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(54) **SYSTEM AND METHOD FOR THREE DIMENSIONAL CALIBRATION OF FORCE PLATES**

SYSTEM UND VERFAHREN ZUR DREIDIMENSIONALEN KALIBRIERUNG VON PRESSKOLBEN

SYSTÈME ET PROCÉDÉ DE CALIBRAGE TRIDIMENSIONNEL DE PLATEFORMES DE FORCE

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- **HUIJING WANG ET AL.: 'Measuring system of a 3D force platform for plantar pressure distribution' PROCEEDINGS OF THE IEEE INTERNATIONAL CONFERENCE ON AUTOMATION AND LOGISTICS 07 August 2009, SHENYANG, CHINA, pages 906 - 910, XP 031532057**

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Description

Field of the Invention

[0001] The present invention relates to a system and a method for three dimensional calibration of force plates, and more particularly to a three dimensional calibration of force plates that provides improved measurement accuracy and reduction of crosstalk errors. More specifically, this invention relates to a method and system according to the preamble parts of claims 1 and 9, respectively, which are known from US 2012/0123701 A1.

Background of the Invention

[0002] A force platform is a measuring dcvicc that measures ground reaction forces. Typically force platforms are mounted in a pit so that their top surface lies flush with the floor. Subjects are then instructed to walk across or stand on the platforms and the generated ground reaction forces are recorded. Force platforms are commonly used for research and clinical studies in biomechanics, medical research, orthopedics, rehabilitation evaluation, prosthetic uses and engineering, among others. In one example, a force platform is used to measure the amount of sway in a person's stance while the person stands on the platform. Force platforms accomplish this by measuring three orthogonal force components (Fx, Fy, Fz) along the x, y and z axes as well as moments (Mx, My, Mz) about those axes.

[0003] Force platform systems usually include a force plate, multi-axis spring members upon which a series of strain gauges are fixed for sensing loads along multiple axes, an amplifier or signal conditioner, either connected to or embedded in the force plate or platform, and a computer for data collcction. Electrical signals from the strain gauges arc transmitted to the amplifier which amplifies the signals to a sufficient voltage for processing in the computer. Data collection can be either digital or analog depending on the medium chosen. In other embodiments, piezoelectric sensors, Hall effect sensors, optical sensors, capacitors or mechanical sensors are used to measure loads along multiple axes of the platform.

[0004] Both the force plate and the signal conditioner require calibration to accurately convert raw data to usable data. Furthermore, a high degree of sensitivity and accuracy is needed in the sensing and transmission of strain signals. As was mentioned above, force platforms are designed to produce multiple channel outputs corresponding to six possible loads, i.e., three orthogonal force components (Fx, Fy, Fz) along the x, y and z axes and three moments (Mx, My, Mz) about those axes. However, small imperfections in the manufacturing and design of the force platform result in slight off-axis sensitivity. In one example, off-axis sensitivity causes the output signal in the Fx channel to be slightly sensitive to a force load Fz applied along the z-direction. This off-axis sensitivity causes the sensing and transmission of erroneous signals, which are commonly referred to as crosstalk errors. Cross talk errors usually result in inaccurate measurements.

[0005] US 2012/0123701 A1 discloses a force platform system. The force platform provides six channels of output. Each channel represents one of the six components of applied load, the three orthogonal forces and the three orthogonal torque and moment components. Crosstalk occurs when some portion of applied load to one channel appears in the output of another. This residual output is caused by the mechanical or electrical limitations of the measuring device and can be corrected for. This is done by applying known force, moments and torques to each platform at key positions and recording the output across all channels. From this output a 6 by 6 calibration matrix is derived. This matrix is then used to both convert the output from each channel into engineering units and to correct for crosstalk.

[0006] Accordingly, there is a need for an improved system and method for calibrating a force plate that corrects for the crosstalk errors.

Summary of the Invention

[0007] It is the object of this invention to provide a method and system implementing an improved calibration procedure that reduces cross-talk errors to less than 1% across the surface area of the force platform.

[0008] This object is achieved by the subject matter of the independent claims.

[0009] Preferred embodiments of the invention are the subject matters of the dependent claims.

[0010] In general, in one aspect, the invention features a method for calibrating a force platform including the following. Providing a force platform and applying an nXm grid on a top surface of the force platform via a computing device. The nXm grid comprises n points along an X-axis, and m points along a Y-axis of the force platform. Next, applying p known loads on each of the nXm grid points of the top surface along a Z-axis being perpendicular to the X and Y axes and along the X and Y axes. Next, taking multipoint measurements at each grid point and for each applied known load along the X, Y and Z axes and generating six measured output signals, exact position coordinates and applied known load magnitude for each grid point. Next, assembling an array of nXmXp of six equations with six unknown for each grid point and applied known load. Next, solving the assembled equations and deriving a position and load specific calibration matrix for each grid point. Finally, entering the derived position and load specific calibration matrices for all grid points in a calibration table and storing the calibration table in a non-volatile memory.

[0011] Implementations of this aspect of the invention may include one or more of the following features. The p known loads are applied via a 3-D Cartesian load apparatus.

[0012] The applied p known loads comprise magnitudes in the range of zero to Full Scale Capacity (FSC) at increments of 10%. The n and m points comprise values in the range of 2 to 20. The six measured output signals comprise three force components Fx, Fy, Fz and three moment components Mx, My, Mz. The method further includes providing an estimate algorithm and storing a global platform calibration matrix in the non-volatile memory. The estimate algorithm is configured to generate first estimates of magnitude and position of an unknown applied load on the force platform by applying the global platform calibration matrix onto measured platform outputs for the unknown applied load. The first estimates of magnitude and position of the unknown applied load are used to determine a position and load specific calibration matrix in the calibration table. The method further includes generating accurate measures of the magnitude and position of the applied unknown load by applying the determined position and load specific calibration matrix onto the measured platform outputs for the unknown load. The method further includes verifying the derived position and load specific calibration matrices by applying NIST traceable dead weights onto the top surface grid points. The method further includes measuring secondary characteristics at eight grid points using a ten point up and a ten point down calibration protocol.

[0013] In general, in another aspect, the invention features a system for calibrating a force platform including a force platform, a computing device, a 3-D Cartesian load apparatus, a sensor, an algorithm, and a non-volatile memory. The computing device is configured to apply an nXm grid on a top surface of the force platform. The nXm grid has n points along an X-axis, and m points along a Y-axis of the force platform. The 3-D Cartesian load apparatus is configured to apply p known loads on each of the nXm grid points of the top surface along a Z-axis being perpendicular to the X and Y axes and along the X and Y axes. The sensor is configured to take multipoint measurements at each grid point and for each applied known load along the X, Y and Z axes and to generate six measured output signals, exact position coordinates and applied known load magnitude for each grid point. The algorithm is used for solving an assembled array of nXmXp of six equations with six unknown for each grid point and applied known load and for deriving a position and load specific calibration matrix for each grid point. The non-volatile memory is configured to store a calibration table comprising the derived position and load specific calibration matrices for all grid points.

[0014] Implementations of this aspect of the invention may include one or more of the following features. The applied p known loads comprise magnitudes in the range of zero to Full Scale Capacity (FSC) at increments of 10%. The n and m points comprise values in the range of 2 to 20. The six measured output signals comprise three force components Fx, Fy, Fz and three moment components Mx, My, Mz. The system further includes an estimate algorithm and a global platform calibration matrix. The estimate algorithm is configured to generate first estimates of magnitude and position of an unknown applied load on the force platform by applying the global platform calibration matrix onto measured platform outputs for the unknown applied load. The first estimates of magnitude and position of the unknown applied load are used to determine a position and load specific calibration matrix in the calibration table. The system further includes a correction algorithm generating accurate measures of the magnitude and position of the applied unknown load by applying the determined position and load specific calibration matrix onto the measured platform outputs for the unknown load.

[0015] In general, in another aspect, the invention features a calibrated force platform including a non-volatile memory storing a calibration table comprising position and load specific calibration matrices.

[0016] Implementations of this aspect of the invention may include one or more of the following features. The position and load specific calibration matrices correspond to nXm grid points of a top surface of the force platform and p known loads applied along an axis perpendicular to the top surface. The calibrated force platform further includes a global calibration matrix. The calibrated force platform further includes an estimate algorithm configured to generate a first estimate of an unknown applied load and position coordinates on the force platform by applying the global calibration matrix onto measured platform outputs. The first estimate of the unknown applied load and position coordinates are used to identify a position specific calibration matrix in the calibration table. The calibrated force platform further includes a correction algorithm configured to generate accurate measures of the applied unknown load magnitude and position coordinates by applying the identified position specific calibration matrix onto the measured platform outputs.

[0017] Among the advantages of this invention may be one or more of the following. The calibration process of this invention improves the accuracy of the force platform measurements, as shown in FIG. 12A-FIG. 12F. The typical cross talk error is in the order of +_0.01% of the applied load, and the typical load error is less than 0.001 or +_0.1% of applied load. The average Center of Pressure (COP) error is typically less than 0.2 mm.

[0018] The details of one or more embodiments of the invention are set forth in the accompanying drawings and description below. Other features, objects, and advantages of the invention will be apparent from the following description of the preferred embodiments, the drawings, and the claims.

Brief Description of the Drawings

[0019] Referring to the figures, wherein like numerals represent like parts throughout the several views:

FIG. 1 illustrates an overview diagram of a force platform system;

FIG. 2 depicts a transducer and the three forces and three moment components that are measured with the transducer;

FIG. 3A and FIG. 3B depict the hardware architecture of the system of FIG. 1;

FIG. 4 depicts a physical coordinate system and an electromechanical coordinate system of a force platform used in a prior art calibration procedure;

FIG. 5 depicts typical prior art crosstalk error distribution for Fy;

FIG. 6A depicts a 3-D grid used in the calibration process;

FIG. 6B depicts a flow diagram of the force platform 3-D calibration process according to this invention;

FIG. 7 depicts a 3-D grid applied on a force platform for performing the 3-D calibration procedure of this invention;

FIG. 8 depicts the 3-D Cartesian load apparatus used in the 3-D calibration procedure of this invention;

FIG. 9 depicts the 3-D loads applied onto the top surface, the front side surface and the right side surface of the force platform during the 3-D calibration procedure of this invention;

FIG. 10 depicts the force platform 3-D calibration system of this invention;

FIG. 11A depicts the force platform measuring system using the 3-D calibrated force platform of this invention;

FIG. 11B depicts a flow diagram of the measuring process using the 3-D calibrated force platform of this invention;

FIG. 12A depicts COPx error distribution generated with the calibration method of this invention;

FIG. 12B depicts COPy error distribution generated with the calibration method of this invention;

FIG. 12C depicts the Fz error distribution generated with the calibration method of this invention;

FIG. 12D depicts the Fz to Fx crosstalk error distribution generated with the calibration method of this invention;

FIG. 12E depicts the Fz to Fy crosstalk error distribution generated with the calibration method of this invention; and

FIG. 12F depicts the Fz to Mz crosstalk error distribution generated with the calibration method of this invention.

Detailed Description of the Invention

[0020] FIG. 1 is an illustration of a force platform system 100 according to an embodiment of the invention. System 100 is used to measure ground reaction forces and includes a force platform 102, a signal conditioner 104, and a computer 108 used for data collection. The system may include more than one force platforms, and/or signal conditioners. Signal conditioner 104 may be an analog amplifier and/or digital processor, and may be connected to or embedded in the force plate. Computer 108 may be a personal computer (PC), a server, a mobile computing device or a computing circuit.

[0021] Force platform 102 shown in FIG. 1 is designed to measure the forces and moments applied to its top surface 101 as a subject stands, steps, or jumps on it. Force platform 102 outputs force signals to output port 103, where platform 102 can connect to and communicate with force signal conditioner 104.

[0022] Force platform 102 includes one or more force transducers or load cells for measuring forces. FIG. 2 shows the three force components Fx, Fy, and Fz and the three moment components Mx, My and Mz that are measured by a force transducer 201 as a subject is in contact with platform 200. Fx, Fy, and Fz are the force components that act along the axes 202, 204, and 206 of an orthogonal x, y, and z-coordinate system. In FIG. 2, the arrows point in the direction of positive force along each of the axes, following the right-hand rule. Fx and Fy are the horizontal or shear force components, and Fz is the vertical force component. Mx, My and Mz are the three torque and moment components. The torque and moments rotate around the corresponding x, y and z axes 202, 204, and 206, respectively. Positive moments are determined according to the right hand rule. When looking down an axis (in its positive direction) positive moments have a clockwise rotation.

[0023] Referring back to FIG. 1, amplifier or signal conditioner 104 is connected to force plate 102. For each of the three forces Fx, Fy, Fz and the three moment Mx, My, Mz components that are measured, the signal conditioner 104 supplies an excitation voltage to a set of strain gauge bridges embedded in the force platform 102. The resulting output is a low level voltage proportional to that component of the applied mechanical load. This output can be sampled by the signal conditioner 104, and various signal conditioning techniques may be applied. The signal conditioner 104 provides digital and/or analog data streams to the connected computer 108.

[0024] The signal conditioner 104 connects to computer 108 through some sort of medium, such as an analog card, a Universal Serial Bus (USB), an Ethernet or a serial interface (not shown). In the example of FIG. 1, signal conditioner 104 is connected via a USB connection 112 to a single computer 108. When the computer 108 receives the ground reaction force data, it performs additional processing and displays or saves the data depending on the software program.

[0025] FIG. 3A and FIG. 3B illustrate the hardware architecture of an embodiment of a force platform system 100 including force platform 102, signal conditioner 104, and computer 108. Force platform 102 is connected to signal conditioner 104 via connection or cable 110, which includes connections for excitation voltages V_{ExE+}, V_{ExE-} and output voltages V_{IN+} and V_{IN-} for multiple channels of force signals. In the example of FIG. 3A, platform 102 includes six force channels associated with six strain gauges, each including a bridge circuit 301-306 driven by excitation voltages V_{ExE+}, V_{ExE-} and providing bridge output voltages V_{IN+}, and V_{IN-}. For simplicity, only circuitry for force channels 1 and 6, including strain gauges 301 and 306 in platform 102 and amplifiers 1 and 6 in signal conditioner 104, are shown in FIG. 3A. The omitted circuitry for channels 2-5 is identical to that shown for channels 1 and 6.

[0026] Connection or cable 110 may also include a communication link, such as a 1-Wire interface, to allow signal conditioner 104 to retrieve data stored in nonvolatile memory 307 of platform 102. Nonvolatile memory 307 may be read only memory (ROM) as shown in FIG. 3A, or may be programmable, including reprogrammable, memory, such as an EPROM. Nonvolatile memory 307 stores force platform calibration data and may also store a platform serial number and platform capacity.

[0027] As shown in FIG. 3B, signal conditioner 104 is connected to PC 108 via a USB connection 112. A primary function of signal conditioner 104 is to condition force data from multiple strain gauge inputs and output the results as multiple analog channels and/or a multiple channel digital data stream. The analog outputs may be high level and suitable as inputs to a multi-channel analog-to-digital converter (ADC). The digital data output may be transmitted to a host PC 108 via USB connection 112. The USB connection 112 may also be used to send and receive control and status information used by signal conditioner 104. It will be understood that additional signal conditioners 104 may be connect via USB to computer 108. Signal conditioner 104 receives commands and timing signals from the host PC 108 and sends digital force signals to the PC 108 via the USB connection 112. Alternatively or in addition, signal conditioner 104 outputs analog force signals, illustrated in FIG. 3B as $V_{OUT(1\text{-}6)}$, at an analog output port 313, which may be further connected to an input port (not shown) of computer 108 for receiving analog signals.

[0028] FIG. 3A and FIG. 3B illustrate further details of the hardware components of signal conditioner 104. Signal conditioner 104 includes a microprocessor 10 for digitizing and conditioning the force signals received from platform 102 and a microprocessor 18 for communicating with PC 108 via a USB connection 112. Microprocessor 10 is connected to and communicates with microprocessor 18 via communication lines that include an I2C bus interface 10.11, an 8-bit extended memory interface 10.12, a 1-bit SOF to Count-and-Capture line 10.16, a 1-bit microprocessor to USB interface bus 10.17, and a 3-bit unidirectional asynchronous bus 10.18. Microprocessor 10 is connected to and communicates with other components of signal conditioner 104 via a Serial Peripheral Interface (SPI) bus. The SPI bus connects to microprocessor 10 at SPI Bus interface 10.9.

[0029] The signal conditioner 104 includes, for force channel 1, an analog signal conditioning circuitry 1 that is connected to the bridge circuitry of strain gauge 301 and includes a differential amplifier 1.1. One input to differential amplifier 1.1 is the bridge output voltage V_{IN+} and another input is a bridge balancing voltage that is provided by the signal conditioning circuitry 1. Differential amplifier 1.1 has a gain G_{ANAL1} and an output that is connected to a multiplexer 9. A differential amplifier 1.2 is connected between strain gauge 301 and differential amplifier 1.1 for inserting the bridge balancing voltage into force channel 1. A digital-to-analog converter (DAC) 1.3 is used to produce the bridge balancing voltage under the control of microprocessor 10. One input of differential amplifier 1.2 is connected to the output of DAC 1.3; the other input of amplifier 1.2 is connected to strain gauge 301 to receive the bridge output voltage V_{IN-} from strain gauge 301. The signal conditioning circuitry 1 also includes a power amplifier 1.4 connected to strain gauge 301 for supplying the positive bridge excitation voltage V_{EXE+} to strain gauge 301. Also included is a power amplifier 1.5 connected to strain gauge 301 for providing a negative bridge excitation voltage V_{EXE-} to strain gauge 301. A DAC 1.6 connected to the input of power amplifier 1.5 is used to produce the negative bridge excitation voltage V_{EXE-} under the control of microprocessor 10. Both DAC 1.3 and DAC 1.6 are connected to the SPI Bus interface 10.9 of microprocessor 10.

[0030] As shown in FIG. 3A, the analog signal conditioning circuitry 6 for force channel 6 includes identical components to signal conditioning circuitry 1 for force channel 1. Conditioning circuitry 6 is connected to strain gauge 306 and includes a differential amplifier 6.1, a differential amplifier 6.2, a DAC 6.3, a power amplifier 6.4, a power amplifier 6.5, and a DAC 6.6. As with amplifier 1.1, differential amplifier 6.1 has a gain G_{ANAL6} and an output connected to multiplexer 9. Similarly, both DAC 6.3 and DAC 6.6 are connected to microprocessor 10 via an SPI bus connection. Like circuitry is provided for each channel but not shown.

[0031] Multiplexor 9 is a 6-to-3 differential line multiplexor that receives the six force channels from the signal conditioning circuitries 1 through 6 and multiplexes the six channels into three differential output lines that are connected to microprocessor 10. Multiplexor 9 receives inputs, e.g., control signals, from microprocessor 10 via a 3-bit bus connection.

[0032] In the example shown in FIG. 3A, microprocessor 10 is a SILICON LABORATORIES (Silab) 8051 based mixed-signal microcontroller that comprises multiple components, including a system clock 10.6, e.g., with a nominal clock rate of 100 MHz, a 8051 based core CPU 10.7, system nonvolatile memory 10.8, e.g., for storing calibration and configuration data, and various interfaces and inputs/outputs to communicate with external circuitry. The components of microprocessor 10 are interconnected to allow for communication among the components and with CPU 10.7. For simplicity, only some of the interconnections are shown in FIG. 3A.

[0033] Microprocessor 10 receives inputs, i.e., force signal inputs, from external multiplexor 9 via a 3-line-to-1-line differential multiplexor 10.1. In turn, microprocessor 10 communicates with external multiplexor 9 via a 3-bit bus interface 10.13. A programmable Gain Amplifier 10.2 having gain G_{PGA} connects the output of multiplexor 10.1 to the input of a 12-bit differential input analog-to-digital converter (ADC) 10.3. Signal conditioner 104 amplifies the multiplexed analog force signal received from the signal conditioning circuitries 1 through 6 using amplifier 10.2 and converts the amplified signal to digital signals using ADC 10.3. The digitized force signals are then available for further processing, such as conditioning the signals based on calibration data. Calibration data include calibration data retrieved from the nonvolatile memory 307 of force platform 102 and may also include signal conditioning calibration data stored in nonvolatile memory 10.8 of microprocessor 10.

[0034] Referring back to FIG. 2, the force components that act along the axes of the force plate's orthogonal x, y, and z coordinate system are designated Fx, Fy, and Fz. The moment and torque components which rotate around each force axis are designated Mx, My and Mz. Force platform 102 provides six channels of output. Each channel represents one of the six components of the applied load, i.e., the three orthogonal forces and the three orthogonal moments and torques. Crosstalk occurs when some portion of applied load to one channel appears in the output of another. This residual output is caused by the mechanical/electrical limitations of the measuring device and can be corrected for. This is done by applying known force, moments and torques to each platform 102 at key positions and recording the output across all channels. From this output a 6 by 6 calibration matrix is derived (see Table 1 below). In Table 1, Fx, Fy, Fz, Mx, My, Mz represent the applied load components and VFx, VFy, VFz, VMx, VMy, VMz are the measured values. This matrix (also referred to as sensitivity matrix) is then used to both convert the output from each channel into engineering units and to correct for crosstalk.

Table 1: Sample Calibration Matrix

	Sample Calibration Matrix					
Channel	0	1	2	3	4	5
	VFx	VFy	VFz	VMx	VMy	VMz
	Input to channel i(lb,in-lb) is B(i,j)times the electrical output j(uV,Vex)					
	BP 400600-2000					
Fx	0.6519	-0.0068	-0.0019	0.0009	-0.0017	-0.0003
Fy	0.0090	0.6515	-0.0037	0.0008	0.0005	0.0010
Fz	0.0018	0.0017	2.5523	-0.0062	0.0001	0.0026
Mx	-0.0044	-0.0032	0.0003	12.8281	0.0108	-0.0138
My	0.0725	-0.0032	0.0003	0.0058	10.1358	-0.0140
Mz	0.0649	0.0821	0.0792	0.0123	0.0340	5.4451

[0035] Platform 102 in the force platform system 100 stores a platform identification and calibration matrix in non volatile memory 307(see FIG. 3A). When a force platform 102 is connected to a signal conditioner 104 the calibration matrix becomes available to the signal conditioner 104, which stores its own calibration settings in non volatile memory (see FIG. 3A, memory 10.8). In other embodiments, the calibration data may be programmable and retrievable by external electronics, e.g., signal conditioner 104.

[0036] When recording data, the signal conditioner 104 reads mV inputs from each platform output channel, and converts them to engineering units. When doing this the signal conditioner 104 uses calibrated gains and excitations, and provides crosstalk corrections by applying the calibration matrix. The signal conditioner 104 digital output stream to the PC 108 consists of fully processed IEEE floating point numbers presented in their respective engineering units.

[0037] The signal conditioner 104 performs extensive numerical processing which includes: using factory calibrated constants in place of nominal values for gains and excitations, correcting for cable losses due to finite bridge resistances, and providing crosstalk corrections by applying a factory calibrated platform correction matrix. Signal conditioner 104 may also remove a DC offset, implement a user defined DC set point, and perform rotational transformation to compensate for physical platform placement considerations.

[0038] Prior art calibration procedures involve loading the force platform at a limited number of location points with known loads and taking the strain gauge readings. At least six locations are needed in order to generate six equations with the six unknown sensitivities of the calibration matrix. The six equations are solved for the six unknown sensitivities of the calibration matrix and the resulting single ("global") calibration matrix is used to calculate the applied forces on the entire surface area of the force platform. The resulting cross talk error distribution on the surface area of the force platform is shown in FIG. 5. As shown in FIG. 5, cross-talk errors of the order of 1% are observed across the surface area of the force platform with this prior art calibration procedure. This type of accuracy is usually not acceptable for diagnostic purposes. Therefore, there is a need for an improved calibration procedure that reduces the cross-talk errors to less than 1% across the surface area of the force platform.

[0039] In a typical prior art calibration procedure, known forces are applied at different spatial locations on the platform surface and six output signals are measured. The six output signals represent the three force components vf_x, vf_y, vf_z and the three moment components vm_x, vm_y, vm_z. The following equation (1) represents the relationship between the six measured outputs including three force components vf_x, vf_y, vf_z and three moment vm_x, vm_y, vm_z components with the three applied forces f_x, f_y, f_z and the three total moments M_x, M_y, M_z, respectively:

$$\begin{aligned} vf_x &= S_{fx}\, f_x \\ vf_y &= S_{fy}\, f_y \\ vf_z &= S_{fz}\, f_z \\ vm_x &= S_{mx}\,(T_x + m_x) = S_{mx}\, M_x \\ vm_y &= S_{my}\,(T_y + m_y) = S_{my}\, M_y \\ vm_{z.} &= S_{mz}\,(T_z + m_z) = S_{mz}\, M_z \end{aligned} \qquad \text{Equation (1)}$$

[0040] The total moments M_x, M_y, M_z are the sums of the applied torques T_x, T_y, T_z around axes x, y, z, respectively, and the applied moments of forces m_x, m_y, m_z around axes x, y, z, respectively. The proportionality factors S_{fx}, S_{fy}, S_{fz}, S_{mx}, S_{my}, S_{mz} are the "global" calibration sensitivity terms. The calibration procedure involves applying known forces and known moments and solving for the sensitivity terms.

[0041] Another indirect measurement involves the X and Y coordinates of the center of pressure (COP) location. The COP is the point where a single force vector may be applied in order to generated the distributed forces applied by the subject's foot (or other contacting element) onto the force platform surface. The X and Y coordinates of the COP are determined according to the following equation:

$$\begin{aligned} COPx &= X_{cop} = m_y/f_z \\ COPy &= Y_{cop} = m_x/f_z \end{aligned} \qquad \text{Equation (2)}$$

[0042] Equation (1) does not take into consideration the crosstalk terms. A general equation that takes crosstalk into consideration is shown in Equation (3) below:

$$v_1 = s_{11}f_1 + s_{12}f_2 + s_{13}f_3 + s_{14}f_4 + s_{15}f_5 + s_{16}f_6$$
$$v_2 = s_{21}f_1 + s_{22}f_2 + s_{23}f_3 + s_{24}f_4 + s_{25}f_5 + s_{26}f_6$$
$$v_3 = s_{31}f_1 + s_{32}f_2 + s_{33}f_3 + s_{34}f_4 + s_{35}f_5 + s_{36}f_6$$
$$v_4 = s_{41}f_1 + s_{42}f_2 + s_{43}f_3 + s_{44}f_4 + s_{45}f_5 + s_{46}f_6$$
$$v_5 = s_{51}f_1 + s_{52}f_2 + s_{53}f_3 + s_{54}f_4 + s_{55}f_5 + s_{56}f_6$$
$$v_6 = s_{61}f_1 + s_{62}f_2 + s_{63}f_3 + s_{64}f_4 + s_{65}f_5 + s_{66}f_6 \qquad \text{Equation (3)}$$

[0043] Terms v1-v6 are equivalent to terms vf_x, vf_y, vf_z, vm_x, vm_y, vm_z in equation (1). Similarly, terms f1-f6 are equivalent to terms f_x, f_y, f_z, M_x, M_y, M_z in equation (1). Equation (3) is rewritten in matrix form as follows:

$$\begin{vmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \end{vmatrix} = \begin{vmatrix} s_{11} & s_{12} & s_{13} & s_{14} & s_{15} & s_{16} \\ s_{21} & s_{22} & s_{23} & s_{24} & s_{25} & s_{26} \\ s_{31} & s_{32} & s_{33} & s_{34} & s_{35} & s_{36} \\ s_{41} & s_{42} & s_{43} & s_{44} & s_{45} & s_{46} \\ s_{51} & s_{52} & s_{53} & s_{54} & s_{55} & s_{56} \\ s_{61} & s_{62} & s_{63} & s_{64} & s_{65} & s_{66} \end{vmatrix} \begin{vmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{vmatrix} \qquad \text{Equation (4)}$$

[0044] In equation (4) the matrix terms s11-s66 represent the calibration sensitivity components. The six diagonal terms represent the transducer calibration sensitivities and the 30 off diagonal terms represent the crosstalk terms. Equation (4) may also be represented as

$$V=SF \qquad \text{Equation (5)}$$

[0045] Where V includes the measured outputs and F includes the applied forces and moments. S is the calibration matrix. The calibration procedure determines the components of the calibration matrix S.

[0046] Once the calibration matrix is determined and stored in the force platform memory, the force platform is used to measure unknown applied forces by measuring the outputs V and using the inverse of the calibration matrix S^{-1} to determine the applied forces and moments, according to the following equation:

$$F=S^{-1}\,V \qquad \text{Equation (6)}$$

[0047] Referring to FIG. 6A and FIG. 6B, the improved calibration procedure 300 of the present invention includes the following steps. First, a 3-dimenisonal (3-D) grid 420 is applied onto the force platform 400 via a computing device, as shown in FIG. 6A (302). The 3-D grid includes n-positions along the X-axis, m-positions along the Y-axis and p- force magnitudes (F-magnitudes) along the Z-axis. In one example, n is in the range of 2-20 m is in the range of 2 -20 and p is in the range of 0-10. In the case where n=20, m=20, and p=10, 400 grid positions are defined on the top surface of the force platform 400. At each selected grid position (X_i, Y_j) ten different loads (F_k) are applied from three different directions X, Y and Z, and force platform measurements are taken and recorded. The applied loads include force values from zero to Full Scale Capacity (FSC) at increments of 10%. These measurements generate the above mentioned six output measuring signals (Fx, Fy, Fz, Mx, My, Mz), which are now measured for each grid position and each applied load. In addition to the six output measuring signals, the exact position coordinate of each grid position and the applied load are recorded (308). Next, an array of nXmXp of 6 equations with 6 unknowns (6X6) is assembled for the nXm grid positions and p loads (310). Next, the assembled equations are solved and a position and load specific calibration matrix S_{ijk} is derived for each position and load. Each position and load specific matrix includes nine specific sensitivity (six main diagonal and three crosstalk) terms (312). Next, the derived position and load specific matrices for each grid position and load are entered into a calibration table and the calibration table is stored in a non-volatile memory (314). The non-volatile memory may be incorporated in the force platform or may be an external memory. The system performance is further verified by applying National Institute of Standards and Technology (NIST) traceable dead weights of 50lbs, 100 lbs and 200 lbs onto the top surface of the force platform (316). Furthermore, secondary characteristics are measured at eight grid locations using a ten point up and ten point down calibration protocol (318). The secondary characteristics include linearity and hysteresis, among others.

[0048] Referring to FIG. 8, the calibration system 450 includes a Cartesian load apparatus 452 having a load applying actuator 454 and at least one transducer 456 measuring loads in X, Y and Z directions. The Cartesian load apparatus 452 is programmed to move from point to point across the top surface 402, the front side surface 406 and the right side surface 404 of the force platform 400. At each programmed point the selected known calibration loads are applied in three different orthogonal load directions (Z, X, Y) and calibration data are measured. Fz loads are applied with a dead weight or an air bearing supported load cell, both of which assure us that there are no shear loads acting on the top surface causing moments Mx or My. The side loads Fx and Fy are applied via the same load cell without the air bearing support. While applying side loads the off axis loads are measured in order to characterize their effect. The three loading conditions permit us to assemble three sets of three equations with three unknowns which can be solved by least squares methods. The Cartesian load apparatus 452 is capable of maintaining positioning accuracy of 0.0001 inches (0.025mm). In one example, load apparatus 452 locates the weights on a grid spacing of 1 inch (25.4 mm) yielding 300 measurement points on the top surface of the platform. Additional 100 locations are tested on the front and right side surfaces of the platform.

[0049] Since we know the three orthogonal loads Fx, Fy, Fz and the point of load application we can determine exactly the moment contribution of each load. Thus we can correct Mx and My for the moment contribution of Fz and then determine the z offset distance. Likewise we can fully determine Mz from Fx and Fy acting at that point.

[0050] Fz to Mz cross talk can be accurately determined from the Fz loading scenarios. Fx to Mx and Fy to My cross talk is estimated by taking two side load measurements at two different dz's.

[0051] Fz loads are applied in a grid pattern extending across the length and width of the plate with the (0,0) point determined to be in the center of the plate. Dead weights are used when possible to assure that there is zero side load. In one example 3 different loads, 50 lbs, 100 lbs and 200 lbs are used. In order to provide a full scale calibration we add at least one additional load point at full scale. Fx and Fy side loads are applied collinear with the top surface grid lines at each grid point. It is somewhat advantageous to apply this load at the edge of the platform top surface, however it is more convenient to apply the load slightly below the top surface. The side load magnitudes are the same as the loads applied on the top surface. The line of action of the side load intersects with multiple load points across the top surface. It is assumed that this side load is applied at each of the nodes of intersection.

[0052] The above procedure results in an array of n X m X p of six equations with six unknowns (6X6) for each grid location (nXm) and each load (p). Each equation is informed with three components of force Fx, Fy, Fz and a vector of six transducer outputs. Least squares regression is used to solve for the nine sensitivity (3 cross talk and 6 main diagonal) terms. The procedure also results in two arrays for side loading, an n x 2 x 2 for the front side surface and an m x 2 x 2 array for the right side surface. For the side loading, each equation has two unknowns, including a force to moment cross talk and a dz term. These equations may also be solve using the least squares method.

[0053] As was mentioned above, the calibration data at each grid location also include exact grid location, magnitude of the applied load and the six measured force platform output signals. Referring to FIG. 10, forward calibration algorithm 480 is used to derive the sensitivity terms of the calibration matrix for each point and for each applied load. The derived sensitivity matrix terms are stored in a three dimensional table 490 and are indexed by x-y position coordinates 491, 492, and applied load levels (Fx, Fy, Fz and Mx) 493, 494, 495 496, respectively.

[0054] Referring to FIG. 11A, the field measuring system 500 includes a force platform 510, a computing device 520 including a microprocessor, a digital signal processor or any other central processing unit (CPU), memory configured to store the table 490 with the calibration matrices, an initial estimate algorithm 530 and a correction calibration algorithm 540. Furthermore, global calibration coefficients are also stored in the field system.

[0055] Referring to FIG. 11B, in operation, an unknown load 550 is applied on the top surface of the force platform 510 and a set of six measured platform outputs are produced (612). The initial estimate algorithm 530 is used to generate a first estimate of the applied load and position coordinates based on the global calibration coefficients (614). The estimated position coordinates, loads and moments are then used to identify an appropriate position and load specific calibration matrix in table 490 (616). A correction algorithm 540 is then used to apply the identified position and load specific calibration to the measured platform outputs and to produce accurate measures of the applied load 560 (618). This process may be repeated in an iterative way until a preset error level is achieved.

[0056] Several embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the scope of the invention as defined in the following claims.

Claims

1. A method for calibrating a force platform (102, 400, 510) comprising:

   providing a force platform (102, 400, 510) and applying an nXm grid (420) on a top surface (402) of the force platform (102, 400, 510) via a computing device (520), wherein said nXm grid (420) comprises n points along an X-axis, and m points along a Y-axis of said force platform (102, 400, 510);
   applying p known loads on each of the nXm grid points of the top surface (402) along a Z-axis being perpendicular to said X and Y axes (202, 204) and along said X and Y axes (202, 204);
   taking multipoint measurements at each grid point and for each applied known load along said X, Y and Z axes (202, 204, 206);
   characterized by
   n and m $\geq$ 2;
   generating six measured output signals, exact position coordinates and applied known load magnitude for each grid point;
   assembling an array of nXmXp of six equations with six unknown for each grid point and applied known load;
   solving the assembled equations and deriving a position and load specific calibration matrix for each grid point;
   entering the derived position and load specific calibration matrices for all grid points in a calibration table and storing the calibration table in a non-volatile memory.

2. The method of claim 1 wherein said p known loads are applied via a 3-D Cartesian load apparatus (452).

3. The method of claim 1 or 2 wherein said applied p known loads comprise magnitudes in the range of zero to Full Scale Capacity (FSC) at increments of 10%, wherein said n and m points comprise values in the range of 2 to 20, wherein said six measured output signals comprise three force components Fx, Fy, Fz and three moment components Mx, My, Mz.

4. The method of one of the preceding claims, further comprising providing an estimate algorithm and storing a global platform calibration matrix in said non-volatile memory, wherein the estimate algorithm is configured to generate first estimates of magnitude and position of an unknown applied load (560) on the force platform (102, 400, 510) by applying the global platform calibration matrix onto measured platform outputs for the unknown applied load (560).

5. The method of claim 4, wherein the first estimates of magnitude and position of the unknown applied load (560) are used to determine a position and load specific calibration matrix in the calibration table.

6. The method of claim 4, further comprising generating accurate measures of the magnitude and position of the applied unknown load (550) by applying the determined position and load specific calibration matrix onto the measured platform outputs for the unknown load (550).

7. The method of one of the preceding claims, further comprising verifying said derived position and load specific calibration matrices by applying NIST traceable dead weights onto the top surface grid points.

8. The method of one of the preceding claims, further comprising measuring secondary characteristics at eight grid points using a ten point up and a ten point down calibration protocol.

9. A system for calibrating a force platform (102, 400, 510) comprising:

   a force platform (102, 400, 510);
   a computing device (520) configured to apply an nXm grid (420) on a top surface (402) of the force platform (102, 400, 510), wherein said nXm grid (420) comprises n points along an X-axis, and m points along a Y-axis of said force platform (102, 400, 510);
   a 3-D Cartesian load apparatus (452) configured to apply p known loads on each of the nXm grid points of the

top surface (402) along a Z-axis being perpendicular to said X and Y axes (202, 204) and along said X and Y axes (202, 204);
characterized by
n and m ≥ 2;
a sensor configured to take multipoint measurements at each grid point and for each applied known load along said X,Y and Z axes (202, 204, 206) and to generate six measured output signals, exact position coordinates and applied known load magnitude for each grid point;
an algorithm for solving an assembled array of nXmXp of six equations with six unknown for each grid point and applied known load and for deriving a position and load specific calibration matrix for each grid point; and
a non-volatile memory configured to store a calibration table comprising the derived position and load specific calibration matrices for all grid points.

10. The system of claim 9 wherein said applied p known loads comprise magnitudes in the range of zero to Full Scale Capacity (FSC) at increments of 10%.

11. The system of claim 9 or 10, wherein said n and m points comprise values in the range of 2 to 20.

12. The system of one of claims 9 to 11, further comprising a global calibration matrix.

13. The system of claim 12, further comprising an estimate algorithm configured to generate a first estimate of an unknown applied load (560) and position coordinates on the force platform (102, 400, 510) by applying the global calibration matrix onto measured platform outputs.

14. The system of claim 13, wherein the first estimate of the unknown applied load (560) and position coordinates are used to identify a position specific calibration matrix in the calibration table.

15. The system of one of claims 12 to 14, further comprising a correction algorithm configured to generate accurate measures of the applied unknown load magnitude and position coordinates by applying the identified position specific calibration matrix onto the measured platform outputs.

Patentansprüche

1. Ein Verfahren zur Kalibrierung einer Kraftmessplatte (102, 400, 510) umfassend:

Bereitstellen einer Kraftmessplatte (102, 400, 510) und Anlegen eines nXm-Gitters (420) auf einer oberen Oberfläche (402) der Kraftmessplatte (102, 400, 510) über eine Rechenvorrichtung (520), wobei das nXm-Gitter (420) n Punkte entlang einer X-Achse und m Punkte entlang einer Y-Achse des Kraftmessplatte (102, 400, 510) umfasst;
Anlegen von p bekannten Lasten auf jedem der nXm-Gitterpunkte auf der oberen Oberfläche (402) entlang einer Z-Achse senkrecht zu den X- und Y-Achsen (202, 204) und entlang der X- und Y-Achsen (202, 204);
Durchführen von Mehrpunktmessungen an jedem Gitterpunkt und für jede angelegte bekannte Last entlang derX-, Y- und Z-Achsen (202, 204, 206);
gekennzeichnet durch
n und m ≥ 2;
Erzeugen von sechs gemessenen Ausgabesignalen, exakten Positionskoordinaten und angelegter bekannter Lastgröße für jeden Gitterpunkt;
Aufstellen eines Arrays von nXmXp aus sechs Gleichungen mit sechs Unbekannten für jeden Gitterpunkt und angelegter bekannter Last,
Lösen der aufgestellten Gleichungen und Ableiten einer positions- und lastspezifischen Kalibrierungsmatrix für jeden Gitterpunkt;
Eingeben der abgeleiteten positions- und lastspezifischen Kalibrierungsmatrizen für alle Gitterpunkte in eine Kalibrierungstabelle und Speichern der Kalibrierungstabelle in einem nichtflüchtigen Speicher.

2. Das Verfahren gemäß Anspruch 1, wobei die p bekannten Lasten über einen kartesischen 3-D Lastapparat (452) angelegt werden.

3. Das Verfahren gemäß Anspruch 1 oder 2, wobei die angelegten p bekannten Lasten Größen im Bereich von Null bis zur Messbereichsgrenze bei einer Schrittweite von 10% umfassen, wobei die n und m Punkte Werte im Bereich von 2 bis 20 umfassen, wobei die sechs gemessenen Ausgabesignale drei Kraftkomponenten Fx, Fy, Fz und drei Drehmomentkomponenten Mx, My, Mz umfassen.

4. Das Verfahren gemäß einem der vorangehenden Ansprüche, ferner umfassend das Bereitstellen eines Schätzalgorithmus und Speichern einer globalen Messplatten-Kalibrierungsmatrix in dem nichtflüchtigen Speicher, wobei der Schätzalgorithmus konfiguriert ist, dass er erste Schätzungen von Drehmoment und Position einer unbekannten angelegten Last (560) auf die Kraftmessplatten (102, 400, 510) durch Anwenden der globalen Messplatten-Kalibrierungsmatrix auf gemessene Messplattenausgaben für die unbekannte angelegte Last (560) erzeugt.

5. Das Verfahren gemäß Anspruch 4, wobei die ersten Schätzungen von Drehmoment und Position der unbekannten angelegten Last (560) verwendet werden, um eine positions- und lastspezifischen Kalibrierungsmatrix in der Kalibrierungstabelle zu bestimmen.

6. Das Verfahren gemäß Anspruch 4, ferner umfassend das Erzeugen von genauen Messungen von Drehmoment und Position der angelegten unbekannten Last (550) durch Anbringen der bestimmten positions- und lastspezifischen Kalibrierungsmatrix auf die gemessenen Messplattenausgaben für die unbekannte Last (550).

7. Das Verfahren gemäß einem der vorangehenden Ansprüche, ferner umfassend Überprüfen der abgeleiteten positions- und lastspezifischen Kalibrierungsmatrizen durch Anbringen von NIST rückverfolgbaren Totgewichten auf den Gitterpunkten der oberen Oberfläche.

8. Das Verfahren gemäß einem der vorangehenden Ansprüche, ferner umfassend das Messen von sekundären Kennlinien an acht Gitterpunkten, wobei ein 10 Punkte nach oben zeigendes und ein 10 Punkte nach unten zeigendes Kalibrierungsprotokoll verwendet wird.

9. Ein System zur Kalibrierung einer Kraftmessplatte (102, 400, 510) umfassend:

eine Kraftmessplatte (102, 400, 510);
eine Rechenvorrichtung (520), die konfiguriert ist, dass sie ein nXm-Gitter (420) auf einer oberen Oberfläche (402) der Kraftmessplatte (102, 400, 510) anlegt, wobei das nXm-Gitter (420) n Punkte entlang einer X-Achse und m Punkte entlang einer Y-Achse der Kraftmessplatte (102, 400, 510) umfasst;
einen kartesischen 3-D Lastapparat (452), der konfiguriert ist, dass er p bekannte Lasten auf jedem der nXm-Gitterpunkte auf der oberen Oberfläche (402) entlang einer Z-Achse, die senkrecht zu den X- und Y-Achsen (202, 204) ist, und entlang der X- und Y-Achse (202, 204) anbringt;
gekennzeichnet durch
n und m $\geq$ 2;
einen Sensor, der konfiguriert ist, dass er Mehrpunktmessungen an jedem Gitterpunkt und für jede angelegte bekannte Last entlang der X-, Y- und Z-Achsen (202, 204, 206) durchführt und sechs gemessene Ausgabesignale, exakte Positionskoordinaten und angelegte bekannte Lastgrößen für jeden Gitterpunkt erzeugt;
einen Algorithmus zum Lösen eines zusammengesetzten Arrays von nXmXp aus sechs Gleichungen mit sechs Unbekannten für jeden Gitterpunkt und angelegter bekannter Last und zum Ableiten einer positions- und lastspezifischen Kalibrierungsmatrix für jeden Gitterpunkt; und
einen nichtflüchtigen Speicher, der konfiguriert ist, dass er eine Kalibrierungstabelle mit der abgeleiteten positions- und lastspezifischen Kalibrierungsmatrix für alle Gitterpunkte speichert.

10. Das System gemäß Anspruch 9, wobei die angelegten p bekannten Lasten Größen im Bereich von Null bis zur Messbereichsgrenze bei einer Schrittweite von 10% umfassen.

11. Das System gemäß Anspruch 10, wobei die n und m Punkte Werte im Bereich von 2 bis 20 umfassen.

12. Das System gemäß einem der Ansprüche 9 bis 11, ferner umfassend eine globale Kalibrierungsmatrix.

13. Das System gemäß Anspruch 12, ferner umfassend einen Schätzalgorithmus, der konfiguriert ist, dass er eine erste Schätzung einer unbekannten angelegten Last (560) und Positionskoordinaten auf der Kraftmessplatte (102, 400, 510) durch Anwenden der globalen Kalibrierungsmatrix auf gemessene Messplattenausgaben erzeugt.

14. Das System gemäß Anspruch 13, wobei die ersten Schätzungen der unbekannten angelegten Last (560) und

Positionskoordinaten verwendet werden, um eine positionsspezifischen Kalibrierungsmatrix in der Kalibrierungstabelle zu identifizieren.

15. Das System gemäß einem der Ansprüche 12 bis 14, ferner umfassend einen Korrektur-Algorithmus, der konfiguriert ist, um genaue Messungen der angelegten unbekannten Last und von Positionskoordinaten durch Anwenden der identifizierten positionsspezifischen Kalibrierungsmatrix auf die gemessenen Messplattenausgaben erzeugen.

Revendications

1. Procédé de calibrage d'une plateforme de force (102, 400, 510) comprenant :

 la mise à disposition d'une plateforme de force (102, 400, 510) et l'application d'une grille nXm (420) sur une surface supérieure (402) de la plateforme de force (102, 400, 510) via un dispositif de calcul (520), dans lequel ladite grille nXm (420) comprend n points le long d'un axe X, et m points le long d'un axe Y de ladite plateforme de force (102, 400, 510) ;
 l'application de p charges connues sur chacun des points de grille nXm de la surface supérieure (402) le long d'un axe Z perpendiculaire auxdits axes X et Y (202, 204) et le long desdits axes X et Y (202, 204) ;
 la prise de mesures multipoints au niveau de chaque point de grille et pour chaque charge connue appliquée le long desdits axes X, Y et Z (202, 204, 206) ;
 caractérisé par :

  n et m $\geq$ 2 ;
  la génération de six signaux de sortie mesurés, des coordonnées de position exactes et de l'amplitude de charge connue appliquée pour chaque point de grille ;
  l'assemblage d'une batterie de nXmXp de six équations avec six inconnues pour chaque point de grille et chaque charge connue appliquée ;
  la résolution des équations assemblées et la dérivation d'une matrice de calibrage spécifique de position et de charge pour chaque point de grille ;
  l'entrée des matrices de calibrage spécifique de position et de charge dérivées pour tous les points de grille dans un tableau de calibrage et la mise en mémoire du tableau de calibrage dans une mémoire non volatile.

2. Procédé selon la revendication 1, dans lequel lesdites p charges connues sont appliquées via un appareil de charge cartésien 3-D (452).

3. Procédé selon la revendication 1 ou 2, dans lequel lesdites p charges connues appliquées comprennent des amplitudes dans la plage de zéro à une capacité à grande échelle (Full Scale Capacity en anglais, FSC) avec des incréments de 10 %, dans lequel lesdits points n et m comprennent des valeurs dans la plage de 2 à 20, dans lequel lesdits six signaux de sortie mesurés comprennent trois composantes de force Fx, Fy, Fz et trois composantes de moment Mx, My, Mz.

4. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre la mise à disposition d'un algorithme d'estimation et la mise en mémoire d'une matrice de calibrage de plateforme globale dans ladite mémoire non volatile, dans lequel l'algorithme d'estimation est configuré pour générer des premières estimations d'amplitude et de position d'une charge appliquée inconnue (560) sur la plateforme de force (102, 400, 510) en appliquant la matrice de calibrage de plateforme globale sur les sorties de plateforme mesurées pour la charge appliquée inconnue (560).

5. Procédé selon la revendication 4, dans lequel les premières estimations d'amplitude et de position de la charge appliquée inconnue (560) sont utilisées pour déterminer une matrice de calibrage spécifique de position et de charge dans le tableau de calibrage.

6. Procédé selon la revendication 4, comprenant en outre la génération de mesures précises de l'amplitude et de la position de la charge inconnue appliquée (550) en appliquant la matrice de calibrage spécifique de position et de charge déterminée sur les sorties de plateforme mesurées pour la charge inconnue (550).

7. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre la vérification desdites matrices de calibrage spécifique de position et de charge dérivées en appliquant les poids morts traçables NIST

sur les points de grille de la surface supérieure.

8. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre la mesure des caractéristiques secondaires au niveau de huit points de grille à l'aide d'un protocole de calibrage de dix points vers le haut et de dix points vers le bas.

9. Système de calibrage d'une plateforme de force (102, 400, 510) comprenant :

une plateforme de force (102, 400, 510) ;
un dispositif de calcul (520) configuré pour appliquer une grille nXm (420) sur une surface supérieure (402) de la plateforme de force (102, 400, 510), dans lequel ladite grille nXm (420) comprend n points le long d'un axe X et m points le long d'un axe Y de ladite plateforme de force (102, 400, 510) ;
un appareil de charge cartésien 3-D (452) configuré pour appliquer p charges connues sur chacun des points de grille nXm de la surface supérieure (402) le long d'un axe Z perpendiculaire auxdits axes X et Y (202, 204) et le long desdits axes X et Y (202, 204) ;
caractérisé par :

n et m $\geq$ 2 ;
un capteur configuré pour prendre des mesures multipoints au niveau de chaque point de grille et pour chaque charge connue appliquée le long desdits axes X, Y et Z (202, 204, 206) et pour générer six signaux de sortie mesurés, des coordonnées de position exactes et l'amplitude de charge connue appliquée pour chaque point de grille ;
un algorithme pour résoudre une batterie assemblée de nXmXp de six équations avec six inconnues pour chaque point de grille et chaque charge connue appliquée et pour dériver une matrice de calibrage spécifique de position et de charge pour chaque point de grille ; et
une mémoire non volatile configurée pour mettre en mémoire un tableau de calibrage comprenant les matrices de calibrage spécifique de charge et de position dérivées pour tous les points de grille.

10. Système selon la revendication 9, dans lequel lesdites p charges connues appliquées comprennent des amplitudes dans la plage de zéro à une capacité à grande échelle (FSC) avec des incréments de 10 %.

11. Système selon la revendication 9 ou 10, dans lequel lesdits points n et m comprennent des valeurs dans la plage de 2 à 20.

12. Système selon l'une quelconque des revendications 9 à 11, comprenant en outre une matrice de calibrage globale.

13. Système selon la revendication 12, comprenant en outre un algorithme d'estimation configuré pour générer une première estimation d'une charge appliquée inconnue (560) et des coordonnées de position sur la plateforme de force (102, 400, 510) en appliquant la matrice de calibrage global sur les sorties de plateforme mesurées.

14. Système selon la revendication 13, dans lequel la première estimation de la charge appliquée inconnue (560) et des coordonnées de position sont utilisées pour identifier une position spécifique de la matrice de calibrage dans le tableau de calibrage.

15. Système selon l'une quelconque des revendications 12 à 14, comprenant en outre un algorithme de correction configuré pour générer des mesures précises des coordonnées de position et d'amplitude de charge inconnues appliquées en appliquant la matrice de calibrage spécifique de position identifiée sur les sorties de plateforme mesurées.

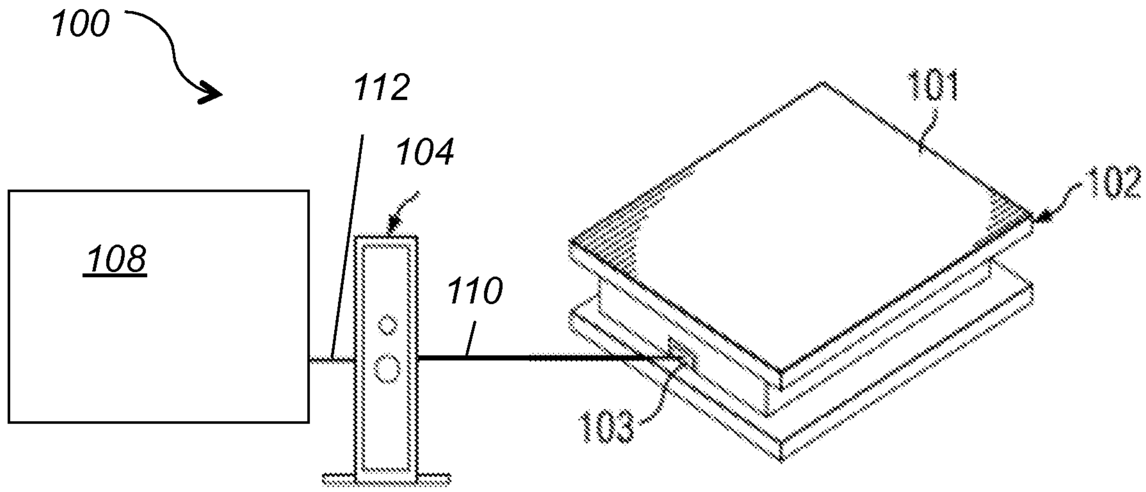

FIG. 1

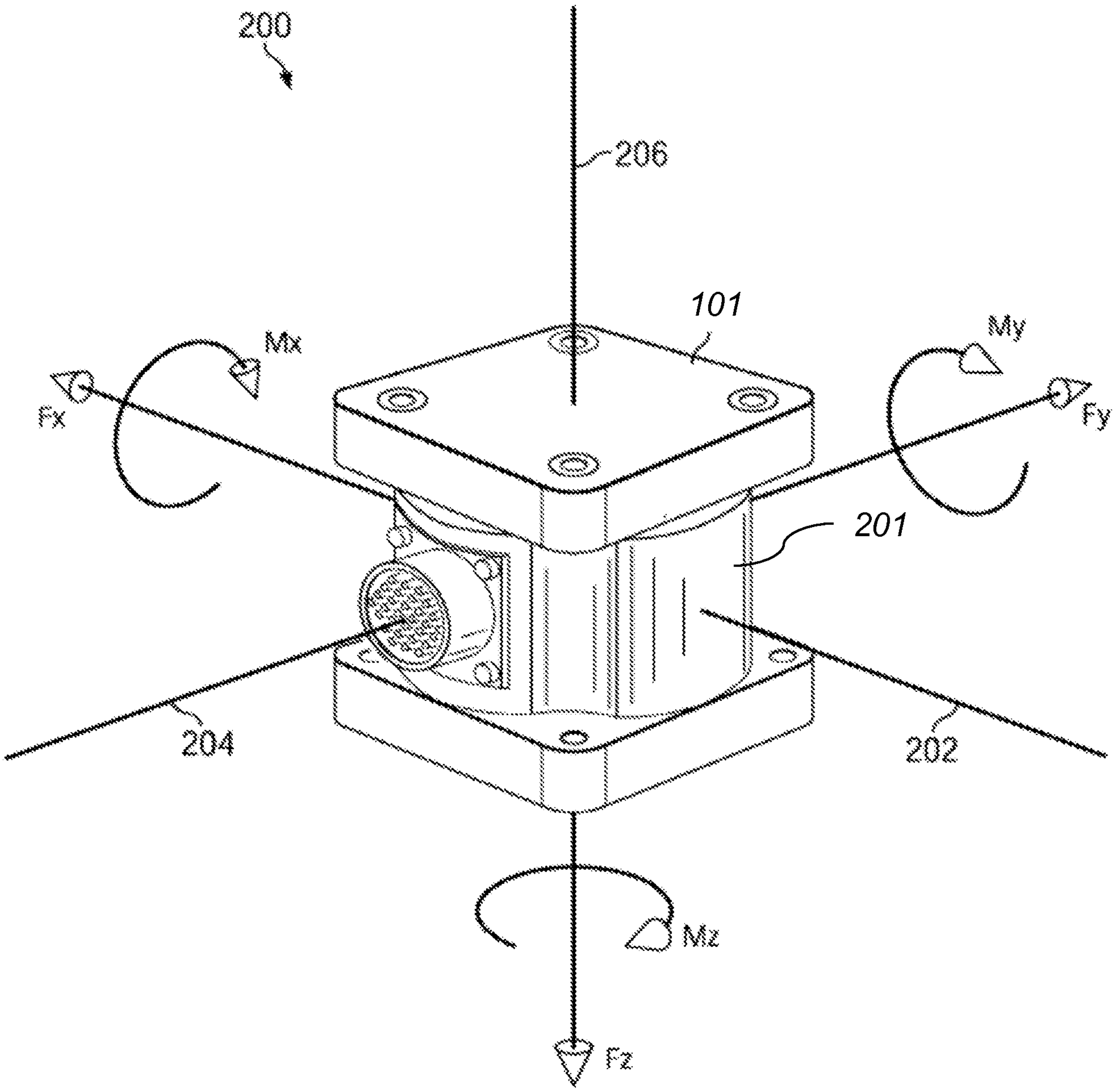

FIG. 2

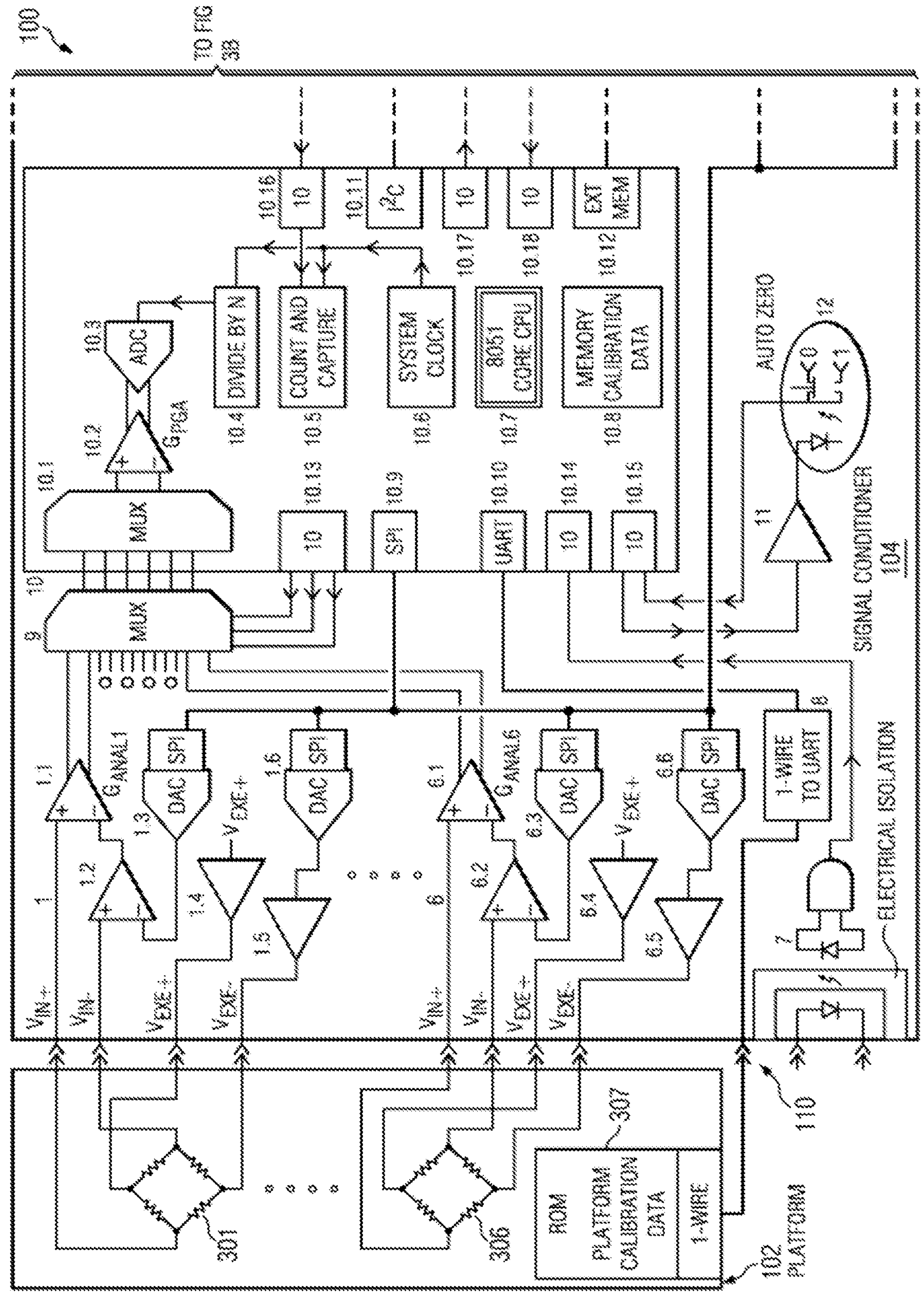
100
TO FIG 3B
MUX
ADC
DIVIDE BY N
COUNT AND CAPTURE
SYSTEM CLOCK
8051 CORE CPU
MEMORY CALIBRATION DATA
EXT MEM
SPI
UART
1-WIRE TO UART
DAC
AUTO ZERO
SIGNAL CONDITIONER 104
ELECTRICAL ISOLATION
ROM PLATFORM CALIBRATION DATA
1-WIRE
102 PLATFORM
301
306
307
110

FIG.3A

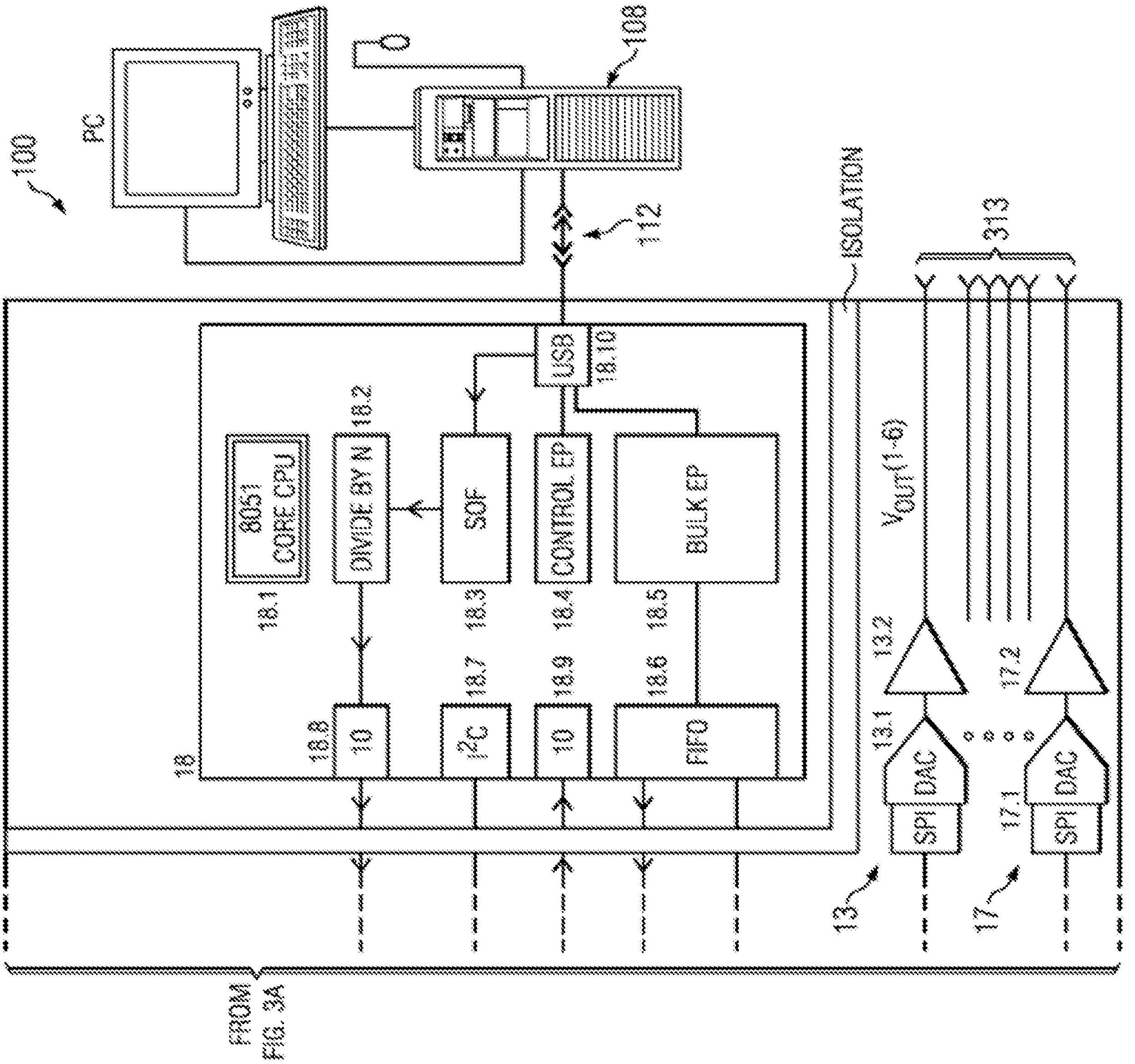
100
PC
108
112
ISOLATION
313
USB
18.10
8051
CORE CPU
18.1
DIVIDE BY N
18.2
SOF
18.3
CONTROL EP
18.4
BULK EP
18.5
18.8
10
I2C
18.7
10
18.9
FIFO
18.6
18
VOUT(1-6)
13.1
13.2
SPI
DAC
13
17.1
17.2
SPI
DAC
17
FROM
FIG. 3A

FIG.3B

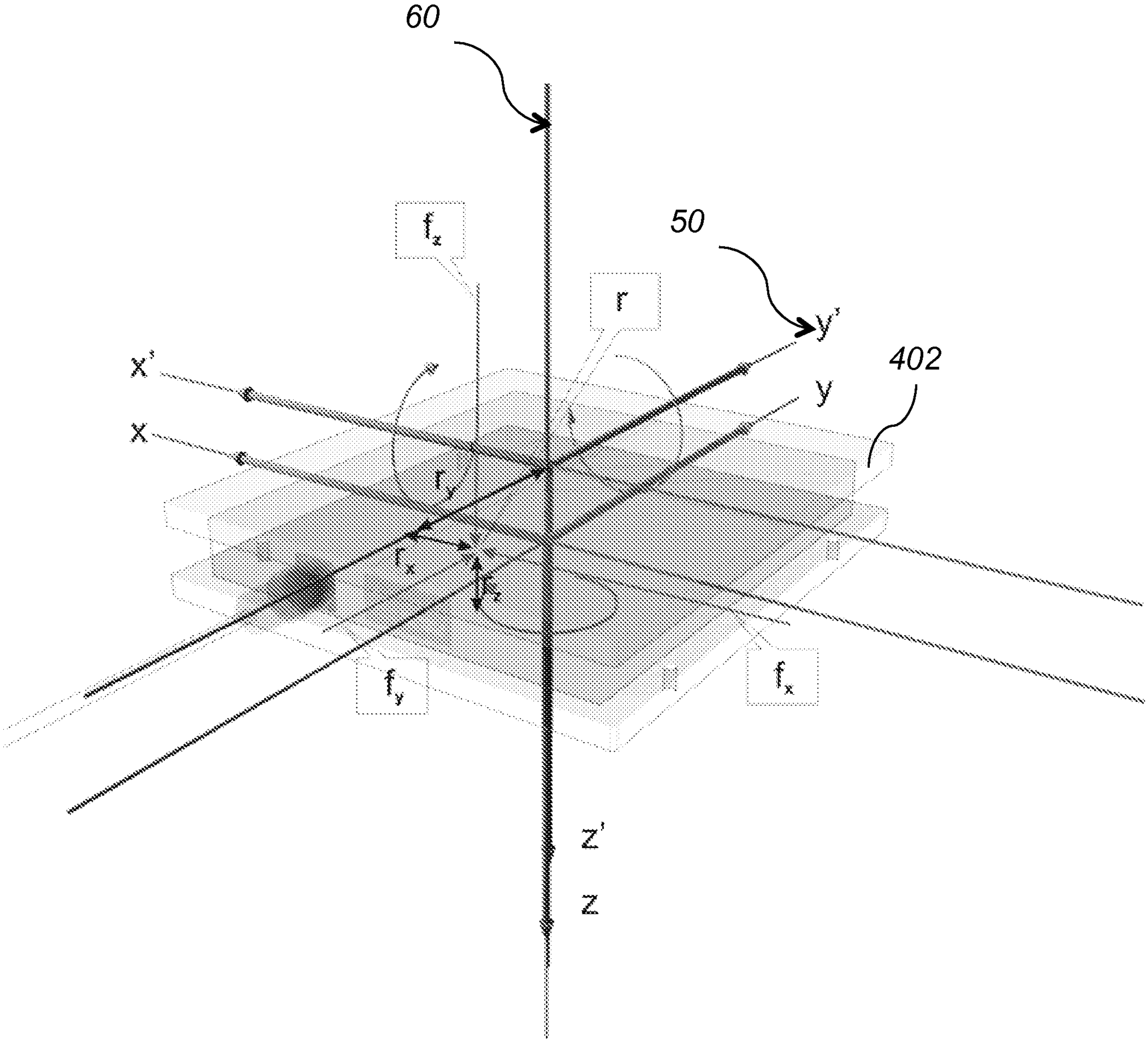

FIG.4 (prior art)

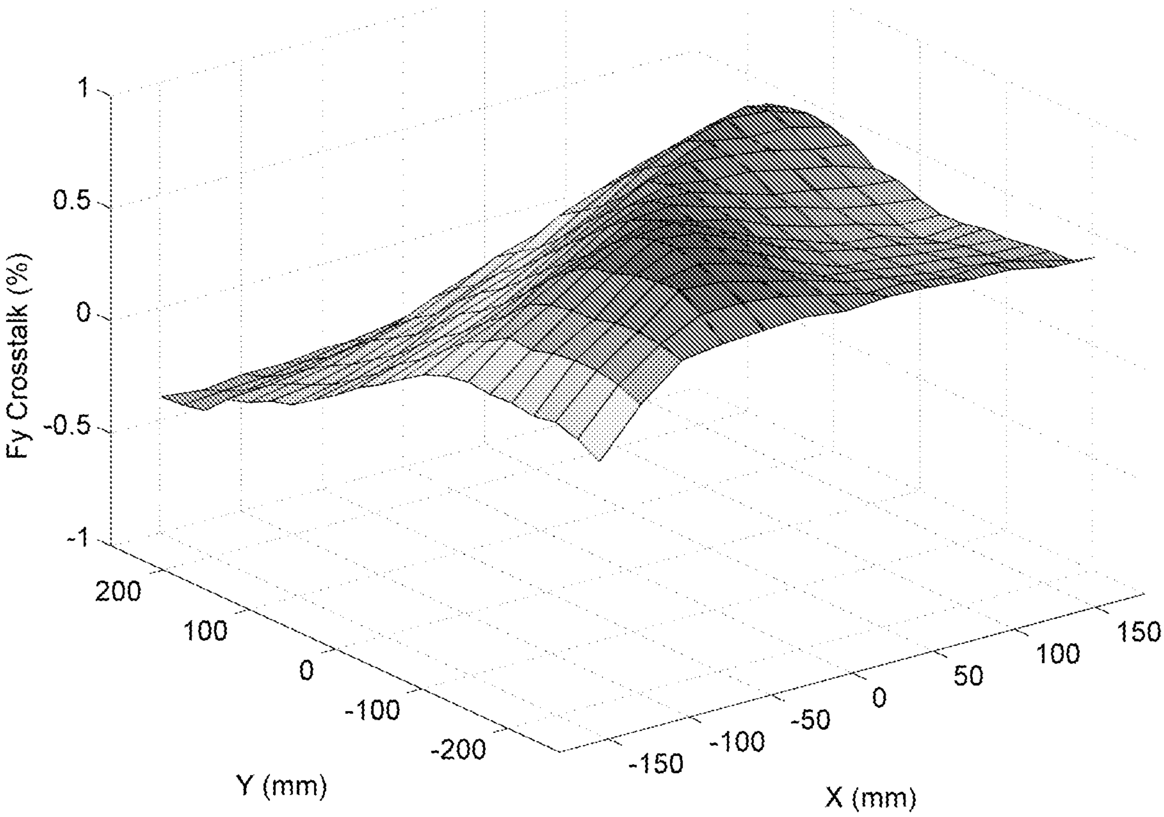

FIG.5 (prior art)

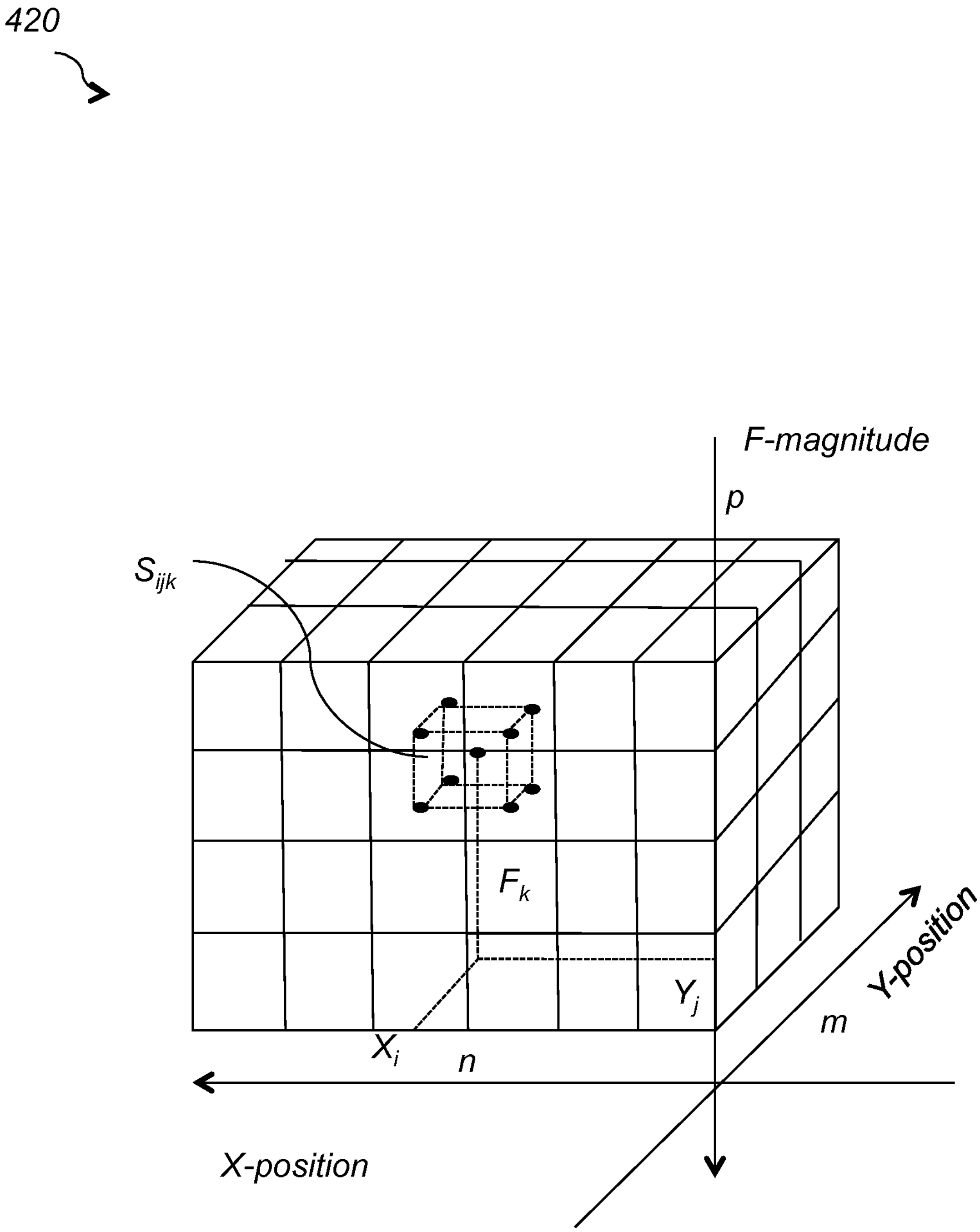

FIG.6A

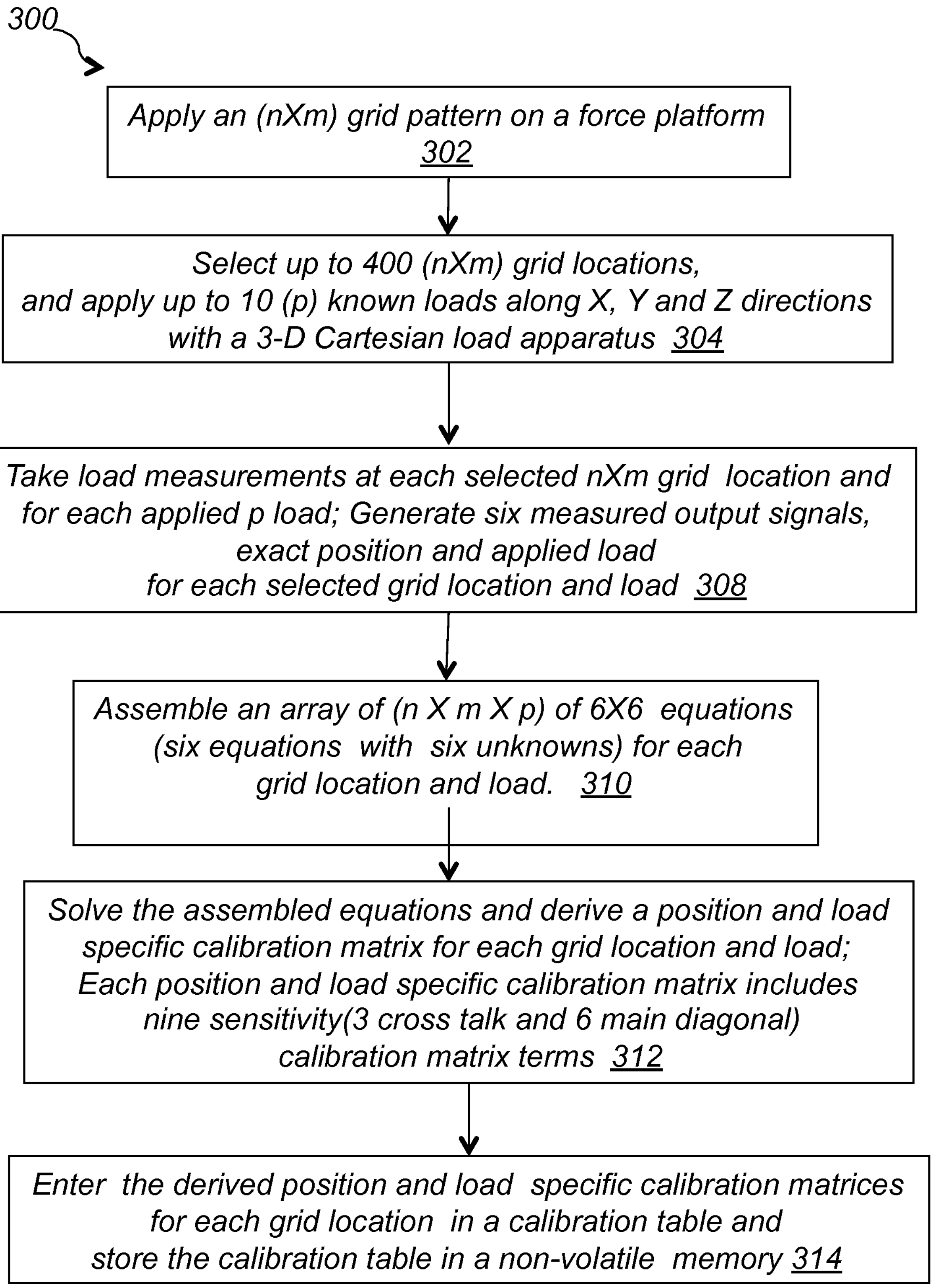
300
Apply an (nXm) grid pattern on a force platform 302
Select up to 400 (nXm) grid locations, and apply up to 10 (p) known loads along X, Y and Z directions with a 3-D Cartesian load apparatus 304
Take load measurements at each selected nXm grid location and for each applied p load; Generate six measured output signals, exact position and applied load for each selected grid location and load 308
Assemble an array of (n X m X p) of 6X6 equations (six equations with six unknowns) for each grid location and load. 310
Solve the assembled equations and derive a position and load specific calibration matrix for each grid location and load; Each position and load specific calibration matrix includes nine sensitivity(3 cross talk and 6 main diagonal) calibration matrix terms 312
Enter the derived position and load specific calibration matrices for each grid location in a calibration table and store the calibration table in a non-volatile memory 314

FIG.6B

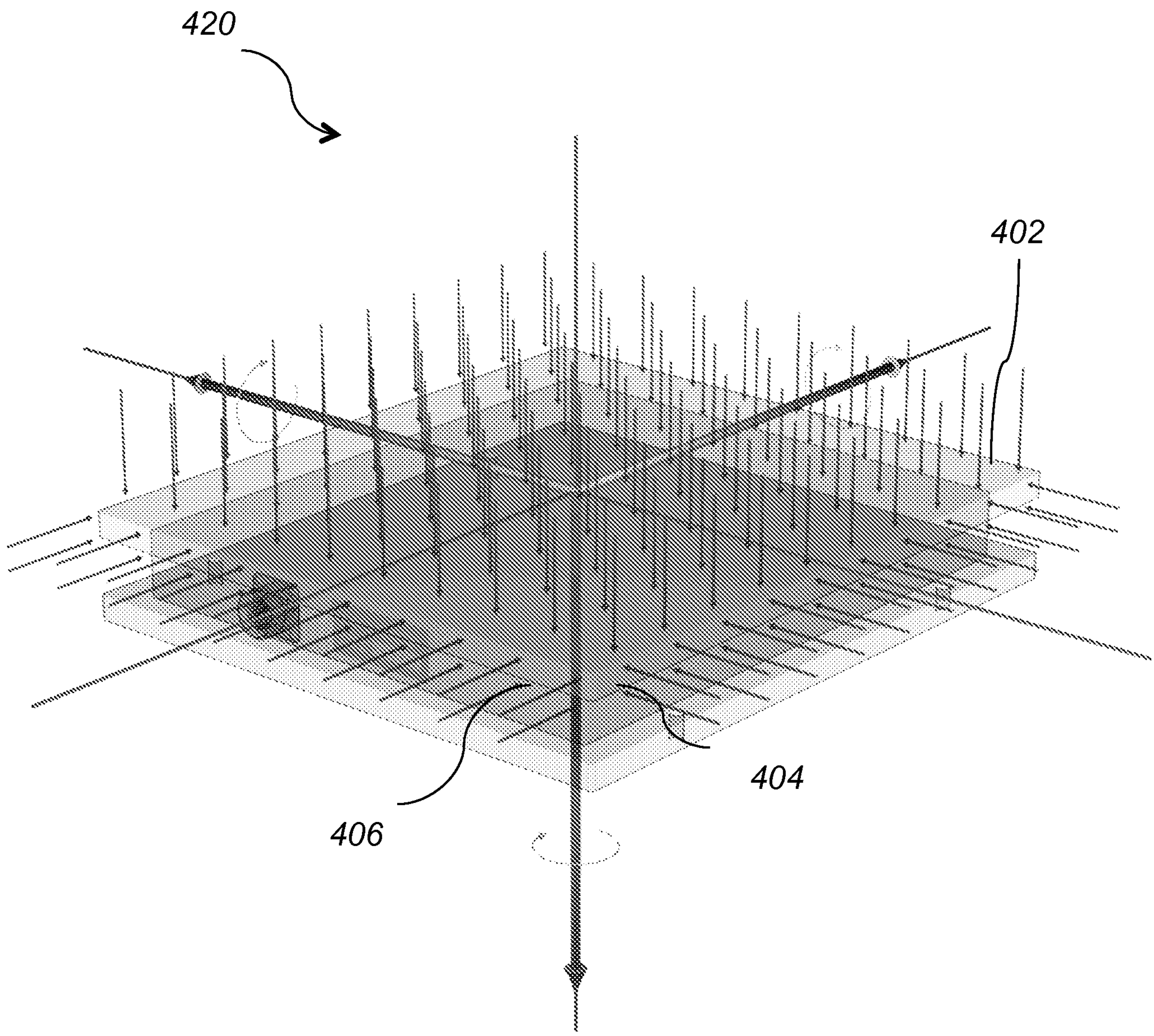

FIG.7

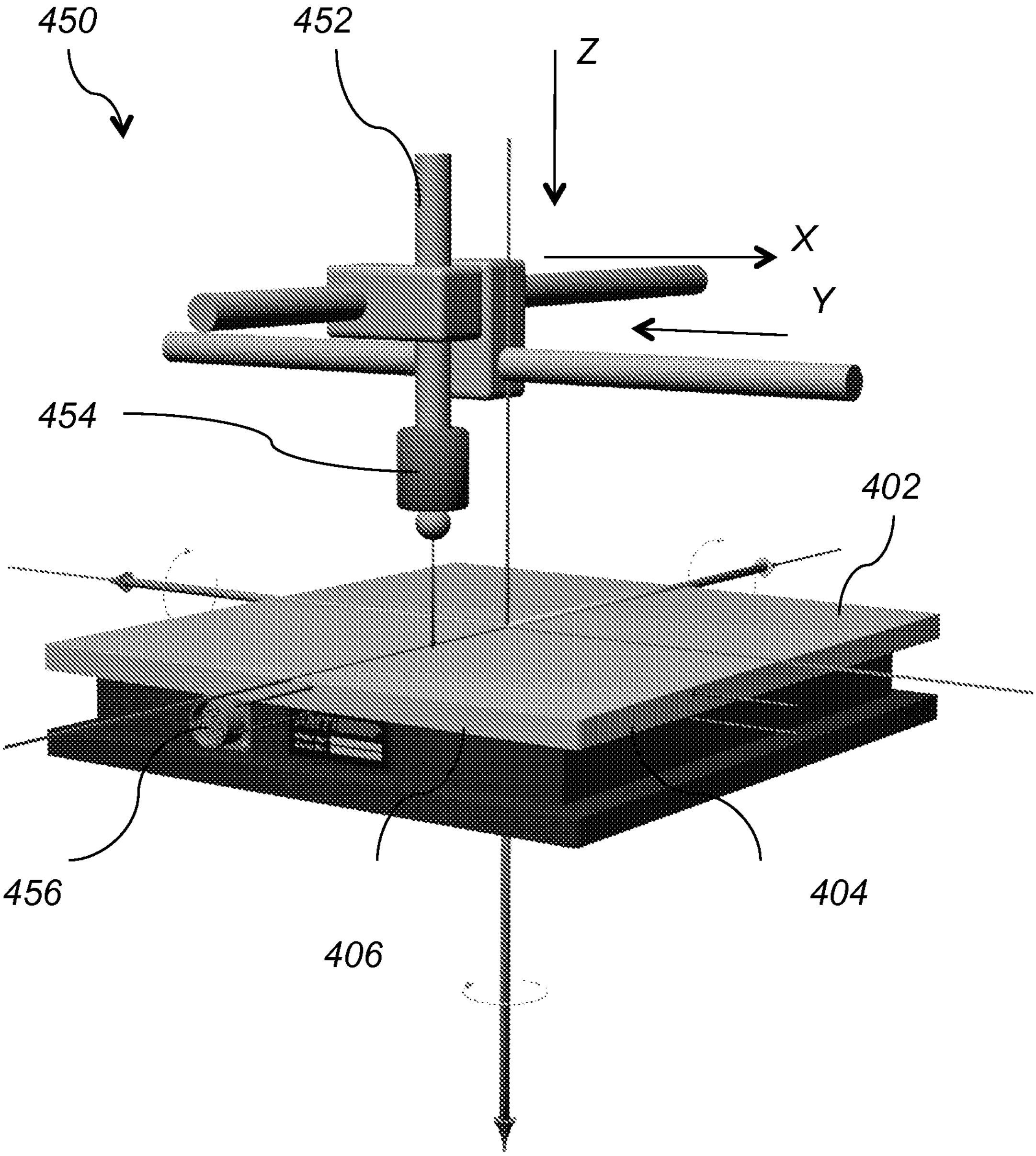

FIG.8

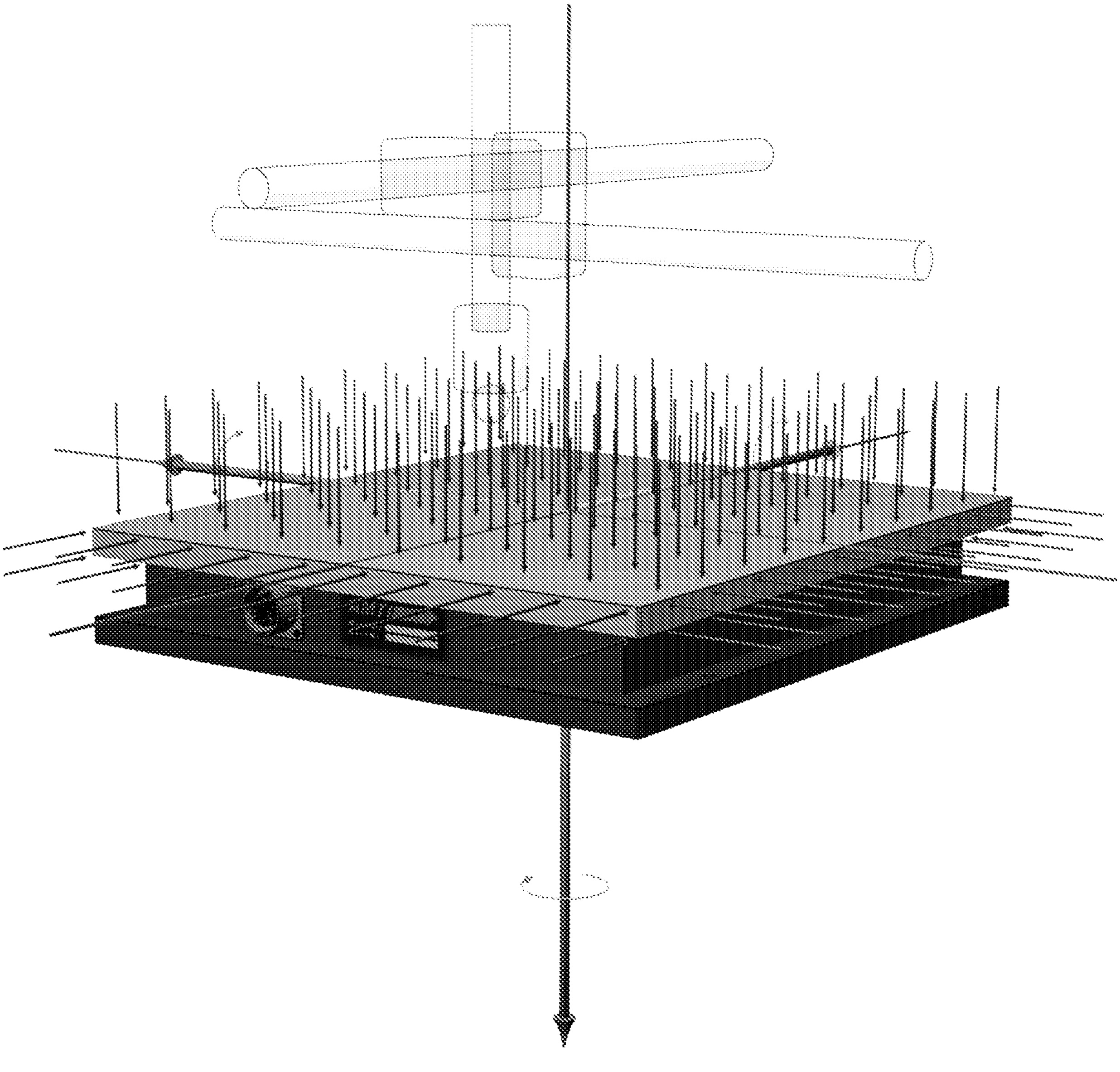

FIG.9

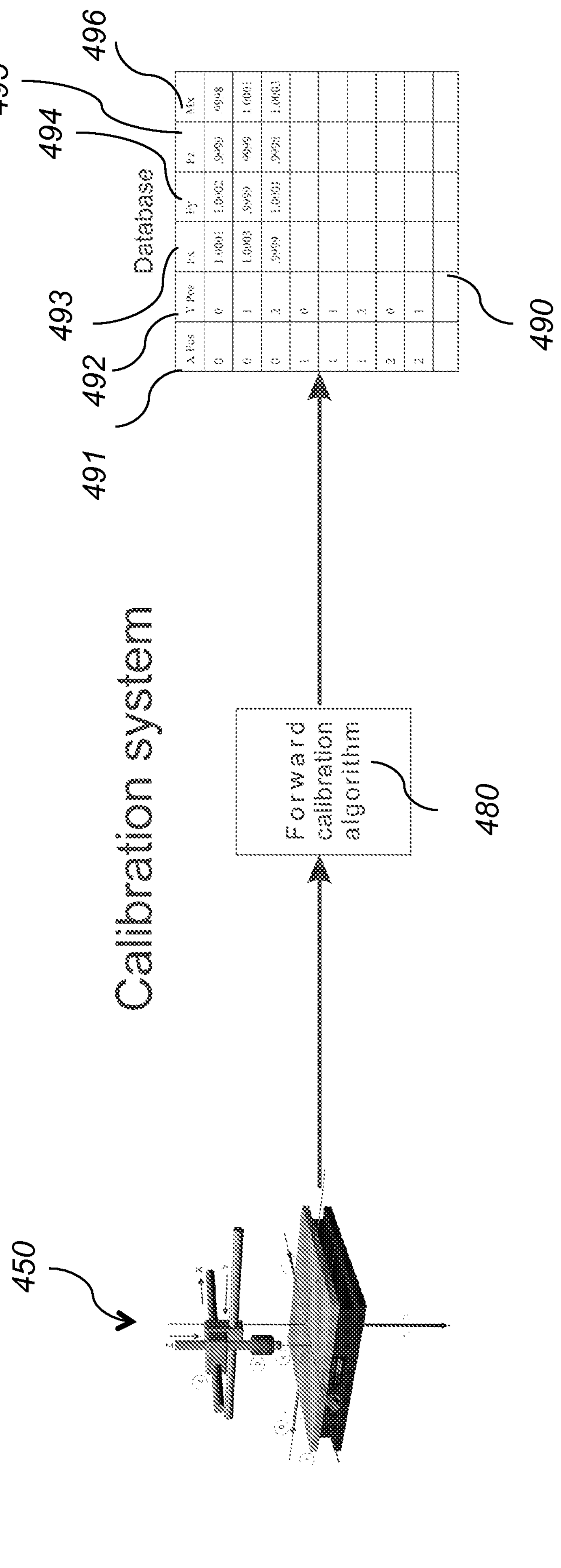
Calibration system
Database
Forward calibration algorithm
491
492
493
494
495
496
490
480
450

FIG.10

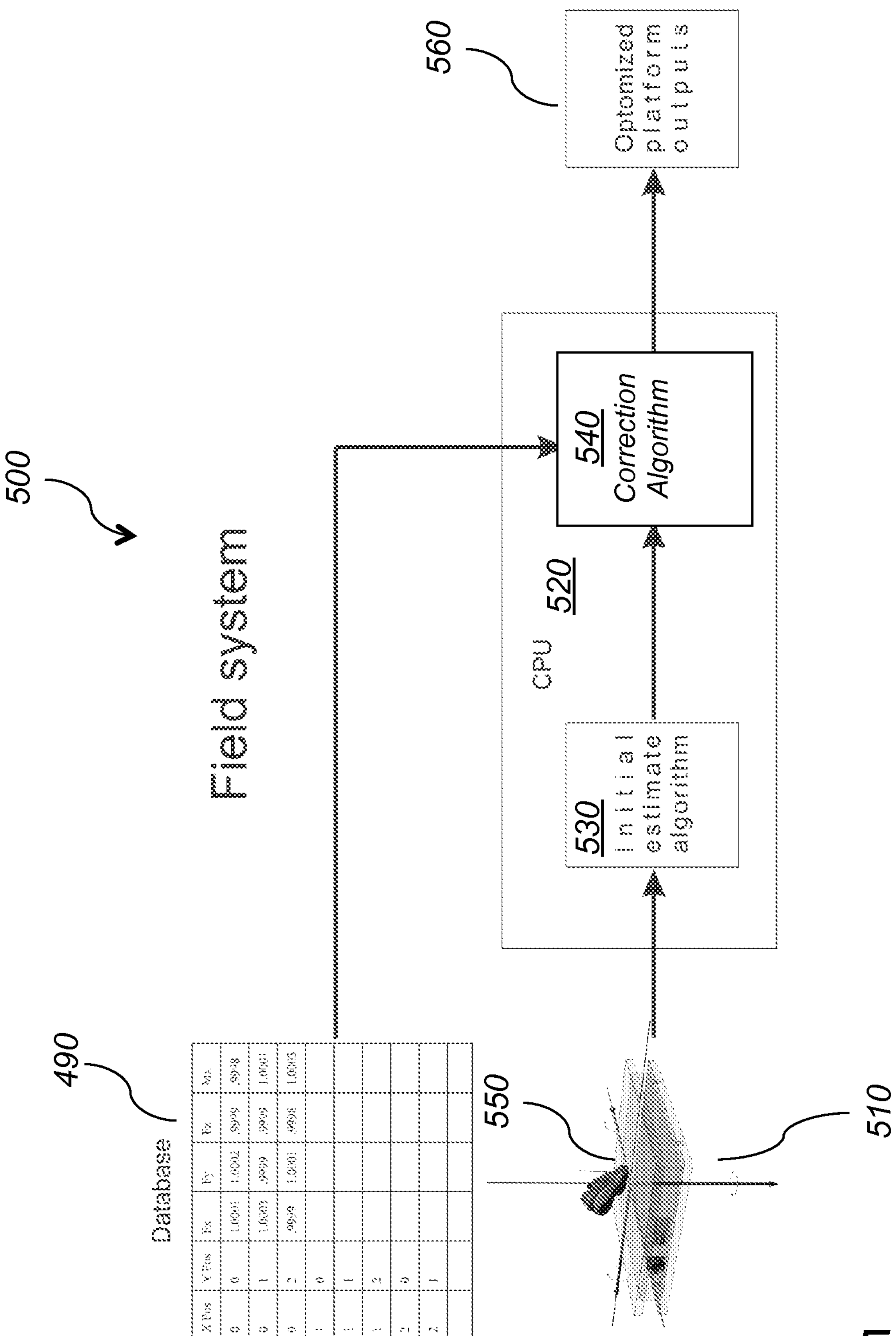
500
Field system
490
Database
CPU 520
530 Initial estimate algorithm
540 Correction Algorithm
560
Optomized platform outputs
550
510

FIG.11A

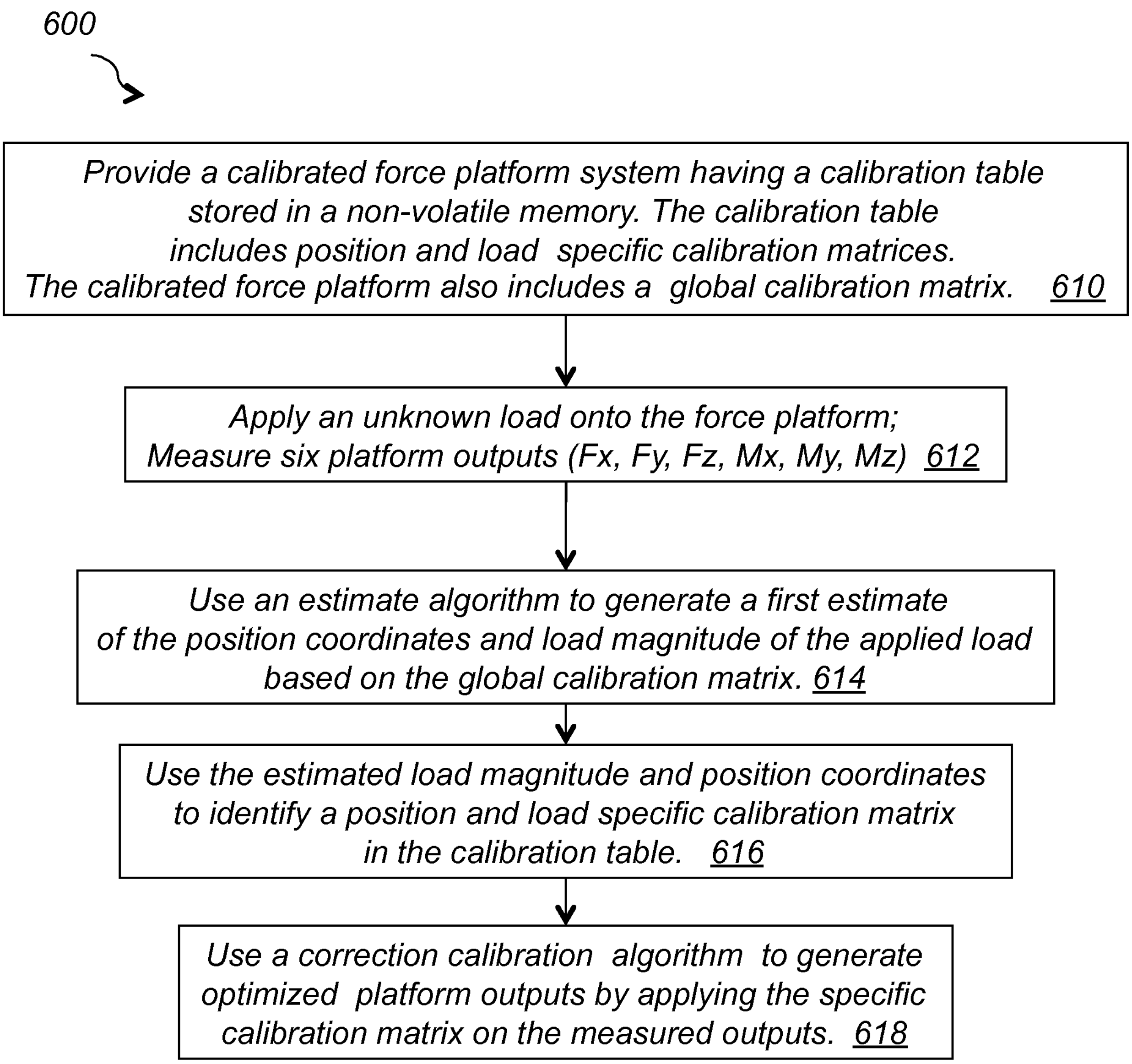
600
Provide a calibrated force platform system having a calibration table stored in a non-volatile memory. The calibration table includes position and load specific calibration matrices. The calibrated force platform also includes a global calibration matrix. 610
Apply an unknown load onto the force platform; Measure six platform outputs (Fx, Fy, Fz, Mx, My, Mz) 612
Use an estimate algorithm to generate a first estimate of the position coordinates and load magnitude of the applied load based on the global calibration matrix. 614
Use the estimated load magnitude and position coordinates to identify a position and load specific calibration matrix in the calibration table. 616
Use a correction calibration algorithm to generate optimized platform outputs by applying the specific calibration matrix on the measured outputs. 618

FIG.11B

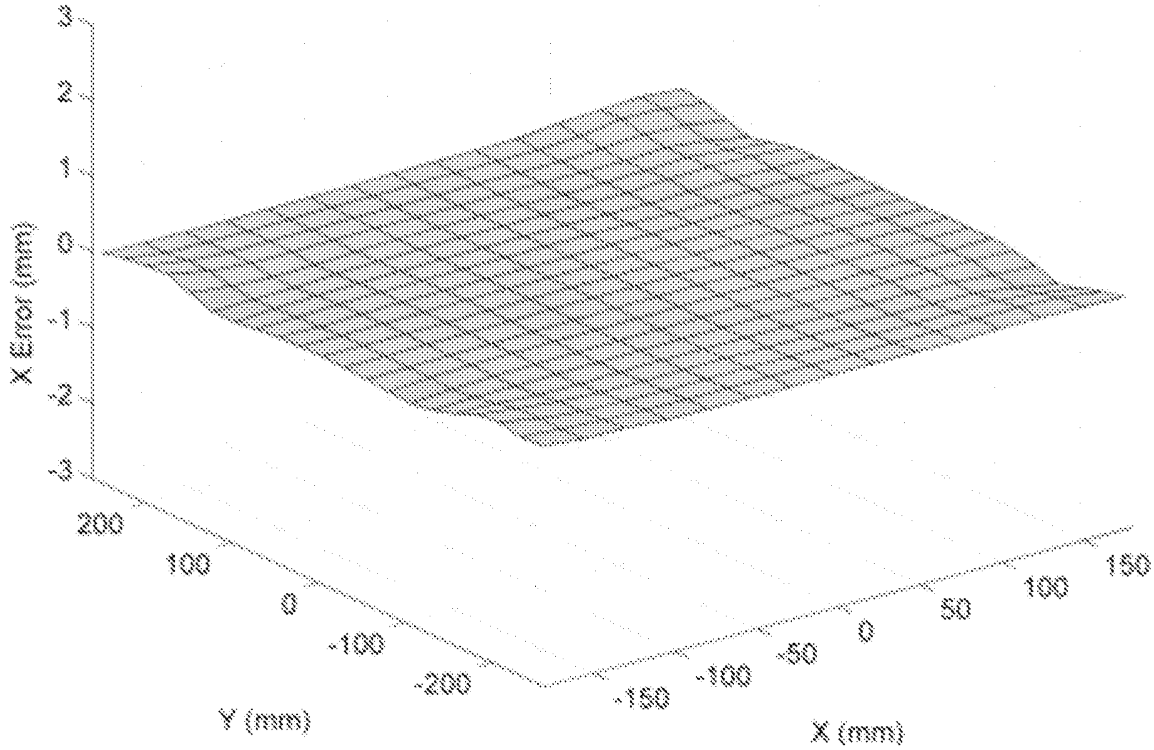

FIG.12A

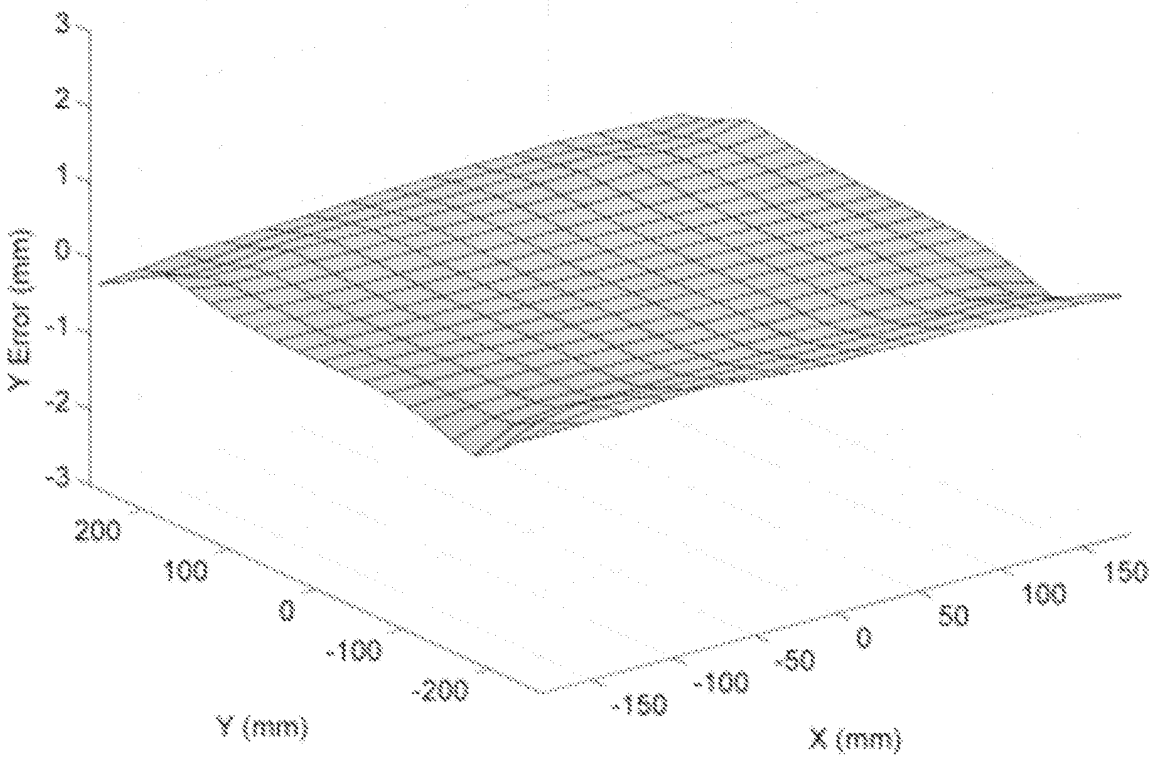

FIG.12B

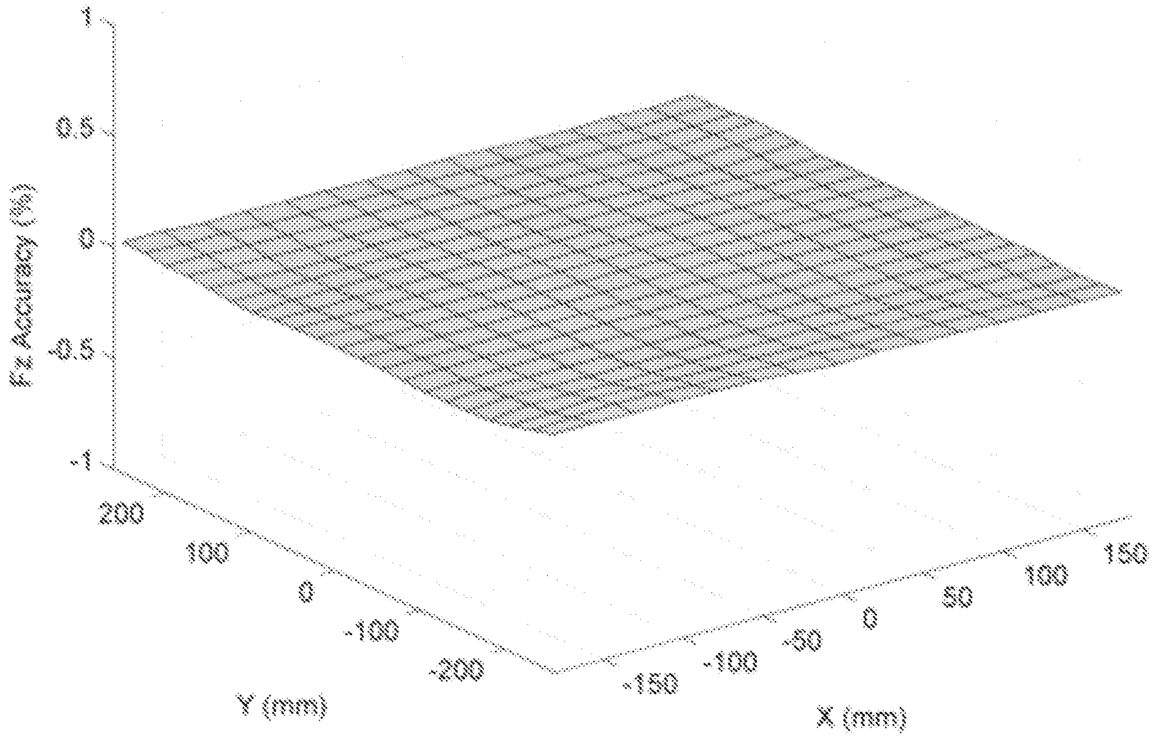

FIG.12C

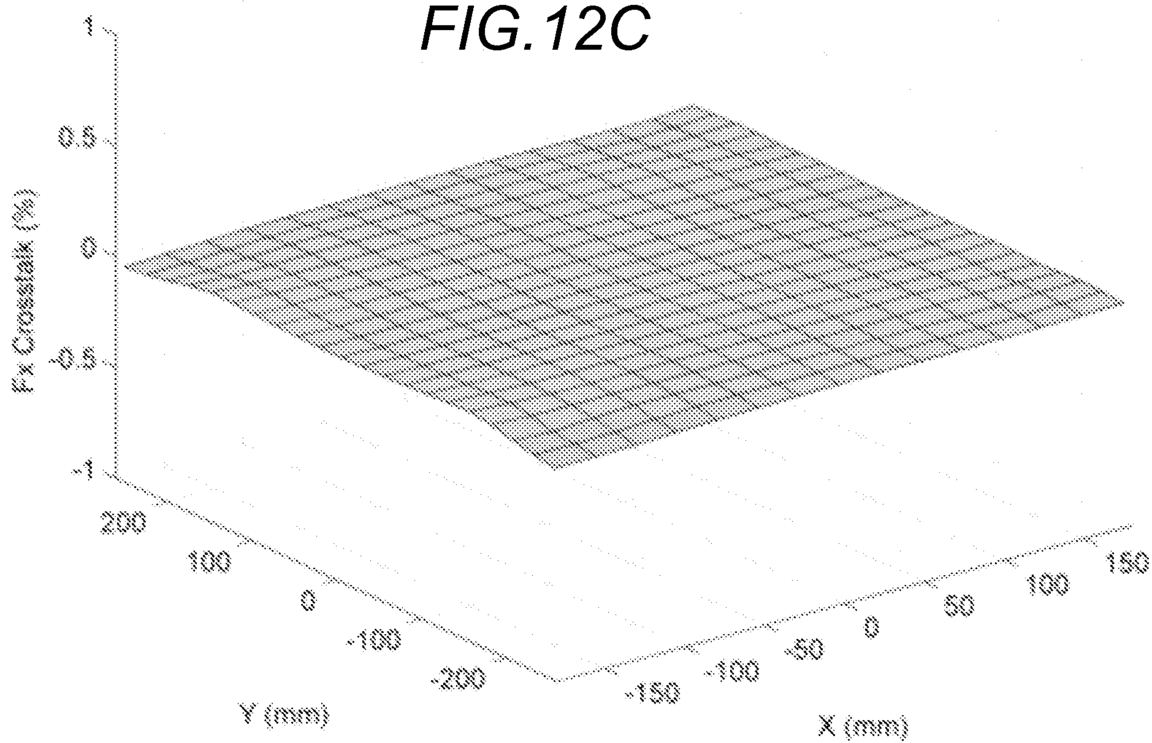

FIG.12D

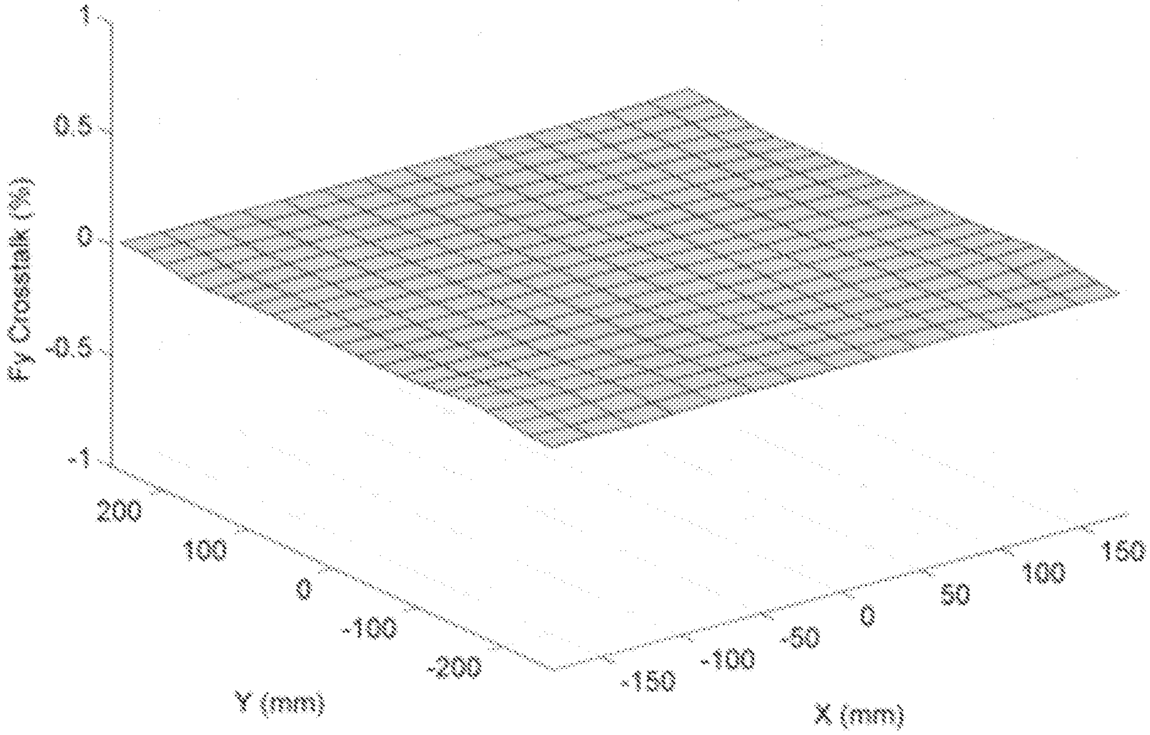

FIG.12E

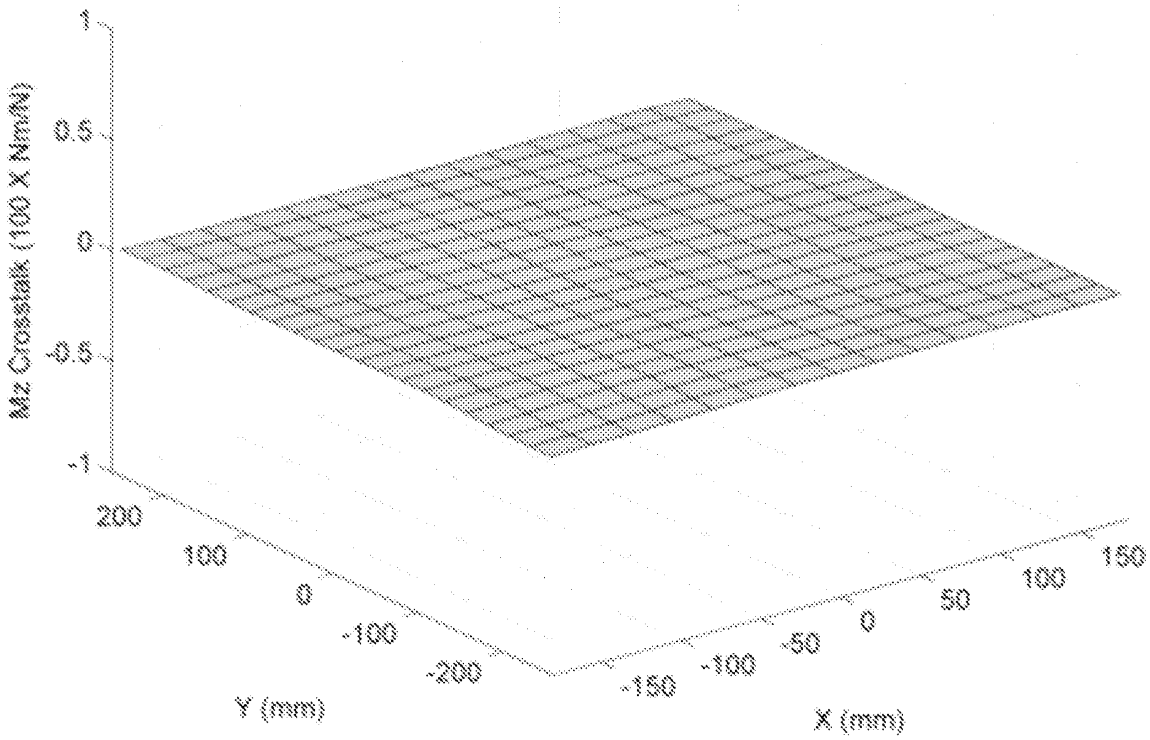

FIG.12F

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 20120123701 A1 **[0001] [0005]**

patsnap

专利名称(译)	用于力板的三维校准的系统和方法		
公开(公告)号	EP2901125A4	公开(公告)日	2016-06-15
申请号	EP2012885216	申请日	2012-09-28
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申请(专利权)人(译)	先进的机械科技股份有限公司.		
当前申请(专利权)人(译)	先进的机械科技股份有限公司.		
[标]发明人	WHITE BRUCE F RULAND FRED CARIGNAN FOREST J DRUEDING ALBERT GLASS GARY		
发明人	WHITE, BRUCE, F. RULAND, FRED CARIGNAN, FOREST, J. DRUEDING, ALBERT GLASS, GARY		
IPC分类号	G01L25/00 G01L5/00 A61B5/00 A61B5/103 A61B5/11 G01G23/01 G01L5/16		
CPC分类号	A61B5/1036 A61B5/1038 A61B5/1116 A61B5/112 A61B5/4023 A61B5/6887 A61B5/7235 A61B2560/0223 A61B2562/0247 G01G23/01 G01L5/16 G01L25/00		
代理机构(译)	HELLMICH，WOLFGANG		
优先权	13/628433 2012-09-27 US		
其他公开文献	EP2901125B1 EP2901125A1		
外部链接	Espacenet		

摘要(译)

一种用于校准力平台的方法包括：提供力平台并经由计算装置在力平台的顶表面上施加n×m网格。接下来，沿着垂直于X和Y轴并且沿着X和Y轴的Z轴在顶表面的n×m个网格点中的每一个上施加p已知负载。接下来，在每个网格点和沿X，Y和Z轴的每个应用已知负载进行多点测量，并生成六个测量输出信号，精确位置坐标和每个网格点应用的已知负载大小。接下来，组装一个n×m×p的六个方程的阵列，其中每个网格点有六个未知数，并应用已知载荷，然后求解组合方程并导出每个网格点的位置和负载特定校准矩阵。