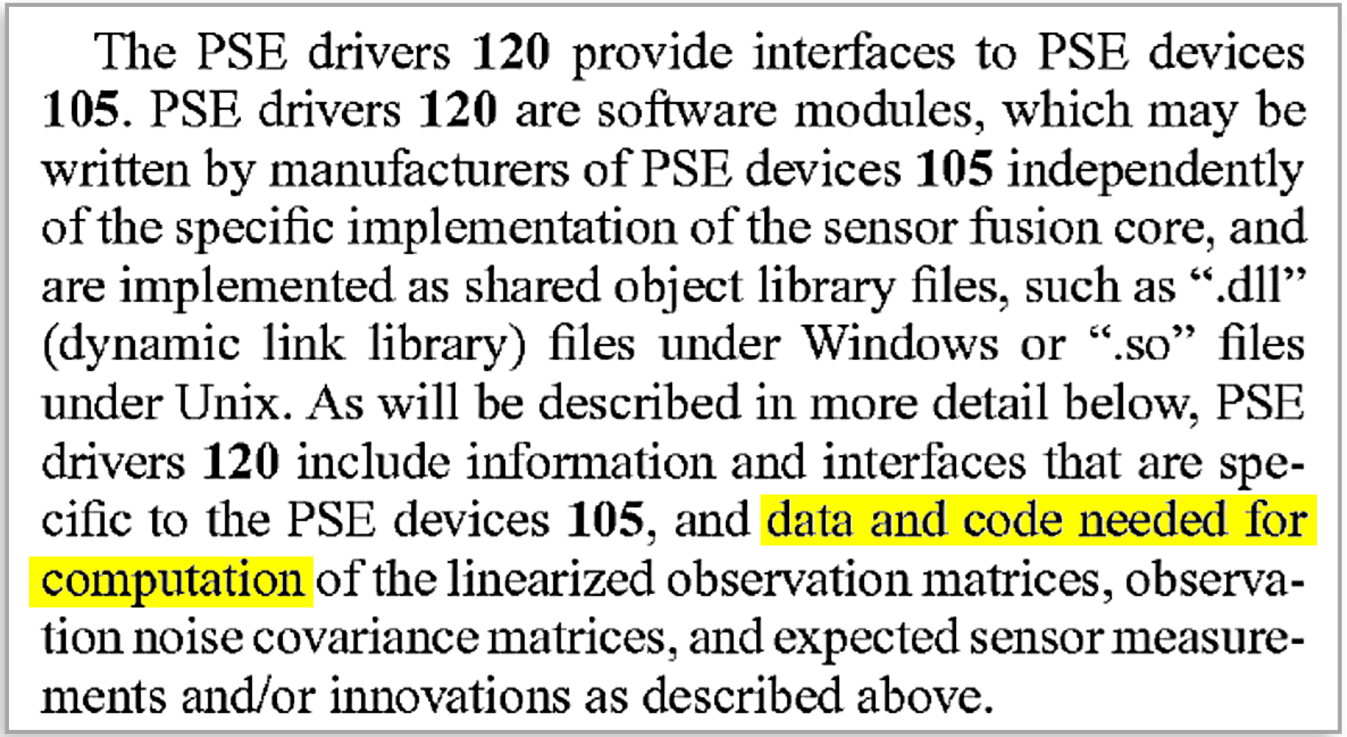
Ex. 1033, 176:14-19; *e.g.*, 1305 Sur-Reply 27

Horton’s LPF/Multiplexer/A/D Converter Do Not Perform Computations

’253 cl. 3

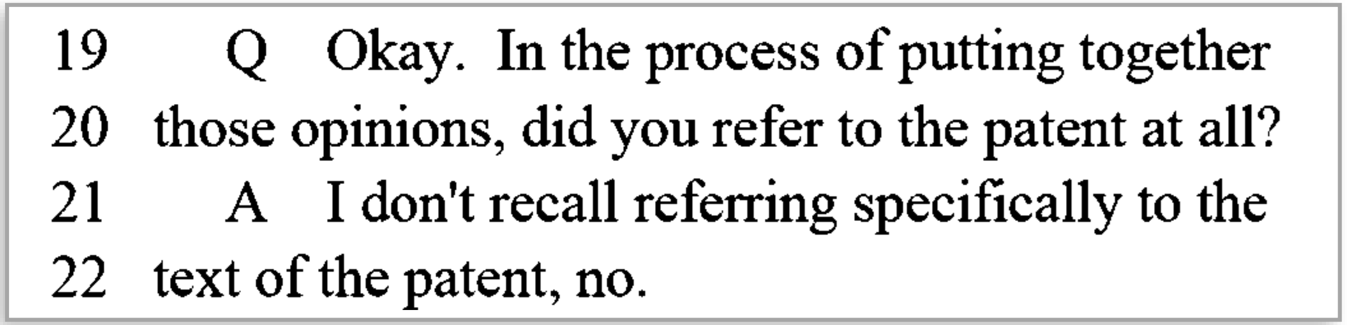
Petitioner	LPFs/Multiplexer/A/D Converter perform computations
Rebuttal	Signal processing of this sort is not “computation” The patent describes computations as mathematical operations carried out using data and code Petitioner’s expert did not consider this context

E.g., Ex. 2007 ¶ 441; 1308 POR 55-57; 1308 Reply 27; 1308 Sur-Reply 20-21



The PSE drivers **120** provide interfaces to PSE devices **105**. PSE drivers **120** are software modules, which may be written by manufacturers of PSE devices **105** independently of the specific implementation of the sensor fusion core, and are implemented as shared object library files, such as “.dll” (dynamic link library) files under Windows or “.so” files under Unix. As will be described in more detail below, PSE drivers **120** include information and interfaces that are specific to the PSE devices **105**, and data and code needed for computation of the linearized observation matrices, observation noise covariance matrices, and expected sensor measurements and/or innovations as described above.

Ex. 1003, 16:20-32



Q Okay. In the process of putting together those opinions, did you refer to the patent at all?

A I don't recall referring specifically to the text of the patent, no.

Ex. 2025, 9:19-22

Grounds and Challenged Claims

Welch & Horton: Enumerating, selecting pairs, and expected utility

Welch 2001 & Welch 1997	1305 Ground I	’632 patent, cls. 33-36
	1308 Ground I	’253 patent, cls. 6-9
Horton	1304 Ground III	’632 patent, cls. 20-21
	1305 Ground IV	’632 patent, cl. 33
	1308 Ground IV	’253 patent, cls. 6-9
Horton & Welch 1997	1305 Ground V	’632 patent, cls. 34-36
	1308 Ground V	’253 patent, cls. 7-9

Other prior art references

Kramer & Chen	1304 Ground V	’632 patent, cls. 66-68
Kramer, Chen & Welch 2001	1304 Ground VI	’632 patent, cl. 69
Welch 2001, Welch 1997 & Harris	1305 Ground III	’632 patent, cls. 54-55 & 57-58
	1308 Ground II	’253 patent, cls. 3-5
Welch 2001, Welch 1997 & Reitmayr	1308 Ground III	’253 patent, cls. 3-4
Horton & Harris	1305 Ground VI	’632 patent, cls. 54-55 & 57-58

Welch & Horton

Grounds and Challenged Claims

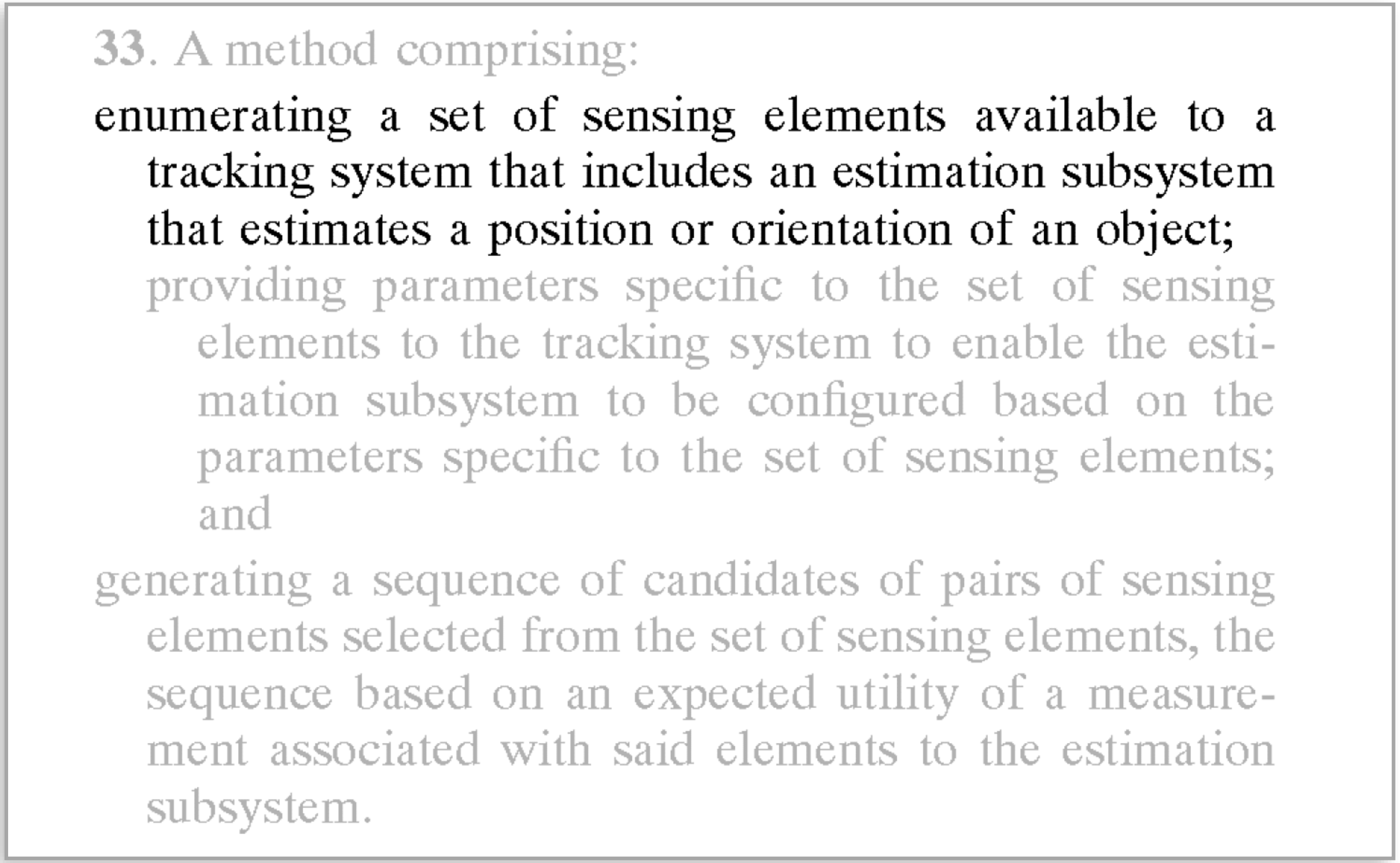
Welch & Horton: **Enumerating**, selecting pairs, and expected utility

Welch 2001 & Welch 1997	1305 Ground I	’632 patent, cls. 33-36
	1308 Ground I	’253 patent, cls. 6-9
Horton	1304 Ground III	’632 patent, cls. 20-21
	1305 Ground IV	’632 patent, cl. 33
	1308 Ground IV	’253 patent, cls. 6-9
Horton & Welch 1997	1305 Ground V	’632 patent, cls. 34-36
	1308 Ground V	’253 patent, cls. 7-9

Other prior art references

Kramer & Chen	1304 Ground V	’632 patent, cls. 66-68
Kramer, Chen & Welch 2001	1304 Ground VI	’632 patent, cl. 69
Welch 2001, Welch 1997 & Harris	1305 Ground III	’632 patent, cls. 54-55 & 57-58
	1308 Ground II	’253 patent, cls. 3-5
Welch 2001, Welch 1997 & Reitmayr	1308 Ground III	’253 patent, cls. 3-4
Horton & Harris	1305 Ground VI	’632 patent, cls. 54-55 & 57-58

"Enumerating": Claim Language



33. A method comprising:

enumerating a set of sensing elements available to a tracking system that includes an estimation subsystem that estimates a position or orientation of an object;

providing parameters specific to the set of sensing elements to the tracking system to enable the estimation subsystem to be configured based on the parameters specific to the set of sensing elements; and

generating a sequence of candidates of pairs of sensing elements selected from the set of sensing elements, the sequence based on an expected utility of a measurement associated with said elements to the estimation subsystem.

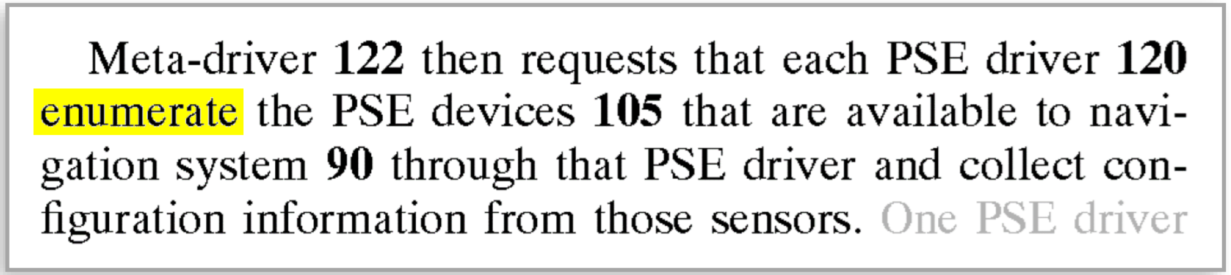
Ex. 1001, cl.33; *see* Ex.1003, cl.6

“Enumerating”: Claim Construction

“enumerating a set of sensing elements available to a tracking system”

Patent Owner’s Construction	Petitioner’s Construction
“specifying or listing each of the sensing elements available to a tracking system”	“determining the number of” sensing elements
Enumeration is a process **<u>performed by the system</u>** prior to the configuration process whereby available sensors are identified	No expert or other evidence that enumeration need not be performed by the system
E.g., 1305 POR 20-23; Ex. 2007 ¶¶74-76	*E.g.*, 1305 Reply 5; 1305 Sur-Reply 7

The Patents Explain that Enumeration Is Performed by the System

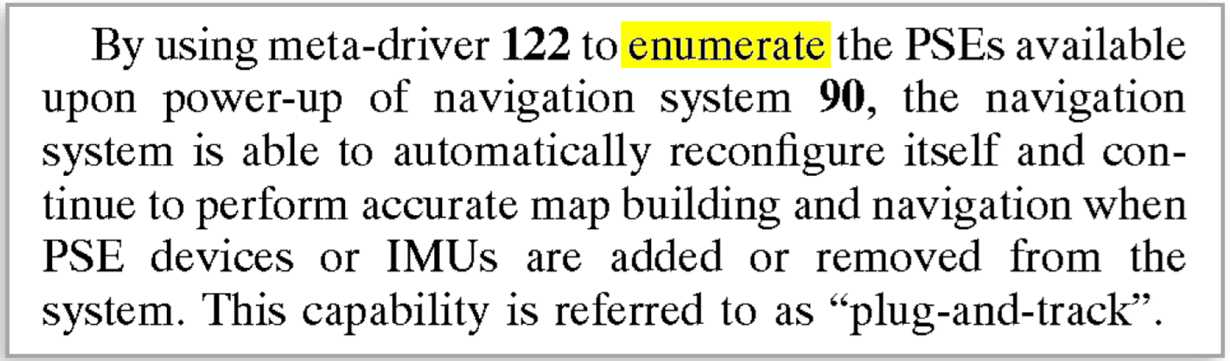


Meta-driver **122** then requests that each PSE driver **120** enumerate the PSE devices **105** that are available to navigation system **90** through that PSE driver and collect configuration information from those sensors. One PSE driver

Ex.1001, 18:48-51; *e.g.*, 1305 POR 22

One function call (e.g., sfMetaEnumerate( )) invokes the enumeration process and returns a list of PSEs available to navigation system **90**. The meta-driver **122** searches driver

Ex.1001, 22:16-18; *e.g.*, 1305 POR 22



By using meta-driver **122** to enumerate the PSEs available upon power-up of navigation system **90**, the navigation system is able to automatically reconfigure itself and continue to perform accurate map building and navigation when PSE devices or IMUs are added or removed from the system. This capability is referred to as "plug-and-track".

Ex.1001, 19:1-6; *e.g.*, 1305 POR 22

Patent Owner’s Expert: Enumeration Is Performed by the System

Yohan Baillot
CEO and Founder, ARCortex Inc.

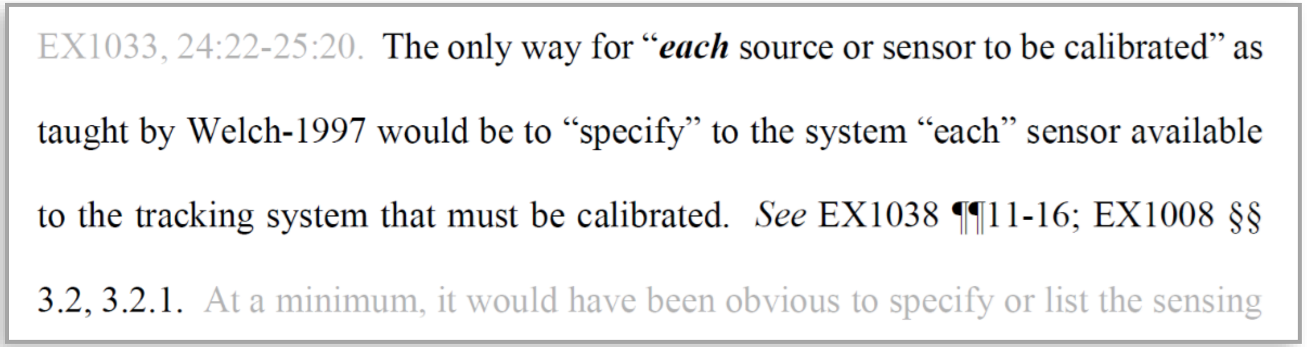
The POSITA would have understood:

- “The patents further explain that ‘enumeration’ is a particular process performed by the system prior to the configuration process whereby the available sensors are identified.” ¶74
- “This enumeration process … is how the system learns which sensors are available to it at any given time, and therefore is important to the … plug-and-track functionality described in the patent, allowing the system to work with varying numbers and types of sensors.” ¶75

Ex. 2007; *e.g.*, 1305 POR 22

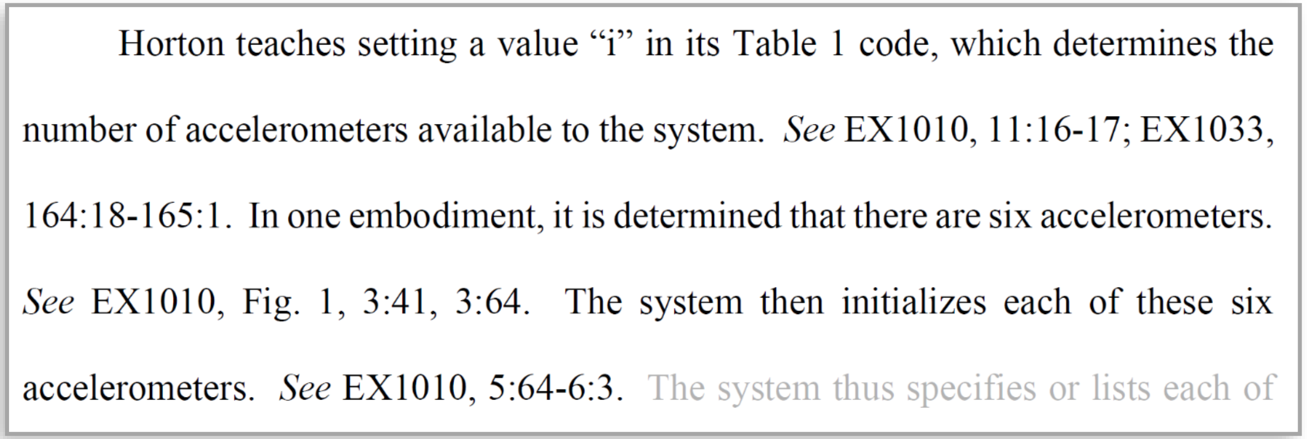
Petitioner Relies on *Designer* Specifying the Sensors

’632 cl. 33 & dependent claims; ’253 cl. 6 & dependent claims



EX1033, 24:22-25:20. The only way for “***each*** source or sensor to be calibrated” as taught by Welch-1997 would be to “specify” to the system “each” sensor available to the tracking system that must be calibrated. *See* EX1038 ¶¶11-16; EX1008 §§ 3.2, 3.2.1. At a minimum, it would have been obvious to specify or list the sensing

E.g., 1305 Reply 8; *see, e.g.*, 1305 Sur-Reply 10-11



Horton teaches setting a value “i” in its Table 1 code, which determines the number of accelerometers available to the system. *See* EX1010, 11:16-17; EX1033, 164:18-165:1. In one embodiment, it is determined that there are six accelerometers. *See* EX1010, Fig. 1, 3:41, 3:64. The system then initializes each of these six accelerometers. *See* EX1010, 5:64-6:3. The system thus specifies or lists each of

E.g., 1305 Reply 22-23; *see, e.g.*, 1305 Sur-Reply 21

Grounds and Challenged Claims

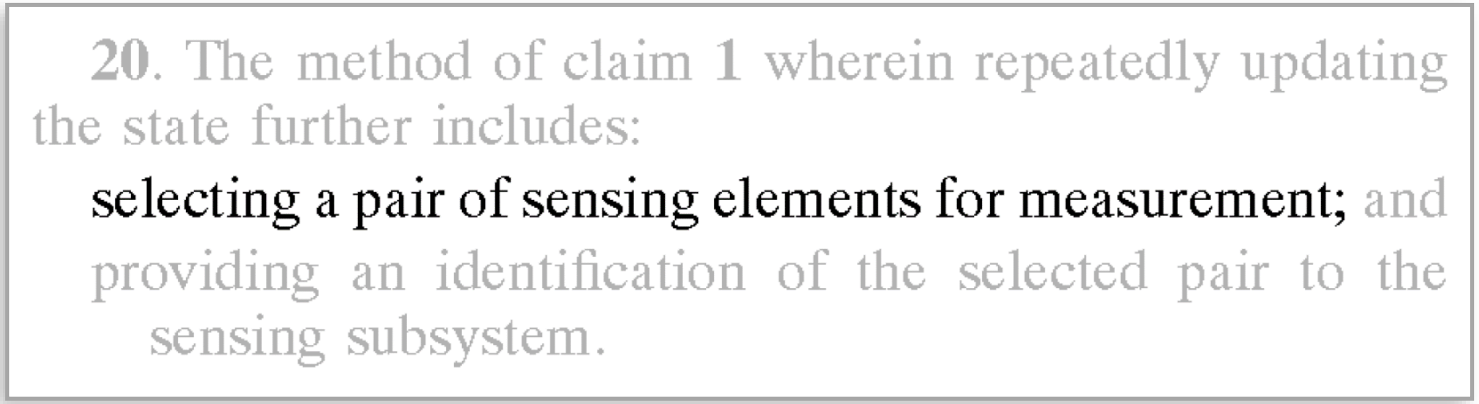
Welch & Horton: Enumerating, **selecting pairs**, and expected utility

Welch 2001 & Welch 1997	1305 Ground I	’632 patent, cls. 33-36
	1308 Ground I	’253 patent, cls. 6-9
Horton	1304 Ground III	’632 patent, cls. 20-21
	1305 Ground IV	’632 patent, cl. 33
	1308 Ground IV	’253 patent, cls. 6-9
Horton & Welch 1997	1305 Ground V	’632 patent, cls. 34-36
	1308 Ground V	’253 patent, cls. 7-9

Other prior art references

Kramer & Chen	1304 Ground V	’632 patent, cls. 66-68
Kramer, Chen & Welch 2001	1304 Ground VI	’632 patent, cl. 69
Welch 2001, Welch 1997 & Harris	1305 Ground III	’632 patent, cls. 54-55 & 57-58
	1308 Ground II	’253 patent, cls. 3-5
Welch 2001, Welch 1997 & Reitmayr	1308 Ground III	’253 patent, cls. 3-4
Horton & Harris	1305 Ground VI	’632 patent, cls. 54-55 & 57-58

"Selecting Pairs": Claim Language

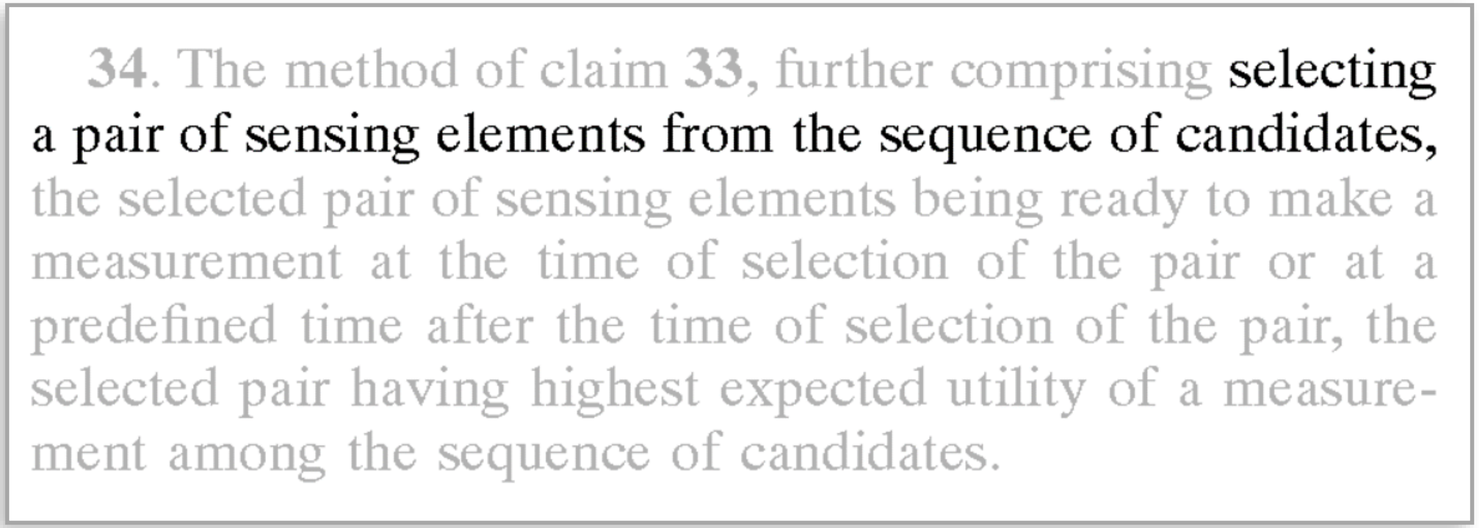


20. The method of claim 1 wherein repeatedly updating the state further includes:

selecting a pair of sensing elements for measurement; and

providing an identification of the selected pair to the sensing subsystem.

Ex. 1001, cl.20



34. The method of claim 33, further comprising **selecting a pair of sensing elements from the sequence of candidates,** the selected pair of sensing elements being ready to make a measurement at the time of selection of the pair or at a predefined time after the time of selection of the pair, the selected pair having highest expected utility of a measurement among the sequence of candidates.

Ex. 1001, cl.34; *see* Ex.1003, cl.7

Horton’s External Tracking System Does Not Select a Pair of Sensing Elements

’632 cls. 20-21, 34-36; ’253 cls. 7-9

Petitioner	Horton’s external tracking system could be an optical tracker that uses pairs of sensing elements
Rebuttal	Horton’s external tracking system does not generate a “sequence of candidates of pairs” of sensors and targets Horton does not describe “selecting” sensors or targets in conjunction with an external tracking system

E.g., 1308 Petition 70; 1308 POR 9, 60-61; 1308 Reply 29

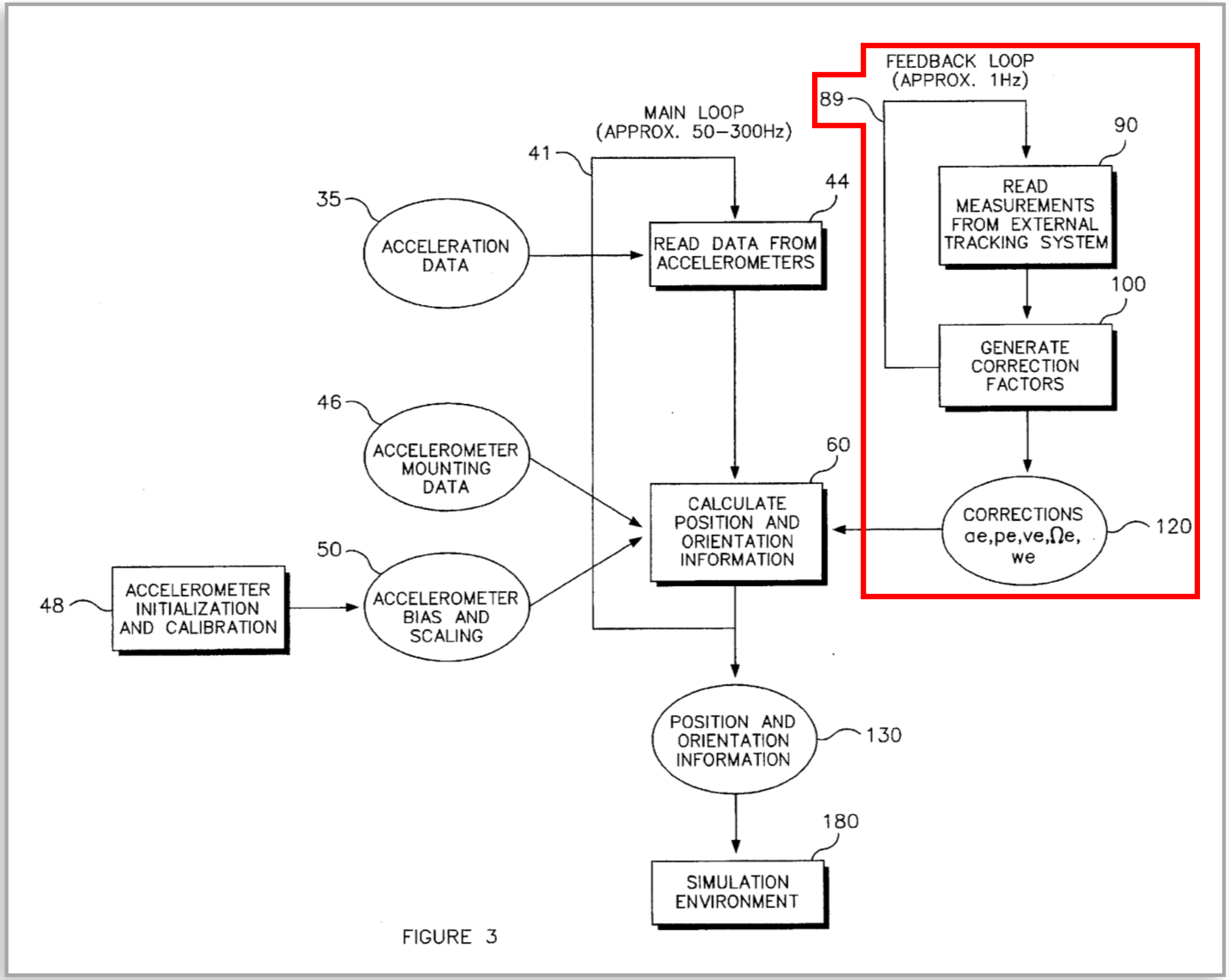


FIGURE 3

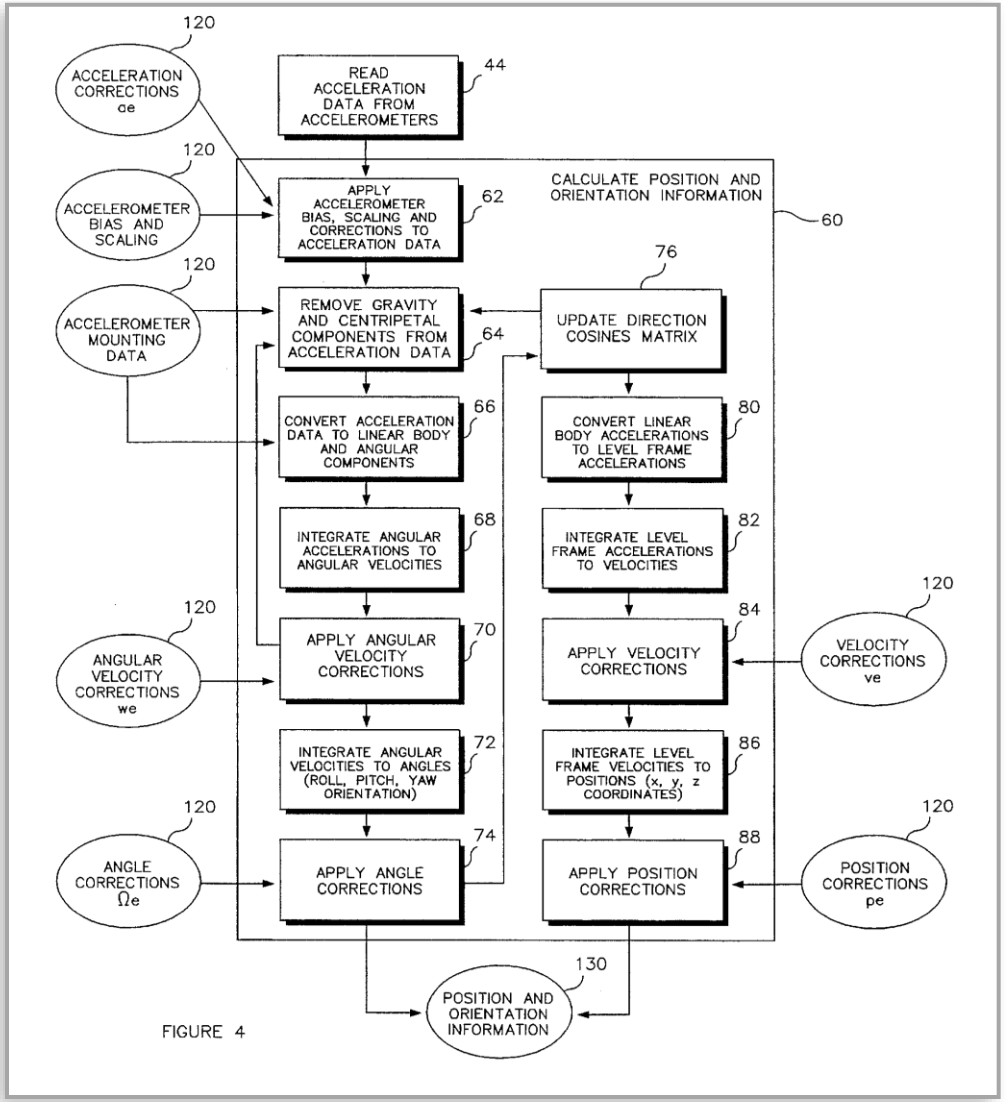
Ex. 1010, Fig.3; *e.g.*, 1304 POR 9

Horton Does Not Disclose Selecting a Pair of Accelerometers

’632 cls. 20-21, 34-36; ’253 cls. 7-9

Petitioner	Horton’s six accelerometers comprise three pairs
Rebuttal	Horton does not pair accelerometers in this way Horton does not “select” pairs No support from Horton or Petitioner’s expert Argument was raised for the first time in reply

E.g., 1308 Petition 70; 1308 Reply 29-30; 1308 Sur-Reply 23-25



Ex. 1010, Fig.4

Grounds and Challenged Claims

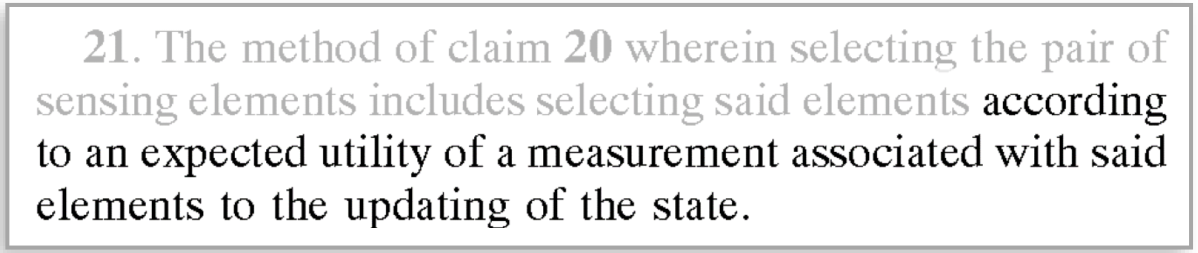
Welch & Horton: Enumerating, selecting pairs, and **expected utility**

Welch 2001 & Welch 1997	1305 Ground I	’632 patent, cls. 33-36
	1308 Ground I	’253 patent, cls. 6-9
Horton	1304 Ground III	’632 patent, cls. 20-21
	1305 Ground IV	’632 patent, cl. 33
	1308 Ground IV	’253 patent, cls. 6-9
Horton & Welch 1997	1305 Ground V	’632 patent, cls. 34-36
	1308 Ground V	’253 patent, cls. 7-9

Other prior art references

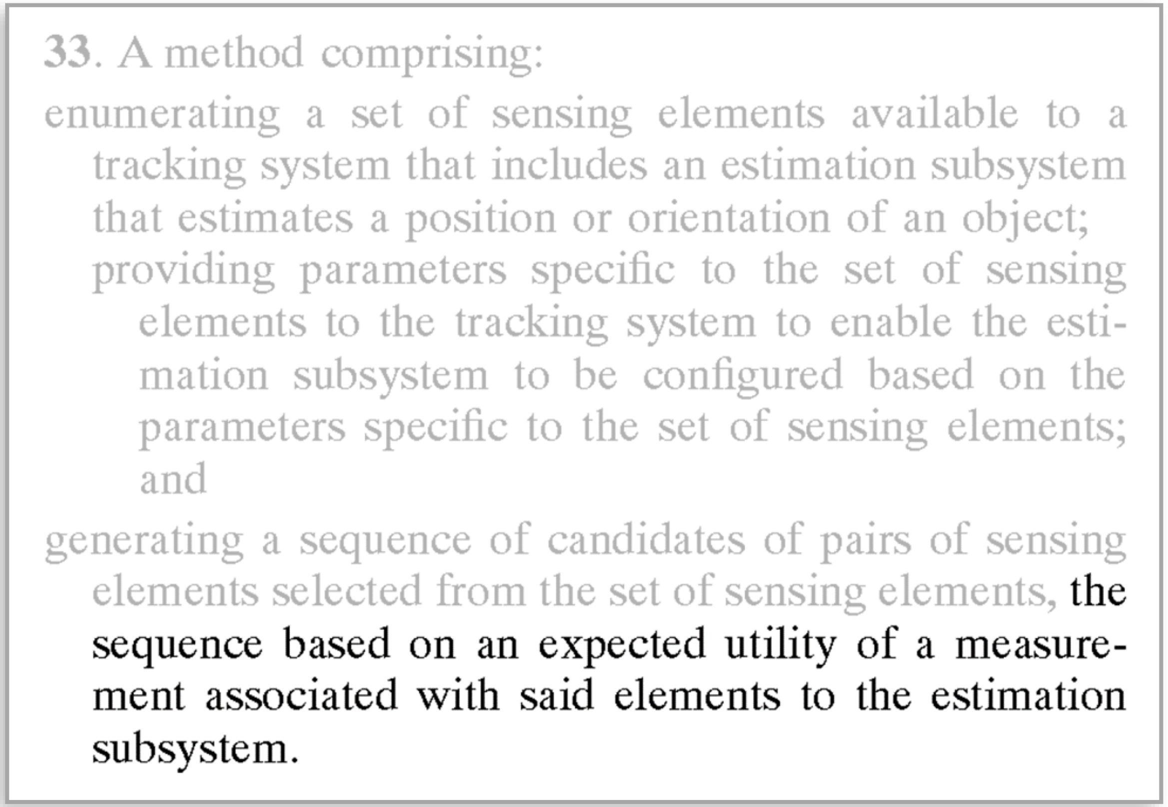
Kramer & Chen	1304 Ground V	’632 patent, cls. 66-68
Kramer, Chen & Welch 2001	1304 Ground VI	’632 patent, cl. 69
Welch 2001, Welch 1997 & Harris	1305 Ground III	’632 patent, cls. 54-55 & 57-58
	1308 Ground II	’253 patent, cls. 3-5
Welch 2001, Welch 1997 & Reitmayr	1308 Ground III	’253 patent, cls. 3-4
Horton & Harris	1305 Ground VI	’632 patent, cls. 54-55 & 57-58

“Expected Utility”: Claim Language



21. The method of claim 20 wherein selecting the pair of sensing elements includes selecting said elements according to an expected utility of a measurement associated with said elements to the updating of the state.

Ex. 1001, cl.21



33. A method comprising:

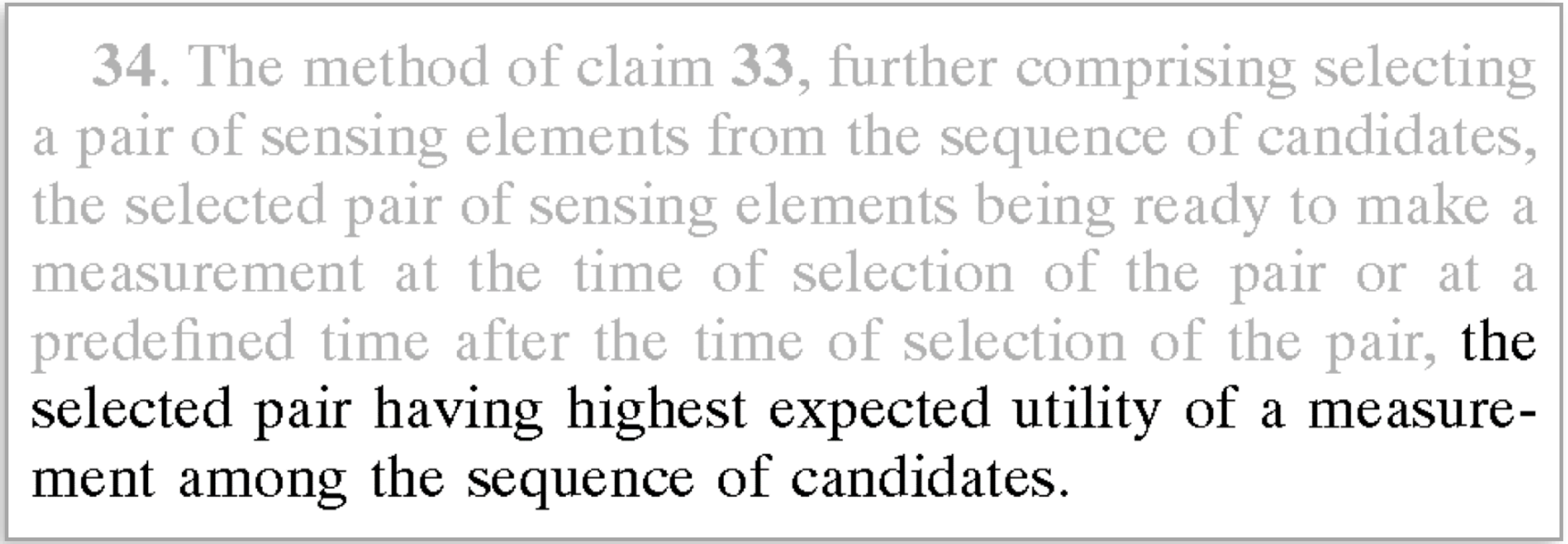
enumerating a set of sensing elements available to a tracking system that includes an estimation subsystem that estimates a position or orientation of an object;

providing parameters specific to the set of sensing elements to the tracking system to enable the estimation subsystem to be configured based on the parameters specific to the set of sensing elements; and

generating a sequence of candidates of pairs of sensing elements selected from the set of sensing elements, the sequence based on an expected utility of a measurement associated with said elements to the estimation subsystem.

Ex. 1001, cl.33

“Highest Expected Utility”: Claim Language



34. The method of claim 33, further comprising selecting a pair of sensing elements from the sequence of candidates, the selected pair of sensing elements being ready to make a measurement at the time of selection of the pair or at a predefined time after the time of selection of the pair, the selected pair having highest expected utility of a measurement among the sequence of candidates.

Ex. 1001, cl.34; *see* Ex. 1003, cl.7

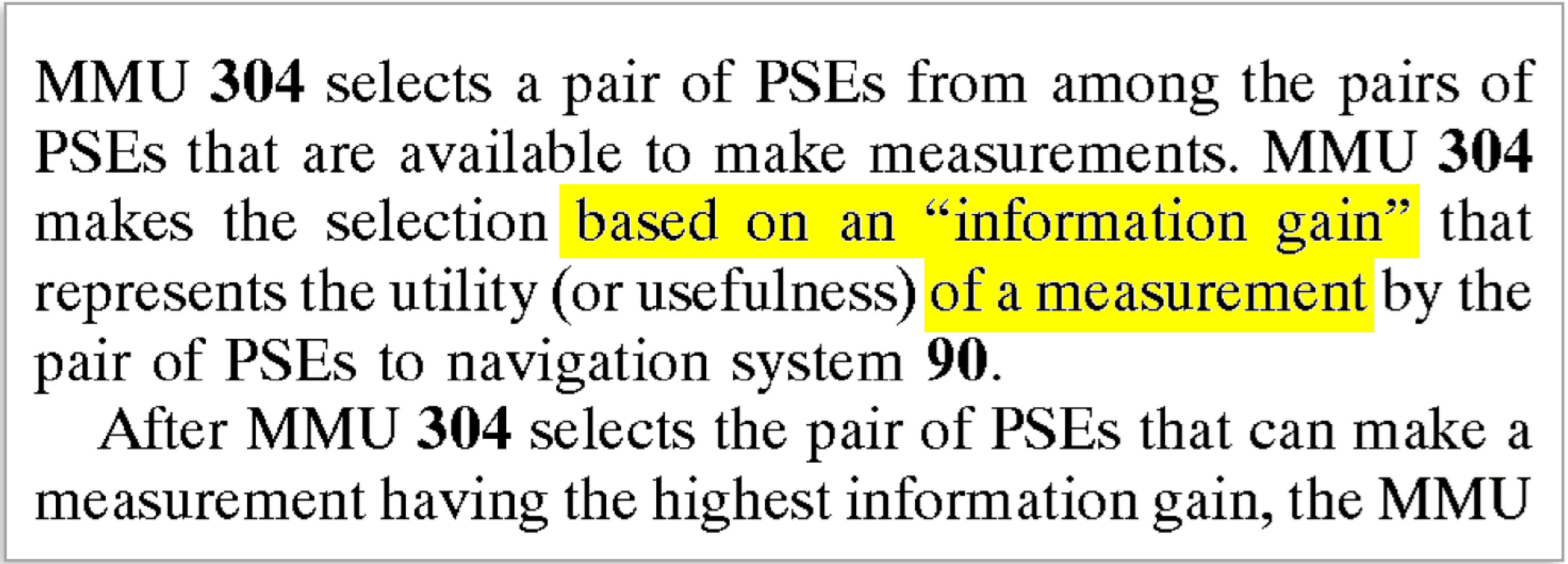
“Expected Utility”: Claim Construction

“expected utility of a measurement”

Patent Owner’s Construction	Petitioner’s Construction
“expected information gain of a measurement”	“utility” means “usefulness”
E.g., 1305 POR 23-24; Baillot ¶¶ 78-82	*E.g.*, 1305 Reply 5

The Specification Supports Patent Owner’s Construction

’632 cls. 21, 33-36; ’253 cls. 7-9



MMU **304** selects a pair of PSEs from among the pairs of PSEs that are available to make measurements. MMU **304** makes the selection based on an “information gain” that represents the utility (or usefulness) of a measurement by the pair of PSEs to navigation system **90**.

After MMU **304** selects the pair of PSEs that can make a measurement having the highest information gain, the MMU

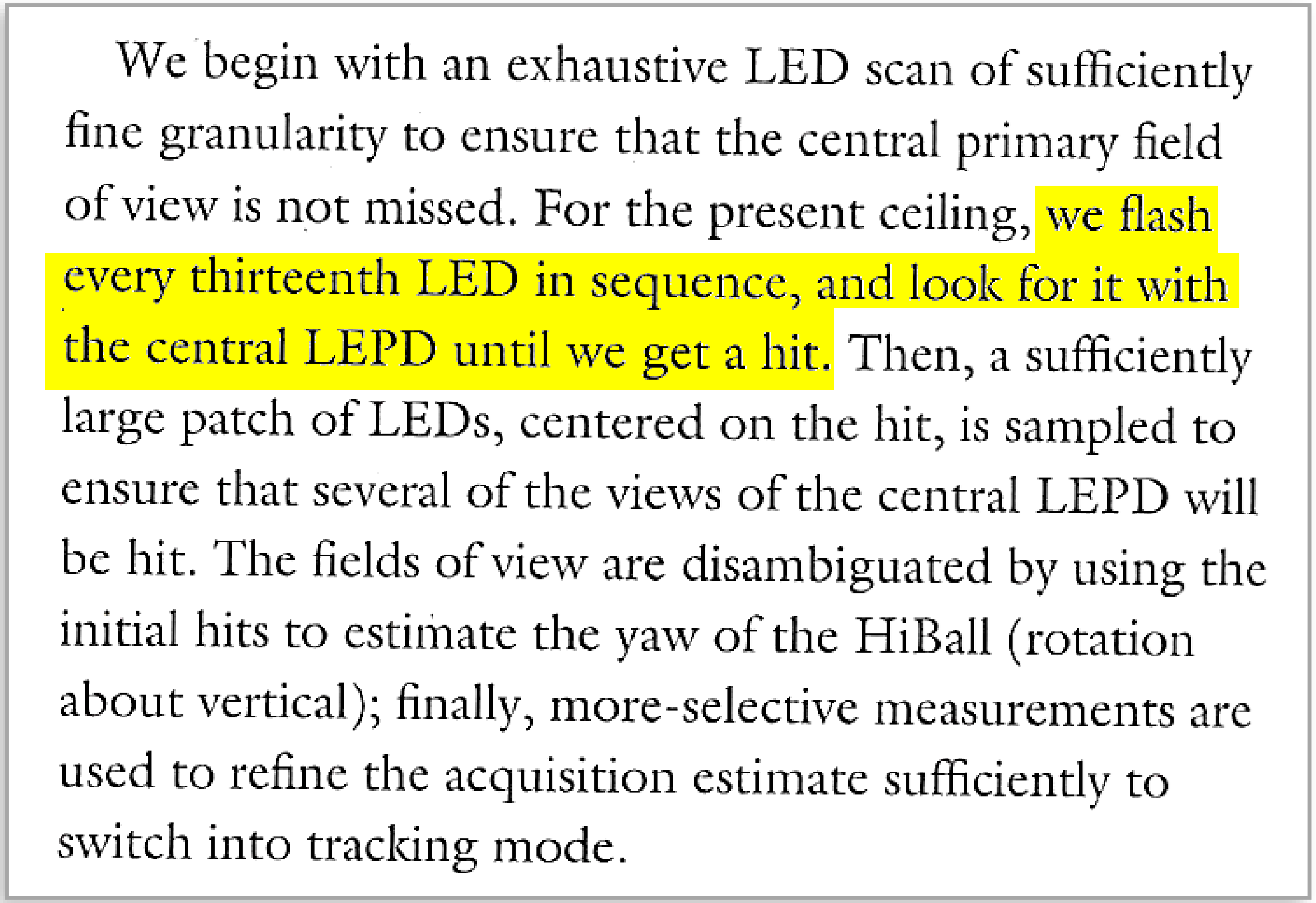
Ex. 1001, 19:33-39; *e.g.*, 1305 POR 23-24

Welch 2001 Does Not Disclose an Expected Utility of a Measurement

’632 cls. 33-36; ’253 cls. 7-9

Petitioner	Petition: Welch 2001 discloses sampling LEDs to estimate yaw Reply: Welch 2001’s every 13th LED sequence has more utility than “more-selective” measurements
Rebuttal	LEDs being useful to estimate yaw is not the same as expected utility Comparing utility across the ***series*** of measurements does not bear on their ***sequence*** No expert support for new argument

E.g., 1305 Petition 24; 1305 POR 31-32; 1305 Reply 9; 1305 Sur-Reply 11-12



We begin with an exhaustive LED scan of sufficiently fine granularity to ensure that the central primary field of view is not missed. For the present ceiling, we flash every thirteenth LED in sequence, and look for it with the central LEPD until we get a hit. Then, a sufficiently large patch of LEDs, centered on the hit, is sampled to ensure that several of the views of the central LEPD will be hit. The fields of view are disambiguated by using the initial hits to estimate the yaw of the HiBall (rotation about vertical); finally, more-selective measurements are used to refine the acquisition estimate sufficiently to switch into tracking mode.

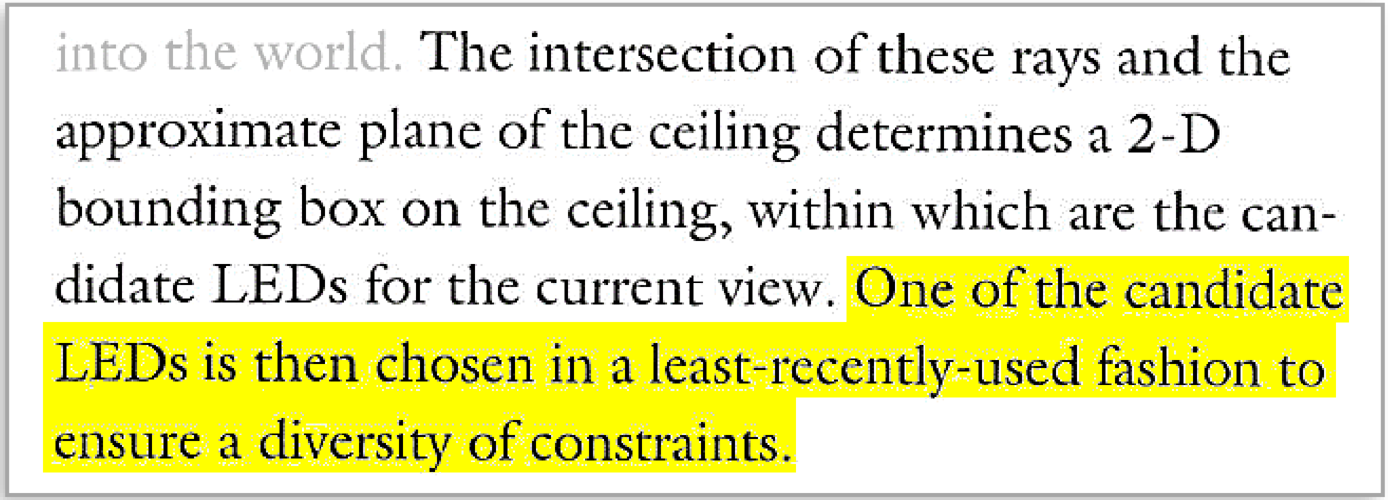
Ex. 1007, 14

Welch 2001's Least-Recently-Used Heuristic Does Not Achieve the Highest Expected Utility

'632 cls. 34-36; '253 cls. 7-9

Petitioner	Welch 2001 selects the least-recently-used LED
Rebuttal	Least-recently-used heuristic does not achieve the ***highest*** expected utility Petitioner improperly imports a "balancing" concept into claims

E.g., 1305 Petition 24-25; 1305 POR 32-33; 1305 Reply 9; 1305 Sur-Reply 12-13



into the world. The intersection of these rays and the approximate plane of the ceiling determines a 2-D bounding box on the ceiling, within which are the candidate LEDs for the current view. One of the candidate LEDs is then chosen in a least-recently-used fashion to ensure a diversity of constraints.

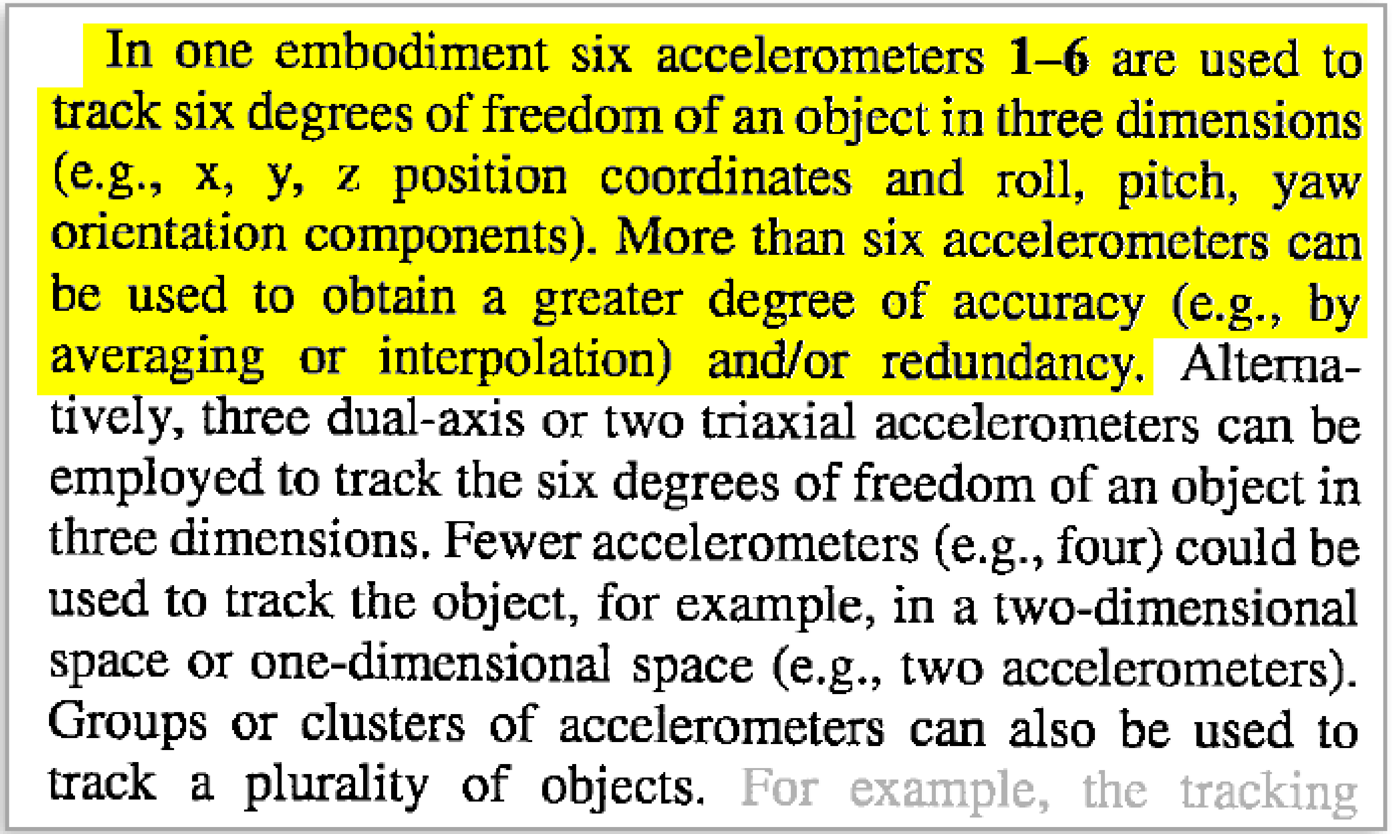
Ex. 1007, 13

Horton Does Not Disclose an Expected Utility of a Measurement

’632 cls. 21, 33-36; ’253 cls. 7-9

Petitioner	Horton discloses using pairs of accelerometers, as well as adding accelerometers
Rebuttal	No sequence of candidates of pairs of accelerometers No sequence based on expected utility No selection based on highest expected utility No expert support for these arguments introduced in reply

E.g., 1305 POR 53-54; 1305 Reply 23; 1305 Sur-Reply 22-23



In one embodiment six accelerometers **1–6** are used to track six degrees of freedom of an object in three dimensions (e.g., x, y, z position coordinates and roll, pitch, yaw orientation components). More than six accelerometers can be used to obtain a greater degree of accuracy (e.g., by averaging or interpolation) and/or redundancy. Alternatively, three dual-axis or two triaxial accelerometers can be employed to track the six degrees of freedom of an object in three dimensions. Fewer accelerometers (e.g., four) could be used to track the object, for example, in a two-dimensional space or one-dimensional space (e.g., two accelerometers). Groups or clusters of accelerometers can also be used to track a plurality of objects. For example, the tracking

Ex. 1010, 3:41-53

Kramer & Chen

Grounds and Challenged Claims

Welch & Horton: Enumerating, selecting pairs, and expected utility

Welch 2001 & Welch 1997	1305 Ground I	’632 patent, cls. 33-36
	1308 Ground I	’253 patent, cls. 6-9
Horton	1304 Ground III	’632 patent, cls. 20-21
	1305 Ground IV	’632 patent, cl. 33
	1308 Ground IV	’253 patent, cls. 6-9
Horton & Welch 1997	1305 Ground V	’632 patent, cls. 34-36
	1308 Ground V	’253 patent, cls. 7-9

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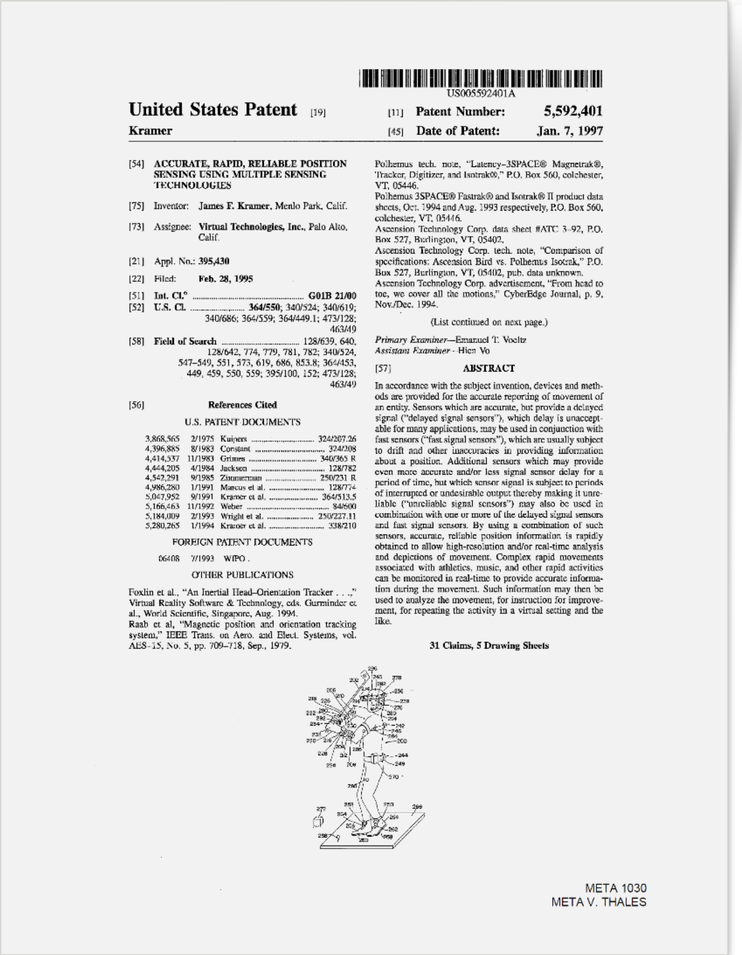
Welch 2001, Welch 1997 & Harris	1305 Ground III	’632 patent, cls. 54-55 & 57-58
	1308 Ground II	’253 patent, cls. 3-5
Welch 2001, Welch 1997 & Reitmayr	1308 Ground III	’253 patent, cls. 3-4
Horton & Harris	1305 Ground VI	’632 patent, cls. 54-55 & 57-58

Kramer (U.S. Patent No. 5,592,401)



US005592401A

United States Patent [19]

Kramer

[11] **Patent Number: 5,592,401**

[45] **Date of Patent: Jan. 7, 1997**

[54] **ACCURATE, RAPID, RELIABLE POSITION SENSING USING MULTIPLE SENSING TECHNOLOGIES**

[75] Inventor: **James F. Kramer**, Menlo Park, Calif.

[73] Assignee: **Virtual Technologies, Inc.**, Palo Alto, Calif.

[21] Appl. No.: **395,430**

[22] Filed: **Feb. 28, 1995**

[51] **Int. Cl.⁶** **G01B 21/00**

[52] **U.S. Cl.** **364/550**; 340/524; 340/619; 340/686; 364/559; 364/449.1; 473/128; 463/49

[58] **Field of Search** 128/639, 640, 128/642, 774, 779, 781, 782; 340/524, 547–549, 551, 573, 619, 686, 853.8; 364/453, 449, 459, 550, 559; 395/100, 152; 473/128; 463/49

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,868,565	2/1975	Kuipers	324/207.26
4,396,885	8/1983	Constant	324/208
4,414,537	11/1983	Grimes	340/365 R
4,444,205	4/1984	Jackson	128/782
4,542,291	9/1985	Zimmerman	250/231 R
4,986,280	1/1991	Marcus et al.	128/774
5,047,952	9/1991	Kramer et al.	364/513.5
5,166,463	11/1992	Weber	84/600
5,184,009	2/1993	Wright et al.	250/227.11
5,280,265	1/1994	Kramer et al.	338/210

FOREIGN PATENT DOCUMENTS

06408 7/1993 WIPO .

OTHER PUBLICATIONS

Foxlin et al., "An Inertial Head–Orientation Tracker . . .," Virtual Reality Software & Technology, eds. Gurminder et al., World Scientific, Singapore, Aug. 1994.

Raab et al, "Magnetic position and orientation tracking system," IEEE Trans. on Aero. and Elect. Systems, vol. AES-15, No. 5, pp. 709–718, Sep., 1979.

Polhemus tech. note, "Latency–3SPACE® Magnetrak®, Tracker, Digitizer, and Isotrak®," P.O. Box 560, colchester, VT, 05446.

Polhemus 3SPACE® Fastrak® and Isotrak® II product data sheets, Oct. 1994 and Aug. 1993 respectively, P.O. Box 560, colchester, VT, 05446.

Ascension Technology Corp. data sheet #ATC 3-92, P.O. Box 527, Burlington, VT, 05402.

Ascension Technology Corp. tech. note, "Comparison of specifications: Ascension Bird vs. Polhemus Isotrak," P.O. Box 527, Burlington, VT, 05402, pub. data unknown.

Ascension Technology Corp. advertisement, "From head to toe, we cover all the motions," CyberEdge Journal, p. 9, Nov./Dec. 1994.

(List continued on next page.)

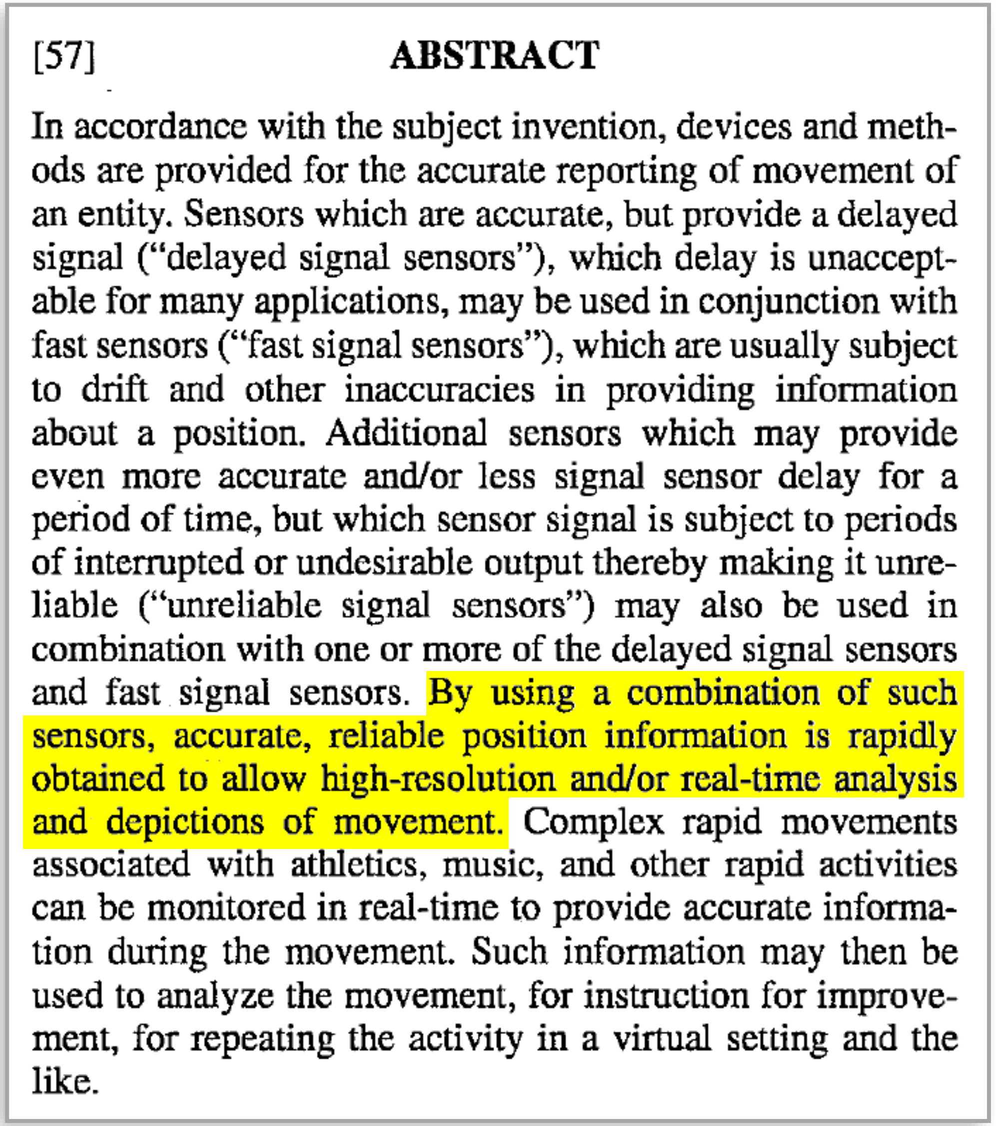
Primary Examiner—Emanuel T. Voeltz
Assistant Examiner—Hien Vo

[57] **ABSTRACT**

In accordance with the subject invention, devices and methods are provided for the accurate reporting of movement of an entity. Sensors which are accurate, but provide a delayed signal ("delayed signal sensors"), which delay is unacceptable for many applications, may be used in conjunction with fast sensors ("fast signal sensors"), which are usually subject to drift and other inaccuracies in providing information about a position. Additional sensors which may provide even more accurate and/or less signal sensor delay for a period of time, but which sensor signal is subject to periods of interrupted or undesirable output thereby making it unreliable ("unreliable signal sensors") may also be used in combination with one or more of the delayed signal sensors and fast signal sensors. By using a combination of such sensors, accurate, reliable position information is rapidly obtained to allow high-resolution and/or real-time analysis and depictions of movement. Complex rapid movements associated with athletics, music, and other rapid activities can be monitored in real-time to provide accurate information during the movement. Such information may then be used to analyze the movement, for instruction for improvement, for repeating the activity in a virtual setting and the like.

31 Claims, 5 Drawing Sheets

META 1030
META V. THALES

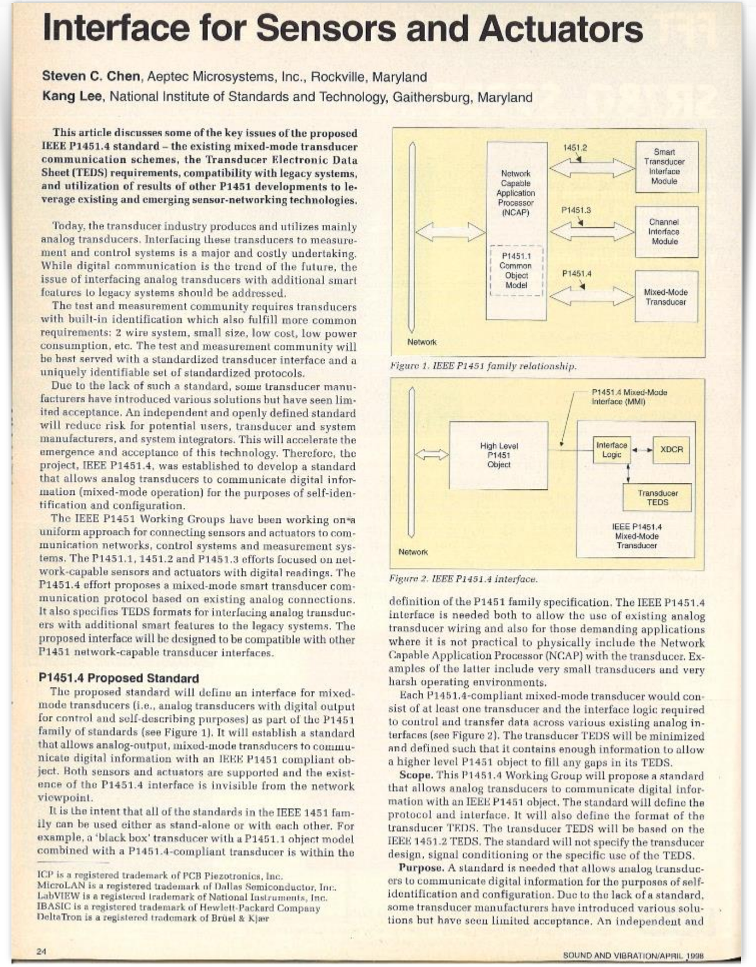


[57] **ABSTRACT**

In accordance with the subject invention, devices and methods are provided for the accurate reporting of movement of an entity. Sensors which are accurate, but provide a delayed signal ("delayed signal sensors"), which delay is unacceptable for many applications, may be used in conjunction with fast sensors ("fast signal sensors"), which are usually subject to drift and other inaccuracies in providing information about a position. Additional sensors which may provide even more accurate and/or less signal sensor delay for a period of time, but which sensor signal is subject to periods of interrupted or undesirable output thereby making it unreliable ("unreliable signal sensors") may also be used in combination with one or more of the delayed signal sensors and fast signal sensors. By using a combination of such sensors, accurate, reliable position information is rapidly obtained to allow high-resolution and/or real-time analysis and depictions of movement. Complex rapid movements associated with athletics, music, and other rapid activities can be monitored in real-time to provide accurate information during the movement. Such information may then be used to analyze the movement, for instruction for improvement, for repeating the activity in a virtual setting and the like.

Ex. 1030, Abstract; *e.g.*, 1304 Petition 60-61

Chen



Interface for Sensors and Actuators

Steven C. Chen, Aeptec Microsystems, Inc., Rockville, Maryland
Kang Lee, National Institute of Standards and Technology, Gaithersburg, Maryland

This article discusses some of the key issues of the proposed IEEE P1451.4 standard – the existing mixed-mode transducer communication schemes, the Transducer Electronic Data Sheet (TEDS) requirements, compatibility with legacy systems, and utilization of results of other P1451 developments to leverage existing and emerging sensor-networking technologies.

Today, the transducer industry produces and utilizes mainly analog transducers. Interfacing these transducers to measurement and control systems is a major and costly undertaking. While digital communication is the trend of the future, the issue of interfacing analog transducers with additional smart features to legacy systems should be addressed.

The test and measurement community requires transducers with built-in identification which also fulfill more common requirements: 2 wire system, small size, low cost, low power consumption, etc. The test and measurement community will be best served with a standardized transducer interface and a uniquely identifiable set of standardized protocols.

Due to the lack of such a standard, some transducer manufacturers have introduced various solutions but have seen limited acceptance. An independent and openly defined standard will reduce risk for potential users, transducer and system manufacturers, and system integrators. This will accelerate the emergence and acceptance of this technology. Therefore, the project, IEEE P1451.4, was established to develop a standard that allows analog transducers to communicate digital information (mixed-mode operation) for the purposes of self-identification and configuration.

The IEEE P1451 Working Groups have been working on a uniform approach for connecting sensors and actuators to communication networks, control systems and measurement systems. The P1451.1, 1451.2 and P1451.3 efforts focused on network-capable sensors and actuators with digital readings. The P1451.4 effort proposes a mixed-mode smart transducer communication protocol based on existing analog connections. It also specifies TEDS formats for interfacing analog transducers with additional smart features to the legacy systems. The proposed interface will be designed to be compatible with other P1451 network-capable transducer interfaces.

P1451.4 Proposed Standard

The proposed standard will define an interface for mixed-mode transducers (i.e., analog transducers with digital output for control and self-describing purposes) as part of the P1451 family of standards (see Figure 1). It will establish a standard that allows analog-output, mixed-mode transducers to communicate digital information with an IEEE P1451 compliant object. Both sensors and actuators are supported and the existence of the P1451.4 interface is invisible from the network viewpoint.

Figure 1. IEEE P1451 family relationship.

Figure 2. IEEE P1451.4 interface.

It is the intent that all of the standards in the IEEE 1451 family can be used either as stand-alone or with each other. For example, a 'black box' transducer with a P1451.1 object model combined with a P1451.4-compliant transducer is within the definition of the P1451 family specification. The IEEE P1451.4 interface is needed both to allow the use of existing analog transducer wiring and also for those demanding applications where it is not practical to physically include the Network Capable Application Processor (NCAP) with the transducer. Examples of the latter include very small transducers and very harsh operating environments.

Each P1451.4-compliant mixed-mode transducer would consist of at least one transducer and the interface logic required to control and transfer data across various existing analog interfaces (see Figure 2). The transducer TEDS will be minimized and defined such that it contains enough information to allow a higher level P1451 object to fill any gaps in its TEDS.

Scope. This P1451.4 Working Group will propose a standard that allows analog transducers to communicate digital information with an IEEE P1451 object. The standard will define the protocol and interface. It will also define the format of the transducer TEDS. The transducer TEDS will be based on the IEEE 1451.2 TEDS. The standard will not specify the transducer design, signal conditioning or the specific use of the TEDS.

Purpose. A standard is needed that allows analog transducers to communicate digital information for the purposes of self-identification and configuration. Due to the lack of a standard, some transducer manufacturers have introduced various solutions but have seen limited acceptance. An independent and

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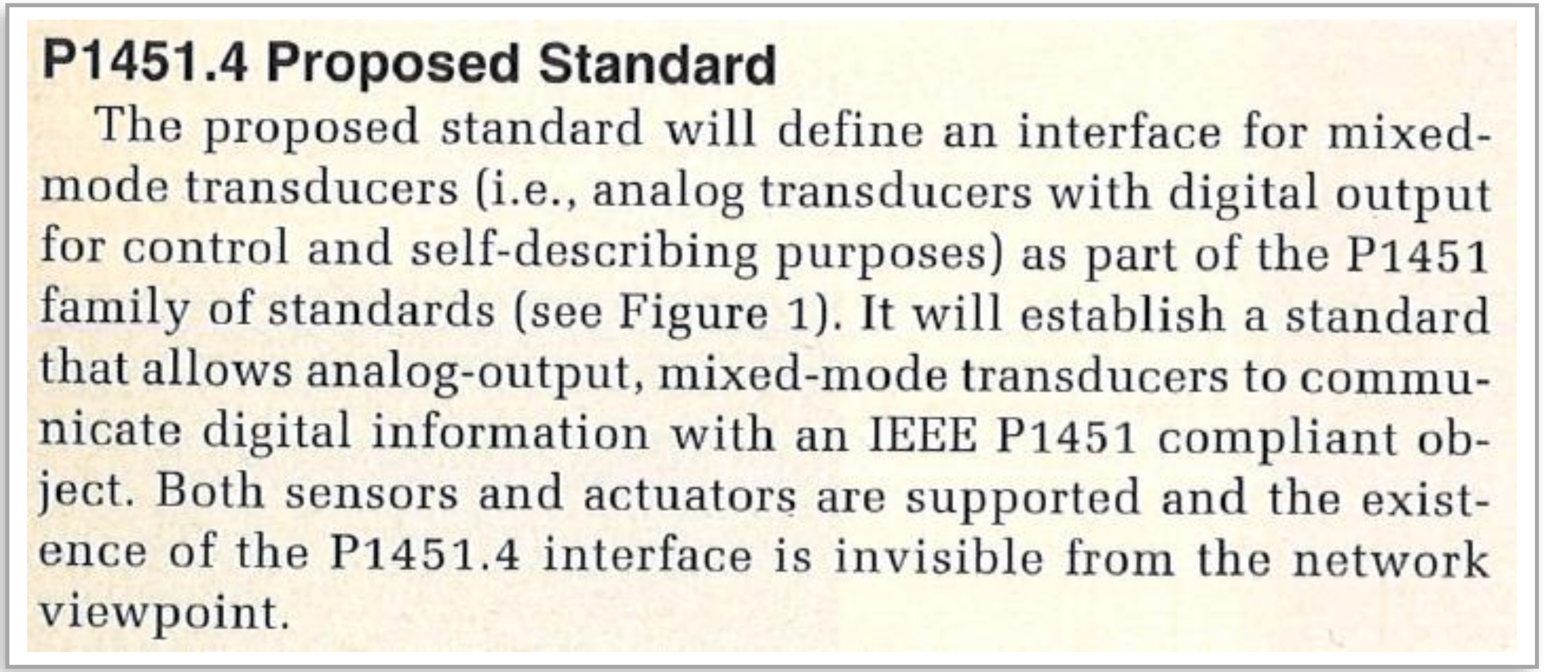
ICP is a registered trademark of PCB Piezotronics, Inc.
MicroLAN is a registered trademark of Dallas Semiconductor, Inc.
LabVIEW is a registered trademark of National Instruments, Inc.
IBASIC is a registered trademark of Hewlett-Packard Company
DeltaTron is a registered trademark of Brüel & Kjær

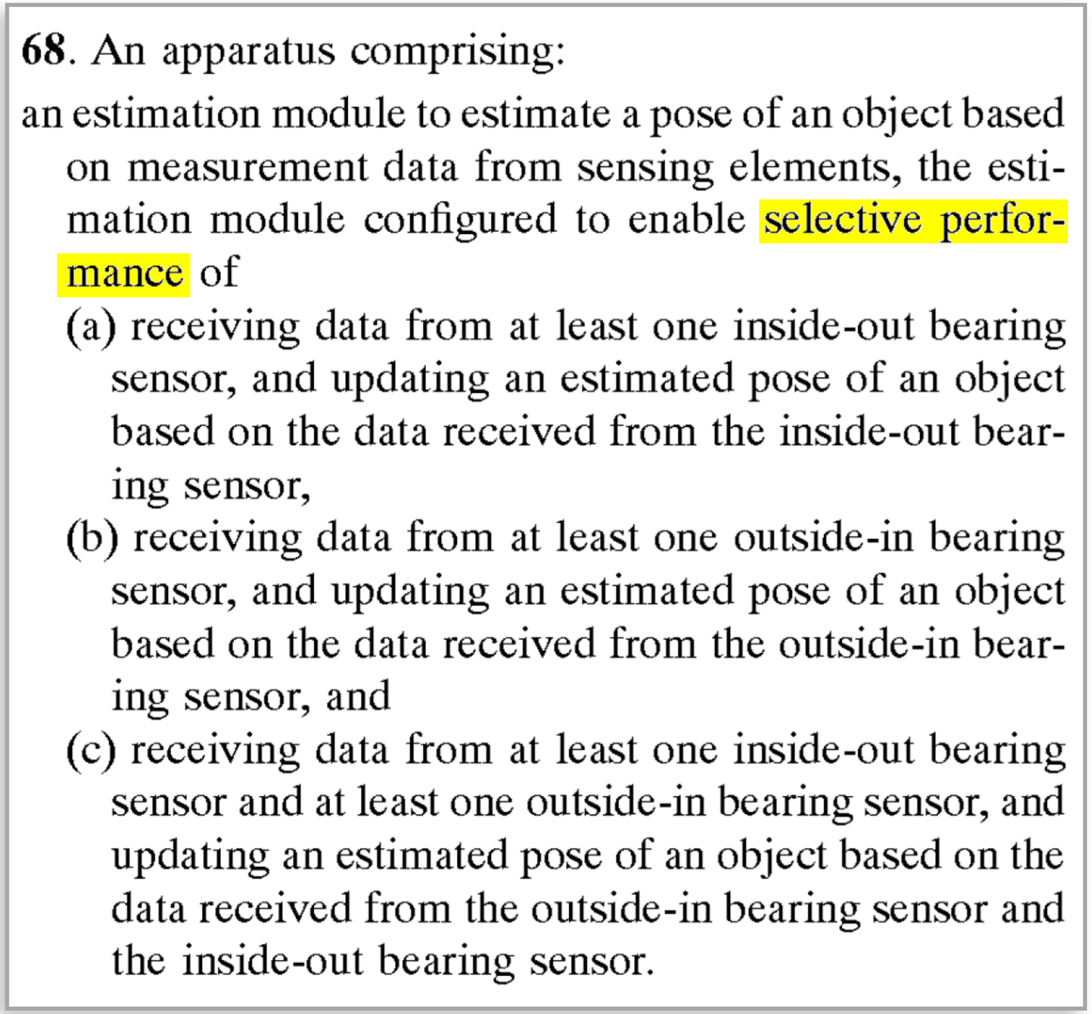


P1451.4 Proposed Standard

The proposed standard will define an interface for mixed-mode transducers (i.e., analog transducers with digital output for control and self-describing purposes) as part of the P1451 family of standards (see Figure 1). It will establish a standard that allows analog-output, mixed-mode transducers to communicate digital information with an IEEE P1451 compliant object. Both sensors and actuators are supported and the existence of the P1451.4 interface is invisible from the network viewpoint.

Ex. 1024, 24; *e.g.*, 1304 Petition 61

“Selective Performance”: Claim Language



68. An apparatus comprising:

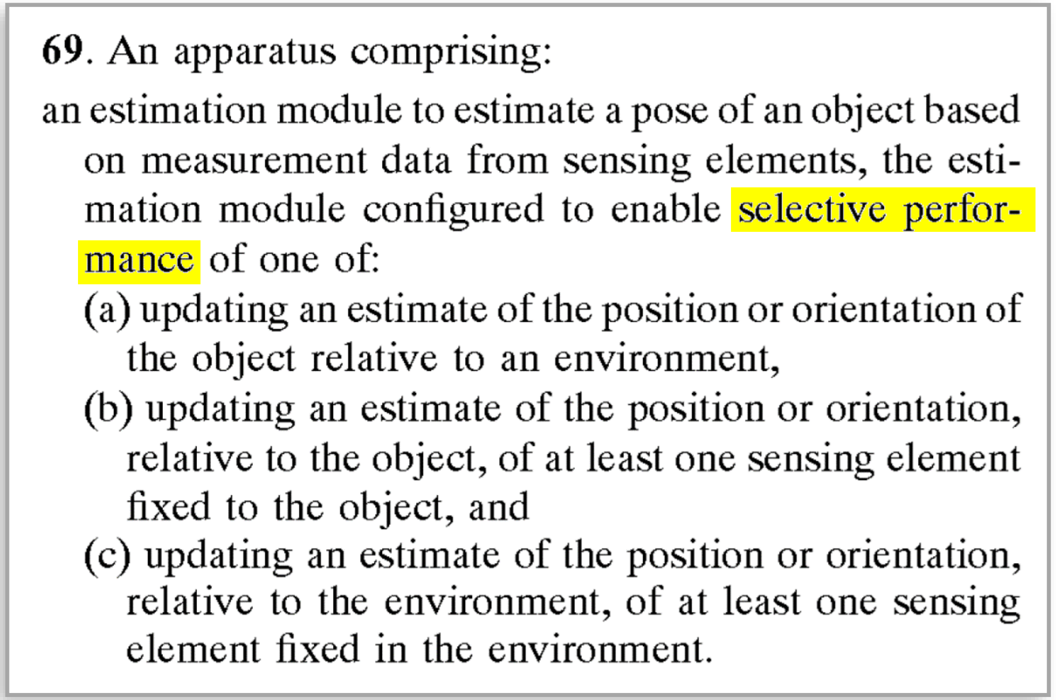
an estimation module to estimate a pose of an object based on measurement data from sensing elements, the estimation module configured to enable selective performance of

(a) receiving data from at least one inside-out bearing sensor, and updating an estimated pose of an object based on the data received from the inside-out bearing sensor,

(b) receiving data from at least one outside-in bearing sensor, and updating an estimated pose of an object based on the data received from the outside-in bearing sensor, and

(c) receiving data from at least one inside-out bearing sensor and at least one outside-in bearing sensor, and updating an estimated pose of an object based on the data received from the outside-in bearing sensor and the inside-out bearing sensor.

Ex. 1001, cl.68; *see id.*, cl.66



69. An apparatus comprising:

an estimation module to estimate a pose of an object based on measurement data from sensing elements, the estimation module configured to enable selective performance of one of:

(a) updating an estimate of the position or orientation of the object relative to an environment,

(b) updating an estimate of the position or orientation, relative to the object, of at least one sensing element fixed to the object, and

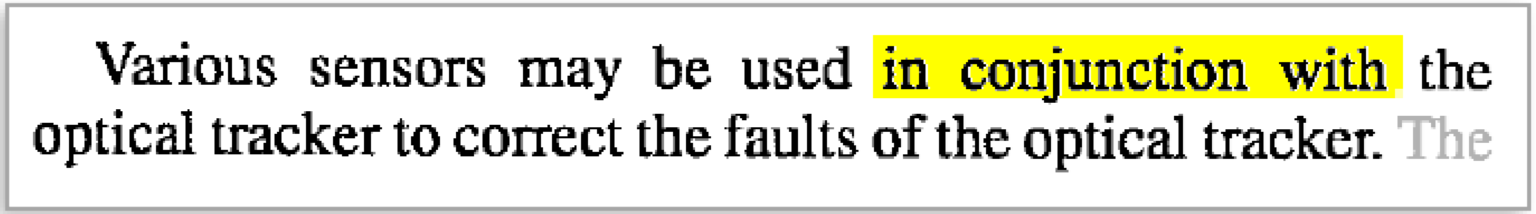
(c) updating an estimate of the position or orientation, relative to the environment, of at least one sensing element fixed in the environment.

Ex. 1001, cl.69

Kramer Does Not Disclose Selecting Among Available Sensors

’632 cls. 66-69

- Kramer discloses different types of sensors that may be used together for more accurate estimation, but not ***selecting*** one type of sensor over another.



Various sensors may be used in conjunction with the optical tracker to correct the faults of the optical tracker. The

Ex. 1030, 8:61-62; 1304 Sur-Reply 26

Harris & Reitmayr

Grounds and Challenged Claims

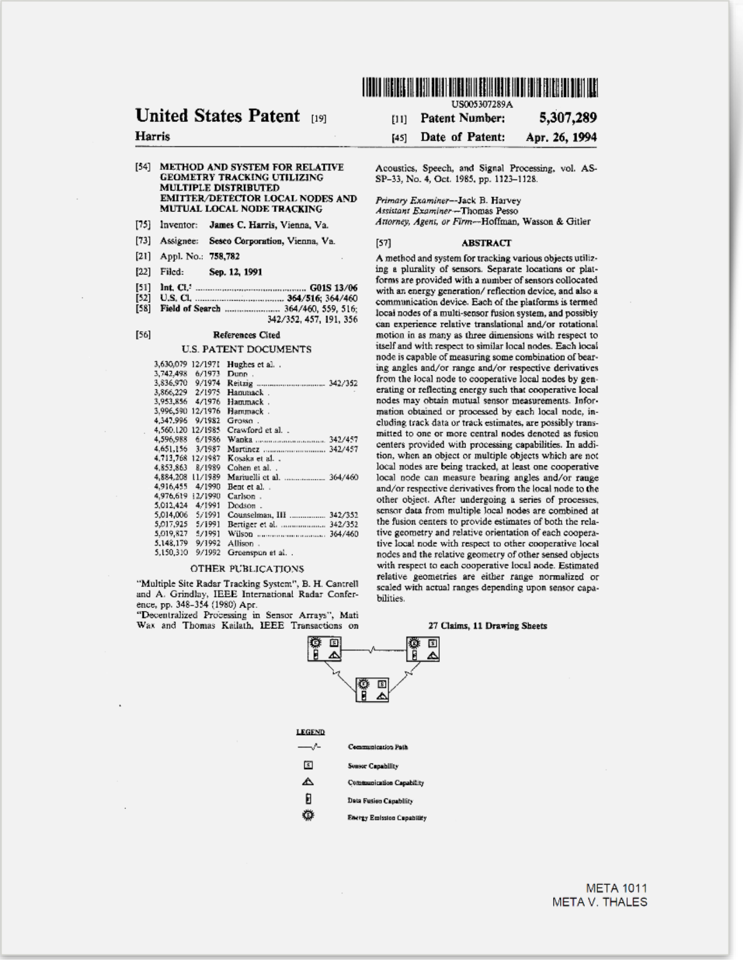
Welch & Horton: Enumerating, selecting pairs, and expected utility

Welch 2001 & Welch 1997	1305 Ground I	’632 patent, cls. 33-36
	1308 Ground I	’253 patent, cls. 6-9
Horton	1304 Ground III	’632 patent, cls. 20-21
	1305 Ground IV	’632 patent, cl. 33
	1308 Ground IV	’253 patent, cls. 6-9
Horton & Welch 1997	1305 Ground V	’632 patent, cls. 34-36
	1308 Ground V	’253 patent, cls. 7-9

Other prior art references

Kramer & Chen	1304 Ground V	’632 patent, cls. 66-68
Kramer, Chen & Welch 2001	1304 Ground VI	’632 patent, cl. 69
Welch 2001, Welch 1997 & Harris	1305 Ground III	’632 patent, cls. 54-55 & 57-58
	1308 Ground II	’253 patent, cls. 3-5
Welch 2001, Welch 1997 & Reitmayr	1308 Ground III	’253 patent, cls. 3-4
Horton & Harris	1305 Ground VI	’632 patent, cls. 54-55 & 57-58

Harris (U.S. Patent No. 5,307,289)



US005307289A

United States Patent [19]
Harris

[11] **Patent Number: 5,307,289**
[45] **Date of Patent: Apr. 26, 1994**

[54] **METHOD AND SYSTEM FOR RELATIVE GEOMETRY TRACKING UTILIZING MULTIPLE DISTRIBUTED EMITTER/DETECTOR LOCAL NODES AND MUTUAL LOCAL NODE TRACKING**

[75] Inventor: **James C. Harris**, Vienna, Va.

[73] Assignee: **Sesco Corporation**, Vienna, Va.

[21] Appl. No.: **758,782**

[22] Filed: **Sep. 12, 1991**

[51] **Int. Cl.^{5}** **G01S 13/06**
[52] **U.S. Cl.** **364/516**; 364/460
[58] **Field of Search** 364/460, 559, 516; 342/352, 457, 191, 356

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,630,079	12/1971	Hughes et al. .	
3,742,498	6/1973	Dunn .	
3,836,970	9/1974	Reitzig	342/352
3,866,229	2/1975	Hammack .	
3,953,856	4/1976	Hammack .	
3,996,590	12/1976	Hammack .	
4,347,996	9/1982	Grosso .	
4,560,120	12/1985	Crawford et al. .	
4,596,988	6/1986	Wanka	342/457
4,651,156	3/1987	Martinez	342/457
4,713,768	12/1987	Kosaka et al. .	
4,853,863	8/1989	Cohen et al. .	
4,884,208	11/1989	Marinelli et al.	364/460
4,916,455	4/1990	Bent et al. .	
4,976,619	12/1990	Carlson .	
5,012,424	4/1991	Dodson .	
5,014,006	5/1991	Counselman, III	342/352
5,017,925	5/1991	Bertiger et al.	342/352
5,019,827	5/1991	Wilson	364/460
5,148,179	9/1992	Allison .	
5,150,310	9/1992	Greenspun et al. .	

OTHER PUBLICATIONS

"Multiple Site Radar Tracking System", B. H. Cantrell and A. Grindlay, IEEE International Radar Conference, pp. 348–354 (1980) Apr.
"Decentralized Processing in Sensor Arrays", Mati Wax and Thomas Kailath, IEEE Transactions on Acoustics, Speech, and Signal Processing, vol. ASSP–33, No. 4, Oct. 1985, pp. 1123–1128.

Primary Examiner—Jack B. Harvey
Assistant Examiner—Thomas Pesso
Attorney, Agent, or Firm—Hoffman, Wasson & Gitler

[57] **ABSTRACT**

A method and system for tracking various objects utilizing a plurality of sensors. Separate locations or platforms are provided with a number of sensors collocated with an energy generation/ reflection device, and also a communication device. Each of the platforms is termed local nodes of a multi-sensor fusion system, and possibly can experience relative translational and/or rotational motion in as many as three dimensions with respect to itself and with respect to similar local nodes. Each local node is capable of measuring some combination of bearing angles and/or range and/or respective derivatives from the local node to cooperative local nodes by generating or reflecting energy such that cooperative local nodes may obtain mutual sensor measurements. Information obtained or processed by each local node, including track data or track estimates, are possibly transmitted to one or more central nodes denoted as fusion centers provided with processing capabilities. In addition, when an object or multiple objects which are not local nodes are being tracked, at least one cooperative local node can measure bearing angles and/or range and/or respective derivatives from the local node to the other object. After undergoing a series of processes, sensor data from multiple local nodes are combined at the fusion centers to provide estimates of both the relative geometry and relative orientation of each cooperative local node with respect to other cooperative local nodes and the relative geometry of other sensed objects with respect to each cooperative local node. Estimated relative geometries are either range normalized or scaled with actual ranges depending upon sensor capabilities.

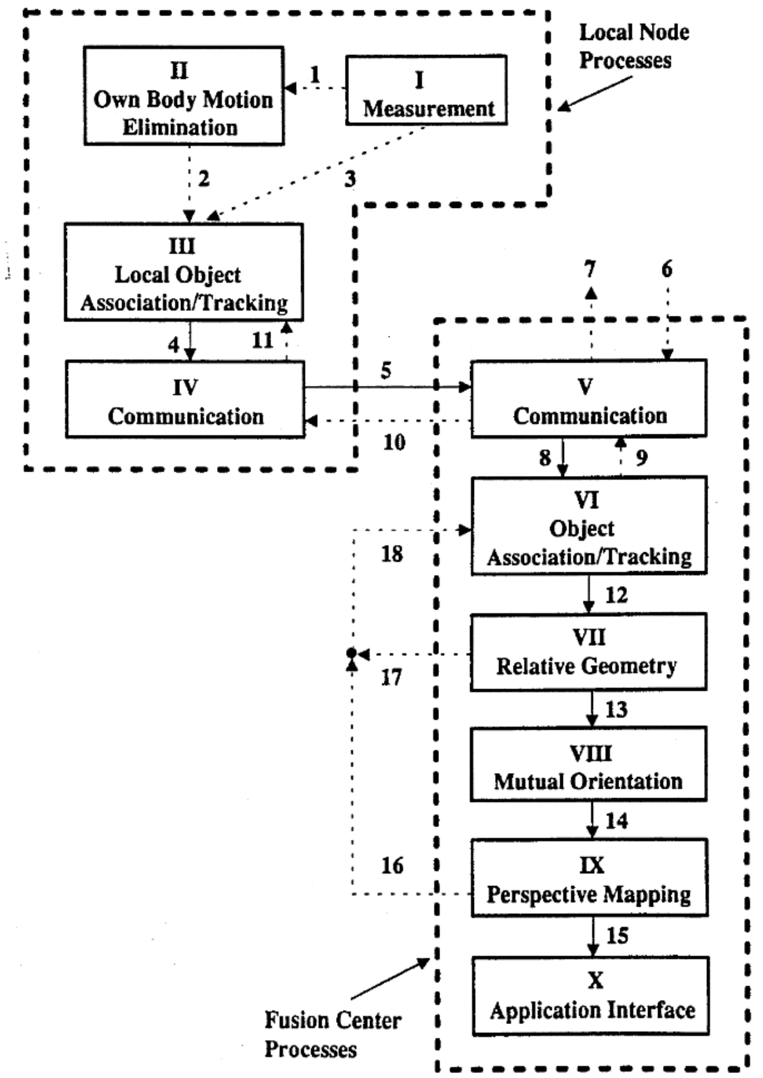
27 Claims, 11 Drawing Sheets

LEGEND

—√— Communication Path
S Sensor Capability
△ Communication Capability
F Data Fusion Capability
E Energy Emission Capability

META 1011
META V. THALES

FIG. 8



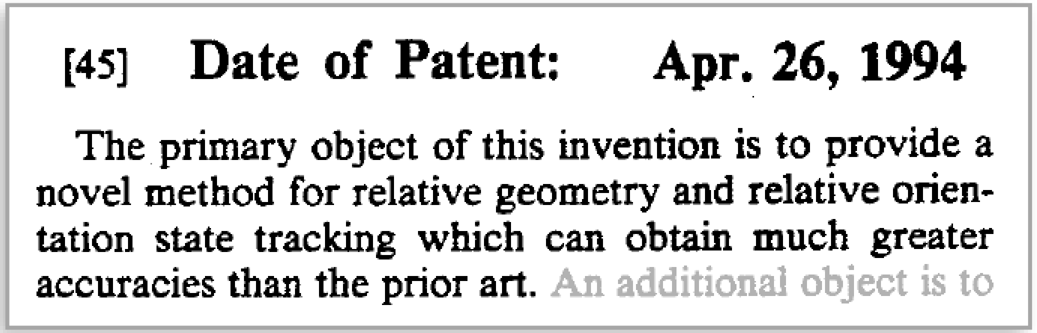
Ex. 1011, Fig. 8; *e.g.*, 1308 Petition 42-43

No Motivation to Combine Welch & Harris

1305 Ground III, 1308 Ground II

Petitioner	POSITA would have modified Welch's HiBall FPGAs to process tracking calculations as in Harris
Rebuttal	FPGAs in HiBall units were not well suited to perform tracking functions Welch's SCAAT approach was already simple and fast, so the POSITA would not have been motivated to modify it

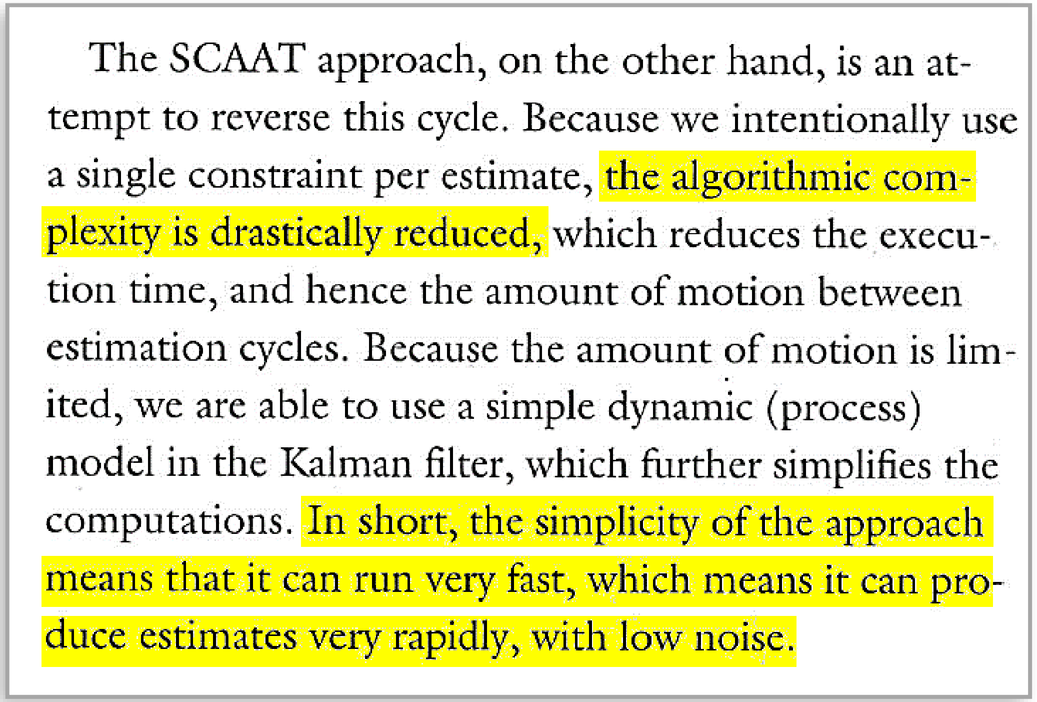
E.g., 1308 Reply 16-18; 1308 Sur-Reply 13-14; Ex. 2007 ¶¶ 396-399



[45] **Date of Patent: Apr. 26, 1994**

The primary object of this invention is to provide a novel method for relative geometry and relative orientation state tracking which can obtain much greater accuracies than the prior art. An additional object is to

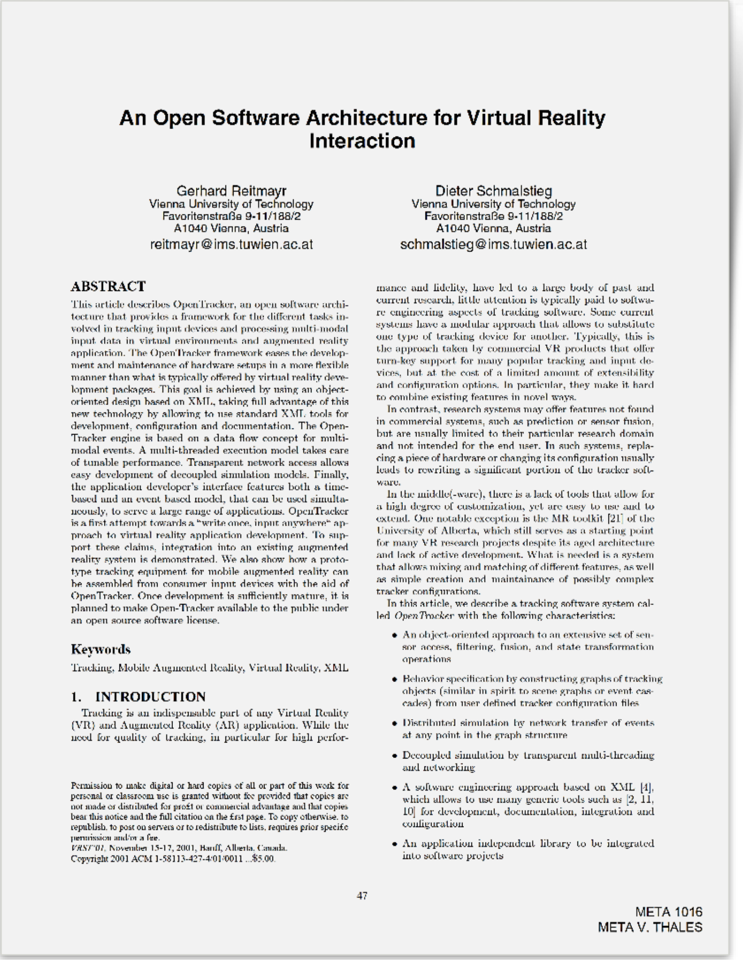
Ex. 1011, Title Page, 4:14-17



The SCAAT approach, on the other hand, is an attempt to reverse this cycle. Because we intentionally use a single constraint per estimate, the algorithmic complexity is drastically reduced, which reduces the execution time, and hence the amount of motion between estimation cycles. Because the amount of motion is limited, we are able to use a simple dynamic (process) model in the Kalman filter, which further simplifies the computations. In short, the simplicity of the approach means that it can run very fast, which means it can produce estimates very rapidly, with low noise.

Ex. 1007, 11

Reitmayr



An Open Software Architecture for Virtual Reality Interaction

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ABSTRACT

This article describes OpenTracker, an open software architecture that provides a framework for the different tasks involved in tracking input devices and processing multi-modal input data in virtual environments and augmented reality application. The OpenTracker framework eases the development and maintenance of hardware setups in a more flexible manner than what is typically offered by virtual reality development packages. This goal is achieved by using an object-oriented design based on XML, taking full advantage of this new technology by allowing to use standard XML tools for development, configuration and documentation. The OpenTracker engine is based on a data flow concept for multimodal events. A multi-threaded execution model takes care of tunable performance. Transparent network access allows easy development of decoupled simulation models. Finally, the application developer's interface features both a time-based and an event based model, that can be used simultaneously, to serve a large range of applications. OpenTracker is a first attempt towards a "write once, input anywhere" approach to virtual reality application development. To support these claims, integration into an existing augmented reality system is demonstrated. We also show how a prototype tracking equipment for mobile augmented reality can be assembled from consumer input devices with the aid of OpenTracker. Once development is sufficiently mature, it is planned to make Open-Tracker available to the public under an open source software license.

Keywords

Tracking, Mobile Augmented Reality, Virtual Reality, XML

1. INTRODUCTION

Tracking is an indispensable part of any Virtual Reality (VR) and Augmented Reality (AR) application. While the need for quality of tracking, in particular for high performance and fidelity, have led to a large body of past and current research, little attention is typically paid to software engineering aspects of tracking software. Some current systems have a modular approach that allows to substitute one type of tracking device for another. Typically, this is the approach taken by commercial VR products that offer turn-key support for many popular tracking and input devices, but at the cost of a limited amount of extensibility and configuration options. In particular, they make it hard to combine existing features in novel ways.

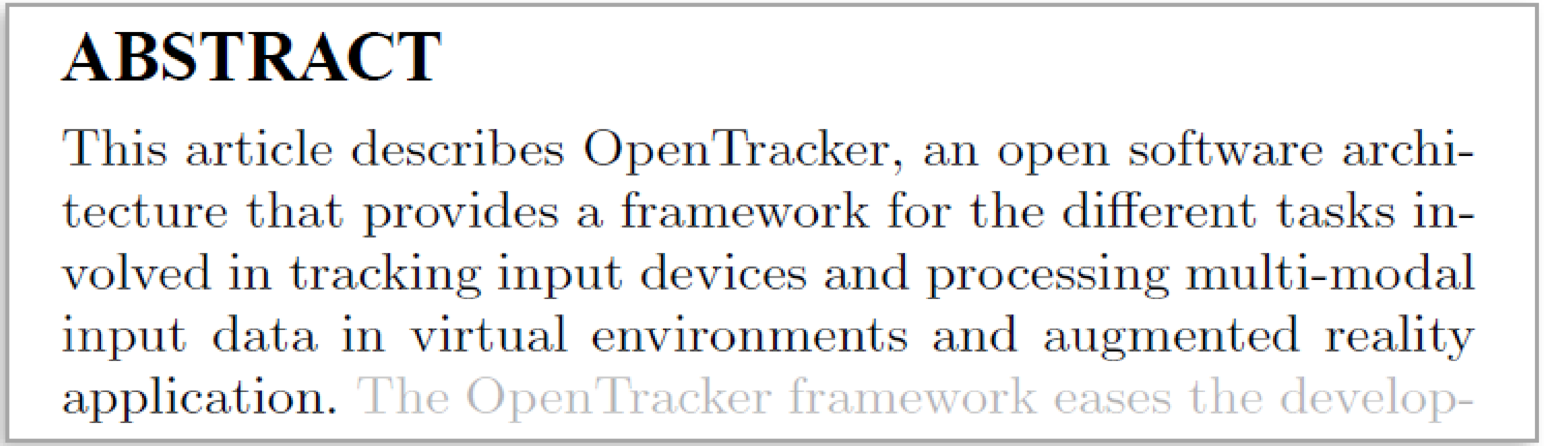
In contrast, research systems may offer features not found in commercial systems, such as prediction or sensor fusion, but are usually limited to their particular research domain and not intended for the end user. In such systems, replacing a piece of hardware or changing its configuration usually leads to rewriting a significant portion of the tracker software.

In the middle(-ware), there is a lack of tools that allow for a high degree of customization, yet are easy to use and to extend. One notable exception is the MR toolkit [21] of the University of Alberta, which still serves as a starting point for many VR research projects despite its aged architecture and lack of active development. What is needed is a system that allows mixing and matching of different features, as well as simple creation and maintainance of possibly complex tracker configurations.

In this article, we describe a tracking software system called *OpenTracker* with the following characteristics:

- An object-oriented approach to an extensive set of sensor access, filtering, fusion, and state transformation operations
- Behavior specification by constructing graphs of tracking objects (similar in spirit to scene graphs or event cascades) from user defined tracker configuration files
- Distributed simulation by network transfer of events at any point in the graph structure
- Decoupled simulation by transparent multi-threading and networking
- A software engineering approach based on XML [4], which allows to use many generic tools such as [2, 11, 10] for development, documentation, integration and configuration
- An application independent library to be integrated into software projects

VRST'01, November 15-17, 2001, Banff, Alberta, Canada.



ABSTRACT

This article describes OpenTracker, an open software architecture that provides a framework for the different tasks involved in tracking input devices and processing multi-modal input data in virtual environments and augmented reality application. The OpenTracker framework eases the develop-

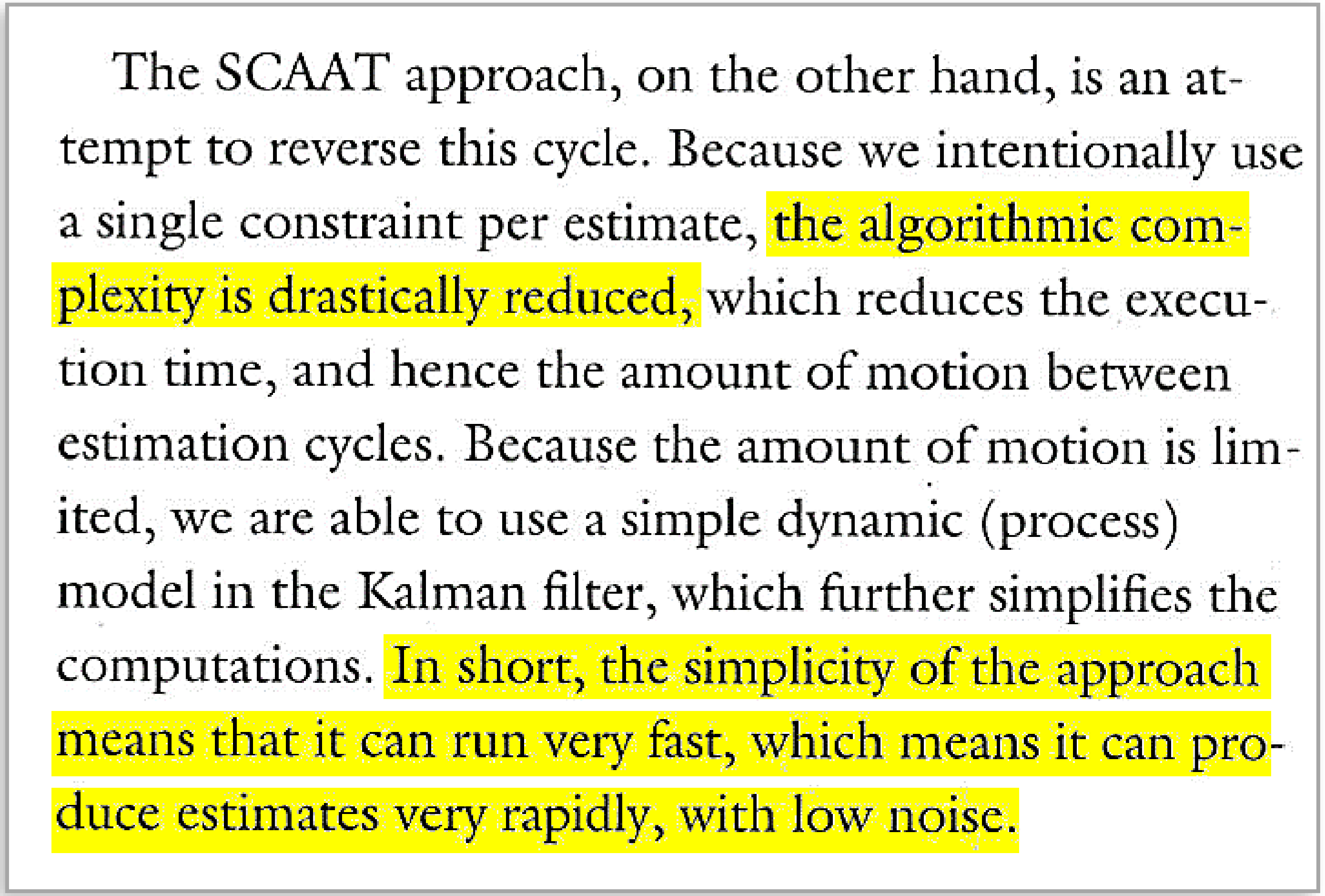
Ex. 1016, 47; *e.g.*, 1308 Petition 54-56

No Motivation to Combine Welch & Reitmayr

1308 Ground III

Petitioner	POSITA would have modified Welch's HiBall FPGAs to perform distributed processing techniques as in Reitmayr
Rebuttal	FPGAs in HiBall units were not well suited to act as nodes in a distributed tracking system Welch's SCAAT approach was already simple and fast, so the POSITA would not have been motivated to modify it

E.g., 1308 POR 42-44; 1308 Reply 18-19; Ex. 2007 ¶ 409



The SCAAT approach, on the other hand, is an attempt to reverse this cycle. Because we intentionally use a single constraint per estimate, the algorithmic complexity is drastically reduced, which reduces the execution time, and hence the amount of motion between estimation cycles. Because the amount of motion is limited, we are able to use a simple dynamic (process) model in the Kalman filter, which further simplifies the computations. In short, the simplicity of the approach means that it can run very fast, which means it can produce estimates very rapidly, with low noise.

Ex. 1007, 11