US 20160175674A1

(19) United States
(12) Patent Application Publication
HAYAISHI
(10) Pub. No.: US 2016/0175674 A1
(43) Pub. Date: Jun. 23, 2016

(54) **MOTION ANALYSIS DEVICE, MOTION ANALYSIS SYSTEM, MOTION ANALYSIS METHOD, PROGRAM, AND RECORDING MEDIUM**

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(21) Appl. No.: **14/965,278**

(22) Filed: **Dec. 10, 2015**

(30) **Foreign Application Priority Data**

Dec. 19, 2014 (JP) 2014-257261

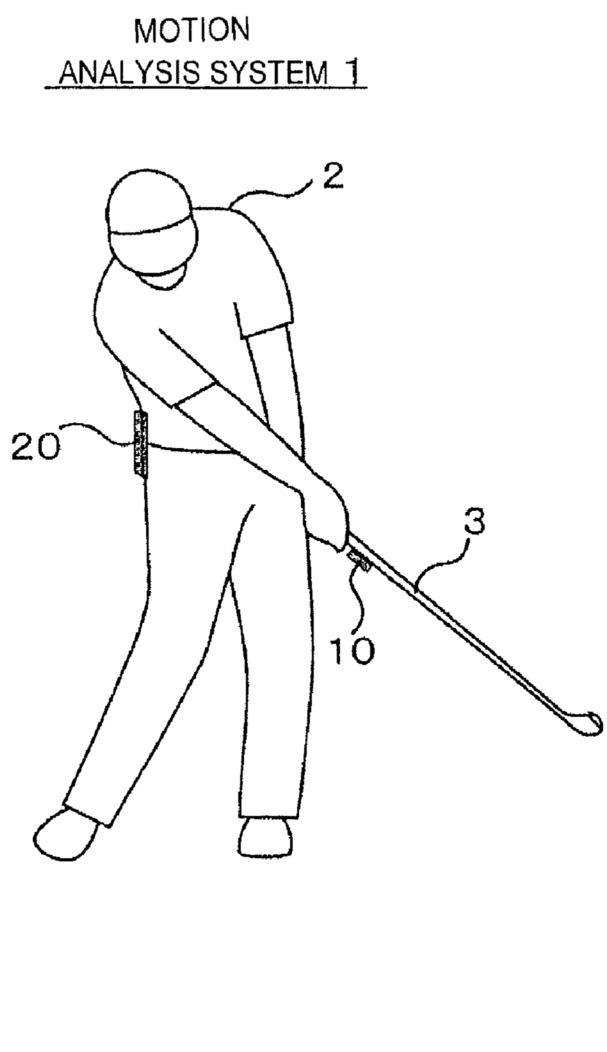
Publication Classification

(51) **Int. Cl.**
A63B 60/46 (2006.01)
A63B 71/06 (2006.01)
A63B 24/00 (2006.01)

(52) **U.S. Cl.**
CPC ***A63B 60/46*** (2015.10); ***A63B 24/0003*** (2013.01); ***A63B 71/06*** (2013.01); *A63B 2220/51* (2013.01); *A63B 2071/0694* (2013.01); *A63B 2220/16* (2013.01)

(57) **ABSTRACT**

A motion analysis device includes: a first specifying unit that specifies a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor; a second specifying unit that specifies a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and an adjustment unit that adjusts sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.



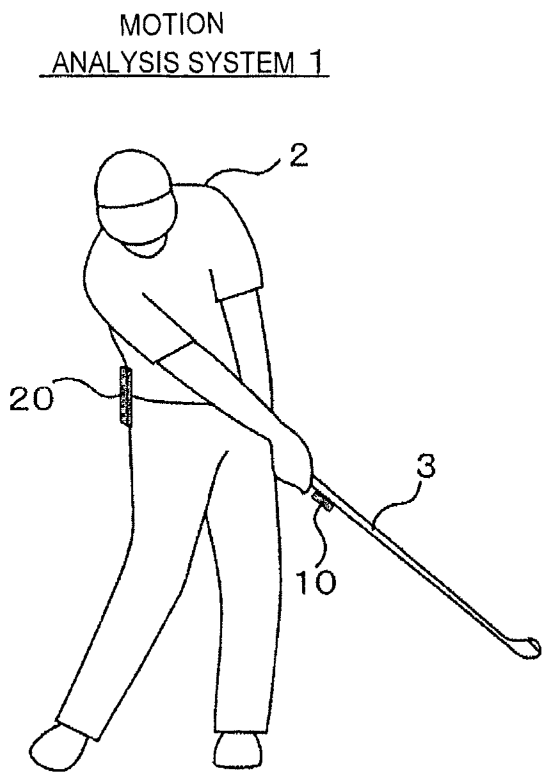


FIG. 1

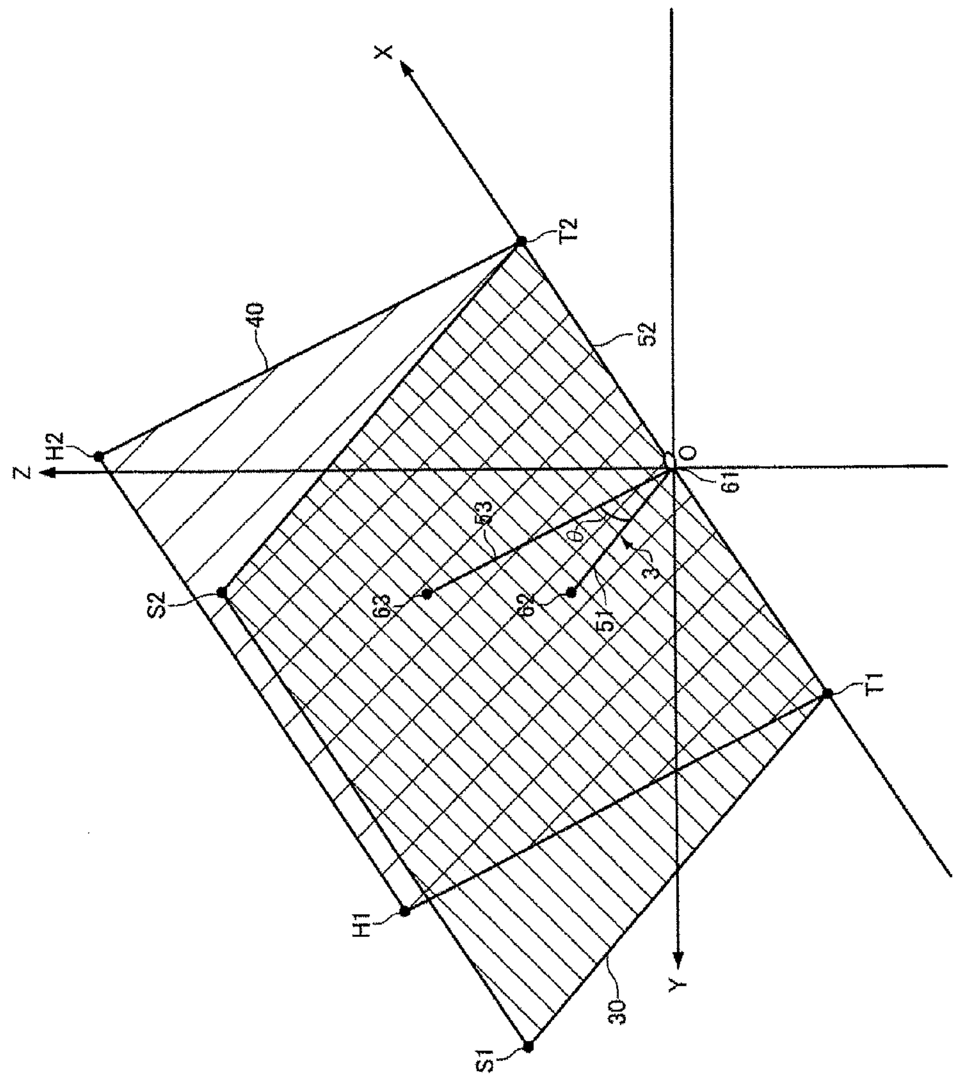


FIG. 2

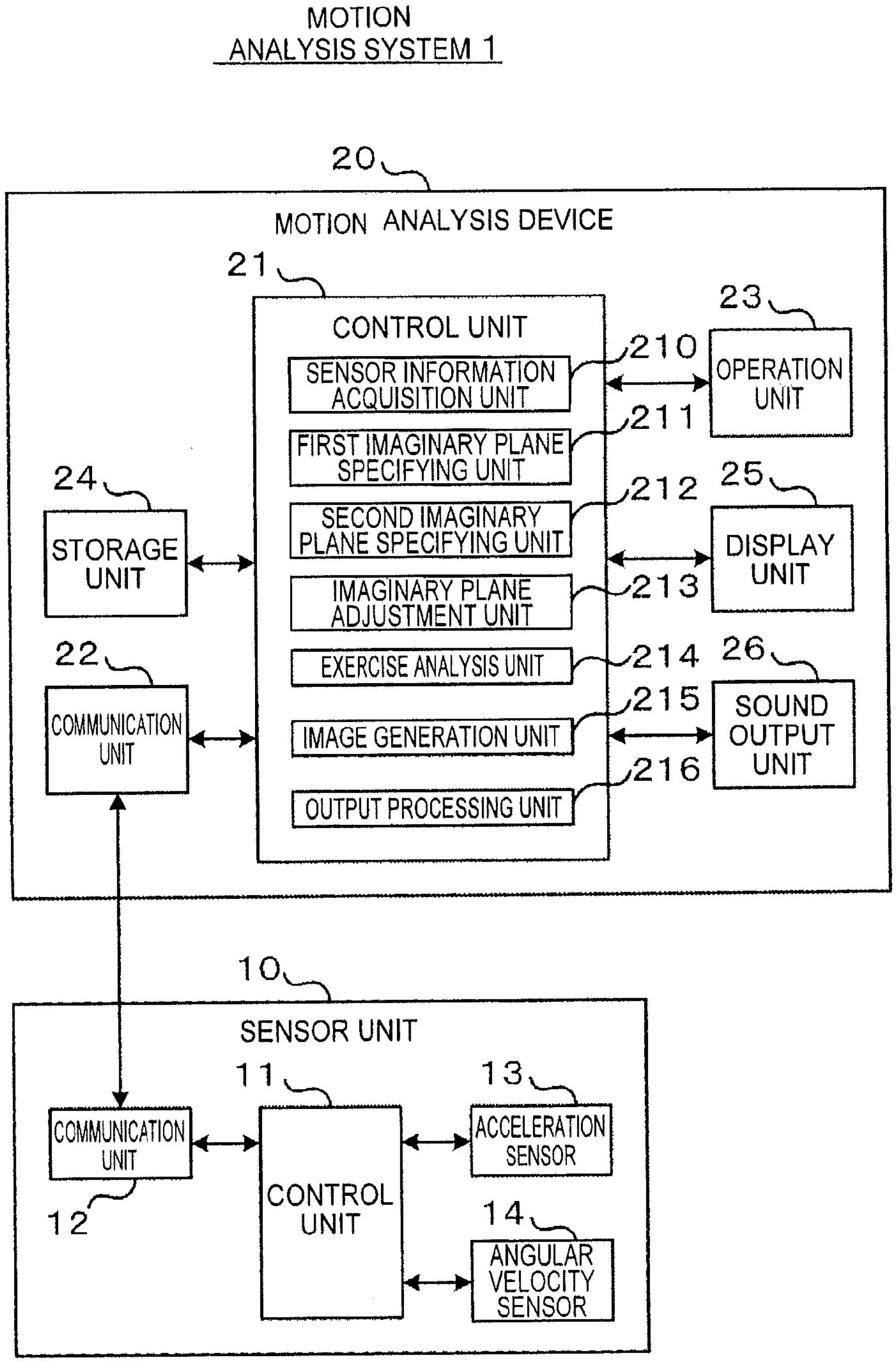

MOTION
ANALYSIS SYSTEM 1
20
MOTION ANALYSIS DEVICE
21
CONTROL UNIT
210
SENSOR INFORMATION ACQUISITION UNIT
211
FIRST IMAGINARY PLANE SPECIFYING UNIT
212
SECOND IMAGINARY PLANE SPECIFYING UNIT
213
IMAGINARY PLANE ADJUSTMENT UNIT
214
EXERCISE ANALYSIS UNIT
215
IMAGE GENERATION UNIT
216
OUTPUT PROCESSING UNIT
23
OPERATION UNIT
24
STORAGE UNIT
25
DISPLAY UNIT
22
COMMUNICATION UNIT
26
SOUND OUTPUT UNIT
10
SENSOR UNIT
11
CONTROL UNIT
12
COMMUNICATION UNIT
13
ACCELERATION SENSOR
14
ANGULAR VELOCITY SENSOR

FIG. 3

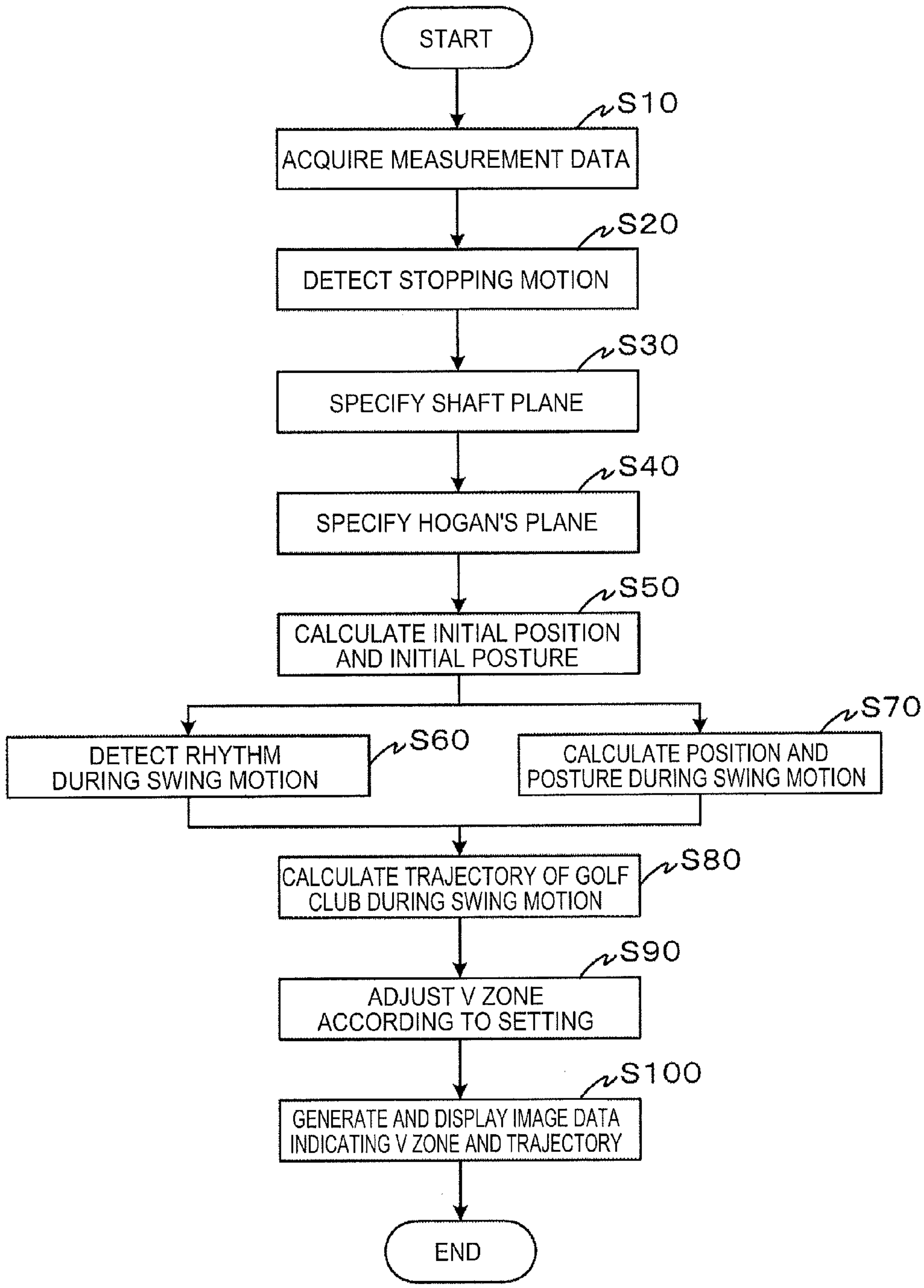

START
S10
ACQUIRE MEASUREMENT DATA
S20
DETECT STOPPING MOTION
S30
SPECIFY SHAFT PLANE
S40
SPECIFY HOGAN'S PLANE
S50
CALCULATE INITIAL POSITION AND INITIAL POSTURE
S60
DETECT RHYTHM DURING SWING MOTION
S70
CALCULATE POSITION AND POSTURE DURING SWING MOTION
S80
CALCULATE TRAJECTORY OF GOLF CLUB DURING SWING MOTION
S90
ADJUST V ZONE ACCORDING TO SETTING
S100
GENERATE AND DISPLAY IMAGE DATA INDICATING V ZONE AND TRAJECTORY
END

FIG. 4

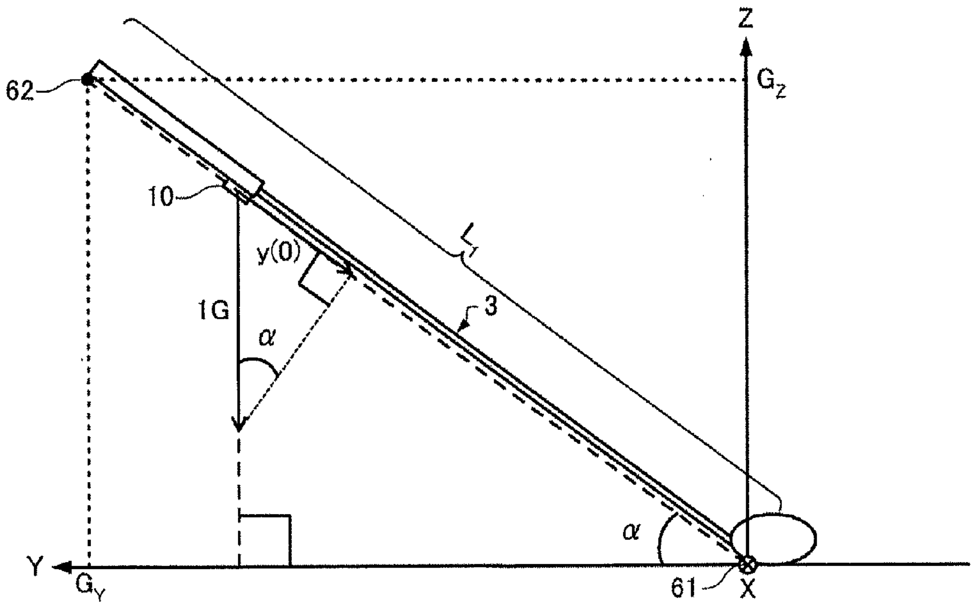

Z
62
G_Z
10
L_1
y(0)
1G
3
α
α
Y
G_Y
61
X

FIG. 5

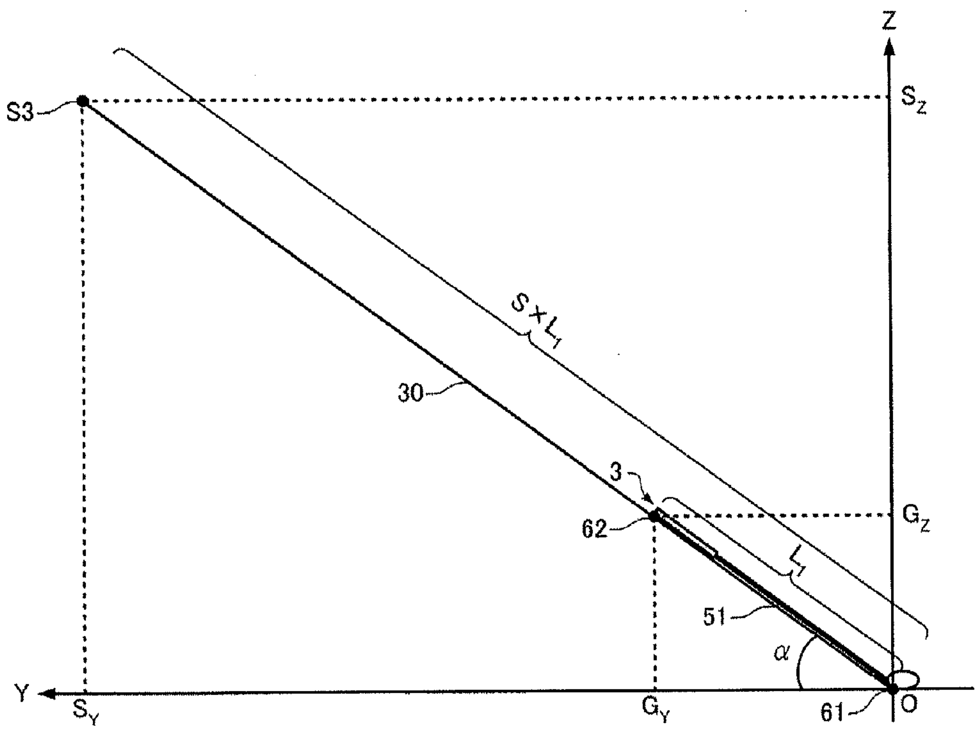

Z
S3
S_Z
$S \times L_1$
30
3
62
G_Z
L_1
51
α
Y
S_Y
G_Y
61
O

FIG. 6

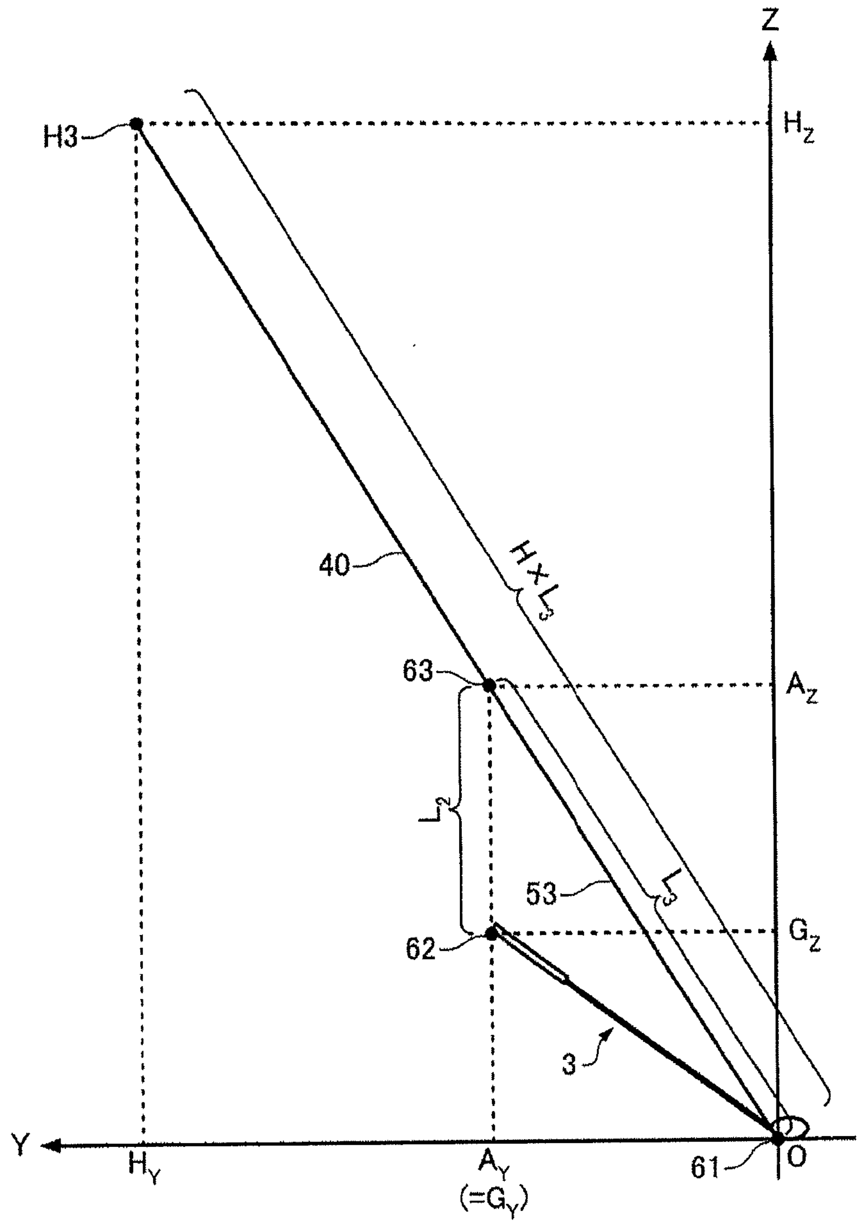


FIG. 7

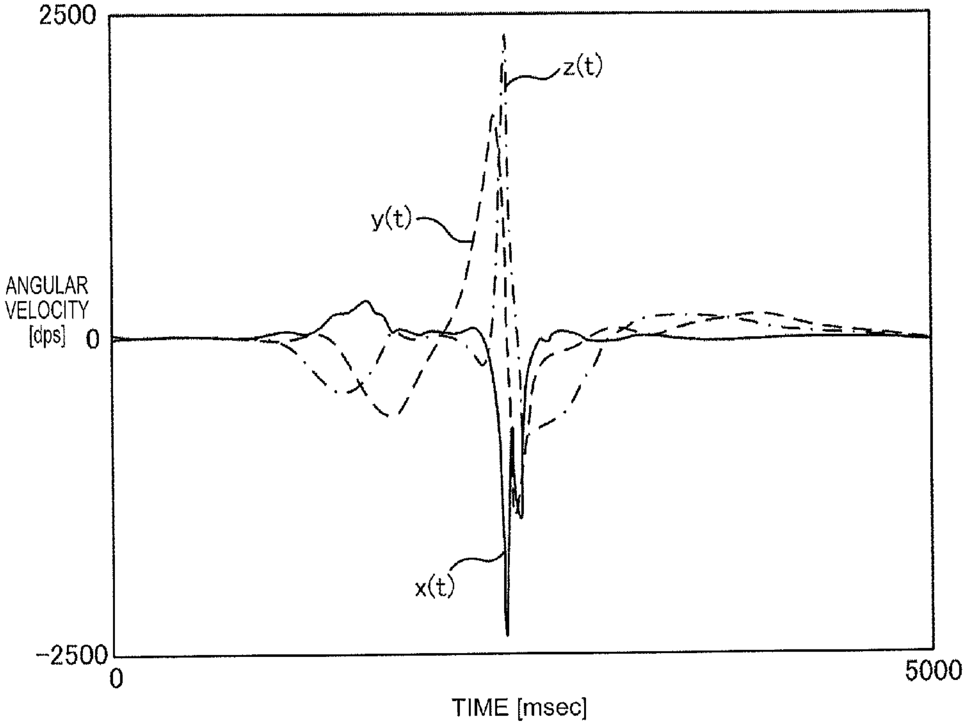


FIG. 8

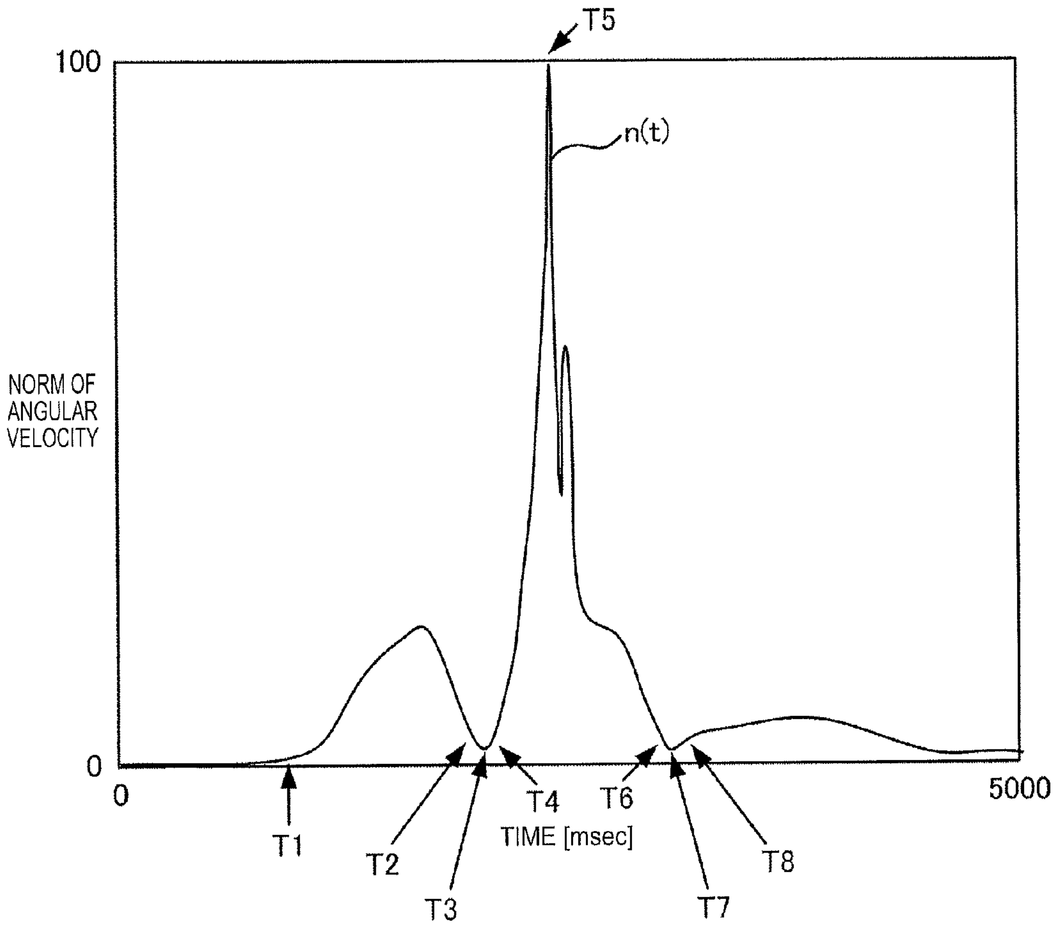

T5
100
n(t)
NORM OF ANGULAR VELOCITY
0
0
5000
TIME [msec]
T1
T2
T3
T4
T6
T7
T8

FIG. 9

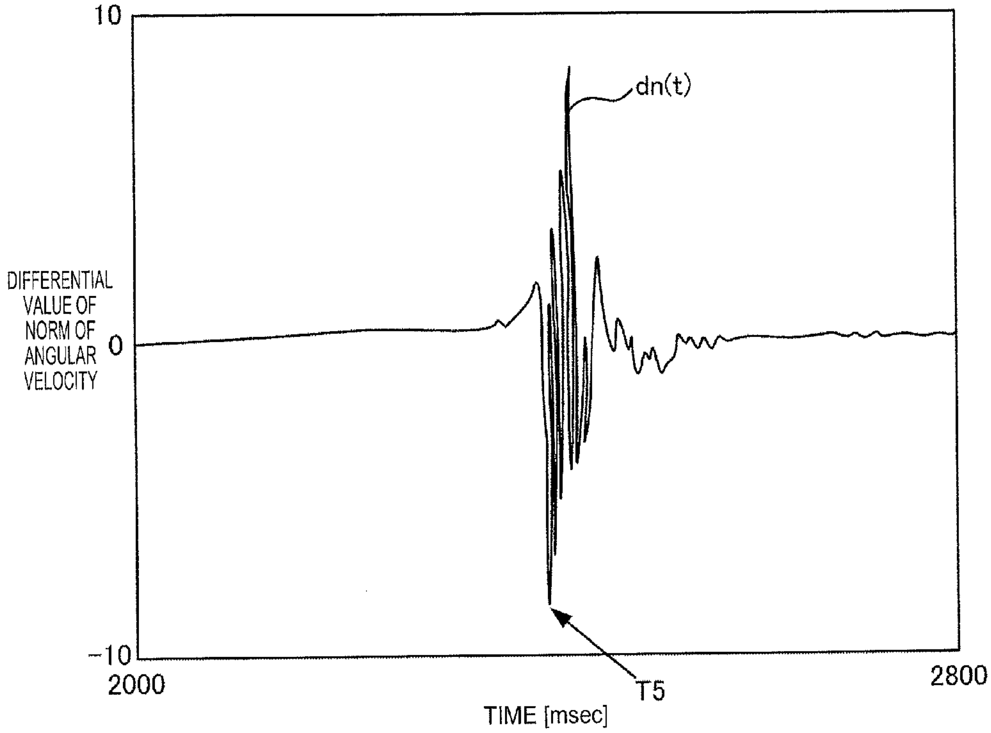

10
dn(t)
DIFFERENTIAL VALUE OF NORM OF ANGULAR VELOCITY
0
−10
2000
2800
T5
TIME [msec]

FIG. 10

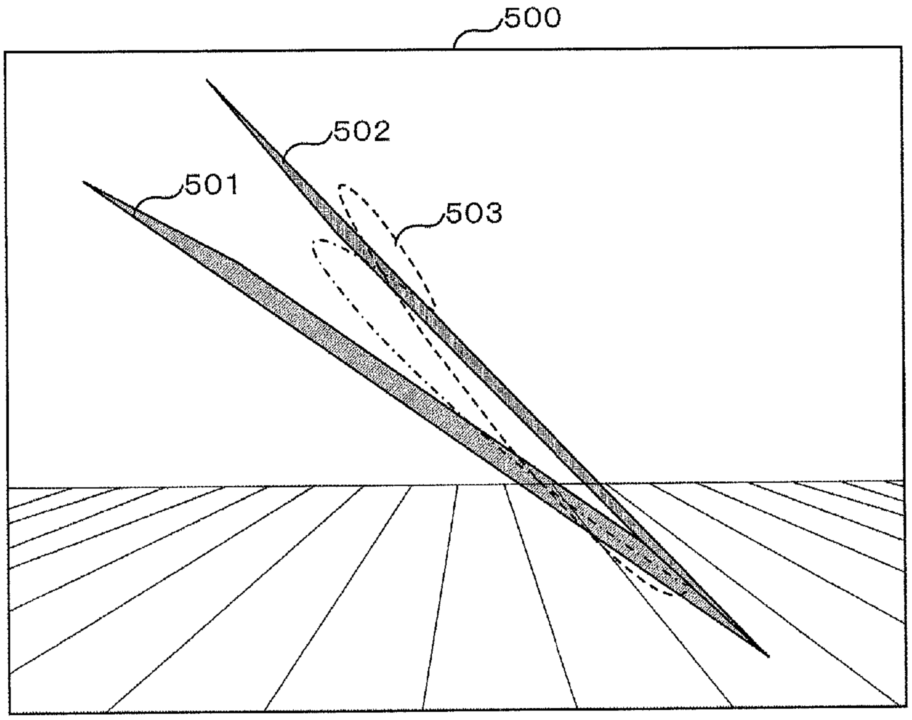


FIG. 11

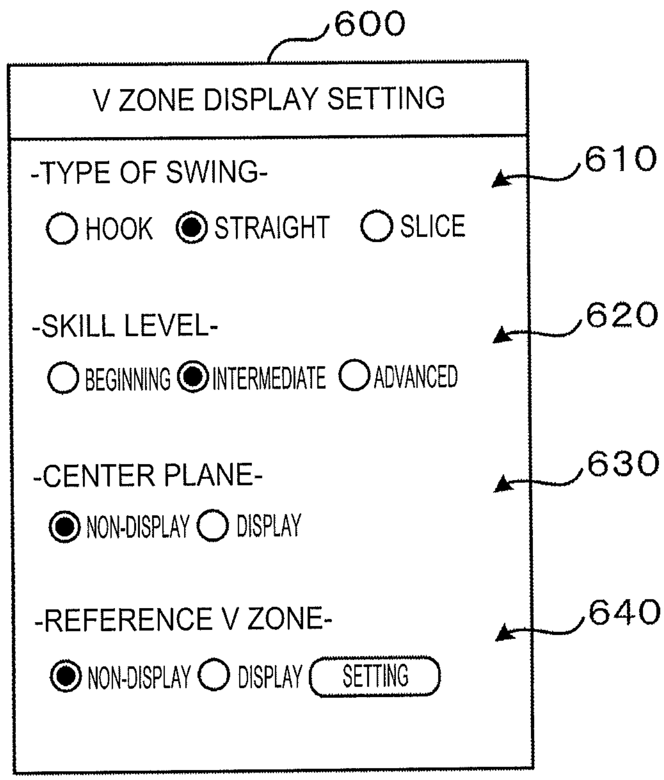

600
V ZONE DISPLAY SETTING
-TYPE OF SWING-
HOOK
STRAIGHT
SLICE
610
-SKILL LEVEL-
BEGINNING
INTERMEDIATE
ADVANCED
620
-CENTER PLANE-
NON-DISPLAY
DISPLAY
630
-REFERENCE V ZONE-
NON-DISPLAY
DISPLAY
SETTING
640

FIG. 12

FIG. 13A

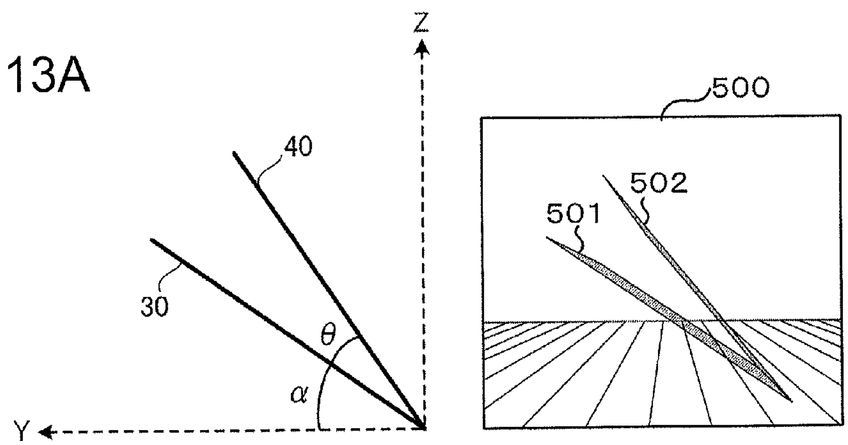


FIG. 13B

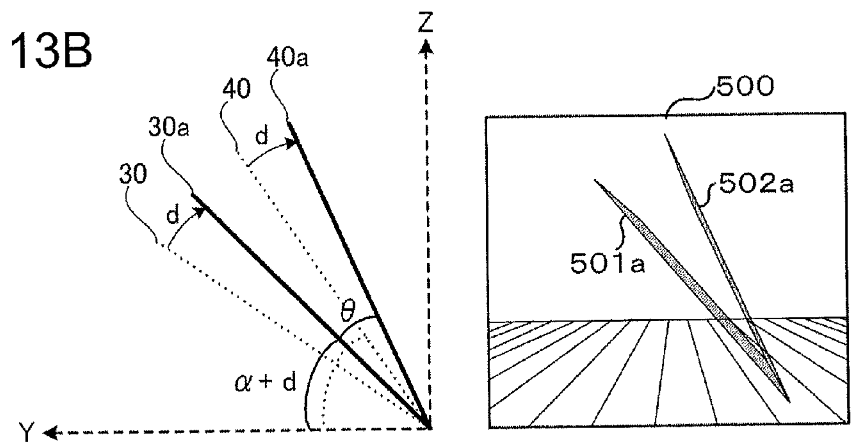


FIG. 13C

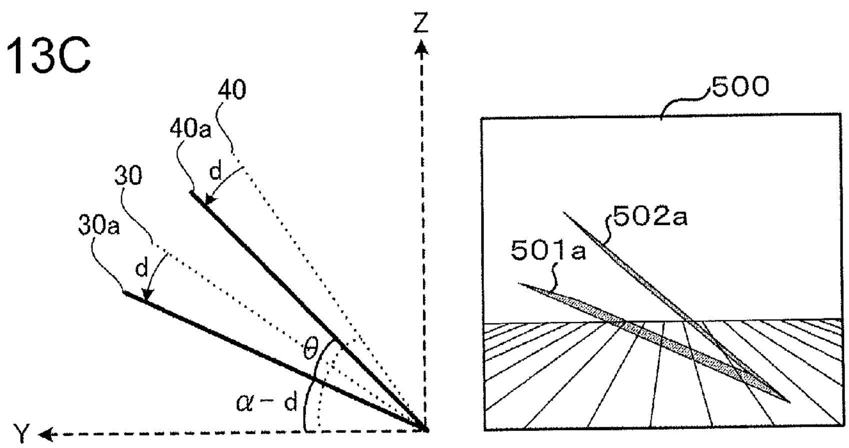


FIG. 14A

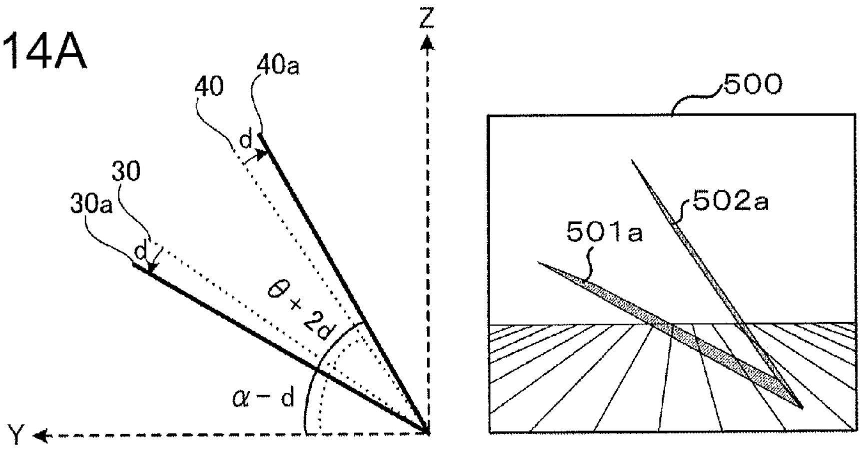


FIG. 14B

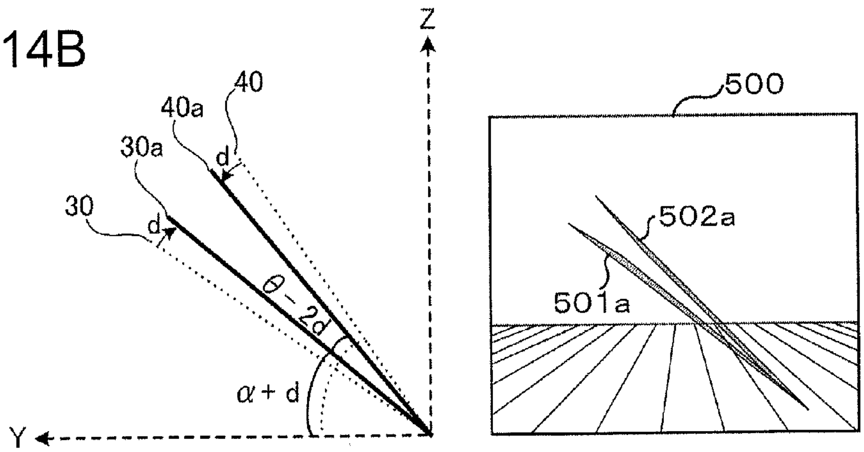
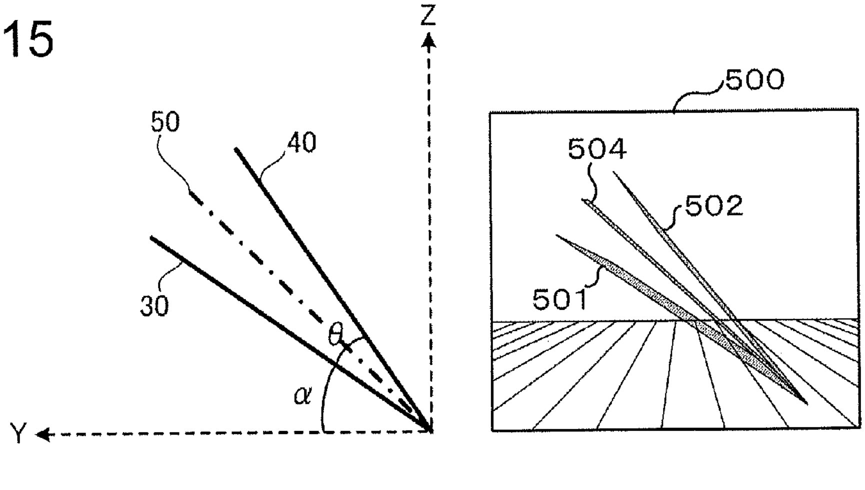


FIG. 15



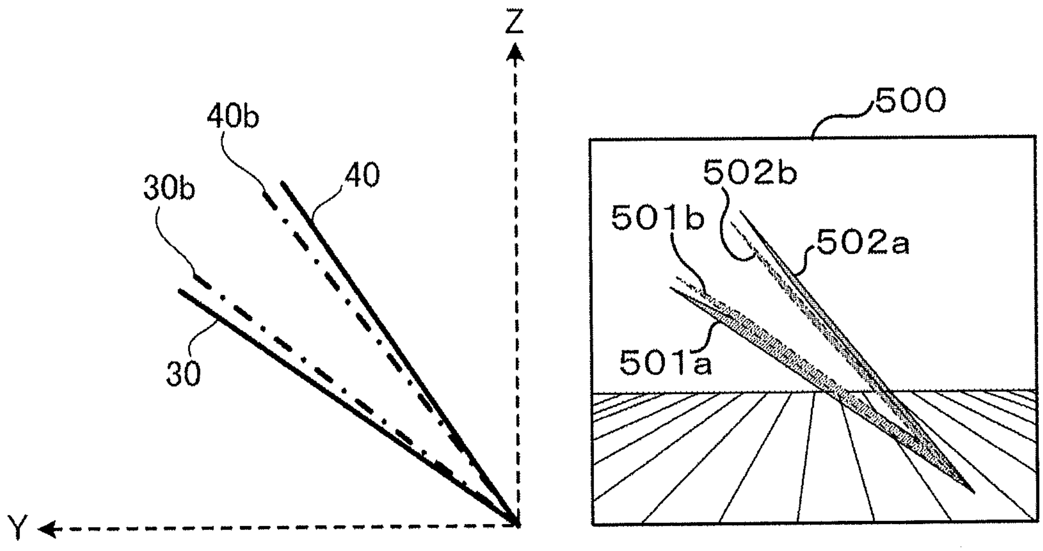


FIG. 16

MOTION ANALYSIS DEVICE, MOTION ANALYSIS SYSTEM, MOTION ANALYSIS METHOD, PROGRAM, AND RECORDING MEDIUM

BACKGROUND

[0001] 1. Technical Field

[0002] The present invention relates to a motion analysis device, a motion analysis system, a motion analysis method, a program, and a recording medium.

[0003] 2. Related Art

[0004] JP-A-2010-82430 discloses that an image is acquired by performing photographing from the rear side in a hitting direction between an address state to the end of a swing and the image is split into at least three regions by a first straight line passing through a shaft axis of a golf club in the address state and a second straight line intersecting the first straight line and passing through the root of an installed tee and the base of the neck of a golfer.

[0005] In coaching of a golf swing, indexes such as a shaft plane and a Hogan's plane are used in many cases. The shaft plane is a plane that is formed by the major axis direction of a shaft of a golf club and a target line (for example, a hitting target direction) at the time of address of golf. The Hogan's plane is a plane that is formed by a target line and an imaginary line connecting a periphery of a shoulder (a shoulder, the base of a neck, or the like) of a golfer to the head (or a ball) of a golf club at the time of a golf address. A region interposed between the shaft plane and the Hogan's plane is called a V zone. A trajectory of a golf club enters the V zone, for example, at the time of downswing, straight-based hitting is known to be realized. Accordingly, goodness and badness of a swing can be estimated according to whether a trajectory of a golf club enters the V zone, for example, at the time of downswing.

[0006] However, a method of simply presenting a shaft plane and a Hogan's plane to a user has not been proposed until now. For example, in JP-A-2010-82430, the V zone is specified by photographing a golfer in an address state with a camera and drawing a straight line in an image based on an instruction input from a user. In JP-A-2010-82430, there are problems in that, for example, it is difficult to install a camera so that an entire golfer is contained in an image, it is difficult to visually confirm the V zone on an image (it is difficult for a user to decide a position at which a straight line is drawn), and it is difficult to visually confirm whether a trajectory of a golf club in a downswing is included in the V zone.

SUMMARY

[0007] An advantage of some aspects of the invention is to support estimation of goodness or badness of a swing more simply than in the related art.

[0008] An aspect of the invention is directed to a motion analysis device including: a first specifying unit that specifies a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor; a second specifying unit that specifies a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and an adjustment unit that adjusts sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

[0009] With this configuration, it is possible for the user to objectively recognize an address posture from the positions and inclinations of the first and second axes, the size of a space between the first and second axes, and the like and to recognize a positional relation between an assumed trajectory of a swing, and the first and second axes. Therefore, the swing can be estimated simply. Further, the position, the posture, the area, or the like of the space between the first and second axes is adjusted according to the predetermined condition. Therefore, even when a way, a habit, a tendency, or the like of the swing of the user is desired to be considered, a swing can be estimated simply and accurately.

[0010] The predetermined condition may be a type of swing of the user. The adjustment unit may adjust at least one of the angle of the first axis and the angle of the second axis according to the type of swing.

[0011] With this configuration, since the position, the posture, or the like of the space between the first and second axes is adjusted according to the type of swing, the swing can be estimated simply and accurately in consideration of a tendency or the like of the swing according to the type of swing.

[0012] The type of swing may be a slice or a hook, when the type of swing is the slice, the adjustment unit may increase at least the angle of the second axis. When the type of swing is the hook, the adjustment unit may decrease at least the angle of the first axis.

[0013] With this configuration, the swing can be estimated simply and accurately in consideration of the position or the like of the trajectory of each of a slice-based swing or a hook-based swing.

[0014] The predetermined condition may be a skill level of the user. The adjustment unit may adjust the predetermined angle between the first and second axes according to the skill level.

[0015] With this configuration, since the position, the posture, the area, or the like of the space between the first and second axes is adjusted according to the skill level, the swing can be estimated simply and accurately in consideration of the tendency or the like of the swing according to the skill level.

[0016] The adjustment unit may increase the predetermined angle as the skill level is lower. The adjustment unit may decrease the predetermined angle as the skill level is higher.

[0017] With this configuration, the swing can be estimated simply and accurately in consideration of a variation or the like in the trajectory of each swing of a high skill or a low skill.

[0018] The first specifying unit may calculate an angle of the shaft relative to the plane using an output of the inertial sensor at the address posture of the user, and may specify the first axis using information regarding a length of the shaft and this angle.

[0019] With this configuration, an inclination angle of the shaft of the exercise tool can be calculated using the fact that the inertial sensor detects only the gravity acceleration at the time of stopping of the user, and thus the direction of the first axis can be specified from the inclination angle.

[0020] When the hitting direction is a third axis, the first specifying unit may specify a first imaginary plane including the first and third axes and the second specifying unit may specify a second imaginary plane including the second and third axes. Accordingly, the user can objectively recognize the address posture from the positions and inclinations of the first and second imaginary planes, the size of the space between the first and second imaginary planes, or the like and can recognize the positional relation between the assumed trajectory of the swing and the first and second imaginary planes. Therefore, the swing can be estimated simply.

[0021] The exercise tool may include a blow surface. The hitting direction may be a direction perpendicular to the blow surface at the address posture of the user.

[0022] With this configuration, by supposing that the user stops at a posture at which the hitting direction is perpendicular to the blow surface of the exercise tool, it is possible to specify the hitting direction using an output of the inertial sensor.

[0023] The motion analysis device may further include an image generation unit that generates image data including the first and second axes.

[0024] With this configuration, the user can objectively and easily recognize the posture at the time of stopping from the positions and inclinations of the first and second axes, the size of the space between the first and second axes, or the like, and can recognize the positional relation between the assumed trajectory of the swing and the first and second axes in the image. Therefore, the swing can be estimated objectively and simply.

[0025] The motion analysis device may further include a motion analysis unit that calculates a trajectory of the exercise tool based on a swing of the user. The image generation unit may generate image data including the first axis, the second axis, and the trajectory.

[0026] With this configuration, the user can determine, from the image, whether the trajectory of the swing is included between the first and second axes. Therefore, goodness and badness of the swing can be estimated objectively and simply.

[0027] Another aspect of the invention is directed to a motion analysis system including: an inertial sensor; a first specifying unit that specifies a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of the inertial sensor; a second specifying unit that specifies a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and an adjustment unit that adjusts sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

[0028] With this configuration, the user can objectively recognize the address posture from the positions and inclinations of the first and second axes, the size of the space between the first and second axes, or the like, and can recognize the positional relation between the assumed trajectory of the swing and the first and second axes. Therefore, the swing can be estimated simply. Further, the position, the posture, the area, or the like of the space between the first and second axes is adjusted according to the predetermined condition. Therefore, even when the way, the habit, the tendency, or the like of the swing of the user is desired to be considered, the swing can be estimated simply and accurately.

[0029] The predetermined condition may be a type of swing of the user. The adjustment unit may adjust at least one of the angle of the first axis and the angle of the second axis according to the type of swing.

[0030] With this configuration, since the position, the posture, or the like of the space between the first and second axes is adjusted according to the type of swing, the swing can be estimated simply and accurately in consideration of a tendency or the like of the swing according to the type of swing.

[0031] The type of swing may be a slice or a hook. When the type of swing is the slice, the adjustment unit may increase at least the angle of the second axis. When the type of swing is the hook, the adjustment unit may decrease at least the angle of the first axis.

[0032] With this configuration, the swing can be estimated simply and accurately in consideration of the position or the like of the trajectory of each of a slice-based swing or a hook-based swing.

[0033] The predetermined condition may be a skill level of the user. The adjustment unit may adjust the predetermined angle between the first and second axes according to the skill level.

[0034] With this configuration, since the position, the posture, the area, or the like of the space between the first and second axes is adjusted according to the skill level, the swing can be estimated simply and accurately in consideration of the tendency or the like of the swing according to the skill level.

[0035] Still another aspect of the invention is directed to a motion analysis method including: specifying a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor; specifying a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and adjusting sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

[0036] With this configuration, the user can objectively recognize the address posture from the positions and inclinations of the first and second axes, the size of the space between the first and second axes, or the like, and can recognize the positional relation between the assumed trajectory of the swing and the first and second axes. Therefore, the swing can be estimated simply. Further, the position, the posture, the area, or the like of the space between the first and second axes is adjusted according to the predetermined condition. Therefore, even when the way, the habit, the tendency, or the like of the swing of the user is desired to be considered, the swing can be estimated simply and accurately.

[0037] The predetermined condition may be a type of swing of the user. In the adjusting of the sizes of the angles, at least one of the angle of the first axis and the angle of the second axis may be adjusted according to the type of swing.

[0038] With this configuration, since the position, the posture, or the like of the space between the first and second axes is adjusted according to the type of swing, the swing can be estimated simply and accurately in consideration of a tendency or the like of the swing according to the type of swing.

[0039] The type of swing may be a slice or a hook. When the type of swing is the slice, at least the angle of the second axis may be increased in the adjusting of the sizes of the angles. When the type of swing is the hook, at least the angle of the first axis may be decreased in the adjusting of the sizes of the angles.

[0040] With this configuration, the swing can be estimated simply and accurately in consideration of the position or the like of the trajectory of each of a slice-based swing or a hook-based swing.

[0041] The predetermined condition may be a skill level of the user. In the adjusting of the sizes of the angles, the predetermined angle between the first and second axes may be adjusted according to the skill level.

[0042] With this configuration, since the position, the posture, the area, or the like of the space between the first and second axes is adjusted according to the skill level, the swing can be estimated simply and accurately in consideration of the tendency or the like of the swing according to the skill level.

[0043] Yet another aspect of the invention is directed to a program causing a computer to perform: specifying a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor; specifying a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and adjusting sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

[0044] With this configuration, the user can objectively recognize the address posture from the positions and inclinations of the first and second axes, the size of the space between the first and second axes, or the like, and can recognize the positional relation between the assumed trajectory of the swing and the first and second axes. Therefore, the swing can be estimated simply. Further, the position, the posture, the area, or the like of the space between the first and second axes is adjusted according to the predetermined condition. Therefore, even when the way, the habit, the tendency, or the like of the swing of the user is desired to be considered, the swing can be estimated simply and accurately.

[0045] Still yet another aspect of the invention is directed to a recording medium that records a program causing a computer to perform: specifying a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor; specifying a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and adjusting sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

[0046] With this configuration, the user can objectively recognize the address posture from the positions and inclinations of the first and second axes, the size of the space between the first and second axes, or the like, and can recognize the positional relation between the assumed trajectory of the swing and the first and second axes. Therefore, the swing can be estimated simply. Further, the position, the posture, the area, or the like of the space between the first and second axes is adjusted according to the predetermined condition. Therefore, even when the way, the habit, the tendency, or the like of the swing of the user is desired to be considered, the swing can be estimated simply and accurately.

[0047] Further another aspect of the invention is directed to a motion analysis device including an adjustment unit that adjusts a size of a center angle of a V zone according to a predetermined condition.

[0048] The predetermined condition may be a skill level of the user. The adjustment unit may adjust the center angle according to the skill level.

[0049] The adjustment unit may increase the center angle as the skill level is lower. The adjustment unit may decrease the center angle as the skill level is higher.

[0050] The exercise tool may include a blow surface. The hitting direction may be a direction perpendicular to the blow surface at a address posture of a user.

[0051] The motion analysis device may further include an image generation unit that generates image data including the V zone.

[0052] The motion analysis device may further include an motion analysis unit that calculates a trajectory of the exercise tool based on a swing of the user. The image generation unit may generate image data including the V zone and the trajectory.

BRIEF DESCRIPTION OF THE DRAWINGS

[0053] The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

[0054] FIG. **1** is a diagram illustrating an overview of a motion analysis system according to an embodiment of the invention.

[0055] FIG. **2** is a diagram illustrating examples of a shaft plane and a Hogan's plane.

[0056] FIG. **3** is a block diagram illustrating an example of the configuration of a motion analysis system.

[0057] FIG. **4** is a flowchart illustrating an example of a motion analysis process.

[0058] FIG. **5** is a plan view illustrating a golf club and a sensor unit at the time of stopping of a user when viewed from the negative side of the X axis.

[0059] FIG. **6** is a diagram illustrating a cross section obtained by cutting the shaft plane along the YZ plane when viewed from the negative side of the X axis.

[0060] FIG. **7** is a diagram illustrating a cross section obtained by cutting the Hogan's plane along the YZ plane when viewed from the negative side of the X axis.

[0061] FIG. **8** is a diagram illustrating examples of angular velocities output from the sensor unit.

[0062] FIG. **9** is a diagram illustrating an example of a norm of an angular velocity.

[0063] FIG. **10** is a diagram illustrating an example of a differential value of the norm of an angular velocity.

[0064] FIG. **11** is a diagram illustrating an example of a screen including a shaft plane and a Hogan's plane.

[0065] FIG. **12** is a diagram illustrating an example of a screen on which display setting of a V zone is performed.

[0066] FIGS. **13**A to **13**C are diagrams illustrating examples of a procedure and a screen for adjusting the V zone according to a type of swing.

[0067] FIGS. **14**A and **14**B are diagrams illustrating examples of a procedure and a screen for adjusting the V zone according to a skill level.

[0068] FIG. **15** is s diagram illustrating examples of a procedure and a screen for setting a center plane.

[0069] FIG. **16** is a diagram illustrating example of a procedure and a screen for setting a reference V zone.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0070] Hereinafter, embodiments of the invention will be described with reference to the drawings. Hereinafter, a motion analysis system performing analysis of a golf swing will be described as an example.

[0071] FIG. **1** is a diagram illustrating an overview of a motion analysis system according to an embodiment of the invention.

[0072] A motion analysis system **1** includes a sensor unit **10** and a motion analysis device **20**.

[0073] The sensor unit **10** can measure acceleration generated in each axis direction of three axes and an angular velocity generated in each rotation of the three axes as an inertial sensor and is mounted on a golf club **3** which is an exercise tool. For example, the sensor unit **10** is fitted on apart of the shaft of the golf club **3** when one axis among three detection axes (the x axis, the y axis, and the z axis), for example, the y axis, conforms to the major axis direction of the shaft. Preferably, the sensor unit **10** is fitted at a position close to a grip in which a shock at the time of a shot is rarely delivered and a centrifugal force is not applied at the time of a swing. The shaft is a portion of the handle excluding the head of the golf club **3** and also includes the grip.

[0074] A user **2** performs a swing motion of hitting a golf ball (not illustrated) in a pre-decided procedure. For example, the user **2** first holds the golf club **3**, takes a posture of address so that the major axis of the shaft of the golf club **3** is vertical to a target line (for example, a hitting target direction), and stops for a predetermined time or more (for example, 1 second or more). Next, the user **2** performs a swing motion to hit the golf ball (which is also referred to as a short or a stroke). The posture of address in the present specification includes a posture in a stop state of the user before start of a swing or a posture in a state in which the user shakes an exercise tool (which is also referred to as waggling or the like) before start of a swing. The target line refers to any hitting direction and is decided as, for example, a hitting target direction in the embodiment.

[0075] While the user **2** performs the motion to hit the golf ball in the above-described procedure, the sensor unit **10** measures triaxial acceleration and triaxial angular velocities at a predetermined period (for example, 1 ms) and sequentially transmits the measurement data to the motion analysis device **20**. The sensor unit **10** may immediately transmit the measurement data, or may store the measurement data in an internal memory and transmit the measurement data at a desired timing such as the end of a swing motion of the user **2**. Communication between the sensor unit **10** and the motion analysis device **20** may be wireless communication or wired communication. Alternatively, the sensor unit **10** may store the measurement data in a recording medium such as a memory card which can be detachably mounted and the motion analysis device **20** may read the measurement data from the recording medium.

[0076] The motion analysis device **20** analyzes a swing exercise performed with the golf club **3** by the user **2** using the data measured by the sensor unit **10**. In particular, in the embodiment, the motion analysis device **20** specifies a shaft plane (which corresponds to a first imaginary plane or a first axis according to the invention) and a Hogan's plane (which corresponds to a second imaginary plane or a second axis according to the invention) at the time of stopping of the user **2** (the time of address) using the data measured by the sensor unit **10**. The motion analysis device **20** calculates a trajectory of the golf club **3** at a swing after the user **2** starts the swing motion. The motion analysis device **20** generates image data including the trajectory of the golf club **3**, the shaft plane, and the Hogan's plane in the swing of the user **2** and causes a display unit to display an image according to the image data. By displaying the shaft plane and the Hogan's plane, it is possible to recognize a space called a V zone between the shaft plane and the Hogan's plane. The motion analysis device **20** may be, for example, a portable device such as a smartphone or a personal computer (PC). In FIG. **1**, the motion analysis device **20** is mounted on the waist of the user **2**, but the mounted position is not particularly limited. Further, the motion analysis device **20** may not be mounted on the user **2**.

[0077] FIG. **2** is a diagram illustrating examples of the shaft plane and the Hogan's plane. In the embodiment, an XYZ coordinate system (global coordinate system) in which a target line indicating a hitting target direction is an X axis, an axis on a horizontal plane vertical to the X axis is a Y axis, and an upward vertical direction (which is an opposite direction to the direction of the gravity acceleration) is a Z axis is defined. In FIG. **2**, the X, Y, and Z axes are shown.

[0078] A shaft plane **30** at the time of address of the user **2** is an imaginary plane which includes a first line segment **51** serving as a first axis which lies in the major axis direction (longitudinal direction) of the shaft of the golf club **3** and a third line segment **52** serving as a third axis indicating a hitting target direction and has four vertexes T**1**, T**2**, S**1**, and S**2**. In the embodiment, a position **61** of the head (blow portion) of the golf club **3** is set as the origin O (0, 0, 0) of the XYZ coordinate system. The first line segment **51** is a line segment which connects the position **61** (the origin O) of the head of the golf club **3** to a position **62** of a grip end. The third line segment **52** is a line segment which has T**1** and T**2** on the X axis as both ends, has a length TL, and centers on the origin O. When the user **2** takes the above-described address posture at the time of the address, the shaft of the golf club **3** is vertical to the target line (the X axis). Therefore, the third line segment **52** is a line segment which is perpendicular to the major axis direction of the shaft of the golf club **3** (which can also be a line segment perpendicular to or intersects the blow surface of the head on which a ball is hit), that is, a line segment perpendicular to the first line segment **51**. The shaft plane **30** is specified by calculating the coordinates of the four vertexes T**1**, T**2**, S**1**, and S**2** in the XYZ coordinate system. A method of calculating the coordinates of the four vertexes T**1**, T**2**, S**1**, and S**2** will be described in detail below.

[0079] A Hogan's plane **40** is an imaginary plane which includes the third line segment **52** and a second line segment **53** serving as a second axis and has four vertexes T**1**, T**2**, H**1**, and H**2**. In the embodiment, for example, the second line segment **53** is a line segment which connects the position **62** (which is an example of a blow position) of the head (which is a blow portion) of the golf club **3** to a predetermined position **63** (which is, for example, the position of the base of the neck or the position of one of the right and left shoulders) on a line segment connecting both shoulders of the user **2** to one another. Here the second line segment **53** may be, for example, a line segment which connects the predetermined position **63** to the position (which is an example of the blow position) of a ball at the time of address. The Hogan's plane **40** is specified by calculating the coordinates of the four vertexes T**1**, T**2**, H**1**, and H**2** in the XYZ coordinate system. A method of calculating the coordinates of the four vertexes T**1**, T**2**, H**1**, and H**2** will be described in detail below.

[0080] FIG. **3** is a block diagram illustrating an example of the configuration of a motion analysis system.

[0081] The sensor unit **10** includes a control unit **11**, a communication unit **12**, an acceleration sensor **13**, and an angular velocity sensor **14**.

[0082] The acceleration sensor **13** measures acceleration generated in each of mutually intersecting (ideally, orthogonal) triaxial directions and outputs digital signals (acceleration data) according to the sizes and directions of the measured triaxial accelerations.

[0083] The angular velocity sensor **14** measures an angular velocity generated at axis rotation of mutually intersecting (ideally, orthogonal) triaxial directions and outputs digital signals (angular velocity data) according to the sizes and directions of the measured triaxial angular velocities.

[0084] The control unit **11** controls the sensor unit in an integrated manner. The control unit **11** receives the acceleration data and the angular velocity data from the acceleration sensor **13** and the angular velocity sensor **14**, appends time information, and stores the acceleration data and the angular velocity data in a storage unit (not illustrated). The control unit **11** generates packet data in conformity to a communication format by appending time information to the stored measurement data (the acceleration data and the angular velocity data) and outputs the packet data to the communication unit **12**.

[0085] The acceleration sensor **13** and the angular velocity sensor **14** are ideally fitted in the sensor unit **10** so that the three axes of each sensor match the three axes (the x axis, the y axis, and the z axis) of the rectangular coordinate system (sensor coordinate system) defined for the sensor unit **10**, but errors of the fitting angles actually occur. Accordingly, the control unit **11** performs a process of converting the acceleration data and the angular velocity data into data of the xyz coordinate system, using correction parameters calculated in advance according to the errors of the fitting angles.

[0086] The control unit **11** may perform a temperature correction process of the acceleration sensor **13** and the angular velocity sensor **14**. Alternatively, a temperature correction function may be embedded in the acceleration sensor **13** and the angular velocity sensor **14**.

[0087] The acceleration sensor **13** and the angular velocity sensor **14** may output analog signals. In this case, the control unit **11** may perform A/D (analog/digital) conversion on each of an output signal of the acceleration sensor **13** and an output signal of the angular velocity sensor **14**, generate measurement data (acceleration data and angular velocity data), and generate packet data for communication using the measurement data.

[0088] The communication unit **12** performs, for example, a process of transmitting the packet data received from the control unit **11** to the motion analysis device **20** or a process of receiving control commands from the motion analysis device **20** and transmitting the control commands to the control unit **11**. The control unit **11** performs various processes according to the control commands.

[0089] The motion analysis device **20** includes a control unit **21**, a communication unit **22**, an operation unit **23**, a storage unit **24**, a display unit **25**, and a sound output unit **26**.

[0090] The communication unit **22** performs, for example, a process of receiving the packet data transmitted from the sensor unit **10** and transmitting the packet data to the control unit **21** or a process of transmitting a control command from the control unit **21** to the sensor unit **10**.

[0091] The operation unit **23** performs a process of acquiring operation data from the user and transmitting the operation data to the control unit **21**. The operation unit **23** may be, for example, a touch panel type display, a button, a key, or a microphone.

[0092] The storage unit **24** is configured of, for example, any of various IC memories such as a read-only memory (ROM), a flash ROM, and a random access memory (RAM) or a recording medium such as a hard disk or a memory card.

[0093] The storage unit **24** stores, for example, programs used for the control unit **21** to perform various calculation processes or control processes, or various program or data used for the control unit **21** to realize application functions. In particular, in the embodiment, the storage unit **24** stores a motion analysis program which is read by the control unit **21** to perform a motion analysis process. The motion analysis program may be stored in advance in a nonvolatile recording medium. Alternatively, the motion analysis program may be received from a server via a network by the control unit **21** and may be stored in the storage unit **24**.

[0094] In the embodiment, the storage unit **24** stores body information of the user **2**, club specification information indicating the specification of the golf club **3**, and sensor-mounted position information. For example, when the user **2** operates the operation unit **23** to input the body information such as a height, a weight, and a sex, the input body information is stored as body information in the storage unit **24**. For example, the user **2** operates the operation unit **23** to input a model number of the golf club **3** (or selects the model number from a model number list) to be used and sets club specification information regarding the input model number as the specification information among pieces of specification information for each model number (for example, information regarding the length of the shaft, the position of the center of gravity, a lie angle, a face angle, a loft angle, and the like) stored in advance in the storage unit **24**. For example, when the user **2** operates the operation unit **23** to input a distance between the position at which the sensor unit **10** is mounted and the grip end of the golf club **3**, information regarding the input distance is stored as the sensor-mounted position information in the storage unit **24**. Alternatively, by mounting the sensor unit **10** at a decided predetermined position (for example, a distance of 20 cm from the grip end), information regarding the predetermined position may be stored in advance as the sensor-mounted position information.

[0095] The storage unit **24** is used as a work area of the control unit **21** and temporarily stores, for example, data input from the operation unit **23** and calculation results performed according to various programs by the control unit **21**. The storage unit **24** may store data necessarily stored for a long time among the data generated through the processes of the control unit **21**.

[0096] The display unit **25** displays a processing result of the control unit **21** as text, a graph, a table, animations, or another image. The display unit **25** may be, for example, a cathode ray tube (CRT) display, a liquid crystal display (LCD), an electrophoretic display (EPD), a display using an organic light-emitting diode (OLED), a touch panel type display, or a head-mounted display (HMD). The functions of the operation unit **23** and the display unit **25** may be realized by one touch panel type display.

[0097] The sound output unit **26** outputs a processing result of the control unit **21** as audio such as a sound or a buzzer tone. The sound output unit **26** may be, for example, a speaker or a buzzer.

[0098] The control unit **21** performs a process of transmitting a control command to the sensor unit **10**, various calculation processes on data received from the sensor unit **10** via the communication unit **22**, and other various control processes according to various programs. In particular, in the embodiment, the control unit **21** executes a motion analysis program to function as a sensor information acquisition unit **210**, a first imaginary plane specifying unit (which corresponds to a first specifying unit according to the invention) **211**, a second imaginary plane specifying unit (which corresponds to a second specifying unit according to the invention) **212**, an imaginary plane adjustment unit (which correspond to an adjustment unit according to the invention) **213**, a motion analysis unit **214**, an image generation unit **215**, and an output processing unit **216**. The first and second specifying units may be realized by separate calculation units or may be realized by the same calculation unit.

[0099] The control unit **21** may be realized, for example, by a computer that includes a central processing unit (CPU) which is a calculation device, a random access memory (RAM) which is a volatile storage device, a ROM which is a non-volatile storage device, an interface (I/F) circuit connecting the control unit **21** to the other units, a bus mutually connecting these units and the like. The computer may include various dedicated processing circuits such as image processing circuits. The control unit **21** may also be realized by an application specific integrated circuit (ASIC) or the like.

[0100] The sensor information acquisition unit **210** receives the packet data received from the sensor unit **10** by the communication unit **22** and acquires the time information and the measurement data from the received packet data. The sensor information acquisition unit **210** stores the acquired time information and measurement data in the storage unit **24** in association therewith.

[0101] The first imaginary plane specifying unit **211** performs a process of specifying the first line segment **51** in the major axis direction of the shaft of the golf club **3** at the time of stopping of the user, using the measurement data output by the sensor unit **10**. Further, the first imaginary plane specifying unit **211** performs a process of specifying the shaft plane (first imaginary plane) **30** (see FIG. **2**) including the first line segment **51** and the third line segment **52** indicating the hitting target direction.

[0102] The first imaginary plane specifying unit **211** may calculate the coordinates of the position **62** of the grip end of the golf club **3** using the measurement data output by the sensor unit **10** and specify the first line segment **51** based on the coordinates of the position **62** of the grip end. For example, the first imaginary plane specifying unit **211** may calculate an inclination angle (an inclination relative to the horizontal plane (the XY plane) or the vertical plane (the XZ plane)) of the shaft of the golf club **3**, using the acceleration data measured by the acceleration sensor **13** at the time of stopping of the user **2** (the time of the address) and specify the first line segment **51** using the calculated inclination angle and information regarding the length of the shaft included in the club specification information.

[0103] The first imaginary plane specifying unit **211** may calculate the width of the shaft plane **30** using the length of an arm of the user **2** based on the body information and the length of the first line segment **51**.

[0104] The second imaginary plane specifying unit **212** performs a process of specifying the second line segment **53** forming a predetermined angle relative to the first line segment **51** specified by the first imaginary plane specifying unit **211**, using the hitting target direction (the third line segment **52**) as the rotation axis. Further, the second imaginary plane specifying unit **212** performs a process of specifying the Hogan's plane (second imaginary plane) **40** (see FIG. **2**) including the second line segment **53** and the third line segment **52**.

[0105] For example, the second imaginary plane specifying unit **212** performs a process of estimating the predetermined position **63** between the head and the chest of the user **2** at the time of stopping of the user **2** (for example, on a line segment connecting both shoulders to one another) using the body information and the measurement data output by the sensor unit **10** and specifying the second line segment **53** connecting the estimated predetermined position **63** to the position **62** of the head (blow portion) of the golf club **3**. The second imaginary plane specifying unit **212** performs a process of specifying the Hogan's plane **40** including the second line segment **53** and the third line segment **52**.

[0106] The second imaginary plane specifying unit **212** may estimate the predetermined position **63** using the coordinates of the position **62** of the grip end calculated by the first imaginary plane specifying unit **211** and the length of the arm of the user **2** based on the body information. Alternatively, the second imaginary plane specifying unit **212** may calculate the coordinates of the position **62** of the grip end of the golf club **3** using the measurement data output by the sensor unit **10**. In this case, the first imaginary plane specifying unit **211** may specify the shaft plane **30** using the coordinates of the position **62** of the grip end calculated by the second imaginary plane specifying unit **212**.

[0107] The second imaginary plane specifying unit **212** may calculate the width of the Hogan's plane **40** using the length of the arm of the user **2** based on the body information and the length of the first line segment **51**.

[0108] The imaginary plane adjustment unit **213** adjusts an angle of the first line segment **51** (an angle of the shaft plane) serving as the first axis and an angle of the second line segment **53** (an angle of the Hogan's plane) serving as the second axis according to the predetermined condition.

[0109] For example, the imaginary plane adjustment unit **213** receives a designation of the type of swing (for example, straight, hook, or slice) as the predetermined condition via the operation unit **23** from the user **2** and increases or decreases the angle of the first line segment **51** and the angle of the second line segment **53** relative to the horizontal plane according to the designated type of swing. In the embodiment, the imaginary plane adjustment unit **213** increases or decreases the angle of the first line segment **51** and the angle of the second line segment **53** while constantly maintaining a predetermined angle θ formed by the second line segment **53** and the angle of the first line segment **51**. That is, the imaginary plane adjustment unit **213** rotates the V zone clockwise or counterclockwise using the hitting target direction (the third line segment **52**) as a rotation axis.

[0110] In general, there are known tendencies in which straight-based hitting is realized when a trajectory of the golf club at the time of a downswing enters the V zone, slice-based hitting is realized when the trajectory is deviated from the V zone to the side of the Hogan's plane, and hook-based hitting is realized when the trajectory is deviated from the V zone to the side of the shaft plane. However, depending on a golfer, for example, a case in which a slice-based swing is performed can be considered to be a good state of a way. Accordingly, when a display position of the V zone can be adjusted so that the trajectory of a downswing enters the V zone in the good state of the way, it is possible to estimate goodness and badness of the swing simply in consideration of a type of swing of a golfer. Accordingly, in the embodiment, adjusting the position of the V zone is designed to be performed, as described above.

[0111] For example, the imaginary plane adjustment unit **213** receives a designation of a skill level (for example, a beginning course, an intermediate course, and an advanced course) as the predetermined condition via the operation unit **23** from the user **2**, and then decreases the angle of the first line segment **51** and increases the angle of the second line segment **53** (the first line segment **51** and the second line segment **53** are kept away from one another) or increases the angle of the first line segment **51** and the decreases the angle of the second line segment **53** (the first line segment **51** and the second line segment **53** are kept close to each other) according to the designated skill level. That is, the imaginary plane adjustment unit **213** increases or decreases the predetermined angle θ formed by the second line segment **53** and the angle of the first line segment **51**, using the hitting target direction (the third line segment **52**) as the rotation axis.

[0112] In general, as the skill level of golf is lower, a trajectory of a golf club at the time of a downswing does not enter the V zone in many swings and the trajectory has an irregular tendency, and thus the swing is not stable. However, in the case of a beginner, when the area of the V zone specified based on the inclination or the like of the club is set as a criterion, as described above, for example, most of the swings are estimated to be bad. Thus, it is difficult to assess whether the swing is improved. In contrast, in the case of an advanced learner, when the area of the V zone specified is set as the criterion, as described above, for example, most of the swings are estimated to be good. Thus, it is difficult to assess whether the swing becomes stable or is further improved. Accordingly, when the area of the V zone can be adjusted in these cases, it is possible to estimate stability or improvement in the swing more accurately. Accordingly, in the embodiment, the area of the V zone described above can be designed to be adjusted.

[0113] The motion analysis unit **214** performs a process of analyzing a swing exercise of the user **2** using the measurement data output by the sensor unit **10**. Specifically, the motion analysis unit **214** first calculates an offset amount included in the measurement data using the measurement data (the acceleration data and the angular velocity data) at the time of stopping of the user **2** (the time of the address), which is stored in the storage unit **24**. Next, the motion analysis unit **214** subtracts the offset amount from the measurement data after start of a swing, which is stored in the storage unit **24** to correct a bias and calculates the position and posture of the sensor unit **10** during a swing motion of the user **2** using the measurement data in which the bias is corrected.

[0114] For example, the motion analysis unit **214** calculates the position (initial position) of the sensor unit **10** at the time of stopping of the user **2** (the time of the address) in the XYZ coordinate system (global coordinate system), using the acceleration data measured by the acceleration sensor **13**, the club specification information, and the sensor-mounted position information, integrates the subsequent acceleration data, and chronologically calculates a change in the position of the sensor unit **10** from the initial position. Since the user **2** stops at a predetermined address posture, the X coordinate of the initial position of the sensor unit **10** is 0. Further, the y axis of the sensor unit **10** is identical to the major axis direction of the shaft of the golf club **3**, and the acceleration sensor **13** measures only the gravity acceleration at the time of stopping of the user **2**. Therefore, the motion analysis unit **214** can calculate an inclination angle of the shaft (an inclination relative to the horizontal plane (the XY plane) or the vertical plane (the XZ plane)), using y-axis acceleration data. Then, the motion analysis unit **214** can calculate the Y and Z coordinates of the initial position of the sensor unit **10** using the inclination angle of the shaft, the club specification information (the length of the shaft), and the sensor-mounted position information (the distance from the grip end) and specify the initial position of the sensor unit **10**. Alternatively, the motion analysis unit **214** may calculate the coordinates of the initial position of the sensor unit **10** using the coordinates of the position **62** of the grip end of the golf club **3** calculated by the first imaginary plane specifying unit **211** or the second imaginary plane specifying unit **212** and the sensor-mounted position information (the distance from the grip end).

[0115] The motion analysis unit **214** calculates the posture (initial posture) of the sensor unit **10** at the time of stopping of the user **2** (the time of the address) in the XYZ coordinate system (global coordinate system), using the acceleration data measured by the acceleration sensor **13**, performs rotation calculation using the angular velocity data measured subsequently by the angular velocity sensor **14**, and chronologically calculates a change in the posture from the initial posture of the sensor unit **10**. The posture of the sensor unit **10** can be expressed by, for example, rotation angles (a roll angle, a pitch angle, and a yaw angle) around the X axis, the Y axis, and the Z axis, Eulerian angles, quaternions, or the like. At the time of stopping of the user **2**, the acceleration sensor **13** measures only the gravity acceleration. Therefore, the motion analysis unit **214** can specify an angle formed between of each of the x axis, y axis, and z axes of the sensor unit **10** and a gravity direction using triaxial acceleration data. Since the user **2** stops at the predetermined address posture, the y axis of the sensor unit **10** is present on the YZ plane at the time of stopping of the user **2**. The motion analysis unit **214** can specify the initial posture of the sensor unit **10**.

[0116] The control unit **11** of the sensor unit **10** may calculate the offset amount of the measurement data and correct the bias of the measurement data or a bias correction function may be embedded in the acceleration sensor **13** and the angular velocity sensor **14**. In this case, it is not necessary to correct the bias of the measurement data by the motion analysis unit **214**.

[0117] The motion analysis unit **214** defines a motion analysis model (a double pendulum model or the like) in consideration of the body information (the height (length of the arm) of the user **2**), the club specification information (the length or the position of the center of the shaft), the sensor-mounted position information (the distance from the grip end), features (rigid body and the like) of the golf club **3**, and features of a human body (for example, a joint bending direction is decided), and then calculate a trajectory of the golf club **3** at a swing of the user **2** using the motion analysis model and the information regarding the position and posture of the sensor unit **10**.

[0118] The motion analysis unit **214** detects a series of motions (also referred to as a "rhythm") from start to end of a swing of the user **2**, for example, start of a swing, a backswing, a top, a downswing, an impact, follow-through, and end of the swing, using time information and the measurement data stored in the storage unit **24**. For example, the motion analysis unit **214** calculates a composite value of the measurement data (the acceleration data or the angular velocity data) output by the sensor unit **10** and specifies a timing (time) of an impact by the user **2** based on the composite value.

[0119] Using the motion analysis model and information regarding the position and posture of the sensor unit **10**, the motion analysis unit **214** may generate a rhythm of a swing from a backswing to follow-through, a head speed, an incident angle (club pass) or a face angle at the time of hitting, shaft rotation (a change amount of face angle during a swing), information regarding a deceleration rate or the like of the golf club **3**, or information regarding a variation in each piece of information when the user **2** performs the swing a plurality of times.

[0120] The image generation unit **215** performs a process of generating image data corresponding to an image of a motion analysis result displayed on the display unit **25**. In particular, in the embodiment, the image generation unit **215** generates image data including the shaft plane **30** specified by first imaginary plane specifying unit **211**, the Hogan's plane **40** specified by the second imaginary plane specifying unit **212**, and the trajectory of the golf club **3** at a swing (in particular, a downswing) of the user **2**, which is calculated by the motion analysis unit **214**. For example, the image generation unit **215** generates polygon data of the shaft plane **30** having the four vertexes T**1**, T**2**, S**1**, and S**2** illustrated in FIG. **2** based on information regarding the coordinates of T**1**, T**2**, S**1**, and S**2** and generates polygon data of the Hogan's plane **40** having the four vertexes T**1**, T**2**, H**1**, and H**2** based on information regarding the coordinates of T**1**, T**2**, H**1**, and H**2**. The image generation unit **215** generates curved-line data indicating the trajectory of the golf club **3** at the time of a downswing of the user **2**. Then, the image generation unit **215** generates image data including the polygon data of the shaft plane **30**, the polygon data of the Hogan's plane **40**, and the curved-line data indicating the trajectory of the golf club **3**.

[0121] The first imaginary plane specifying unit **211**, the second imaginary plane specifying unit **212**, the imaginary plane adjustment unit **213**, the motion analysis unit **214**, and the image generation unit **215** also perform a process of storing various kinds of calculated information in the storage unit **24**.

[0122] The output processing unit **216** performs a process of causing the display unit **25** to display various images (including not only an image corresponding to the image data generated by the image generation unit **215** but also text or signs). For example, the output processing unit **216** causes the display unit **25** to display the image corresponding to the image data generated by the image generation unit **215** automatically or according to an input operation of the user **2** after a swing motion of the user **2** ends. Alternatively, the sensor unit **10** may include a display unit, the output processing unit **216** may transmit the image data to the sensor unit **10** via the communication unit **22**, and various images may be displayed on the display unit of the sensor unit **10**.

[0123] The output processing unit **216** performs a process of causing the sound output unit **26** to output various kinds of audio (also including sound or buzzer tone). For example, the output processing unit **216** reads various kinds of information stored in the storage unit **24** and causes the sound output unit **26** to output audio or sound for motion analysis automatically or at the time of performing a predetermined input operation after a swing motion of the user **2** ends. Alternatively, the sensor unit **10** may include an sound output unit, the output processing unit **216** may transmit various kinds of audio data or sound data to the sensor unit **10** via the communication unit **22**, and the sound output unit of the sensor unit **10** may be caused to output the various kinds of audio or sound.

[0124] The motion analysis device **20** or the sensor unit **10** may include a vibration mechanism and various kinds of information may be converted into vibration information by the vibration mechanism to be presented to the user **2**.

[0125] FIG. **4** is a flowchart illustrating an example of an motion analysis process. The control unit **21** executes a motion analysis program stored in the storage unit **24** to perform the motion analysis process in the procedure of the flowchart illustrated in FIG. **4**.

[0126] First, the sensor information acquisition unit **210** acquires the measurement data of the sensor unit **10** (step S**10**). When the control unit **21** acquires the first measurement data in a swing motion (also including a stopping motion) of the user **2**, the control unit **21** may perform processes subsequent to step S**20** in real time. Alternatively, after the control unit **21** acquires some or all of the series of measurement data in the swing motion of the user **2** from the sensor unit **10**, the control unit **21** may perform the processes subsequent to step S**20**.

[0127] Next, the motion analysis unit **214** detects a stopping motion (address motion) of the user **2** using the measurement data acquired from the sensor unit **10** (step S**20**). When the control unit **21** performs the process in real time and detects the stopping motion (address motion), for example, the control unit **21** outputs a predetermined image or audio. Alternatively, for example, the sensor unit **10** may include a light-emitting unit such as a light emitting diode (LED) and blinks the light-emitting unit to notify the user **2** that the stopped state is detected so that the user **2** confirms the notification and subsequently starts a swing.

[0128] Next, the first imaginary plane specifying unit **211** specifies the shaft plane **30** (the first imaginary plane) using the measurement data (the measurement data in the stopping motion (address motion) of the user **2**) acquired from the sensor unit **10** and the club specification information (step S**30**).

[0129] Next, the second imaginary plane specifying unit **212** specifies the Hogan's plane **40** (the second imaginary plane) using the measurement data (the measurement data in the stopping motion (address motion) of the user **2**) acquired from the sensor unit **10** and the body information (step S**40**).

[0130] Next, the motion analysis unit **214** calculates the initial position and the initial posture of the sensor unit **10** using the measurement data (the measurement data in the stopping motion (address motion) of the user **2**) acquired from the sensor unit **10** (step S**50**).

[0131] Next, the motion analysis unit **214** detects a series of motions (rhythm) from the start of the swing to the end of the swing using the measurement data acquired from the sensor unit **10** (step S**60**).

[0132] The motion analysis unit **214** calculates the position and posture of the sensor unit **10** during the swing motion of the user **2** concurrently with the process of step S**60** (step S**70**).

[0133] Next, the motion analysis unit **214** calculates the trajectory of the golf club **3** during the swing motion of the user **2** using the rhythm detected in step S**60** and the position and posture of the sensor unit **10** calculated in step S**70** (step S**80**).

[0134] Next, the imaginary plane adjustment unit **213** adjusts the angle (the angle of the shaft plane) of the first line segment **51** serving as the first axis and the angle (the angle of the Hogan's plane) of the second line segment **53** serving as the second axis, that is, the V zone, according to the setting (the predetermined condition) (step S**90**).

[0135] Next, the image generation unit **215** generates the image data including the shaft plane specified in step S**30** and the Hogan's plane specified in step S**40** or the shaft plane and the Hogan's plane adjusted in step S**90**, and the trajectory of the golf club calculated in step S**80** during the swing motion, and then the output processing unit **216** causes the display unit **25** to display the image data (step S**100**). Then, the control unit **21** ends the processes of the flowchart illustrated in FIG. **4**.

[0136] In the flowchart of FIG. **4**, the sequence of the processes may be appropriately changed within a possible range.

[0137] Next, an example of the process (the process of step S**30** in FIG. **4**) of specifying the shaft plane (the first imaginary plane) will be described in detail.

[0138] As illustrated in FIG. **2**, the first imaginary plane specifying unit **211** first calculates the coordinates (0, G_Y, G_Z) of the position **62** of the grip end based on the acceleration data at the time of the stopping measured by the sensor unit **10** and the club specification information by using the position **61** of the head of the golf club **3** as the origin O (0, 0, 0) of the XYZ coordinate system (global coordinate system). FIG. **5** is a plan view illustrating the golf club **3** and the sensor unit **10** at the time of stopping of the user **2** (the time of the address) when viewed from the negative side of the X axis. In FIG. **5**, the position **61** of the head of the golf club **3** is the origin O (0, 0, 0) and the coordinates of the position **62** of the grip end are (0, G_Y, G_Z). Since the gravity acceleration G is applied to the sensor unit **10** at the time of stopping of the user **2**, a relation between the y axis acceleration y(0) and an inclination angle (an angle formed by the major axis of the shaft and the horizontal plane (XY plane)) α of the shaft of the golf club **3** is expressed in equation (1).

$$y(0)=G\cdot\sin\alpha \tag{1}$$

[0139] Accordingly, when L_1 is the length of the shaft of the golf club **3** included in the club specification information, G_Y and G_Z are calculated using the length L_1 and the inclination angle α of the shaft in equations (2) and (3), respectively.

$$G_Y=L_1\cdot\cos\alpha \tag{2}$$

$$G_Z=L_1\cdot\sin\alpha \tag{3}$$

[0140] Next, the first imaginary plane specifying unit **211** multiplies the coordinates (0, G_Y, G_Z) of the position **62** of the grip end of the golf club **3** by a scale factor S to calculate the coordinates (0, S_Y, S_Z) of a midpoint S**3** of the vertexes S**1** and S**2** of the shaft plane **30**. That is, S_Y and S_Z are calculated using equations (4) and (5).

$$S_Y=G_Y\cdot S \tag{4}$$

$$S_Z=G_Z\cdot S \tag{5}$$

[0141] FIG. **6** is a diagram illustrating a cross section obtained by cutting the shaft plane **30** in FIG. **2** along the YZ plane when viewed from the negative side of the X axis. The length (the width of the shaft plane **30** in a direction perpendicular to the X axis) of a line segment connecting the origin O to the midpoint S**3** of the vertexes S**1** and S**2** is S times the length L_1 of the first line segment **51**. The scale vector S is set to a value so that the trajectory of the golf club **3** during the swing motion of the user **2** falls within the shaft plane **30**. For example, when L_2 is the length of an arm of the user **2**, the scale factor S may be set as in equation (6) so that a width $S\times L_1$ in the direction perpendicular to the X axis of the shaft plane **30** is twice a sum of the length L_1 of the shaft and the length L_2 of the arm.

$$S=\frac{2\cdot(L_1+L_2)}{L_1} \tag{6}$$

[0142] The length L_2 of the arm of the user **2** has correlation with a height L_0 of the user **2**. For example, based on statistical information, a correlation equation as in equation (7) is expressed when the user **2** is male, and a correlation equation as in equation (8) is expressed when the user **2** is female.

$$L_2=0.41\times L_0-45.5\ [\text{mm}] \tag{7}$$

$$L_2=0.46\times L_0-126.9\ [\text{mm}] \tag{8}$$

[0143] Accordingly, the length L_2 of the arm of the user is calculated by equation (7) or (8) using the height L_0 and sex of the user **2** included in the body information.

[0144] Next, the first imaginary plane specifying unit **211** calculates the coordinates (−TL/2, 0, 0) of the vertex T**1**, the coordinates (TL/2, 0, 0) of the vertex T**2**, the coordinates (−TL/2, S_Y, S_Z) of the vertex S**1**, and the coordinates (TL/2, S_Y, S_Z) of the S**2** of the shaft plane **30** using the coordinates (0, S_Y, S_Z) of the midpoint S**3** calculated as described above and the width (the length of the third line segment **52**) TL of the shaft plane **30** in the X axis direction. The width TL in the X axis direction is set to a value so that the trajectory of the golf club **3** during the swing motion of the user **2** falls within the shaft plane **30**. For example, the width TL in the X axis direction may be set to be the same as the width $S\times L_1$ in the direction perpendicular to the X axis, that is, twice the sum of the length L_1 of the shaft and the length L_2 of the arm.

[0145] The shaft plane **30** is specified based on the coordinates of the four vertexes T**1**, T**2**, S**1**, and S**2** calculated in this way.

[0146] Next, an example of the process (the process of step S**40** in FIG. **4**) of specifying the Hogan's plane (the second imaginary plane) will be described in detail.

[0147] First, the second imaginary plane specifying unit **212** estimates the predetermined position **63** on the line segment connecting both shoulders of the user **2** to one another to calculate the coordinates (A_X, A_Y, A_Z), using the coordinates (0, G_Y, G_Z) of the position **62** of the grip end of the golf club **3** calculated as described above and the body information of the user **2**.

[0148] FIG. **7** is a diagram illustrating a cross section obtained by cutting the Hogan's plane **40** in FIG. **2** along the YZ plane when viewed from the negative side of the X axis. In FIG. **7**, the midpoint of the line segment connecting both shoulders of the user **2** to one another is set as the predetermined position **63**, and the predetermined position **63** is present on the YZ plane. Accordingly, the X coordinate A_X of the predetermined position **63** is 0. Then, the second imaginary plane specifying unit **212** estimates that a position obtained by moving the position **62** of the grip end of the golf club **3** by the length L_2 of the arm of the user **2** in the positive direction of the Z axis is the predetermined position **63**. Accordingly, the Y coordinate A_Y of the predetermined position **63** is the same as the Y coordinate G_Y of the position **62** of the grip end, and the Z coordinate A_Z of the predetermined position **63** is calculated as a sum of the Z coordinate G_Z of the position **62** of the grip end and the length L_2 of the arm of the user **2**, as in equation (9).

$$A_Z = G_Z + L_2 \tag{9}$$

[0149] The length L_2 of the arm of the user is calculated in equation (7) or (8) using the height L_0 and sex of the user **2** included in the body information.

[0150] Next, the second imaginary plane specifying unit **212** multiples the Y coordinate A_Y and the Z coordinate A_Z of the predetermined position **63** by a scale factor H to calculate the coordinates (0, H_Y, H_Z) of a midpoint H**3** of the vertexes H**1** and H**2** of the Hogan's plane **40**. That is, H_Y and H_Z are calculated using equations (10) and (11).

$$H_Y = A_Y \cdot H \tag{10}$$

$$H_Z = A_Z \cdot H \tag{11}$$

[0151] As illustrated in FIG. **7**, a length (a width of the Hogan's plane **40** in a direction perpendicular to the X axis) of a line segment connecting the origin O to the midpoint H**3** of the vertexes H**1** and H**2** is H times the length L_3 of the second line segment **53**. The scale factor H is set to a value so that the trajectory of the golf club **3** during the swing motion of the user **2** falls within the Hogan's plane **40**. For example, the Hogan's plane **40** may have the same shape and size as the shaft plane **30**. In this case, since a width $H \times L_3$ of the Hogan's plane **40** in the direction perpendicular to the X axis is identical to the width $S \times L_1$ of the shaft plane **30** in the direction perpendicular to the X axis and is twice the sum of the length L_1 of the shaft of the golf club **3** and the length L_2 of the arm of the user **2**, the scale factor H may be set as in equation (12).

$$H = \frac{2 \cdot (L_1 + L_2)}{L_3} \tag{12}$$

[0152] The length L_3 of the second line segment **53** is calculated from equation (13) using the Y coordinate A_Y and the Z coordinate A_Z of the predetermined position **63**.

$$L_3 = \sqrt{A_Y^2 + A_Z^2} \tag{13}$$

[0153] Next, the second imaginary plane specifying unit **212** calculates the coordinates (−TL/2, 0, 0) of the vertex T**1**, the coordinates (TL/2, 0, 0) of the vertex T**2**, the coordinates (−TL/2, H_Y, H_Z) of the vertex H**1**, and the coordinates (TL/2, H_Y, H_Z) of the H**2** of the Hogan's plane **40** using the coordinates (0, H_Y, H_Z) of the midpoint H**3** calculated as described above and the width (the length of the third line segment **52**) TL of the Hogan's plane **40** in the X axis direction. The width TL in the X axis direction is set to a value so that the trajectory of the golf club **3** during the swing motion of the user **2** falls within the Hogan's plane **40**. In the embodiment, for example, the width TL Hogan's plane **40** in the X axis direction may be set to be the same as the width of the shaft plane **30** in the X axis direction, and thus may be set to be twice the sum of the length L_1 of the shaft and the length L_2 of the arm, as described above.

[0154] The Hogan's plane **40** is specified based on the coordinates of the four vertexes T**1**, T**2**, H**1**, and H**2** calculated in this way.

[0155] Next, an example of the process (the process of step S**60** in FIG. **4**) of detecting a series of motions (rhythm) from the start of the swing to the end of the swing of the user **2** will be described in detail.

[0156] The motion analysis unit **214** detects a series of motions (rhythm) from the start of the swing to the end of the swing, for example, the start of the swing, a backswing, a top, a downswing, an impact, follow-through, and the end of the swing, using the measurement data acquired from the sensor unit **10**. A specific rhythm detection procedure is not particularly limited. For example, the following procedure can be adopted.

[0157] First, the motion analysis unit **214** calculates a sum (referred to as a composite value or a norm) of the magnitudes of the angular velocities around the axes at each time t using the acquired angular velocity data of each time t. The motion analysis unit **214** may integrate the norm of the angular velocities at each time t by time.

[0158] Here, a case of a graph in which angular velocities around three axes (x, y, and z axes) are shown, for example, in FIG. **8** (which is a diagram illustrating examples of angular velocities output from the sensor unit) will be considered. In FIG. **8**, the horizontal axis represents a time (msec) and the vertical axis represents an angular velocity (dps). The norm of the angular velocities is shown in the graph illustrated in, for example, FIG. **9** (which is a diagram illustrating an example of the norm of the angular velocities). In FIG. **9**, the horizontal axis represents a time (msec) and the vertical axis represents the norm of the angular velocities. A differential value of the norm of the angular velocities is shown in a graph illustrated in, for example, FIG. **10** (which is a diagram illustrating an example of the differential value of the norm of the angular velocities). In FIG. **10**, the horizontal axis represents a time (msec) and the vertical axis represents the differential value of the norm of the vertical angular. FIGS. **8** to **10** are exemplified to facilitate understanding of the embodiment and do not show accurate values.

[0159] The motion analysis unit **214** detects a timing of an impact in the swing using the calculated norm of the angular velocities. For example, the motion analysis unit **214** detects a timing at which the norm of the angular velocities is the maximum as the timing of the impact (T**5** in FIG. **9**). Alternatively, for example, the motion analysis unit **214** may detect a former timing between timings at which the value of the differential of the calculated norm of the angular velocities is the maximum and the minimum as the timing of the impact (T**5** in FIG. **10**).

[0160] For example, the motion analysis unit **214** detects a timing at which the calculated norm of the angular velocities is the minimum before the impact as a timing of a top of the swing (T**3** in FIG. **9**). For example, the motion analysis unit **214** specifies a period in which the norm of the angular velocities is continuously equal to or less than a first threshold value before the impact, as a top period (which is an accumulation period at the top) (T**2** to T**4** in FIG. **9**).

[0161] For example, the motion analysis unit **214** detects a timing at which the norm of the angular velocities is equal to or less than a second threshold value before the top, as a timing of the start of the swing (T**1** in FIG. **9**).

[0162] For example, the motion analysis unit **214** detects a timing at which the norm of the angular velocities is the minimum after the impact, as a timing of the end (finish) of the swing (T**7** in FIG. **9**). For example, the motion analysis unit **214** may detect a timing at which the norm of the angular velocities is first equal to or less than the third threshold value after the impact, as the timing of the end (finish) of the swing. For example, the motion analysis unit **214** specifies a period in which the norm of the angular velocities is continuously equal to or less than a fourth threshold value after the timing of the impact and close to the timing of the impact, as a finish period (T**6** to T**8** in FIG. **9**).

[0163] In this way, the motion analysis unit **214** can detect the rhythm of the swing. The motion analysis unit **214** can specify each period (for example, a backswing period from the start of the swing to the start of the top, a downswing period from the end of the top to the impact, and a follow-through period from the impact to the end of the swing) during the swing by detecting the rhythm.

[0164] Next, an example of the process (the process of step S**100** in FIG. **4**) of generating and displaying the image data indicating the V zone and the trajectory will be described in detail. Here, a case in which the V zone is not adjusted in step S**90** of FIG. **4** will be described.

[0165] FIG. **11** is a diagram illustrating an example of a screen including the shaft plane and the Hogan's plane. FIG. **11** is a diagram in which the shaft plane and the Hogan's plane are projected to the YZ plane.

[0166] An image **500** includes polygon data **501** indicating the shaft plane **30**, polygon data **502** indicating the Hogan's plane **40**, and a curved line **503** indicating the trajectory of the golf club **3** at the time of a downswing of the user **2**. In the image **500**, a V zone which is a space between the polygon data **501** and the polygon data **502** can be recognized.

[0167] In FIG. **11**, when the V zone is displayed, the V zone may not necessarily be displayed with the planes, but only the first line segment **51** (or a straight line along the first line segment **51**) included in the shaft plane **30** and the second line segment **53** (or a straight line along the second line segment **53**) included in the Hogan's plane **40** may be displayed. The image illustrated in FIG. **11** may be a 3-dimensional image of which a display angle (a viewpoint for viewing an image) can be changed according to an operation of the user **2**.

[0168] Next, an example of the process (the process of step S**90** in FIG. **4**) of adjusting the V zone will be described in detail.

[0169] In the embodiment, the motion analysis device **20** receives setting of the adjusting of the V zone in advance from the user **2**. For example, the imaginary plane adjustment unit **213** causes the display unit **25** to display a screen **600** illustrated in FIG. **12** (which is a diagram illustrating an example of a screen on which display setting of the V zone is performed) and receives an operation input on the screen **600** via the operation unit **23** from the user **2**.

[0170] The screen **600** includes a type-of-swing field **610** for designating the type of swing, a skill level field **620** for designating the skill level, a center plane field **630** for designating display or non-display of a center plane, and a V zone field **640** for designating display or non-display of a reference V zone. In the example of FIG. **12**, the type-of-swing field **610** includes three buttons so that anyone of three types of swings (straight, hook, and slice) can be designated. The skill level field **620** includes three buttons so that any one of three skill levels (beginning, intermediate, and advanced) can be designated.

[0171] The center plane is a plane that is formed by the third line segment **52** and a line segment bisecting a predetermined angle θ formed by the first line segment **51** and the second line segment **53** using the target direction (the third line segment **52**) of the hitting as the rotation axis. In the example of FIG. **12**, the center plane field **630** includes two buttons so that display or non-display of the center plane can be designated.

[0172] The reference V zone is a V zone (for example, a V zone of a professional golfer or a past V zone of the user **2**) that is displayed for comparison reference apart from the V zone of the user **2** specified and displayed as above described. Information regarding the reference V zone (for example, data specifying the angle of the shaft plane and the angle of the Hogan's plane of the reference V zone) may be stored in, for example, the storage unit **24** or a storage device on a network. In the example of FIG. **12**, the reference V zone field **640** includes two buttons so that display or non-display of the reference V zone can be designated. The reference V zone field **640** includes a button for setting an acquisition destination (for example, a URL or a file path) of the information regarding the reference V zone.

[0173] The description will be continued below with reference to FIGS. **13**A to **16** assuming the initial setting in which the type of swing is "straight", the skill level is "intermediate", the center plane is "non-display", and the reference V zone is "non-display".

[0174] FIGS. **13**A to **13**C are diagrams illustrating examples of a procedure and a screen for adjusting the shaft plane and the Hogan's plane according to the type of swing.

[0175] When "straight" is set in the above-described type-of-swing field **610**, the imaginary plane adjustment unit **213** does not adjust the V zone. Specifically, the imaginary plane adjustment unit **213** does not change the angle of the shaft plane **30** specified in step S**30** and the angle of the Hogan's plane **40** specified in step S**40**. In FIG. **13**A, the shaft plane **30** at the inclination angle α and the Hogan's plane **40** forming a predetermined angle θ relative to the shaft plane **30** are specified. The image generation unit **215** generates and displays the image **500** including the polygon data **501** of the shaft plane **30**, the polygon data **502** of the Hogan's plane **40**, and the curved line **503** (not illustrated) indicating the trajectory of the golf club **3**.

[0176] When "slice" is set in the above-described type-of-swing field **610**, the imaginary plane adjustment unit **213** performs adjustment by rotating the V zone clockwise. Specifically, the imaginary plane adjustment unit **213** specifies a shaft plane **30***a* and a Hogan's plane **40***a* after the adjustment by rotating the angle of the shaft plane **30** specified in step S**30** and the angle of the Hogan's plane **40** specified in step S**40** by an angle adjustment amount d in the Z axis direction, using the third line segment **52** as the rotation axis. In FIG. **13**B, the shaft plane **30***a* at an inclination angle α+d and the Hogan's plane **40***a* forming the predetermined angle θ relative to the shaft plane **30***a* are specified. The image generation unit **215** generates and displays the image **500** including polygon data **501***a* of the shaft plane **30***a*, polygon data **502***a* of the Hogan's plane **40***a*, and the curved line **503** (not illustrated) indicating the trajectory of the golf club **3**.

[0177] When "hook" is set in the above-described type-of-swing field **610**, the imaginary plane adjustment unit **213** performs adjustment by rotating the V zone counterclockwise. Specifically, the imaginary plane adjustment unit **213** specifies the shaft plane **30***a* and the Hogan's plane **40***a* after the adjustment by rotating the angle of the shaft plane **30** specified in step S**30** and the angle of the Hogan's plane **40** specified in step S**40** by the angle adjustment amount d in the Y axis direction, using the third line segment **52** as the rotation axis. In FIG. **13**C, the shaft plane **30***a* at an inclination angle α−d and the Hogan's plane **40***a* forming the predetermined angle θ relative to the shaft plane **30***a* are specified. The image generation unit **215** generates and displays the image **500** including the polygon data **501***a* of the shaft plane **30***a*, the polygon data **502***a* of the Hogan's plane **40***a*, and the curved line **503** (not illustrated) indicating the trajectory of the golf club **3**.

[0178] Since the position of the V zone is adjusted according to the type of swing designated by the user **2** in the above-described manner, the swing can be estimated accurately according to the type of swing. For example, when a golfer performing a sliced-based swing usually sets the display setting of the V zone to "slice", the trajectory of a downswing easily falls within the V zone, and thus goodness and the badness of a way or the goodness and the badness of a swing can be determined simply and accurately.

[0179] FIGS. **14**A and **14**B are diagrams illustrating examples of a procedure and a screen for adjusting shaft plane and the Hogan's plane according to a skill level.

[0180] When "intermediate" is set in the above-described skill level field **620**, the imaginary plane adjustment unit **213** does not adjust the V zone. Since this case is the same as the case of FIG. **13**A, the description thereof will be omitted.

[0181] When "beginning" is set in the above-described skill level field **620**, the imaginary plane adjustment unit **213** performs adjustment so that the center angle of the V zone formed by the shaft plane **30** and the Hogan's plane **40** is large. Specifically, the imaginary plane adjustment unit **213** specifies the shaft plane **30***a* after adjustment by rotating the angle of the shaft plane **30** specified in step S**30** by an angle adjustment amount d in the Y axis direction, using the third line segment **52** as the rotation axis. The imaginary plane adjustment unit **213** specifies the Hogan's plane **40***a* after adjustment by rotating the angle of the Hogan's plane **40** specified in step s**40** by the angle adjustment amount d in the Z axis direction, using the third line segment **52** as the rotation axis. In FIG. **14**A, the shaft plane **30***a* at the inclination angle α−d and the Hogan's plane **40***a* forming a predetermined angle θ+2d relative to the shaft plane **30***a* are specified. The image generation unit **215** generates and displays the image **500** including the polygon data **501***a* of the shaft plane **30***a*, the polygon data **502***a* of the Hogan's plane **40***a*, and the curved line **503** (not illustrated) indicating the trajectory of the golf club **3**.

[0182] When "advanced" is set in the above-described skill level field **620**, the imaginary plane adjustment unit **213** performs adjustment so that the center angle of the V zone formed by the shaft plane **30** and the Hogan's plane **40** is small. Specifically, the imaginary plane adjustment unit **213** specifies the shaft plane **30***a* after adjustment by rotating the angle of the shaft plane **30** specified in step S**30** by the angle adjustment amount d in the Z axis direction, using the third line segment **52** as the rotation axis. The imaginary plane adjustment unit **213** specifies the Hogan's plane **40***a* after adjustment by rotating the angle of the Hogan's plane **40** specified in step S**40** by the angle adjustment amount d in the Y axis direction, using the third line segment **52** as the rotation axis. In FIG. **14**B, the shaft plane **30***a* at the inclination angle α+d and the Hogan's plane **40***a* forming a predetermined angle θ−2d relative to the shaft plane **30***a* are specified. The image generation unit **215** generates and displays the image **500** including the polygon data **501***a* of the shaft plane **30***a*, the polygon data **502***a* of the Hogan's plane **40***a*, and the curved line **503** (not illustrated) indicating the trajectory of the golf club **3**.

[0183] The area of the V zone is adjusted according to the skill level designated by the user **2** in the above-described manner. That is, as the skill level is lower, the adjustment is performed so that the center angle of the V zone is larger. As the skill level is higher, the adjustment is performed so that the center angle of the V zone is smaller. Therefore, the swing can be estimated accurately according to the skill level. For example, when a beginning golfer sets the display setting of the V zone to "beginning", the trajectory of a downswing easily falls within the V zone, and thus goodness and the badness of a way, the goodness and the badness of a swing, or the degree of improvement can be determined simply and accurately.

[0184] FIG. **15** is s diagram illustrating examples of a procedure and a screen for setting a center plane.

[0185] When "display" is set in the above-described center plane field **630**, the imaginary plane adjustment unit **213** specifies the center plane. Specifically, the imaginary plane adjustment unit **213** specifies a middle inclination of the inclination of the shaft plane **30** specified in step S**30** and the inclination of the Hogan's plane **40** specified in step S**40** as an inclination of the center plane, using the third line segment **52** as the rotation axis. In FIG. **15**, a center plane **50** at an inclination angle α+θ/2 is specified. The image generation unit **215** generates and displays the image **500** including the polygon data **501** of the shaft plane **30**, the polygon data **502** of the Hogan's plane **40**, polygon data **504** of the center plane **50**, and the curved line **503** (not illustrated) indicating the trajectory of the golf club **3**.

[0186] In the above-described manner, the center plane is displayed according to designation of the user **2**. Referring to the center plane, the user **2** can simply determine to which side the trajectory of the swing is biased between the shaft plane and the Hogan's plane, for example.

[0187] FIG. **16** is a diagram illustrating example of a procedure and a screen for setting a reference V zone.

[0188] When "display" is set in the above-described reference V zone **640** and the acquisition destination of the information regarding the reference V zone is set, the imaginary plane adjustment unit **213** acquires the information regarding the reference V zone from the acquisition destination. The imaginary plane adjustment unit **213** specifies a shaft plane and a Hogan's plane forming the reference V zone based on the information regarding the acquired reference V zone. In FIG. **16**, a shaft plane **30***b* and a Hogan's plane **40***b* forming the reference V zone are specified in addition to the shaft plane **30** specified in step S**30** and the Hogan's plane **40** specified in step S**40**. The image generation unit **215** generates and displays the image **500** including the polygon data **501** of the shaft plane **30**, the polygon data **502** of the Hogan's plane **40**, polygon data **501***b* of the shaft plane **30***b*, polygon data **502***b* of the Hogan's plane **40***b*, and the curved line **503** (not illustrated) indicating the trajectory of the golf club **3**.

[0189] In the above-described manner, the reference V zone is displayed according to designation of the user **2**. The user **2** can estimate the address posture or improve the address posture by comparing the V zone of the user to the reference V zone.

[0190] The designation of the type of swing, the designation of the skill level, the designation of the display of the center plane, and the designation of the display of the reference V zone have been separately described in FIGS. **13**A to **16**, but the designation can also be performed by combining at least one thereof. For example, when the type of swing "slice" and the skill level "beginning" are designated, the imaginary plane adjustment unit **213** may rotate the V zone clockwise and enlarge the center angle. For example, when the type of swing "hook" and the skill level "advanced" are designated, the imaginary plane adjustment unit **213** may rotate the V zone counterclockwise and narrow the center angle. The center plane **50** may be specified based on the shaft plane **30**a and the Hogan's plane **40**a after the adjustment of the V zone.

[0191] The magnitude of the above-described adjustment amount d in FIGS. **13**A to **14**B may be able to be designated by the user **2**. For example, when the type of swing is designated, the degrees of slice and hook may be able to be designated in a plurality of stages with reference to the straight on the screen **600** and the imaginary plane adjustment unit **213** may perform setting such that the adjustment amount d is larger as the designated degree of slice or hook is larger. For example, when the skill level is designated, a plurality of levels may be able to be designated at each of the higher and lower levels using the intermediate as a criterion on the screen **600** and the imaginary plane adjustment unit **213** may perform setting so that the adjustment amount d is larger as the skill is higher (or the skill is lower).

[0192] In the example of FIGS. **13**A to **13**C, the same adjustment amount d is used for the shaft plane **30** and the Hogan's plane **40**, but the imaginary plane adjustment unit **213** may use different adjustment amounts (one of the adjustment amounts may be 0). Similarly, in the example of FIGS. **14**A and **14**B, the same adjustment amount d is used for the shaft plane **30** and the Hogan's plane **40**, but the imaginary plane adjustment unit **213** may use different adjustment amounts (one of the adjustment amounts may be 0).

[0193] The imaginary plane adjustment unit **213** may decide the magnitude of the adjustment amount d according to the type of club (for example, a driver and a driver model number, an iron and an iron model number, and a putter) or specification information (for example, the length of the shaft, the position of the center of gravity, a lie angle, a face angle, and a loft angle) of the designated club. The imaginary plane adjustment unit **213** may decide the magnitude of the adjustment amount d according to designated body information (for example, the length of an arm and the height) regarding the user.

[0194] The embodiment of the invention has been described above. According to the embodiment, since the user can objectively recognize the address posture from the positions and inclinations of the shaft plane and the Hogan's plane, the size of the V zone, and the like, it is possible to estimate the goodness and badness of a swing more simply. Since the user can recognize the positional relation between the trajectory of the golf club and the shaft plane and the Hogan's plane at the time of a swing, it is possible to estimate the goodness and badness of a swing more accurately than in the related art.

[0195] According to the embodiment, by imposing the restriction that the user performs address so that the major axis of the shaft of the golf club is vertical to the target line, the motion analysis device can specify the third line segment indicating the target direction of the hitting using the measurement data of the sensor unit at the time of the address. Accordingly, the motion analysis device can appropriately specify the shaft plane in accordance with the direction of the third line segment.

[0196] According to the embodiment, since the predetermined position on the line segment connecting both shoulders of the user in the Hogan's plane is specified in consideration of the body information of the user, the shaft plane and the Hogan's plane can be specified using the measurement data of one sensor unit. It is possible to specify the Hogan's plan suitable for the body shape of the user more accurately than a case in which an imaginary plane obtained by rotating the shaft plane by a predetermined angle (for example, 30°) is specified as the Hogan's plane.

[0197] According to the embodiment, the position, the posture, or the like of they zone specified based on the address posture of the user is adjusted according to the type of swing. Accordingly, even when the estimation is desired to be performed in consideration of a swing tendency or the like according to the type of swing, it is possible to estimate the goodness and badness of a swing simply and accurately.

[0198] According to the embodiment, the position, the posture, the area, or the like of the V zone specified based on the address posture of the user is adjusted according to the skill level. Accordingly, even when the estimation is desired to be performed in consideration of a swing tendency or the like according to the skill level, it is possible to estimate the goodness and badness of a swing simply and accurately.

[0199] According to the embodiment, since the shaft plane and the Hogan's plane are specified using the sensor unit, it is not necessary to use a large-scale device such as a camera and restriction of a place where a swing is analyzed is small.

[0200] The invention is not limited to the above-described embodiments, but may be modified in various forms within the scope of the gist of the invention.

[0201] In the foregoing embodiments, the second imaginary plane specifying unit **212** specifies the second line segment **53** using the body information and the measurement data output by the sensor unit **10**. However, a process of specifying the second line segment **53** connecting the positions **63** and **62** of the head (the blow portion) of the golf club **3** may be performed using the first line segment **51** specified by the first imaginary plane specifying unit **211** and the predetermined angle θ relative to the first line segment **51**.

[0202] In the foregoing embodiments, the motion analysis device **20** specifies the shaft plane and the Hogan's plane using the measurement data of the sensor unit **10** mounted on the golf club **3** and calculates the trajectory of the golf club **3** during the swing. Besides, for example, the shaft plane and the Hogan's plane may be specified and the trajectory of the golf club **3** may be calculated using the measurement data of the sensor unit **10** mounted on an arm (wrist or the like) of the user **2** in the same method as that of the foregoing embodiment. Alternatively, the plurality of sensor units **10** may be mounted on parts such as the golf club **3** or the arms, shoulders, or the like of the user. Then, the shaft plane and the Hogan's plane may be specified and the trajectory of the golf club **3** may be calculated using the measurement data of each of the plurality of sensor units **10**.

[0203] In the foregoing embodiments, the acceleration sensor **13** and the angular velocity sensor **14** are embedded in the sensor unit **10** to be integrated, but the acceleration sensor **13** and the angular velocity sensor **14** may not be integrated. Alternatively, the acceleration sensor **13** and the angular velocity sensor **14** may not be embedded in the sensor unit **10**, but may be mounted directly on the golf club **3** or the user **2**. In the foregoing embodiments, the sensor unit **10** and the motion analysis device **20** are separated, but the acceleration sensor **13** and the angular velocity sensor **14** may be integrated to be mounted on the golf club **3** or the user **2**.

[0204] In the foregoing embodiments, the motion analysis device **20** calculates the Z coordinate A_Z of the predetermined position **63** on the line segment connecting both shoulders of the user **2** to one another as the sum of the Y coordinate G_Y of the position **62** of the grip end and the length L_2 of the arm of the user **2** as in equation (9), but another equation may be used. For example, the motion analysis device **20** may multiply L_2 by a coefficient K and adds G_Y to calculate A_Z as in $A_Z=G_Y+K \cdot L_2$.

[0205] In the foregoing embodiments, the motion analysis system (the motion analysis device) analyzing a golf swing has been exemplified. However, the invention can be applied to an motion analysis system (motion analysis device) analyzing swings of various exercises of tennis, baseball, and the like.

[0206] The above-described embodiments and modification examples are merely examples and the invention is not limited thereto. For example, the embodiments and the modification examples can also be appropriately combined.

[0207] The configuration of the motion analysis system **1** illustrated in FIG. **3** is classified according to main processing content in order to facilitate understanding of the configuration of the motion analysis system **1**. The invention is not limited by the method of classifying the constituent elements or the names of the constituent elements. The configuration of the motion analysis system **1** can be classified into further many constituent elements according to the processing content. One constituent element can be classified to perform more processes. The process of each constituent element may be performed by one piece of hardware or may be performed by a plurality of pieces of hardware. Charge of the processor function of each constituent element is not limited to the above description as long as the goal and advantage of the invention can be achieved. In the foregoing embodiment, the sensor unit **10** and the motion analysis device **20** have been described as separate units, but the function of the motion analysis device **20** may be mounted on the sensor unit **10**.

[0208] Units of processes in the flowchart illustrated in FIG. **4** are divided according to main processing content in order to facilitate understanding of the process of the motion analysis device **20**. The invention is not limited by a method of dividing the units of processes or the names of the units of processes. The process of the motion analysis device **20** can be divided in more units of processes according to the processing content. One unit of process can be divided to include more processes. The processing procedure of the foregoing flowchart is not limited to the example illustrated in the drawing.

[0209] The entire disclosure of Japanese Patent Application No. 2014-257261, filed Dec. 19, 2014 is expressly incorporated by reference herein.

What is claimed is:

1. A motion analysis device comprising:

a first specifying unit that specifies a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor;

a second specifying unit that specifies a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and

an adjustment unit that adjusts sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

2. The motion analysis device according to claim **1**,

wherein the predetermined condition is a type of swing of the user, and

wherein the adjustment unit adjusts at least one of the angle of the first axis and the angle of the second axis according to the type of swing.

3. The motion analysis device according to claim **2**,

wherein the type of swing is a slice or a hook,

wherein when the type of swing is the slice, the adjustment unit increases at least the angle of the second axis, and

wherein when the type of swing is the hook, the adjustment unit decreases at least the angle of the first axis.

4. The motion analysis device according to claim **1**,

wherein the predetermined condition is a skill level of the user, and

wherein the adjustment unit adjusts the predetermined angle between the first and second axes according to the skill level.

5. The motion analysis device according to claim **4**,

wherein the adjustment unit increases the predetermined angle as the skill level is lower, and

wherein the adjustment unit decreases the predetermined angle as the skill level is higher.

6. The motion analysis device according to claim **1**,

wherein the first specifying unit calculates an angle of the shaft relative to the plane using an output of the inertial sensor at the address posture, and specifies the first axis using information regarding a length of the shaft and this angle.

7. The motion analysis device according to claim **1**,

wherein when the hitting direction is a third axis, the first specifying unit specifies a first imaginary plane including the first and third axes and the second specifying unit specifies a second imaginary plane including the second and third axes.

8. The motion analysis device according to claim **1**,

wherein the exercise tool includes a blow surface, and

wherein the hitting direction is a direction perpendicular to the blow surface at the address posture.

9. The motion analysis device according to claim **1**, further comprising:

an image generation unit that generates image data including the first and second axes.

10. The motion analysis device according to claim **9**, further comprising:

a motion analysis unit that calculates a trajectory of the exercise tool based on a swing of the user,

wherein the image generation unit generates image data including the first axis, the second axis, and the trajectory.

11. A motion analysis system comprising:

an inertial sensor;

a first specifying unit that specifies a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of the inertial sensor;

a second specifying unit that specifies a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and
an adjustment unit that adjusts sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

12. The motion analysis system according to claim **11**,
wherein the predetermined condition is a type of swing of the user, and
wherein the adjustment unit adjusts at least one of the angle of the first axis and the angle of the second axis according to the type of swing.

13. The motion analysis system according to claim **12**,
wherein the type of swing is a slice or a hook,
wherein when the type of swing is the slice, the adjustment unit increases at least the angle of the second axis, and
wherein when the type of swing is the hook, the adjustment unit decreases at least the angle of the first axis.

14. The motion analysis system according to claim **11**,
wherein the predetermined condition is a skill level of the user, and
wherein the adjustment unit adjusts the predetermined angle between the first and second axes according to the skill level.

15. An motion analysis method comprising:
specifying a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor;
specifying a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and
adjusting sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

16. The motion analysis method according to claim **15**,
wherein the predetermined condition is a type of swing of the user, and
wherein in the adjusting of the sizes of the angles, at least one of the angle of the first axis and the angle of the second axis is adjusted according to the type of swing.

17. The motion analysis method according to claim **16**,
wherein the type of swing is a slice or a hook,
wherein when the type of swing is the slice, at least the angle of the second axis is increased in the adjusting of the sizes of the angles, and
wherein when the type of swing is the hook, at least the angle of the first axis is decreased in the adjusting of the sizes of the angles.

18. The motion analysis method according to claim **15**,
wherein the predetermined condition is a skill level of the user, and
wherein in the adjusting of the sizes of the angles, the predetermined angle between the first and second axes is adjusted according to the skill level.

19. A program causing a computer to perform:
specifying a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor;
specifying a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and
adjusting sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

20. A recording medium that records a program causing a computer to perform:
specifying a first axis which lies in a longitudinal direction of a shaft of an exercise tool at an address posture of a user, using an output of an inertial sensor;
specifying a second axis forming a predetermined angle along with the first axis, using a hitting direction as a rotation axis; and
adjusting sizes of an angle of the first axis and an angle of the second axis relative to a plane according to a predetermined condition.

21. A motion analysis device comprising:
an adjustment unit that adjusts a size of a center angle of a V zone according to a predetermined condition.

22. The motion analysis device according to claim **21**,
wherein the predetermined condition is a skill level of the user, and
wherein the adjustment unit adjusts the center angle according to the skill level.

23. The motion analysis device according to claim **22**,
wherein the adjustment unit increases the center angle as the skill level is lower, and
wherein the adjustment unit decreases the center angle as the skill level is higher.

24. The motion analysis device according to claim **21**,
wherein an exercise tool includes a blow surface, and
wherein the hitting direction is a direction perpendicular to the blow surface at a address posture of a user.

25. The motion analysis device according to claim **21**, further comprising:
an image generation unit that generates image data including the V zone.

26. The motion analysis device according to claim **25**, further comprising:
a motion analysis unit that calculates a trajectory of an exercise tool based on a swing of the user,
wherein the image generation unit generates image data including the V zone and the trajectory.

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