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(54) **HEAD-MOUNTED DISPLAY DEVICE, CONTROL METHOD FOR HEAD-MOUNTED DISPLAY DEVICE, AND COMPUTER PROGRAM**

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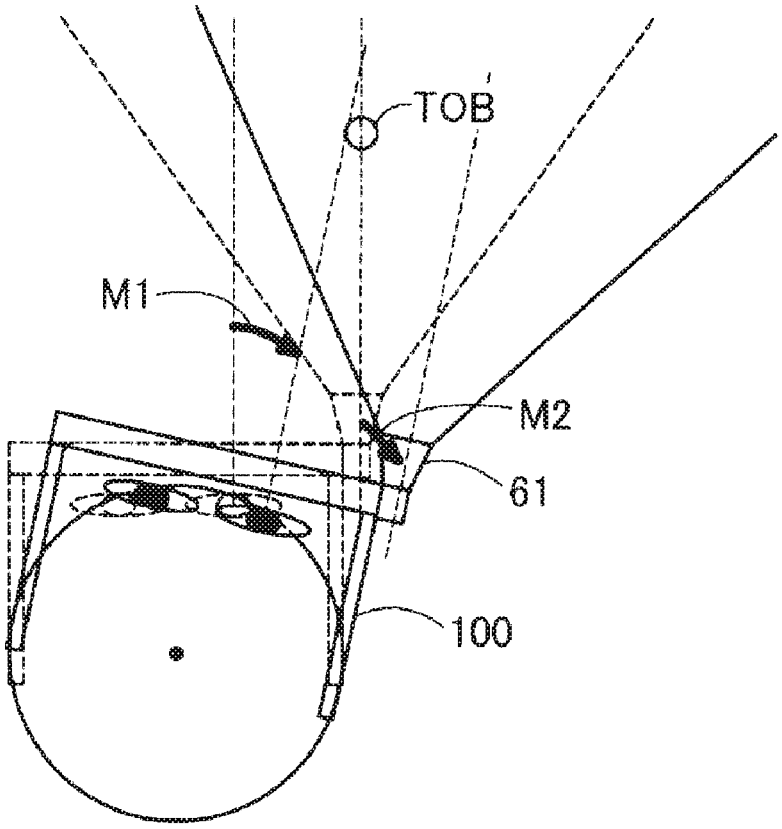
CPC ***G06T 11/60*** (2013.01); ***G06T 7/74*** (2017.01); ***G02B 27/0172*** (2013.01); *G06T 2207/30201* (2013.01)

(57) **ABSTRACT**

A head-mounted display device with which a user can visually recognize a virtual image and an outside scene includes an outside-scene acquiring unit configured to acquire outside scene information including at least a feature of the outside scene in a visual field direction of the user, a position estimating unit configured to estimate, on the basis of at least two kinds of the outside scene information acquired by the outside-scene acquiring unit over time, a position of any target object present in a real world, and an augmented-reality processing unit configured to cause the image display unit to form, on the basis of the estimated position of the target object, the virtual image representing a virtual object to be added to the target object.



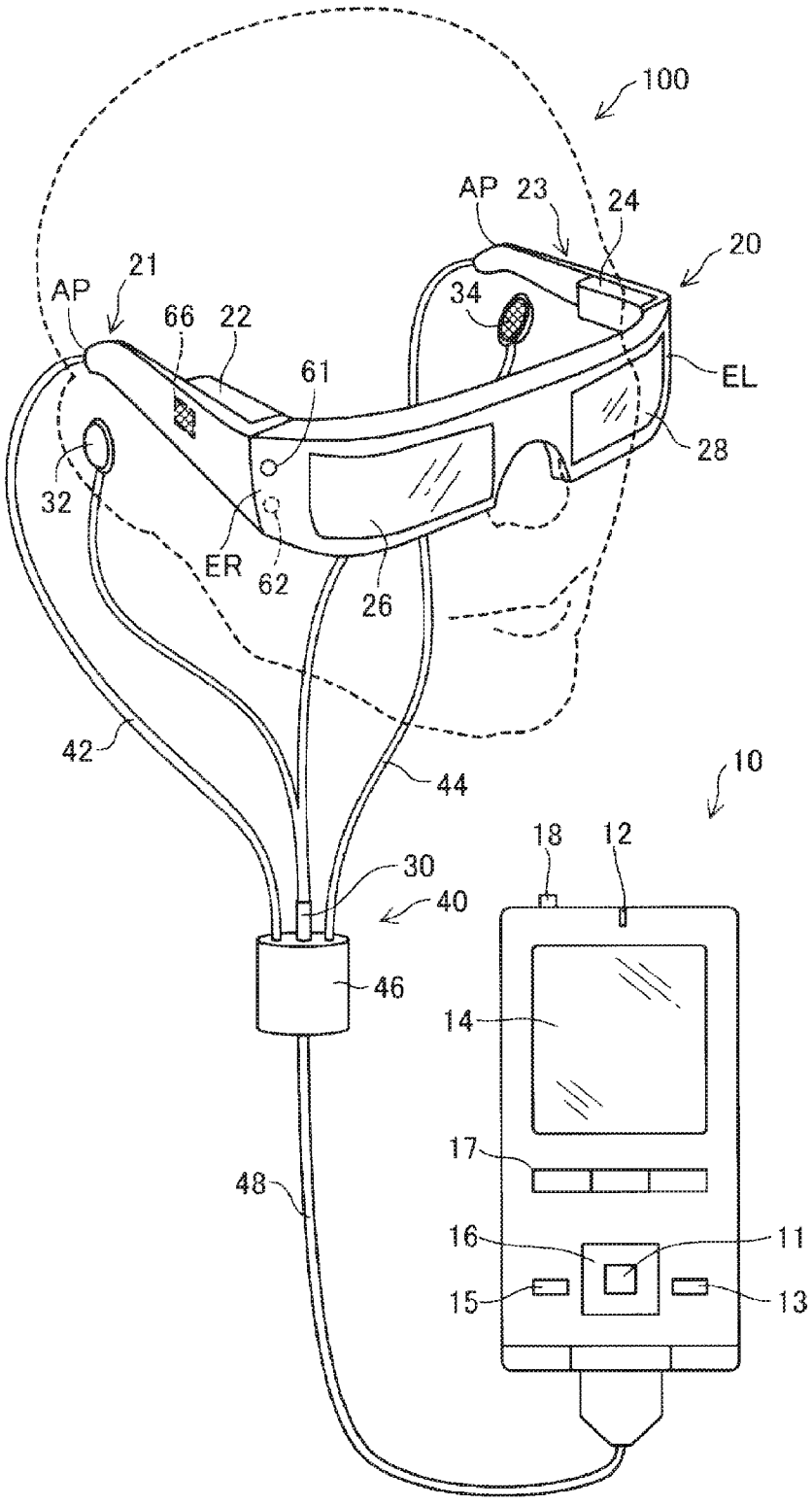

100
AP
23
24
20
AP
21
66
22
34
61
EL
28
32
ER
62
26
42
44
10
18
12
30
40
46
14
17
48
16
11
15
13

FIG. 1

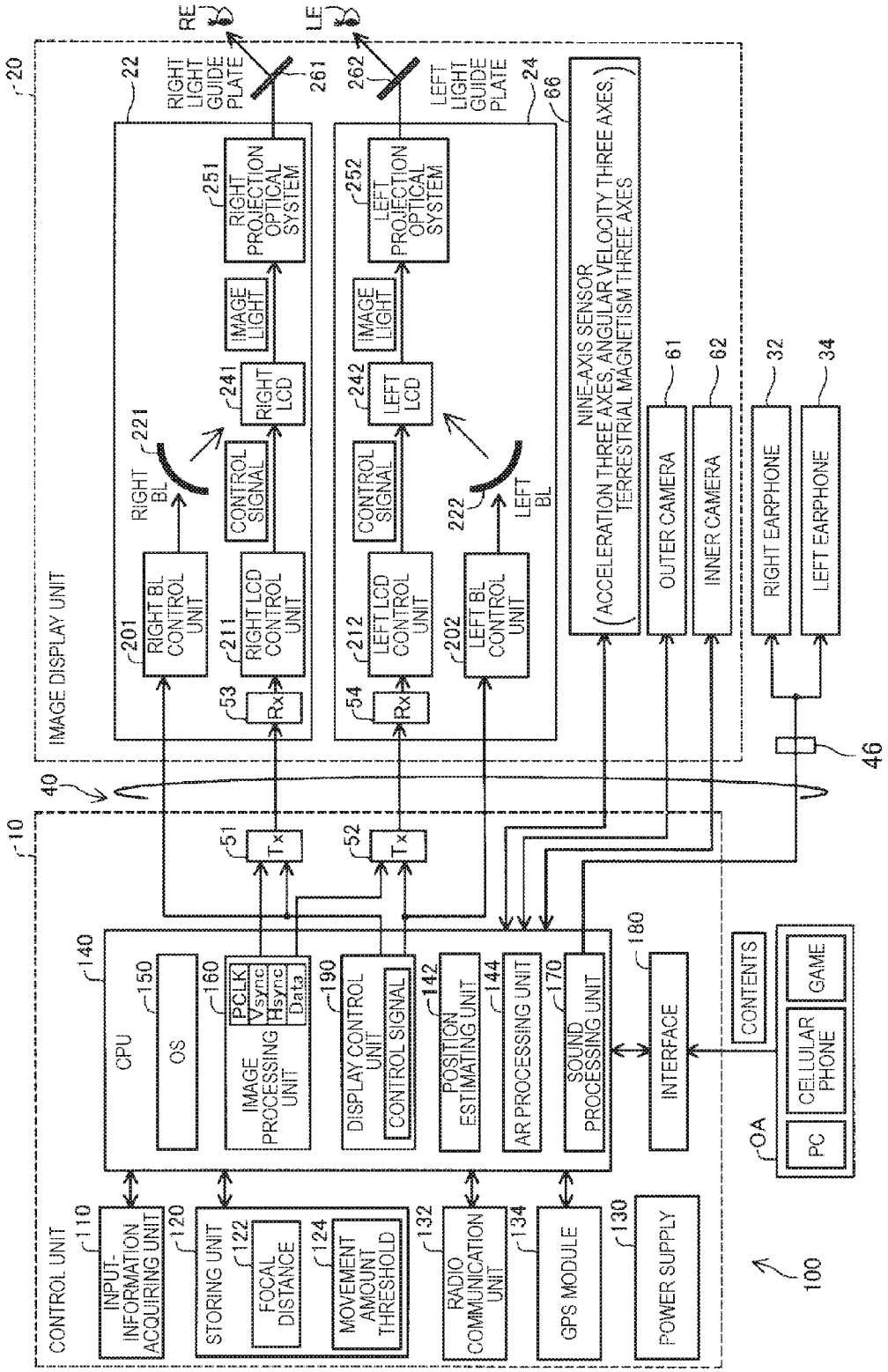

100
CONTROL UNIT
10
INPUT-INFORMATION ACQUIRING UNIT
110
STORING UNIT
120
FOCAL DISTANCE
122
MOVEMENT AMOUNT THRESHOLD
124
RADIO COMMUNICATION UNIT
132
GPS MODULE
134
POWER SUPPLY
130
CPU
140
OS
150
IMAGE PROCESSING UNIT
160
PCLK
Vsync
Hsync
Data
DISPLAY CONTROL UNIT
190
CONTROL SIGNAL
POSITION ESTIMATING UNIT
142
AR PROCESSING UNIT
144
SOUND PROCESSING UNIT
170
INTERFACE
180
CONTENTS
GAME
CELLULAR PHONE
PC
OA
40
Tx
51
Tx
52
46
IMAGE DISPLAY UNIT
20
RIGHT BL CONTROL UNIT
201
RIGHT LCD CONTROL UNIT
211
Rx
53
RIGHT BL
221
CONTROL SIGNAL
RIGHT LCD
241
IMAGE LIGHT
RIGHT PROJECTION OPTICAL SYSTEM
251
RIGHT LIGHT GUIDE PLATE
22
261
RE
LEFT BL CONTROL UNIT
202
LEFT LCD CONTROL UNIT
212
Rx
54
LEFT BL
222
CONTROL SIGNAL
LEFT LCD
242
IMAGE LIGHT
LEFT PROJECTION OPTICAL SYSTEM
252
LEFT LIGHT GUIDE PLATE
24
262
LE
NINE-AXIS SENSOR (ACCELERATION THREE AXES, ANGULAR VELOCITY THREE AXES, TERRESTRIAL MAGNETISM THREE AXES)
66
OUTER CAMERA
61
INNER CAMERA
62
RIGHT EARPHONE
32
LEFT EARPHONE
34

FIG. 2

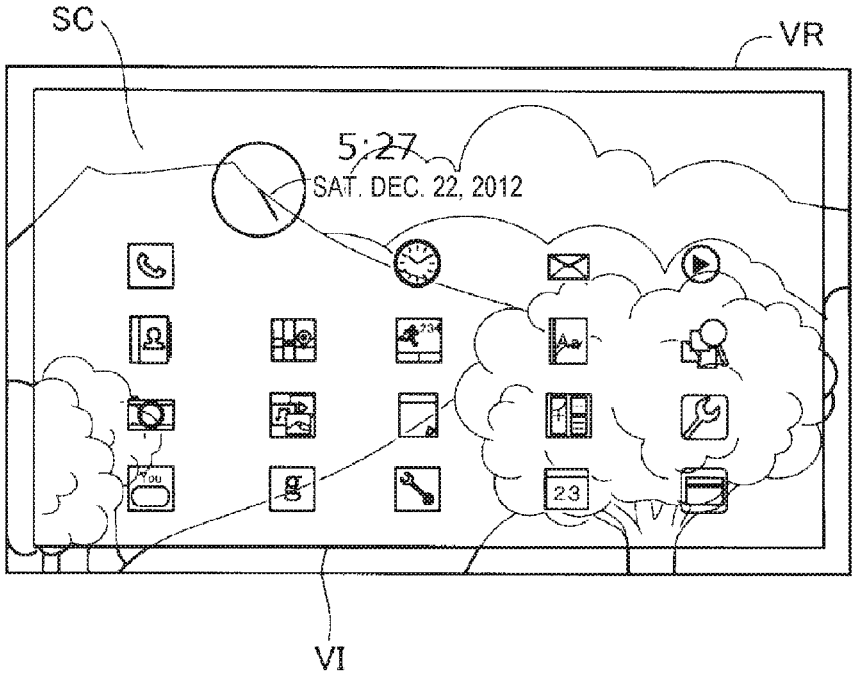


FIG. 3A

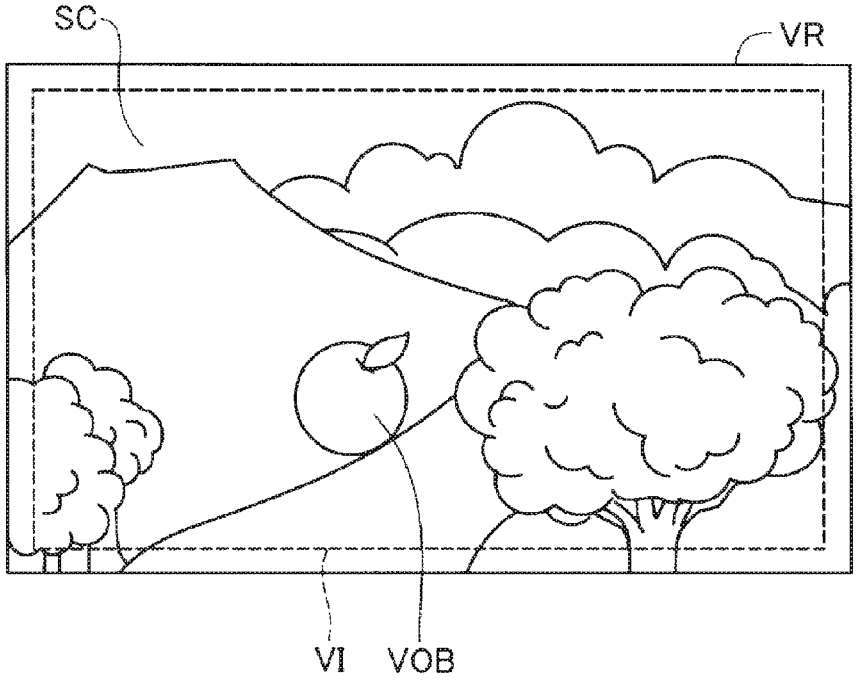


FIG. 3B

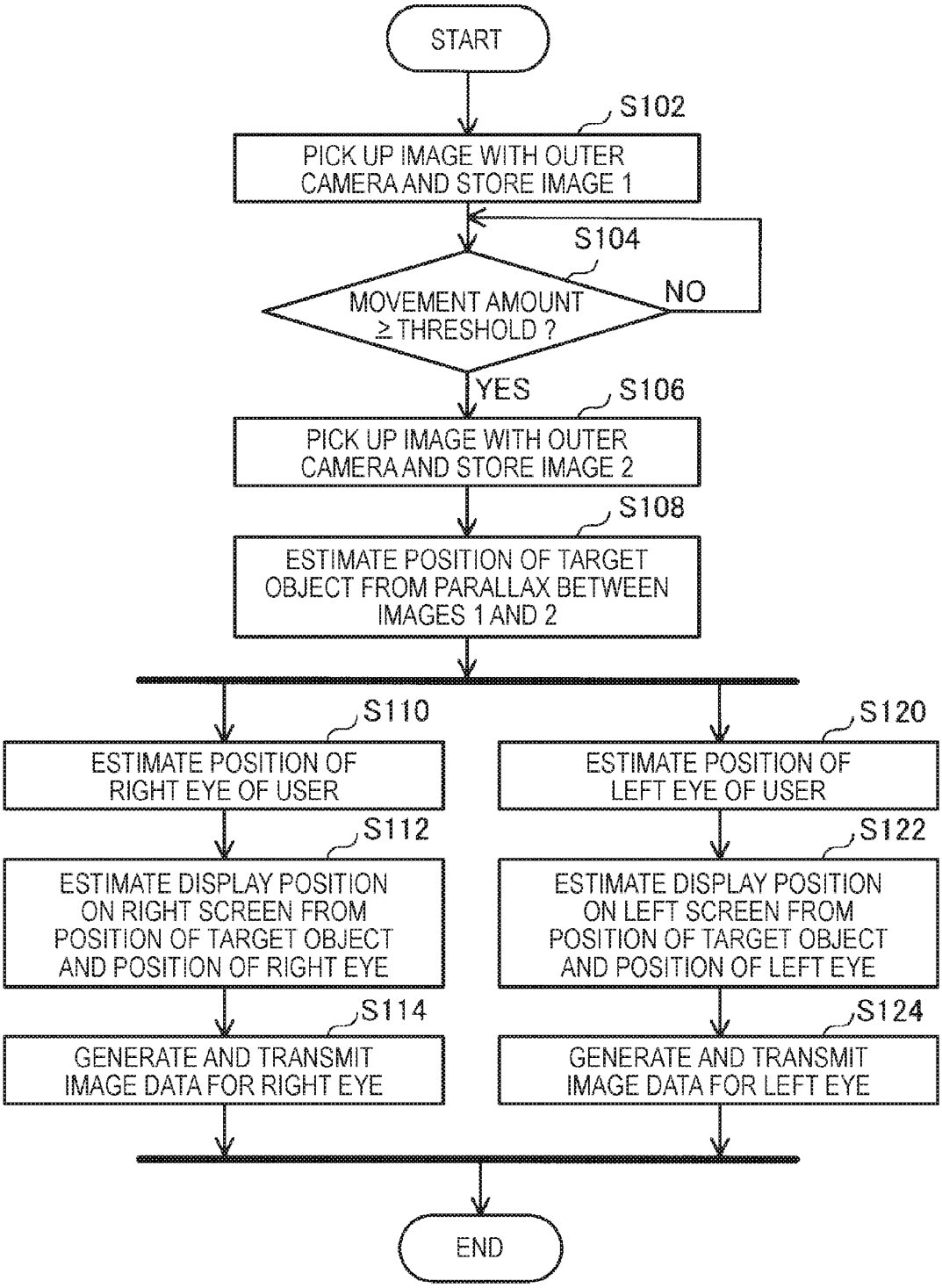

START
S102
PICK UP IMAGE WITH OUTER CAMERA AND STORE IMAGE 1
S104
MOVEMENT AMOUNT ≥ THRESHOLD ?
NO
YES
S106
PICK UP IMAGE WITH OUTER CAMERA AND STORE IMAGE 2
S108
ESTIMATE POSITION OF TARGET OBJECT FROM PARALLAX BETWEEN IMAGES 1 AND 2
S110
ESTIMATE POSITION OF RIGHT EYE OF USER
S112
ESTIMATE DISPLAY POSITION ON RIGHT SCREEN FROM POSITION OF TARGET OBJECT AND POSITION OF RIGHT EYE
S114
GENERATE AND TRANSMIT IMAGE DATA FOR RIGHT EYE
S120
ESTIMATE POSITION OF LEFT EYE OF USER
S122
ESTIMATE DISPLAY POSITION ON LEFT SCREEN FROM POSITION OF TARGET OBJECT AND POSITION OF LEFT EYE
S124
GENERATE AND TRANSMIT IMAGE DATA FOR LEFT EYE
END

FIG. 4

FIG. 5

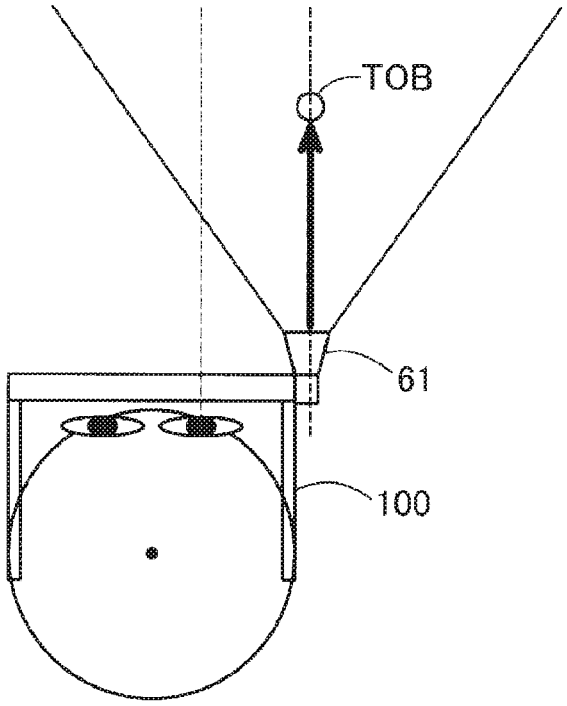
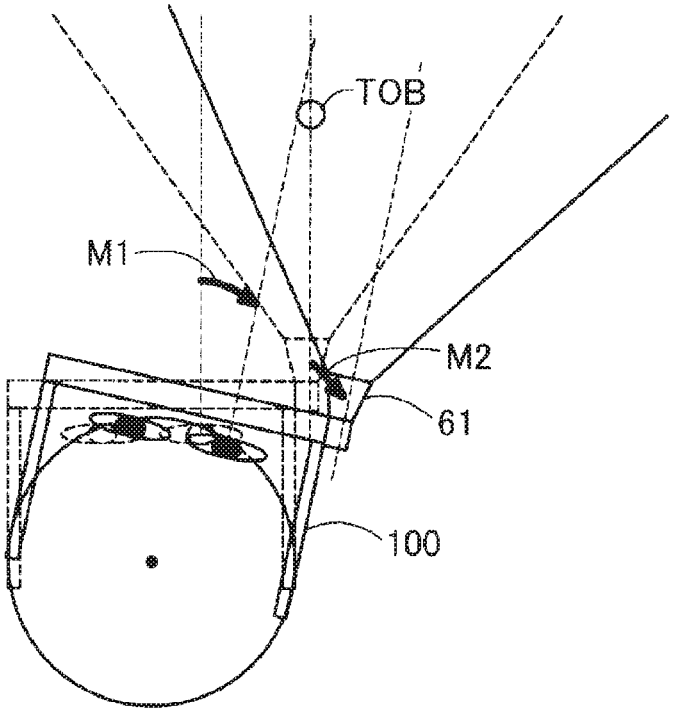


FIG. 6



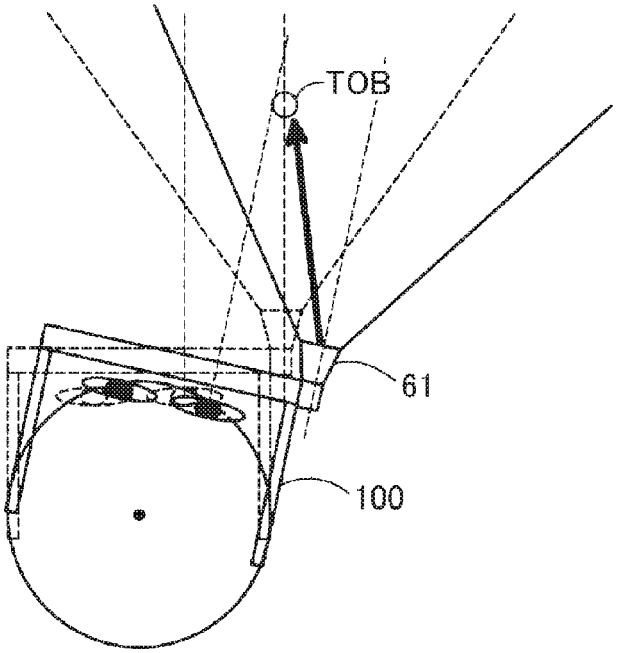


FIG. 7

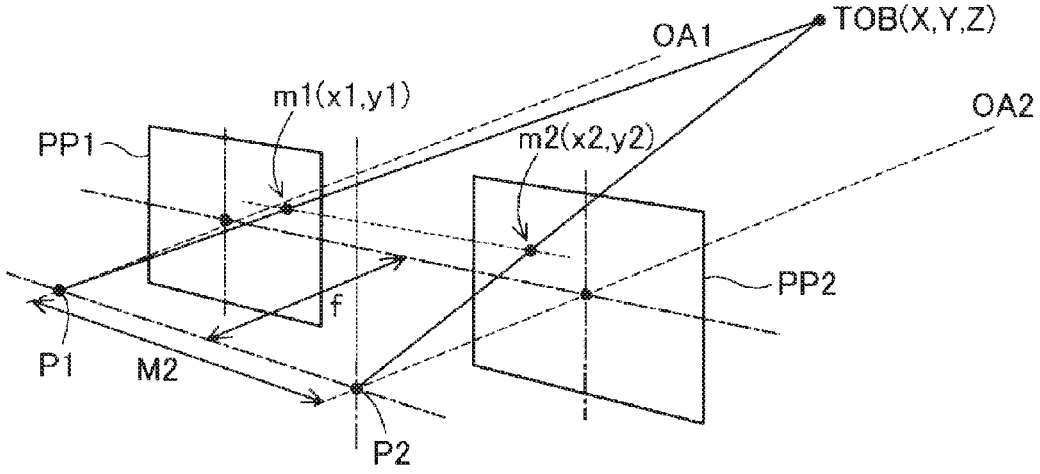


FIG. 8

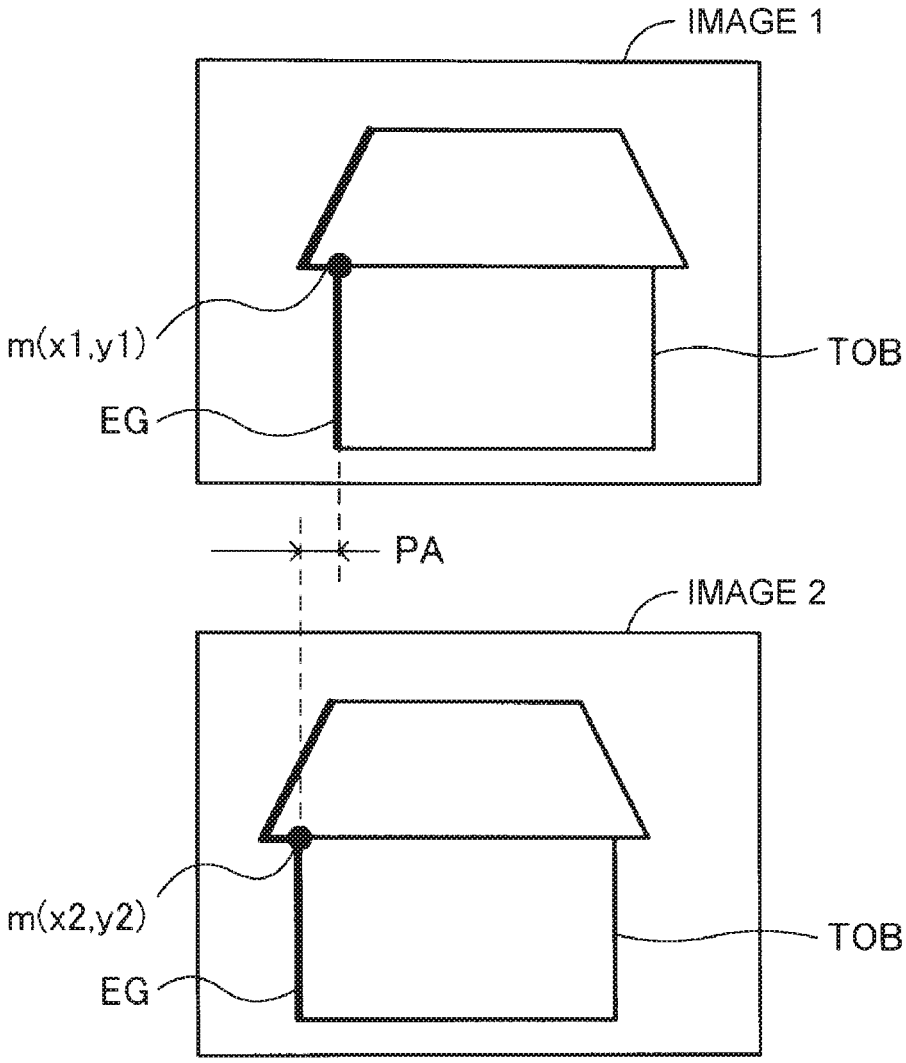


FIG. 9

FIG.10

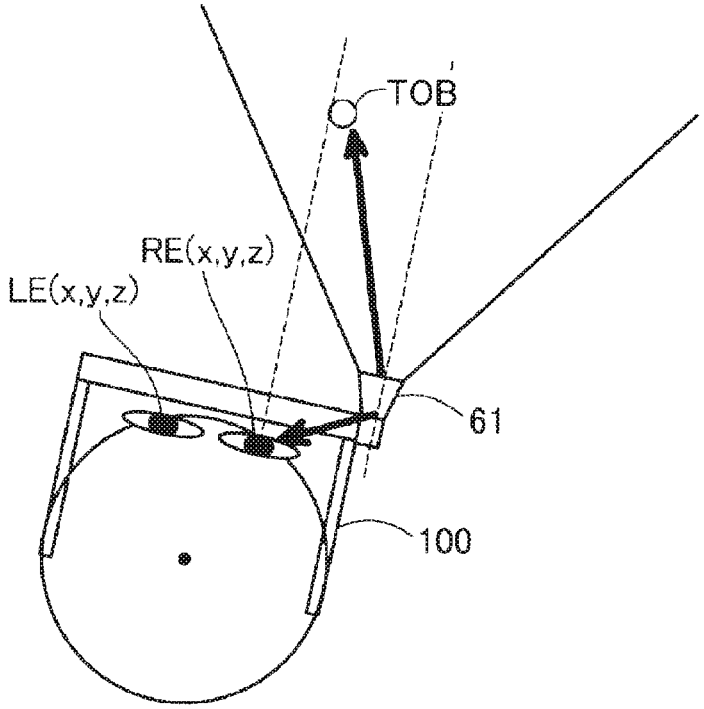
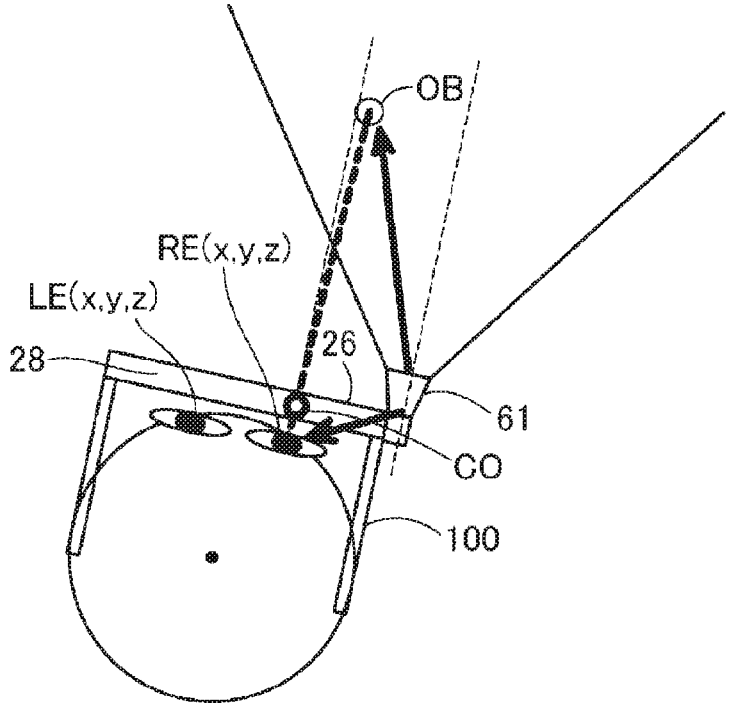


FIG.11



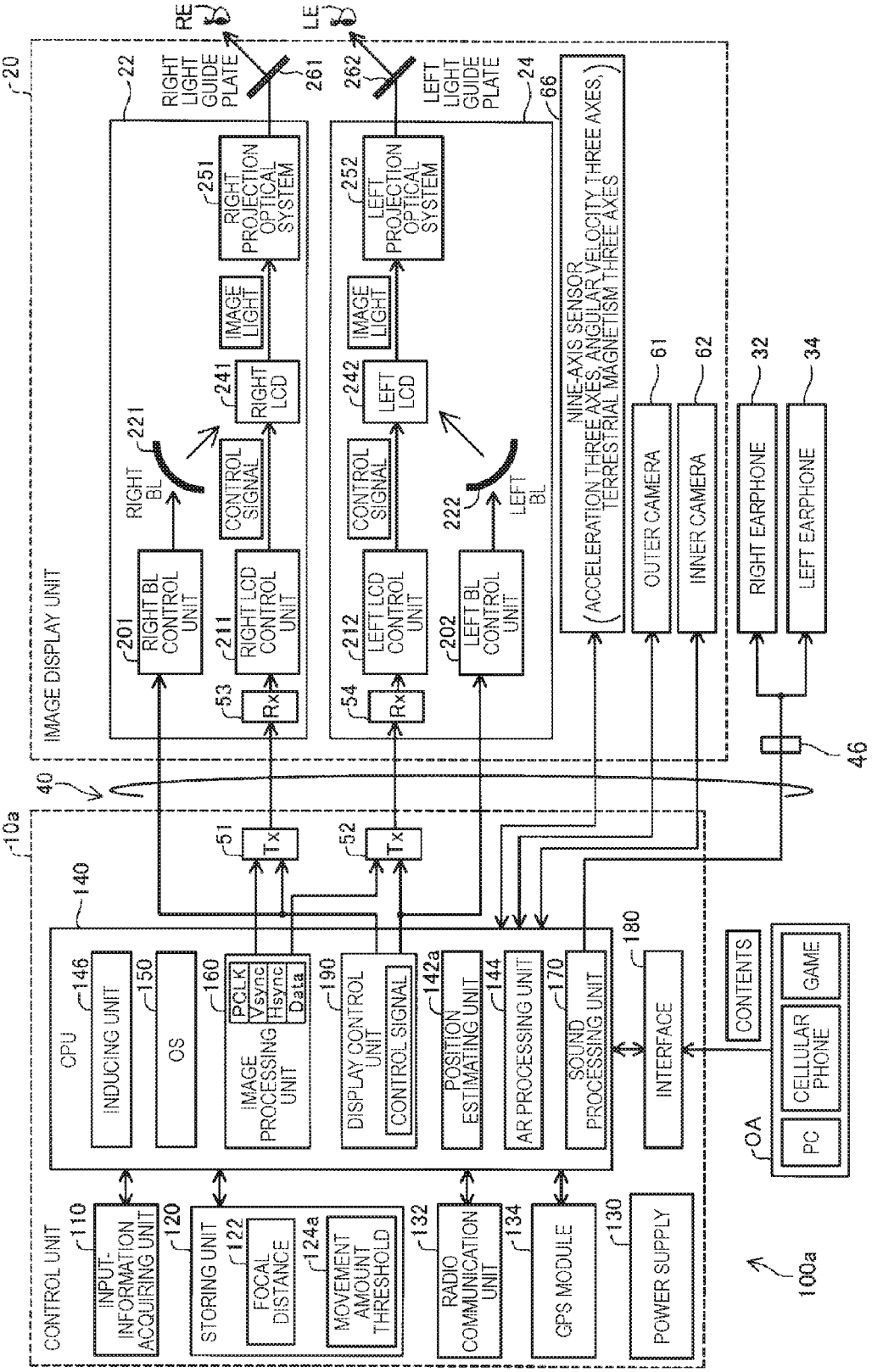

100a
CONTROL UNIT
10a
INPUT-INFORMATION ACQUIRING UNIT
110
STORING UNIT
120
FOCAL DISTANCE
122
MOVEMENT AMOUNT THRESHOLD
124a
RADIO COMMUNICATION UNIT
132
GPS MODULE
134
POWER SUPPLY
130
CPU
140
INDUCING UNIT
146
OS
150
IMAGE PROCESSING UNIT
160
PCLK
Vsync
Hsync
Data
DISPLAY CONTROL UNIT
190
CONTROL SIGNAL
POSITION ESTIMATING UNIT
142a
AR PROCESSING UNIT
144
SOUND PROCESSING UNIT
170
INTERFACE
180
Tx
51
Tx
52
40
46
OA
PC
CELLULAR PHONE
CONTENTS
GAME
IMAGE DISPLAY UNIT
20
RIGHT BL CONTROL UNIT
201
RIGHT LCD CONTROL UNIT
211
Rx
53
RIGHT BL
221
CONTROL SIGNAL
RIGHT LCD
241
IMAGE LIGHT
RIGHT PROJECTION OPTICAL SYSTEM
251
RIGHT LIGHT GUIDE PLATE
22
261
RE
LEFT BL CONTROL UNIT
202
LEFT LCD CONTROL UNIT
212
Rx
54
LEFT BL
222
CONTROL SIGNAL
LEFT LCD
242
IMAGE LIGHT
LEFT PROJECTION OPTICAL SYSTEM
252
LEFT LIGHT GUIDE PLATE
24
262
LE
NINE-AXIS SENSOR
(ACCELERATION THREE AXES, ANGULAR VELOCITY THREE AXES, TERRESTRIAL MAGNETISM THREE AXES)
66
OUTER CAMERA
61
INNER CAMERA
62
RIGHT EARPHONE
32
LEFT EARPHONE
34

FIG. 12

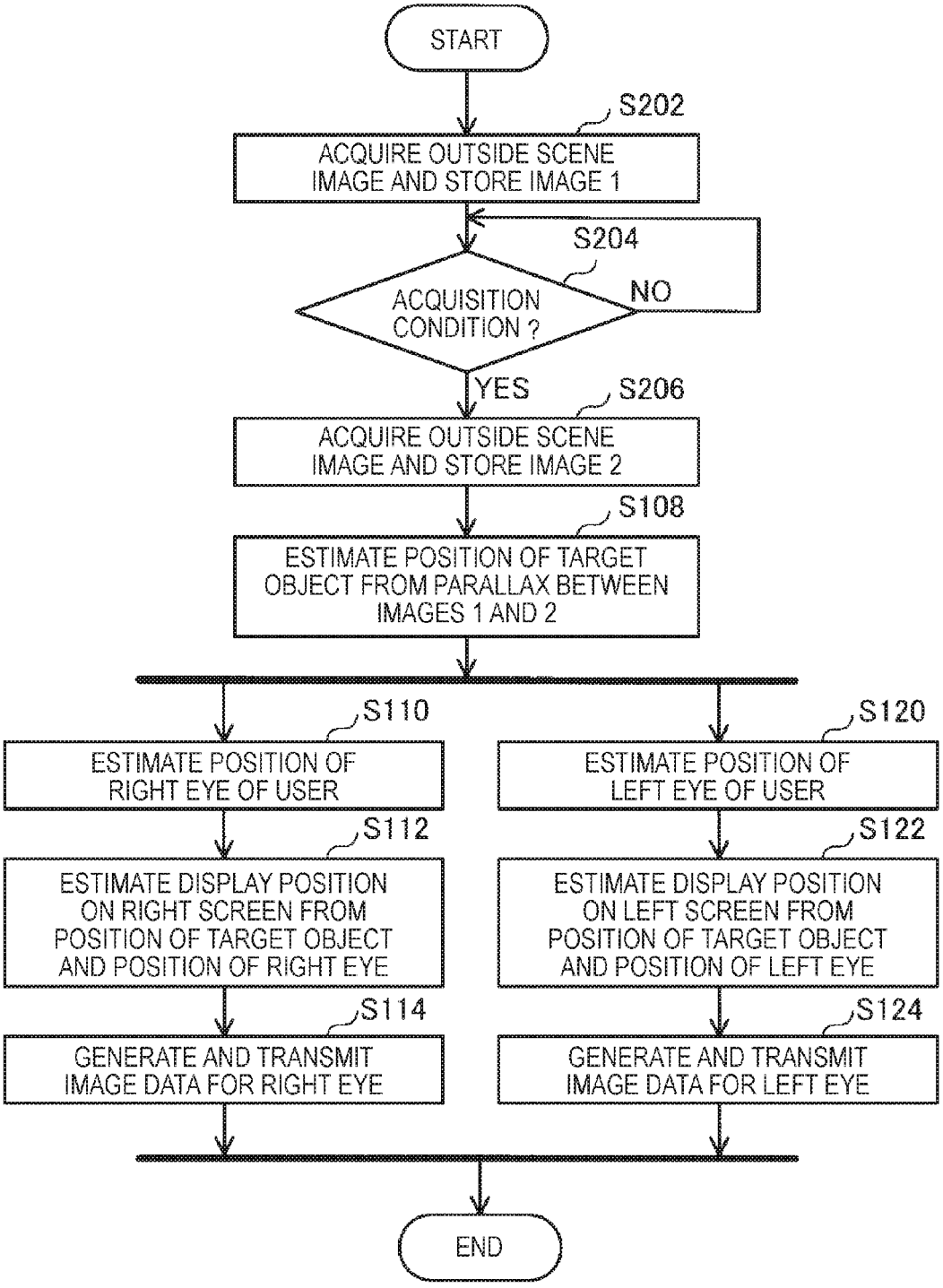

START
S202
ACQUIRE OUTSIDE SCENE IMAGE AND STORE IMAGE 1
S204
ACQUISITION CONDITION ?
NO
YES
S206
ACQUIRE OUTSIDE SCENE IMAGE AND STORE IMAGE 2
S108
ESTIMATE POSITION OF TARGET OBJECT FROM PARALLAX BETWEEN IMAGES 1 AND 2
S110
ESTIMATE POSITION OF RIGHT EYE OF USER
S112
ESTIMATE DISPLAY POSITION ON RIGHT SCREEN FROM POSITION OF TARGET OBJECT AND POSITION OF RIGHT EYE
S114
GENERATE AND TRANSMIT IMAGE DATA FOR RIGHT EYE
S120
ESTIMATE POSITION OF LEFT EYE OF USER
S122
ESTIMATE DISPLAY POSITION ON LEFT SCREEN FROM POSITION OF TARGET OBJECT AND POSITION OF LEFT EYE
S124
GENERATE AND TRANSMIT IMAGE DATA FOR LEFT EYE
END

FIG.13

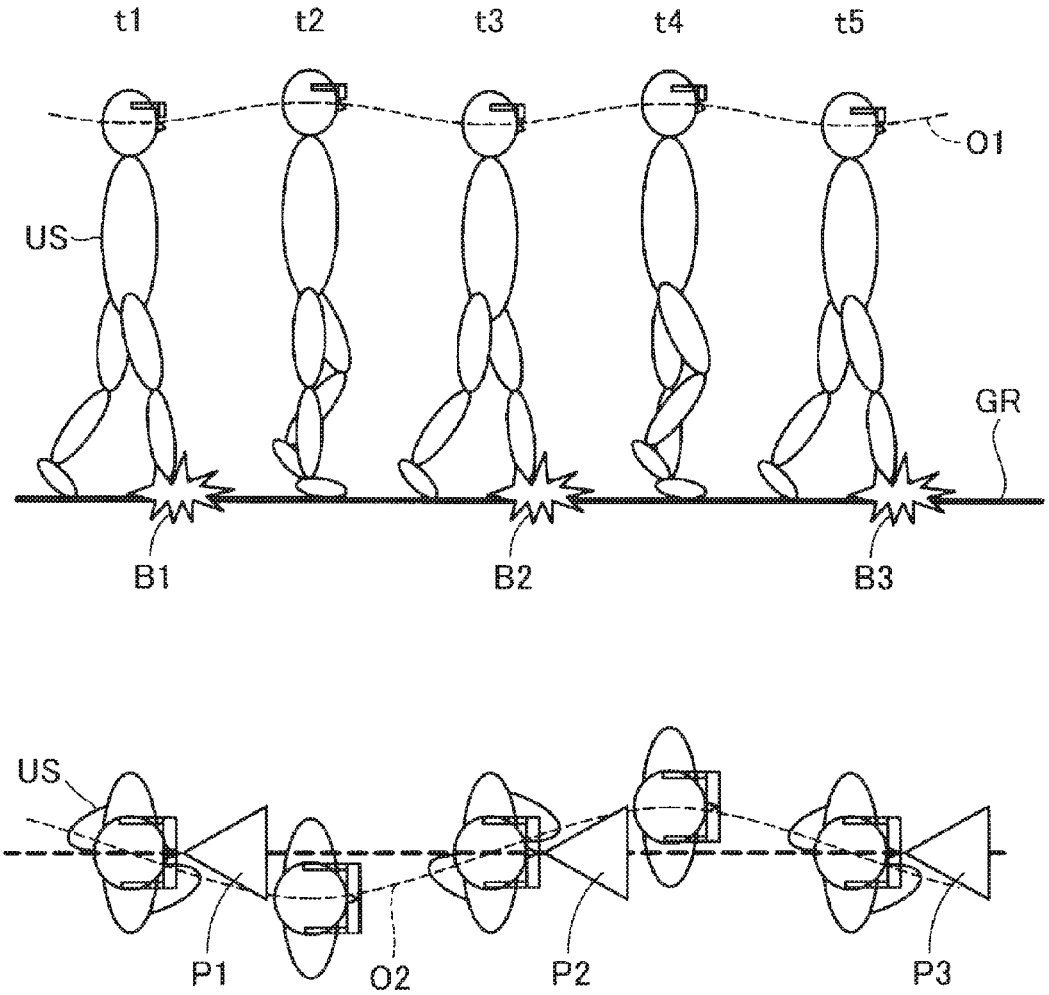


FIG.14

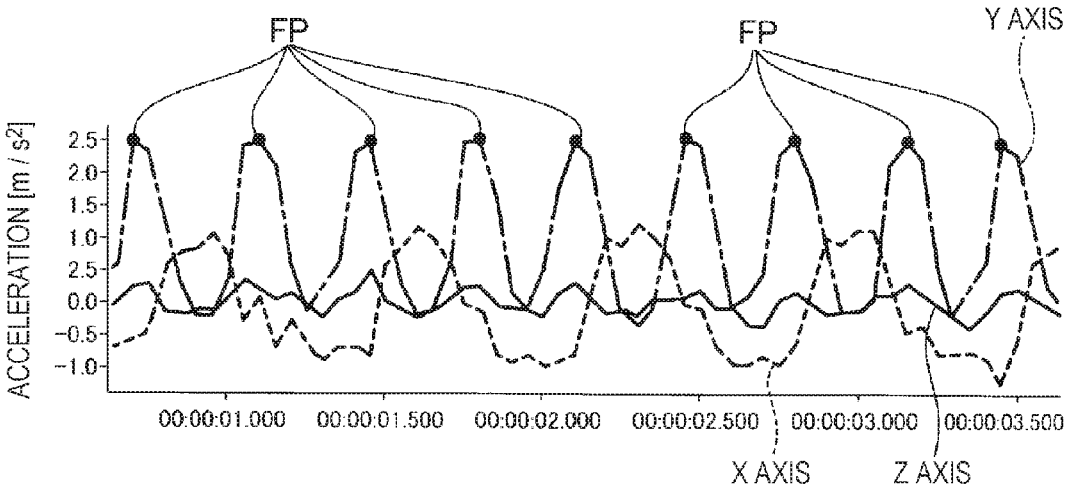

FP
FP
Y AXIS
ACCELERATION [m / s²]
2.5
2.0
1.5
1.0
2.5
0.0
−0.5
−1.0
00:00:01.000
00:00:01.500
00:00:02.000
00:00:02.500
00:00:03.000
00:00:03.500
X AXIS
Z AXIS

FIG.15

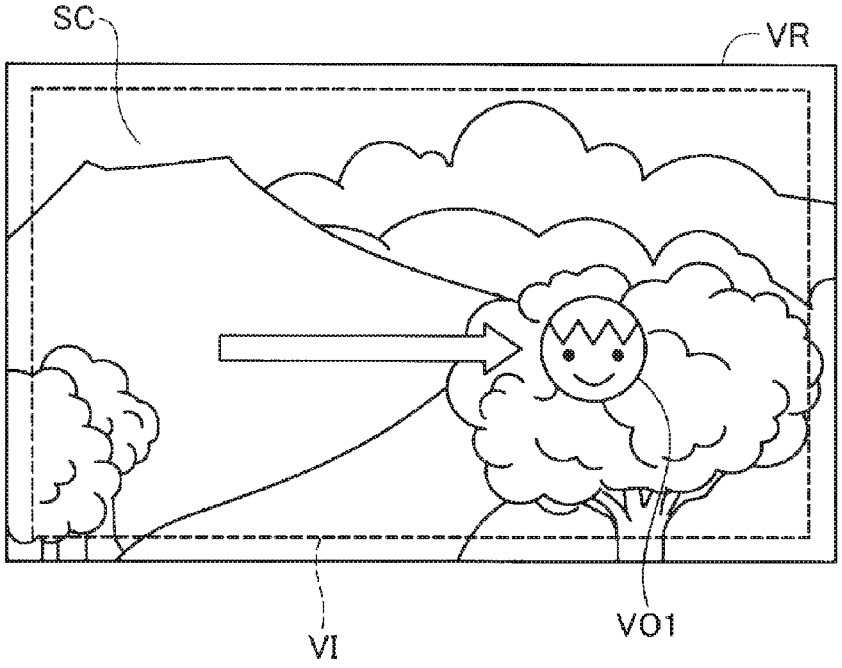

SC
VR
VI
VO1

FIG.16

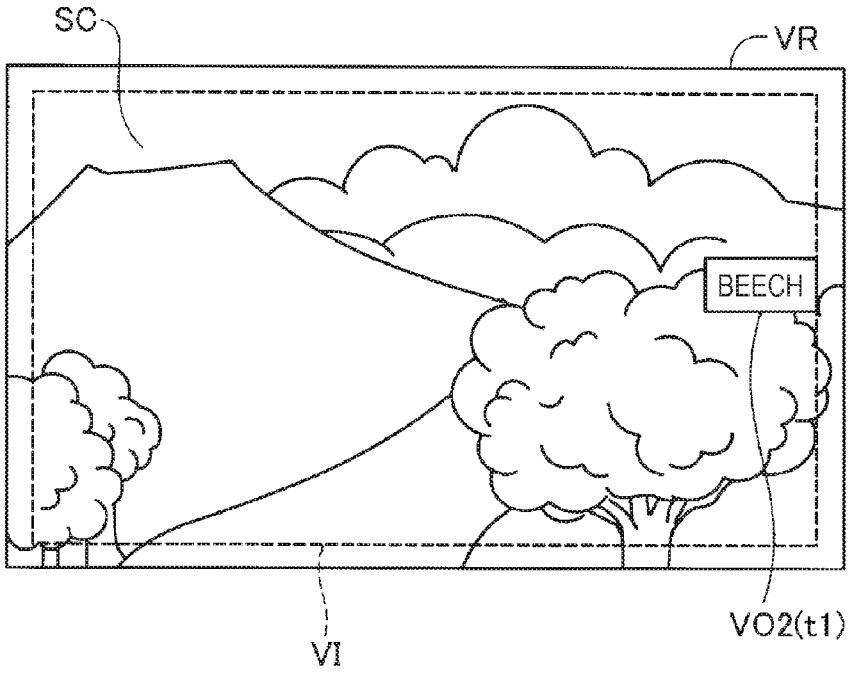


FIG.17

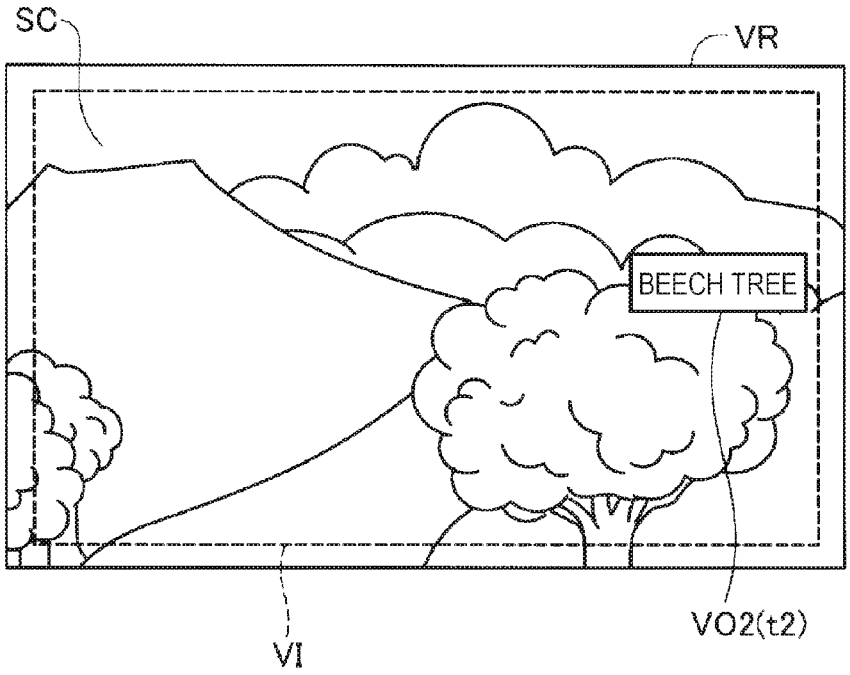


FIG.18

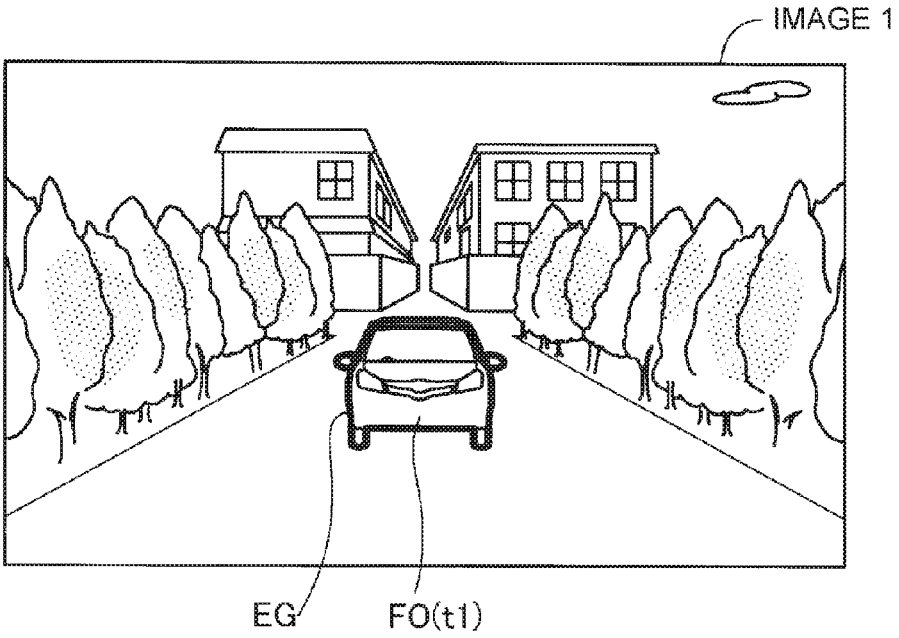


FIG.19

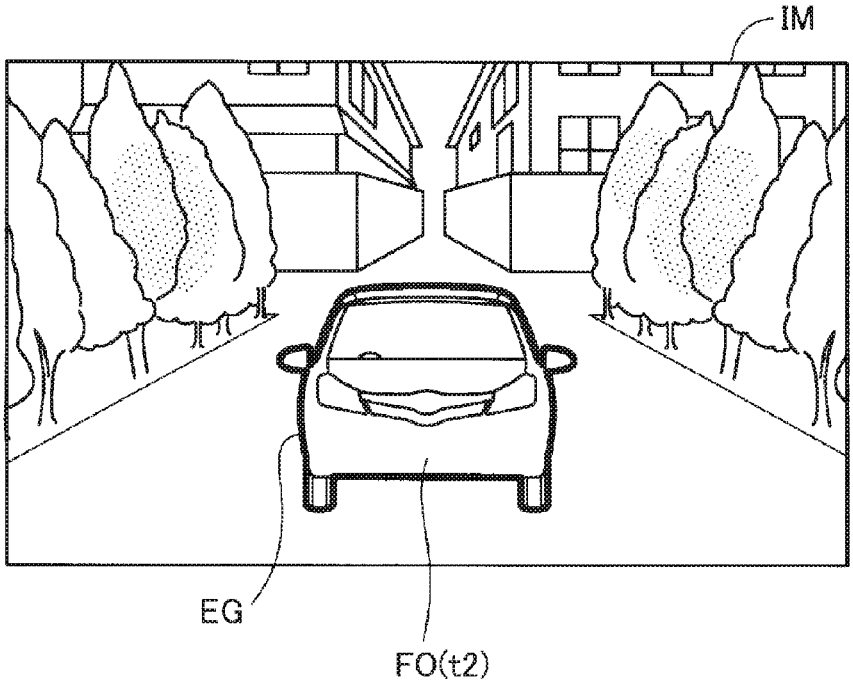


FIG.20

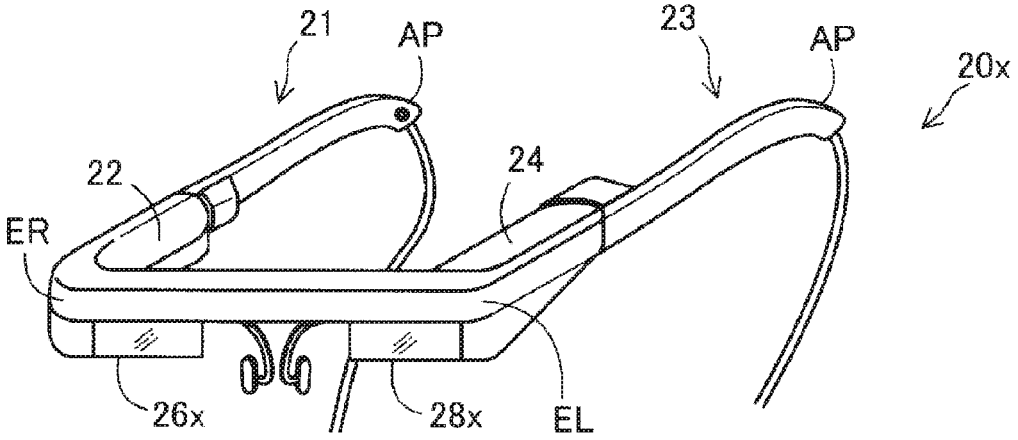


FIG.21A

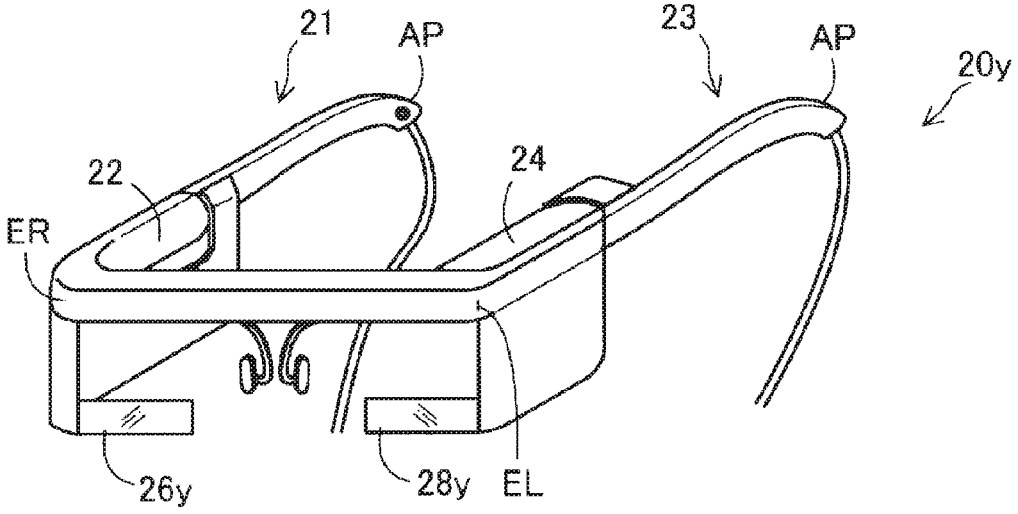


FIG.21B

HEAD-MOUNTED DISPLAY DEVICE, CONTROL METHOD FOR HEAD-MOUNTED DISPLAY DEVICE, AND COMPUTER PROGRAM

[0001] This is a Continuation of U.S. application Ser. No. 14/626,103 filed Feb. 19, 2015, which claims the benefit of priority of Japanese Application Nos. 2014-224114 and 2014-054395 filed Nov. 4, 2014 and Mar. 18, 2014, respectively. The disclosure of the prior applications are hereby incorporated by reference herein in their entirety.

BACKGROUND

1. Technical Field

[0002] The present invention relates to a head-mounted display device.

2. Related Art

[0003] There is known a head-mounted display device mounted on the head of an observer and used to form a virtual image in a visual field area of the observer. The head-mounted display device is also called head mounted display (HMD). As the head-mounted display device, there are a non-transmissive head-mounted display device that blocks the visual field of a user in a mounted state and a transmissive head-mounted display device that does not block the visual field of a user in a mounted state.

[0004] On the other hand, there is known a technique called augmented reality (AR) for additionally presenting information in a real environment using a computer. In order to realize the augmented reality in the transmissive head-mounted display device, the transmissive head-mounted display device causes a liquid crystal display to display only information for additional presentation (e.g., characters and images) for decorating an object present in the real world. A user can bodily sense the augmented reality by visually recognizing both of the information for additional presentation displayed as a virtual image via the liquid crystal display and an outside scene of the real world seen via lenses in front of the eyes.

[0005] When the augmented reality is realized by the transmissive head-mounted display device in this way, if a deviation between a position where the information for additional presentation is displayed as a virtual image and the object in the real world increases, the user feels a sense of discomfort. Therefore, there is a demand for grasping the position of the object in the real world when the augmented reality is realized. JP-A-2003-316510 (Patent Literature 1) describes a technique for grasping the position of the object in the real world using a stereo camera configured by a camera with two or more lenses.

[0006] In a technique described in Patent literature 1, the camera with two or more lenses is necessary to grasp the position of the object in the real world. Techniques described in JP-A-2011-259341 (Patent Literature 2) and JP-A-2005-122100 (Patent Literature 3) do not take into account that the position of the object in the real world is grasped in the head-mounted display device. Note that such problems occur not only when the position of the object in the real world is grasped using an image of an outside scene acquired by the camera but also when the position of the object in the real world is grasped using information concerning an outside scene (hereinafter referred to as "outside scene information") acquired by other means (e.g., an infrared sensor).

[0007] Therefore, there is a demand for a head-mounted display device capable of grasping the position of the object in the real world using single outside scene information acquiring means. Besides, there is a demand for a reduction in size, a reduction in costs, resource saving, facilitation of manufacturing, improvement of usability, and the like for the head-mounted display device.

SUMMARY

[0008] An advantage of some aspects of the invention is to solve at least a part of the problems described above, and the invention can be implemented as the following aspects.

[0009] (1) An aspect of the invention provides a head-mounted display device with which a user can visually recognize a virtual image and an outside scene. The head-mounted display device includes: an image display unit configured to cause the user to visually recognize the virtual image; an outside-scene acquiring unit configured to acquire outside scene information including at least a feature of the outside scene in a visual field direction of the user; a position estimating unit configured to estimate, on the basis of at least two kinds of the outside scene information acquired by the outside-scene acquiring unit over time, the position of any target object present in a real world; and an augmented-reality processing unit configured to cause the image display unit to form, on the basis of the estimated position of the target object, the virtual image representing a virtual object to be added to the target object. With the head-mounted display device in this aspect, the position estimating unit estimates the position of the target object with respect to the outside-scene acquiring unit on the basis of the at least two kinds of outside scene information acquired by the outside-scene acquiring unit over time. Therefore, it is possible to provide the head-mounted display device capable of grasping the position of any target object present in the real world using single outside scene information acquiring means (e.g., a monocular camera). The augmented-reality processing unit causes the image display unit to form, on the basis of the estimated position of the target object, the virtual image representing the virtual object to be added to the target object. Therefore, it is possible to reduce a deviation between the target object, which is an object in the real world, and the virtual object displayed as the virtual image.

[0010] (2) In the head-mounted display device according to the aspect described above, the position estimating unit may estimate the position of the target object using first outside scene information and second outside scene information acquired according to a movement amount of the outside-scene acquiring unit after acquisition of the first outside scene information. With the head-mounted display device according to this aspect, it is possible to improve accuracy of the estimation of the position of the target object in the position estimating unit. For example, when the movement amount of the outside-scene acquiring unit is equal to or larger than a predetermined amount, the position estimating unit acquires the second outside scene information. Then, if the predetermined amount is designed as appropriate, the position estimating unit can estimate the position of the target object using the first outside scene information in which a difference between features of the

outside scene included in the outside scene information is large and the second outside scene information.

[0011] (3) The head-mounted display device according to the aspect described above may further include a first motion detecting unit configured to detect motion of the head of the user. The position estimating unit may estimate the movement amount of the outside-scene acquiring unit from the motion of the head detected by the first motion detecting unit. With the head-mounted display device according to this aspect, the position estimating unit can estimate the movement amount of the outside-scene acquiring unit using the motion of the head of the user and acquire the second outside scene information. Therefore, the position estimating unit can estimate the position of the target object using a difference between features of the outside scene included the first and second outside scene information caused when the user moves the head.

[0012] (4) The head-mounted display device according to the aspect described above may further include a second motion detecting unit configured to detect motion of the body of the user. The position estimating unit may estimate the movement amount of the outside-scene acquiring unit from the motion of the body detected by the second motion detecting unit. With the head-mounted display device according to this aspect, the position estimating unit can estimate the movement amount of the outside-scene acquiring unit using the motion of the body of the user and acquire the second outside scene information. Therefore, the position estimating unit can estimate the position of the target object using a difference between features of the outside scene included the first and second outside scene information caused when the user moves the body.

[0013] (5) The head-mounted display device according to the aspect described above may further include a present-position acquiring unit configured to acquire present position information of the user. The position estimating unit may estimate the movement amount of the outside-scene acquiring unit from the present position information acquired by the present-position acquiring unit. With the head-mounted display device according to this aspect, the position estimating unit can estimate the movement amount of the outside-scene acquiring unit using the present position information of the user and acquire the second outside scene information. Therefore, even in a head-mounted display device not including a component configured to detect motion of the user (motion of the head or motion of the body), the position estimating unit can acquire the second outside scene information.

[0014] (6) The head-mounted display device according to the aspect described above may further include an inducing unit configured to cause the image display unit to form the virtual image for inducing motion of the user. With the head-mounted display device according to this aspect, the inducing unit induces motion of the user (motion of the head or motion of the body). Therefore, the position estimating unit can easily acquire the second outside scene information.

[0015] (7) In the head-mounted display device according to the aspect described above, the position estimating unit may estimate the position of the target object using first outside scene information and second outside scene information acquired according to a difference between features of the outside scene included in the outside scene information after acquisition of the first outside scene. With the head-mounted display device according to this aspect, it is possible to improve accuracy of the estimation of the position of the target object in the position estimating unit. For example, when the difference between the features of the outside scene included in the outside scene information is equal to or larger than a predetermined amount, the position estimating unit acquires the second outside scene information. Then, if the predetermined amount is designed as appropriate, the position estimating unit can estimate the position of the target object using the first outside scene information in which the difference between the features of the outside scene included in the outside scene information is large and the second outside scene information.

[0016] (8) In the head-mounted display device according to the aspect described above, the position estimating unit may calculate a parallax between the first outside scene information and the second outside scene information and estimate the position of the target object using the calculated parallax, the movement amount of the outside-scene acquiring unit, and a focal length of the outside-scene acquiring unit. With the head-mounted display device according to this aspect, the position estimating unit can estimate the position of the target object using the parallax between the first outside scene information and the second outside scene information, the movement amount of the outside-scene acquiring unit, and the focal length of the outside-scene acquiring unit.

[0017] (9) In the head-mounted display device according to the aspect described above, the position estimating unit may calculate the parallax with reference to an edge of the target object included in the first outside scene information and an edge of the target object included in the second outside scene information. With the head-mounted display device according to this aspect, the position estimating unit calculates the parallax with reference to the edges of the target object included in the first and second outside scene information. Therefore, the position estimating unit can accurately calculate the parallax between the first outside scene information and the second outside scene information.

[0018] (10) In the head-mounted display device according to the aspect described above, the image display unit may include an optical-image display unit configured to form the virtual image in front of the eye of the user. The position estimating unit may further calculate the position of the optical image corresponding to an extended line of the estimated position of the target object and the position of the eye of the user. The augmented-reality processing unit may determine the position of the virtual object on the basis of the calculated position of the optical-image display unit. With the head-mounted display device according to this aspect, the augmented-reality processing unit determines the position of the virtual object on the basis of the position of the optical-image display unit corresponding to the extended line of the position of the target object and the position of the eye of the user. That is, the augmented-reality processing unit can determine the position of the virtual object on the basis of the position of the target object visually recognized by the user through the optical-image display unit. As a result, the augmented-reality processing unit can display, in a position where the user does not feel a sense of discomfort, the virtual object to be added to the target object.

[0019] (11) The head-mounted display device according to the aspect described above may further include an eye-image acquiring unit configured to acquire an image of the eye of the user. The position estimating unit may analyze the

image of the eye acquired by the eye-image acquiring unit, acquire the size of the eye of the user, and estimate the position of the eye of the user on the basis of the acquired size of the eye. With the head-mounted display device according to this aspect, the position estimating unit can estimate the position of the eye of the user on the basis of the image of the eye acquired by the eye-image acquiring unit.

[0020] (12) In the head-mounted display device according to the aspect described above, the eye-image acquiring unit may be arranged near the outside-scene acquiring unit. With the head-mounted display device according to this aspect, the eye-image acquiring unit is arranged near the outside-scene acquiring unit. Therefore, it is possible to improve accuracy of the estimation of the position of the eye of the user by the position estimating unit.

[0021] Not all of a plurality of constituent elements in the aspects of the invention are essential. In order to solve a part or all of the problems described above or in order to attain a part or all of effects described in this specification, it is possible to perform a change, deletion, replacement with new constituent elements, and partial deletion of limited contents concerning a part of the plurality of constituent elements as appropriate. In order to solve a part or all of the problems described above or in order to attain a part or all of the effects described in this specification, it is also possible to combine a part or all of technical features included in one aspect of the invention described above with a part or all of technical features included in the other aspects of the invention described above to obtain an independent aspect of the invention.

[0022] For example, one aspect of the invention can be implemented as a device including a part or all of the four components, i.e., the image display unit, the outside-scene acquiring unit, the augmented-reality processing unit, and the position estimating unit. That is, the device may or may not include the image display unit. The device may or may not include the outside-scene acquiring unit. The device may or may not include the augmented-reality processing unit. The device may or may not include the position estimating unit. Such a device can be implemented as, for example, a head-mounted display device but can also be implemented as devices other than the head-mounted display device. A part or all of the technical features of the aspects of the head-mounted display device can be applied to the device.

[0023] Note that the invention can be implemented in various forms. The invention can be implemented in forms of, for example, a head-mounted display device, a control method for the head-mounted display device, a head-mounted display system, a computer program for implementing functions of the method, the device, or the system, and a recording medium having the computer program recorded therein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

[0025] FIG. **1** is an explanatory diagram showing the schematic configuration of a head-mounted display device in an embodiment of the invention.

[0026] FIG. **2** is a block diagram functionally showing the configuration of the HMD.

[0027] FIGS. **3**A and **3**B are explanatory diagrams showing an example of a virtual image visually recognized by a user.

[0028] FIG. **4** is a flowchart for explaining a procedure of augmented reality processing.

[0029] FIG. **5** is an explanatory diagram for explaining step S**102** of the augmented reality processing.

[0030] FIG. **6** is an explanatory diagram for explaining step S**104** of the augmented reality processing.

[0031] FIG. **7** is an explanatory diagram for explaining step S**106** of the augmented reality processing.

[0032] FIG. **8** is an explanatory diagram for explaining step S**108** of the augmented reality processing.

[0033] FIG. **9** is an example an image **1** and an image **2**.

[0034] FIG. **10** is an explanatory diagram for explaining step S**110** of the augmented reality processing.

[0035] FIG. **11** is an explanatory diagram for explaining step S**112** of the augmented reality processing.

[0036] FIG. **12** a block diagram functionally showing the configuration of an HMD in a second embodiment.

[0037] FIG. **13** is a flowchart for explaining a procedure of augmented reality processing in the second embodiment.

[0038] FIG. **14** is a diagram for explaining an example of step S**204** (a method a2) of the augmented reality processing.

[0039] FIG. **15** is a diagram for explaining another example of step S**204** (the method a2) of the augmented reality processing.

[0040] FIG. **16** is a diagram showing an example of a virtual image for inducing motion of a user.

[0041] FIG. **17** is a diagram showing another example of the virtual image for inducing motion of the user.

[0042] FIG. **18** is a diagram showing another example of the virtual image for inducing motion of the user.

[0043] FIG. **19** is a diagram for explaining step S**204** (a condition b) of the augmented reality processing.

[0044] FIG. **20** is a diagram for explaining step S**204** (the condition b) of the augmented reality processing.

[0045] FIGS. **21**A and **21**B are explanatory diagrams showing the configurations of the external appearances of HMDs in a modification.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

A. First Embodiment

A-1. Configuration of a Head-Mounted Display Device

[0046] FIG. **1** is an explanatory diagram showing the schematic configuration of a head-mounted display device in an embodiment of the invention. A head-mounted display device **100** is a display device mounted on a head and is also called head mounted display (HMD). The HMD **100** in this embodiment is an optically transmissive head-mounted display device with which a user can visually recognize a virtual image and at the same time directly visually recognize an outside scene. Note that, in this embodiment, the virtual image visually recognized by the user using the HMD **100** is also referred to as "displayed image" for convenience. Emitting image light generated on the basis of image data is also referred to as "display an image".

[0047] The HMD **100** includes an image display unit **20** that causes the user to visually recognize the virtual image in a state in which the image display unit **20** is worn on the

head of the user and a control unit (a controller) **10** that controls the image display unit **20**.

[0048] The image display unit **20** is a wearing body worn on the head of the user. In this embodiment, the image display unit **20** has an eyeglass shape. The image display unit **20** includes a right holding unit **21**, a right display driving unit **22**, a left holding unit **23**, a left display driving unit **24**, a right optical-image display unit **26**, a left optical-image display unit **28**, an outer camera **61**, an inner camera **62**, and a nine-axis sensor **66**. The right optical-image display unit **26** and the left optical-image display unit **28** are respectively arranged to be located in front of the right and left eyes of the user when the user wears the image display unit **20**. One end of the right optical-image display unit **26** and one end of the left optical-image display unit **28** are connected to each other in a position corresponding to the middle of the forehead of the user when the user wears the image display unit **20**.

[0049] The right holding unit **21** is a member provided to extend from an end portion ER, which is the other end of the right optical-image display unit **26**, to a position corresponding to the temporal region of the user when the user wears the image display unit **20**. Similarly, the left holding unit **23** is a member provided to extend from an end portion EL, which is the other end of the left optical-image display unit **28**, to a position corresponding to the temporal region of the user when the user wears the image display unit **20**. The right holding unit **21** and the left holding unit **23** hold the image display unit **20** on the head of the user like temples of eyeglasses.

[0050] The right display driving unit **22** is arranged on the inner side of the right holding unit **21**, in other words, a side opposed to the head of the user when the user wears the image display unit **20**. The left display driving unit **24** is arranged on the inner side of the left holding unit **23**. Note that, in the following explanation, the right holding unit **21** and the left holding unit **23** are also collectively simply referred to as "holding units". The right display driving unit **22** and the left display driving unit **24** are also collectively simply referred to as "display driving units". The right optical-image display unit **26** and the left optical-image display unit **28** are also collectively simply referred to as "optical-image display units".

[0051] The display driving units include liquid crystal displays (hereinafter referred to as "LCDs") **241** and **242** and projection optical systems **251** and **252** (see FIG. **2**). Details of the configuration of the display driving units are explained below. The optical-image display units functioning as optical members include light guide plates **261** and **262** (see FIG. **2**) and dimming plates. The light guide plates **261** and **262** are formed of a light transmissive resin material or the like and guide image lights output from the display driving units to the eyes of the user. The dimming plates are thin plate-like optical elements and are arranged to cover the front side (a side opposite to the side of the eyes of the user) of the image display unit **20**. The dimming plates protect the light guide plates **261** and **262** and suppress damage, adhesion of soil, and the like to the light guide plates **261** and **262**. By adjusting the light transmittance of the dimming plates, it is possible to adjust an external light amount entering the eyes of the user and adjust easiness of visual recognition of the virtual image. Note that the dimming plates can be omitted.

[0052] The outer camera **61** is arranged in a position corresponding to the right temple of the user when the user wears the image display unit **20**. The outer camera **61** picks up an image of an outside scene (a scene on the outside) in the front side direction of the image display unit **20**, in other words, a visual field direction of the user in a state in which the HMD **100** is worn and acquires an outside scene image. The outer camera **61** is a so-called visible light camera. The outside scene image acquired by the outer camera **61** is an image representing the shape of an object from visible light emitted from the object. The outer camera **61** functions as an "outside-scene acquiring unit" and "outside-scene-information acquiring means". The outside scene image functions as "outside scene information".

[0053] Note that, as the outside-scene acquiring unit, any configuration can be adopted as long as the outside-scene acquiring unit can acquire "outside scene information" including at least features of the outside scene in the visual field direction of the user. For example, the outside-scene acquiring unit may be configured by an infrared sensor, an ultrasonic sensor, a radar, or the like instead of the visible light camera. In this case, a detection value by the sensor or the radar functions as the "features of the outside scene".

[0054] The inner camera **62** is arranged in a position corresponding to the right temple of the user when the user wears the image display unit **20**. The inner camera **62** picks up an image of the rear side direction of the image display unit **20**, in other words, the left and right eyes of the user in the state in which the HMD **100** is worn and acquires an image of the eyes of the user. The inner camera **62** is a so-called visible light camera like the outer camera **61**. The inner camera **62** functions as an "eye-image acquiring unit". The inner camera **62** is used for estimating the distance between the outer camera **61** and the eyes of the user in augmented reality processing. Therefore, the inner camera **62** is preferably arranged near the outer camera **61**.

[0055] The nine-axis sensor **66** is arranged in a position corresponding to the right temple of the user when the user wears the image display unit **20**. The nine-axis sensor **66** is a motion sensor that detects acceleration (three axes), angular velocity (three axes), and terrestrial magnetism (three axes). The nine-axis sensor **66** is provided in the image display unit **20**. Therefore, when the image display unit **20** is worn on the head of the user, the nine-axis sensor **66** functions as a "first motion detecting unit" that detects motion of the head of the user. The motion of the head includes the velocity, the acceleration, the angular velocity, the direction, and a change in the direction of the head.

[0056] The image display unit **20** further includes a connecting unit **40** for connecting the image display unit **20** to the control unit **10**. The connecting unit **40** includes a main body cord **48** connected to the control unit **10**, a right cord **42** and a left cord **44**, which are two cords branching from the main body cord **48**, and a coupling member **46** provided at a branching point. The right cord **42** is inserted into a housing of the right holding unit **21** from a distal end portion AP in an extending direction of the right holding unit **21** and connected to the right display driving unit **22**. Similarly, the left cord **44** is inserted into a housing of the left holding unit **23** from a distal end portion AP in an extending direction of the left holding unit **23** and connected to the left display driving unit **24**. A jack for connecting an earphone plug **30** is provided in the coupling member **46**. A right earphone **32** and a left earphone **34** extend from the earphone plug **30**.

[0057] The image display unit **20** and the control unit **10** perform transmission of various signals via the connecting unit **40**. Connectors (not shown in the figure), which fit with each other, are respectively provided at an end of the main body cord **48** on the opposite side of the coupling member **46** and in the control unit **10**. The control unit **10** and the image display unit **20** are connected and disconnected according to fitting and unfitting of the connector of the main body cord **48** and the connector of the control unit **10**. For example, a metal cable or an optical fiber can be adopted as the right cord **42**, the left cord **44**, and the main body cord **48**.

[0058] The control unit **10** is a device for controlling the HMD **100**. The control unit **10** includes a determination key **11**, a lighting unit **12**, a display switching key **13**, a track pad **14**, a luminance switching key **15**, a direction key **16**, a menu key **17**, and a power switch **18**. The determination key **11** detects pressing operation and outputs a signal for determining contents of the operation in the control unit **10**. The lighting unit **12** notifies, with a light emission state thereof, an operation state of the HMD **100**. As the operation state of the HMD **100**, there is, for example, ON/OFF of a power supply. As the lighting unit **12**, for example, an LED (Light Emitting Diode) is used. The display switching key **13** detects pressing operation and outputs, for example, a signal for switching a display mode of a content moving image to **3**D and **2**D.

[0059] The track pad **14** detects operation by a finger of the user on an operation surface of the track pad **14** and outputs a signal corresponding to detected content. As the track pad **14**, various types such as an electrostatic type, a pressure type, and an optical type can be adopted. The luminance switching key **15** detects pressing operation and outputs a signal for increasing or reducing the luminance of the image display unit **20**. The direction key **16** detects pressing operation on keys corresponding to the up, down, left, and right directions and outputs a signal corresponding to detected content. The power switch **18** detects slide operation of the switch to switch a power supply state of the HMD **100**.

[0060] FIG. **2** is a block diagram functionally showing the configuration of the HMD **100**. The control unit **10** includes an input-information acquiring unit **110**, a storing unit **120**, a power supply **130**, a radio communication unit **132**, a GPS module **134**, a CPU **140**, an interface **180**, and transmitting units (Tx) **51** and **52**. The units are connected to one another by a not-shown bus.

[0061] The input-information acquiring unit **110** acquires signals corresponding to operation input to the determination key **11**, the display switching key **13**, the track pad **14**, the luminance switching key **15**, the direction key **16**, the menu key **17**, and the power switch **18**. Note that the input-information acquiring unit **110** can acquire operation inputs by various methods other than the operation inputs explained above. For example, the input-information acquiring unit **110** may acquire an operation input by a foot switch (a switch operated by the foot of the user). For example, a visual-line detecting unit such as an infrared sensor may be provided in the image display unit **20**. The visual-line detecting unit may detect a visual line of the user and acquire an operation input by a command associated with movement of the visual line. For example, a gesture of the user may be detected using the outer camera **61**. An operation input by a command associated with the gesture may be acquired. In the gesture detection, a fingertip of the user, a ring worn on the hand of the user, a medical instrument held by the user, or the like can be used as a mark for motion detection. If the operation input by the foot switch or the visual line can be acquired, even in work in which it is difficult for the user to release the hands, the input-information acquiring unit **110** can acquire the operation input from the user.

[0062] The storing unit **120** is configured by a ROM, a RAM, a DRAM, a hard disk, or the like. Various computer programs such as an operating system (OS) are stored in the storing unit **120**. The storing unit **120** includes a focal length **122** and a movement amount threshold **124**.

[0063] The focal length **122** is a storage area for storing a focal length of the outer camera **61** in advance. As the focal length of the outer camera **61** stored in the focal length **122**, a predetermined value is stored as a default value. The predetermined value stored in the focal length **122** may be changed by the user. In the movement amount threshold **124**, threshold representing "a movement amount of the outer camera **61**" for performing second image pickup by the outer camera **61** in augmented reality processing explained below is stored. The threshold stored in the movement amount threshold **124** may be changed by the user.

[0064] The power supply **130** supplies electric power to the units of the HMD **100**. As the power supply **130**, for example, a secondary cell can be used. The radio communication unit **132** performs radio communication with other apparatuses according to a predetermined radio communication standard such as a wireless LAN or a Bluetooth (registered trademark). The GPS module **134** receives a signal from a GPS satellite to thereby detect the present position of the user of the HMD **100** and generates present position information representing present position information of the user. The present position information can be implemented by, for example, coordinates representing latitude and longitude.

[0065] The CPU **140** reads out and executes a computer program stored in the storing unit **120** to thereby function as an OS **150**, an image processing unit **160**, a sound processing unit **170**, a display control unit **190**, a position estimating unit **142**, and an AR (Augmented Reality) processing unit **144**.

[0066] The position estimating unit **142** estimates the position of an object, which is present in the real world, with respect to the outer camera **61** in the augmented reality processing explained below. The position estimating unit **142** estimates position of a right eye RE and a left eye LE of the user with respect to the outer camera **61** in the augmented reality processing. The AR processing unit **144** cooperates with the position estimating unit **142** to thereby realize the augmented reality processing. The augmented reality processing is processing for realizing augmented reality, in other words, processing for displaying an image representing information for additional presentation (e.g., characters and images) for expanding (adding) the object in the real world. Note that the AR processing unit **144** is equivalent to an "augmented-reality processing unit".

[0067] The image processing unit **160** generates a signal on the basis of contents (a video) input via the interface **180** or the radio communication unit **132**. The image processing unit **160** supplies the generated signal to the image display unit **20** via the connecting unit **40**. The signal to be supplied to the image display unit **20** is different in an analog format and a digital format. In the case of the analog format, the

image processing unit **160** acquires an image signal included in the contents, separates synchronization signals such as a vertical synchronization signal VSync and a horizontal synchronization signal HSync from the acquired image signal, and generates a clock signal PCLK with a PLL circuit or the like according to cycles of the synchronization signals. The image processing unit **160** converts an analog image signal, from which the synchronization signals are separated, into a digital image signal using an A/D conversion circuit or the like. The image processing unit **160** stores the digital image signal after the conversion in a DRAM in the storing unit **120** frame by frame as image data Data of RGB data. On the other hand, in the case of the digital format, the image processing unit **160** generates and transmits the clock signal PCLK and the image data Data. Specifically, when the contents are the digital format, the clock signal PCLK is output in synchronization with the image signal. Therefore, the generation of the vertical synchronization signal VSync and the horizontal synchronization signal HSync and the A/D conversion for the analog image signal are unnecessary. Note that the image processing unit **160** may execute, on the image data Data stored in the storing unit **120**, image processing such as resolution conversion processing, various kinds of tone correction processing for adjustment of luminance and chroma, and keystone correction processing.

[0068] The image processing unit **160** transmits the clock signal PCLK, the vertical synchronization signal VSync, and the horizontal synchronization signal HSync generated by the image processing unit **160** and the image data Data stored in the DRAM in the storing unit **120** respectively via the transmitting units **51** and **52**. Note that the image data Data transmitted via the transmitting unit **51** is referred to as "image data for right eye Data**1**" as well. The image data Data transmitted via the transmitting unit **52** is referred to as "image data for left eye Data**2**" as well. The transmitting units **51** and **52** function as a transceiver for serial transmission between the control unit **10** and the image display unit **20**.

[0069] The display control unit **190** generates control signals for controlling the right display driving unit **22** and the left display driving unit **24**. Specifically, the display control unit **190** individually controls, using the control signals, ON/OFF of driving of the right and left LCDs **241** and **242** by right and left LCD control units **211** and **212** and ON/OFF of driving of right and left backlights **221** and **222** by the right and left backlight control units **201** and **202** to thereby control generation and emission of image lights by the right display driving unit **22** and the left display driving unit **24**. The display control unit **190** transmits control signals for the right LCD control unit **211** and the left LCD control unit **212** respectively via the transmitting units **51** and **52**. The display control unit **190** respectively transmits control signals for the right backlight control unit **201** and the left backlight control unit **202**.

[0070] The sound processing unit **170** acquires a sound signal included in the contents, amplifies the acquired sound signal, and supplies the amplified sound signal to a not-shown speaker in the right earphone **32** or a not-shown speaker in the left earphone **34** connected to the coupling member **46**. Note that, for example, when a Dolby (registered trademark) system is adopted, processing for the sound signal is performed. Different sounds, the frequencies or the like of which are varied, are respectively output from the right earphone **32** and the left earphone **34**.

[0071] The interface **180** is an interface for connecting various external apparatuses OA, which are supply sources of contents, to the control unit **10**. Examples of the external apparatuses OA include a personal computer PC, a cellular phone terminal, and a game terminal. As the interface **180**, for example, a USB interface, a micro USB interface, or an interface for a memory card can be used.

[0072] The image display unit **20** includes the right display driving unit **22**, the left display driving unit **24**, the right light guide plate **261** functioning as the right optical-image display unit **26**, the left light guide plate **262** functioning as the left optical-image display unit **28**, the outer camera **61**, the inner camera **62**, and the nine-axis sensor **66**.

[0073] The right display driving unit **22** includes a receiving unit (Rx) **53**, the right backlight (BL) control unit **201** and the right backlight (BL) **221** functioning as a light source, the right LCD control unit **211** and the right LCD **241** functioning as a display element, and the right projection optical system **251**. Note that the right backlight control unit **201**, the right LCD control unit **211**, the right backlight **221**, and the right LCD **241** are collectively referred to as "image-light generating unit" as well.

[0074] The receiving unit **53** functions as a receiver for serial transmission between the control unit **10** and the image display unit **20**. The right backlight control unit **201** drives the right backlight **221** on the basis of an input control signal. The right backlight **221** is, for example, a light emitting body such as an LED or an electroluminescence (EL). The right LCD control unit **211** drives the right LCD **241** on the basis of the clock signal PCLK, the vertical synchronization signal VSync, the horizontal synchronization signal HSync, and the image data for right eye Data**1** input via the receiving unit **53**. The right LCD **241** is a transmissive liquid crystal panel on which a plurality of pixels are arranged in a matrix shape.

[0075] The right projection optical system **251** is configured by a collimate lens that changes the image light emitted from the right LCD **241** to light beams in a parallel state. The right light guide plate **261** functioning as the right optical-image display unit **26** guides the image light output from the right projection optical system **251** to the right eye RE of the user while reflecting the image light along a predetermined optical path. For the optical-image display unit, any system can be used as long as the optical-image display unit forms a virtual image in front of the eyes of the user using the image light. For example, a diffraction grating may be used or a semitransparent reflection film may be used.

[0076] The left display driving unit **24** includes a configuration same as the configuration of the right display driving unit **22**. That is, the left display driving unit **24** includes a receiving unit (Rx) **54**, the left backlight (BL) control unit **202** and the left backlight (BL) **222** functioning as a light source, the left LCD control unit **212** and the left LCD **242** functioning as a display element, and the left projection optical system **252**. Detailed explanation is omitted.

[0077] FIGS. **3**A and **3**B are explanatory diagrams showing examples of a virtual image visually recognized by the user. FIG. **3**A illustrates a visual field VR of the user during normal display processing. The image lights guided to both the eyes of the user of the HMD **100** are focused on the retinas of the user, whereby the user visually recognizes a virtual image VI. In the example shown in FIG. **3**A, the

virtual image VI is a standby screen of the OS of the HMD **100**. The user visually recognizes an outside scene SC through the right optical-image display unit **26** and the left optical-image display unit **28**. In this way, concerning a portion where the virtual image VI is displayed in the visual field VR, the user of the HMD **100** in this embodiment can view the virtual image VI and the outside scene SC behind the virtual image VI. Concerning a portion where the virtual image VI is not displayed in the visual field VR, the user can directly view the outside scene SC through the optical-image display units.

[0078] FIG. **3**B illustrates the visual field VR of the user during the augmented reality processing. In the augmented reality processing, the AR processing unit **144** generates image data representing information for additional presentation (e.g., characters and images) to be added to an object present in the real world and transmits the generated image data to the image display unit **20**. "The object present in the real world" means any object included in a real environment around the user. The object present in the real world and serving as a target of the augmented reality processing is also referred to as "target object". The target object can be determined by any method. For example, all objects included in the outside scene SC visually recognized by the user may be set as target objects. Objects selected by the user out of the objects included in the outside scene SC may be set as target objects. Contents reproduced in the HMD **100** or objects selected according to an application executed in the HMD **100** may be set as target objects out of the objects included in the outside scene SC. "Adding to the object" means that information is, for example, added to or deleted from the target object, highlighted, or attenuated. Information to be, for example, added to or deleted from the target object, highlighted, or attenuated (information for additional presentation) is also referred to as "virtual object". In the example shown in FIG. **3**B, an image VOB (a virtual object VOB) representing an apple is displayed as the virtual image VI to overlap a real road (the target object) included in the outside scene SC. Consequently, the user can obtain a feeling as if the apple is fallen on the road where nothing is present.

A-2. Augmented Reality Processing

[0079] FIG. **4** is a flowchart showing a procedure of the augmented reality processing. The augmented reality processing is triggered by a processing start request from the OS **150** or any application and started.

[0080] FIG. **5** is an explanatory diagram for explaining step S**102** of the augmented reality processing. In step S**102** in FIG. **4**, the position estimating unit **142** instructs the outer camera **61** to perform image pickup and acquires an outside scene image in a visual field direction of the user of the HMD **100** including the target object TOB (FIG. **5**) of the augmented reality processing. The position estimating unit **142** stores the acquired outside scene image in the storing unit **120**. Note that, for convenience of explanation, the outside scene image acquired in step S**102** is also referred to as "image **1**". The image **1** functions as "first outside scene information". For convenience of illustration, in FIGS. **5** to **7**, **10**, and **11**, the outer camera **61** is highlighted.

[0081] FIG. **6** is an explanatory diagram for explaining step S**104** of the augmented reality processing. In step S**104** in FIG. **4**, the position estimating unit **142** determines whether a movement amount M**2** (FIG. **6**) of the outer camera **61** starting from a point in time when the image **1** is acquired in step S**102** is equal to larger than a threshold stored in the movement amount threshold **124**. Specifically, the position estimating unit **142** repeatedly acquires motion (velocity, acceleration, angular velocity, a direction, and a change in the direction) of the head of the user of the HMD **100** from the nine-axis sensor **66**. The position estimating unit **142** estimates, from an acquired rotation amount M**1** of the head, the movement amount M**2** of the outer camera **61** starting from the point in time when the image **1** is acquired. In this way, the position estimating unit **142** in this embodiment estimates a movement amount of the outer camera **61** using the motion of the head of the user wearing the HMD **100**.

[0082] Thereafter, when the estimated movement amount M**2** of the outer camera **61** is smaller than the threshold of the movement amount threshold **124** in step S**104** in FIG. **4**, the position estimating unit **142** transitions the processing to step S**104** and continues monitoring of the movement amount M**2**. On the other hand, when the estimated movement amount M**2** of the outer camera **61** is equal to or larger than the threshold of the movement amount threshold **124**, the position estimating unit **142** transitions the processing to step S**106**.

[0083] FIG. **7** is an explanatory diagram for explaining step S**106** of the augmented reality processing. In step S**106** of FIG. **4**, the position estimating unit **142** instructs the outer camera **61** to perform image pickup and acquires an outside scene image in a visual field direction of the user of the HMD **100** including the target object TOB (FIG. **7**) of the augmented reality processing. The position estimating unit **142** stores the acquired outside scene image in the storing unit **120** in a form distinguishable from the image **1** acquired in step S**102**. Note that, for convenience of explanation, the outside scene image acquired in step S**106** is also referred to as "image **2**". The image **2** functions as "second outside scene information".

[0084] In step S**108** in FIG. **4**, the position estimating unit **142** estimates the position of the target object with respect to the outer camera **61** from a parallax between the image **1** and the image **2** using a technique of stereo image processing. Note that the "position" to be estimated by the position estimating unit **142** includes a distance between the HMD **100** and the target object and a direction of the target object with respect to the HMD **100**. Specifically, the position estimating unit **142** can estimate the position of the target object TOB with respect to the outer camera **61** as explained below.

[0085] FIG. **8** is an explanatory diagram for explaining step S**108** of the augmented reality processing. FIG. **9** is an example of the image **1** and the image **2**. In FIG. **8**, a focal point of image pickup of the image **1** is represented as P**1** and a focal point of image pickup of the image **2** is represented as P**2**. A projection point of the target objet TOB on an image pickup surface PP**1** of the image **1** is represented as m(x1, y1) and a projection point of the target object TOB on an image pickup surface PP**2** of the image **2** is represented as m (x2, y2). Further, a point on a real space of the target object TOB is represented as TOB (X, Y, Z). OA**1** represent a parallel optical axis of the outer camera **61** in step S**102**. OA**2** is a parallel optical axis of the outer camera **61** in step S**106**.

[0086] Movement of the outer camera **61** involved in rotation of the head of the user is movement in the horizontal

direction. Therefore, in the above explanation, y1=y2. In this case, the point TOB(X, Y, Z) on the real space of the target object TOB, the projection point m(x1, y1) of the target object TOB of the image **1**, and the projection point m (x2, y2) of the target object TOB of the image **2** can be represented by Expressions 1 to 3 below.

$$Z=(M2\times f)/(x1-x2) \quad (1)$$

$$X=(Z/f)\times x2 \quad (2)$$

$$Y=(Z/f)\times y2 \quad (3)$$

[0087] The distance between the focal point P**1** and the focal point P**2** can be regarded as the movement amount M**2** of the outer camera **61**. The distance f between the focal point P**1** and the image pickup surface PP**1** and the distance f between the focal point P**2** and the image pickup surface PP**2** are a focal length of the outer camera **61** stored in the focal length **122** in advance.

[0088] Therefore, first, the position estimating unit **142** measures a parallax PA (x1−x2) (FIG. **9**) between the image **1** and the image **2**. The position estimating unit **142** can calculate the point TOB(X, Y, Z) on the real space of the target object TOB using the measured parallax PA, Expressions 1 to 3, the movement amount M**2**, and the focal length f of the focal length **122**. Note that a reference point for measuring the parallax PA can be arbitrarily set. For example, the position estimating unit **142** can set an edge EG (FIG. **9**) of the target object as the reference point for measuring the parallax PA. In general, an edge can be simply calculated by an algorithm of edge detection known in general (an algorithm for specifying a part where the brightness of an image acutely changes). The edge is often detected as a set (a line) of continuous points. Therefore, in this way, the position estimating unit **142** can accurately calculate a parallax between the images **1** and **2** compared with when one point is set as a reference point. Note that the edge functions as a "feature".

[0089] FIG. **10** is an explanatory diagram for explaining step S**110** of the augmented reality processing. In step S**110** in FIG. **4**, the position estimating unit **142** estimates a position of the right eye RE (FIG. **10**) of the user with respect to the outer camera **61**. Specifically, the position estimating unit **142** instructs the inner camera **62** to perform image pickup and acquires an image of the eyes of the user. The position estimating unit **142** estimates a position RE(x, y, z) of the right eye RE of the HMD **100** with respect to the outer camera **61** on the basis of the size of the right eye RE of the user obtained by analyzing the obtained image of the eyes.

[0090] FIG. **11** is an explanatory diagram for explaining step S**112** of the augmented reality processing. In step S**112** in FIG. **4**, the position estimating unit **142** estimates a display position of a virtual object on a right screen from the position of the target object TOB and the position of the right eye RE. Specifically, the position estimating unit **142** calculates a coordinate CO of the right optical-image display unit **26** corresponding to an extended line of the position TOB(X, Y, Z) of the target object TOB estimated in step S**108** and the position RE(x, y, z) of the right eye RE of the user estimated in step S**110**.

[0091] In step S**114** in FIG. **4**, the position estimating unit **142** transmits the coordinate CO calculated in step S**112** to the AR processing unit **144**. The AR processing unit **144** converts the coordinate CO of the right optical-image display unit **26** into a coordinate COx of the right LCD **241**. Thereafter, the AR processing unit **144** generates image data for right eye Data**1** in which the virtual object is arranged in the coordinate COx and transmits the image data for right eye Data**1** to the image processing unit **160**. Note that the AR processing unit **144** only has to arrange the virtual object on the basis of the coordinate COx. Therefore, the AR processing unit **144** can arrange the virtual object in any place determined on the basis of the coordinate COx (e.g., a place apart from the coordinate COx by a predetermined distance).

[0092] In steps S**120** to S**124** in FIG. **4**, the position estimating unit **142** carries out, for the left eye LE of the user, processing same as the processing explained in steps S**110** to S**114**. That is, in step S**120**, the position estimating unit **142** estimates the position of the left eye LE of the user with respect to the outer camera **61**. In step S**122**, the position estimating unit **142** estimates a display position of the virtual object on a left screen (the left optical-image display unit **28**) from the position of the target object TOB and the position of the left eye LE. In step S**124**, the AR processing unit **144** converts a coordinate of the left optical-image display unit **28** into a coordinate of the left LCD **242**, generates image data for left eye Data**2** in which the virtual object is arranged in the coordinate after the conversion, and transmits the image data for left eye Data**2** to the image processing unit **160**.

[0093] The image processing unit **160** transmits the image data for right eye Data**1** and the image data for left eye Data**2** received from the AR processing unit **144** to the image display unit **20**. Thereafter, the display processing explained with reference to FIG. **2** is executed, whereby, as explained with reference to FIG. **3**B, the user of the HMD **100** can visually recognize a stereoscopic virtual object VOB in the visual field VR.

[0094] Note that, in the embodiment, the position estimating unit **142** estimates the position of the target object with respect to the outer camera **61** using the two images **1** and **2**. However, the position estimating unit **142** may estimate the position of the target object with respect to the outer camera **61** by using three or more images. If the three or more images are used, it is possible to improve accuracy of estimation of the position of the target object.

[0095] According to the augmented reality processing, the position estimating unit **142** estimates the position of the target object TOB with respect to the outside-scene acquiring unit of the head-mounted display device (the HMD **100**) on the basis of at least two kinds of outside scene information (the image **1** functioning as first outside scene information and the image **2** functioning as second outside scene information) acquired by the outside-scene acquiring unit (the outer camera **61**) over time. Therefore, it is possible to provide a head-mounted display device capable of grasping the position of any target object TOB present in the real world using single outside scene information acquiring means (e.g., a monocular camera). The augmented-reality processing unit (the AR processing unit **144**) causes the image display unit **20** to form, on the basis of the estimated position of the target object TOB, the virtual image VI representing the virtual object VOB to be added to the target object TOB. Therefore, it is possible to reduce a deviation between the target object TOB, which is the object in the real world, and the virtual object VOB displayed as the virtual image.

[0096] Further, according to the augmented reality processing, it is possible to improve accuracy of the estimation of the position TOB(X, Y, Z) of the target object TOB in the position estimating unit **142**. For example, as explained in the embodiment, when a movement amount of the outside-scene acquiring unit (the outer camera **61**) is equal to or larger than the predetermined amount (the movement amount threshold **124**), the position estimating unit **142** acquires the second outside scene information (the image **2**). Then, if the predetermined amount (the movement amount threshold **124**) is designed as appropriate, the position estimating unit **142** can estimate the position TOB(X, Y, Z) of the target object TOB using the outside scene information (the image **1**) in which the difference (the parallax PA, FIG. **9**) in the feature (the edge) of the outside scene included in the outside scene information is large and the second outside scene information (the image **2**).

[0097] Further, according to the augmented reality processing, the position estimating unit **142** can estimate the movement amount M2 (FIG. **6**) of the outside-scene acquiring unit (the outer camera **61**) using the motion (the rotation amount M1) of the head of the user and acquire the second outside scene information (the image **2**). Therefore, the position estimating unit **142** can estimate the position TOB (X, Y, Z) of the target object TOB using the difference (parallax PA, FIG. **9**) in the feature (the edge) of the outside scene included in the first and second outside scene information (the images **1** and **2**) caused when the user moves the head.

[0098] Further, according to the augmented reality processing, the augmented-reality processing unit **144** determines the position of the virtual object VOB on the basis of the positions of the optical-image display units (the right optical-image display unit **26** and the left optical-image display unit **28**) corresponding to extended lines of the position TOB (X, Y, Z) of the target object TOB and the positions (RE(x, y, z) and LE(x, y, z)) of the eyes of the user. That is, the augmented-reality processing unit **144** can determine the position of the virtual object VOB on the basis of the position of the target object TOB visually recognized by the user through the optical-image display units. As a result, the augmented-reality processing unit **144** can display, in a position where the user does not feel a sense of discomfort, the virtual object VOB to be added to the target object TOB.

[0099] Further, according to the augmented reality processing, the position estimating unit **142** can estimate the positions (RE(x, y, z) and LE(x, y, z)) of the eyes of the user with respect to the outside-scene acquiring unit (the outer camera **61**) of the head-mounted display device (the HMD **100**) on the basis of the image of the eyes acquired by the eye-image acquiring unit (the inner camera **62**). The eye-image acquiring unit is arranged near the outside-scene acquiring unit. Therefore, it is possible to improve accuracy when the position estimating unit **142** estimates the positions of the eyes of the user.

B. Second Embodiment

[0100] In a second embodiment of the invention, a configuration is explained in which an acquisition trigger for the second outside scene information in the position estimating unit is varied. In the following explanation, only sections having components and operations different from those in the first embodiment are explained. Note that, in the figures, components same as those in the first embodiment are denoted by reference numerals and signs same as those in the first embodiment. Detailed explanation of the components is omitted. The components and steps denoted by reference numerals and signs same as those in the first embodiment in the figures are the same as those in the first embodiment.

B-1. Configuration of a Head-Mounted Display Device

[0101] FIG. **12** is a block diagram functionally showing the configuration of an HMD **100***a* in a second embodiment. The HMD **100***a* is different from the HMD **100** in the first embodiment shown in FIG. **2** in that the HMD **100***a* includes a control unit **10***a* instead of the control unit **10**. The control unit **10***a* includes a movement amount threshold **124***a* instead of the movement amount threshold **124**, includes a position estimating unit **142***a* instead of the position estimating unit **142**, and further includes an inducing unit **146**.

[0102] In the movement amount threshold **124***a*, two threshold (a first threshold and a second threshold) used in augmented reality processing in the second embodiment are stored in advance. The first threshold is a threshold representing "a movement amount of the outer camera **61**" as in the first embodiment. The second threshold is a threshold representing "a difference between features of an outside scene". Note that the first and second thresholds stored in the movement amount threshold **124***a* may be changeable by a user. The position estimating unit **142***a* is different from the position estimating unit **142** in the first embodiment in processing content in the augmented reality processing. The inducing unit **146** causes the image display unit **20** to form a virtual image for inducing motion of the user in the augmented reality processing.

B-2. Augmented Reality Processing

[0103] FIG. **13** is a flowchart for explaining a procedure of the augmented reality processing in the second embodiment. The augmented reality processing is different from the augmented reality processing in the first embodiment shown in FIG. **4** in that the augmented reality processing includes steps S**202** to S**206** instead of the steps S**102** to S**106**.

[0104] In step S**202**, the position estimating unit **142***a* acquires an outside scene image picked up by the outer camera **61** (an outside scene image in a visual field direction of the user of the HMD **100***a* including the target object TOB of the augmented reality processing shown in FIG. **5**) picked up by the outer camera **61**. In this embodiment, the outer camera **61** is configured to repeatedly pick up an outside scene image irrespective of an instruction of the position estimating unit **142***a*. Therefore, in this step, the position estimating unit **142***a* acquires one outside scene image at a point in time when step S**202** is executed out of outside scene images repeatedly picked up. Note that, as in the first embodiment, the position estimating unit **142***a* may instruct the outer camera **61** to perform image pickup. The position estimating unit **142***a* stores the acquired outside scene image in the storing unit **120** as the "image **1**". The image **1** functions as a "first outside scene image".

[0105] In step S**204**, the position estimating unit **142***a* determines whether an acquisition condition for the next outside scene image holds. Details of the acquisition condition are explained below. When the acquisition condition

does not hold (NO in step S**204**), the position estimating unit **142***a* monitors whether the acquisition condition holds.

[0106] When the acquisition condition holds (Yes in step S**204**), in step S**206**, the position estimating unit **142***a* acquires one outside scene image at a point in time when step S**206** is executed out of the outside scene images repeatedly picked up by the outer camera **61**. The position estimating unit **142***a* stores the acquired outside scene image in the storing unit **120** as the "image **2**". The image **2** functions as a "second outside scene image".

[0107] Subsequent processing is the same as the processing in the first embodiment explained with reference to FIG. **4**.

[0108] "The acquisition condition for the next outside scene image" in step S**204** in FIG. **13** is explained. The acquisition condition in this embodiment is conditions "a" and "b" explained below. The position estimating unit **142***a* may adopt the condition "a" alone or may adopt the condition "b" alone. The position estimating unit **142***a* may adopt both of the conditions "a" and "b" and determine in step S**204** whether any one of the conditions "a" and "b" holds.

(a) When a movement amount of the outer camera **61** is equal to or larger than a predetermined amount

(b) When a difference between features of an outside scene included in the outside scene information is equal to or larger than a predetermined amount

B-2-1. Condition "a" (when a Movement Amount of the Outer Camera **61** is Equal to or Larger than the Predetermined Amount)

[0109] When the condition "a" is adopted, the position estimating unit **142***a* determines whether the movement amount M**2** (FIG. **6**) of the outer camera **61** starting from a point in time when the image **1** is acquired in step S**202** is equal to or larger than a first threshold stored in the movement amount threshold **124***a*. The position estimating unit **142***a* estimates the movement amount M**2** of the outer camera **61** using at least any one of methods a1 to a3 described below. The methods a1 to a3 may be used in combination.

[0110] (a1) In the method a1, the position estimating unit **142***a* estimates a movement amount of the outer camera **61** from motion of the head of the user. Specifically, the position estimating unit **142***a* repeatedly acquires, from the nine-axis sensor **66**, velocity, acceleration, angular velocity, a direction, and a change in the direction (hereinafter also collectively referred to as "acceleration and the like") involved in the motion of the head of the user of the HMD **100***a*.

[0111] When the motion of the head is rotational movement, the position estimating unit **142***a* calculates a rotation amount M**1** (FIG. **6**) of the head from the acquired acceleration and the like. The position estimating unit **142***a* calculates the movement amount M**2** of the outer camera **61** from the calculated rotation amount M**1** to estimate the movement amount M**2** of the outer camera **61**. Specifically, when the motion of the head is linear movement or curved line movement in X, Y, and Z axis directions, the position estimating unit **142***a* calculates a movement amount of the head from the acquired acceleration and the like. The position estimating unit **142***a* estimates a movement amount of the outer camera **61** regarding the calculated movement amount as the movement amount M**2** of the outer camera **61**. In this way, the motion of the head and the motion of the outer camera **61** include not only the rotational movement but also the liner movement and the curved line movement in the X, Y, and Z axis directions. The same applies to the methods a2 and a3 explained below. Note that, in this case, the nine-axis sensor **66** functions as the "first motion detecting unit" that detect motion of the head of the user.

[0112] As explained above, with the method a1, the position estimating unit **142***a* can estimate the movement amount M**2** (FIG. **6**) of the outside-scene acquiring unit (the outer camera **61**) using the motion of the head of the user and acquire the second outside scene information (the image **2**). The motion of the head of the user may be motion consciously performed by the user or may be motion unconsciously performed by the user. The position estimating unit **142***a* can estimate the position TOB (X, Y, Z) of the target object TOB using a difference (the parallax PA, FIG. **9**) of a feature (an edge) of an outside scene included in the first and second outside scene information (the images **1** and **2**) caused when the user moves the head.

[0113] (a2) In the method a2, the position estimating unit **142***a* estimates a movement amount of the outer camera **61** from motion of the body of the user.

[0114] FIG. **14** is a diagram for explaining an example of step S**204** (the method a2) of the augmented reality processing. In FIG. **14**, the upper figure represents transition of a change in the vertical direction of the head of a user US during walking. The lower figure represents a change in the horizontal direction of the head of the user US during the walking. The position of the head of the user US during the walking cyclically changes along the vertical direction and draws a track O**1** according to the elapse of time (t**1** to t**5**) (the upper figure in FIG. **14**). At the same time, the position of the head of the user US during the walking cyclically changes along the horizontal direction and draws a track O**2** according to the elapse of time (t**1** to t**5**) (the lower figure in FIG. **14**). As shown at times t**1**, t**3**, and t**5**, when the foot of the user US lands on the ground GR, shocks B**1**, B**2**, and B**3** involved in the landing occur. In this case, positions P**1**, P**2**, and P**3** of the outer camera **61** move by the size of a step of the user.

[0115] The position estimating unit **142***a* repeatedly acquires velocity, acceleration, angular velocity, a direction, and a change in the direction (hereinafter also collectively referred to as "acceleration and the like") detected by the nine-axis sensor **66**. In this case, the nine-axis sensor **66** functions as a "second motion detecting unit" that detects motion of the body of the user. The position estimating unit **142***a* detects the shocks B**1** to B**3** involved in the landing during the walking on the basis of change amounts of the acquired acceleration and the like. When a shock is detected, the position estimating unit **142***a* can regard a movement amount of the outer camera **61** from the last shock detection time as the size of the step of the user. Note that the size of the step of the user may be stored in the storing unit **120** in advance or may be calculated on the basis of the change amounts of the acceleration and the like. In an example of the method a2, a movement amount of the outer camera **61** is estimated in this way.

[0116] Note that the method explained above can be adopted in cases other than the landing during the walking (e.g., when the user is running, skipping, or stumbles) as long as a shock is involved in the motion of the body of the user.

[0117] FIG. **15** is a diagram for explaining another example of step S**204** (the method a2) of the augmented reality processing. In this example, the user wears a three-

axis acceleration sensor on the arm separately from the HMD **100***a*. The three-axis acceleration sensor may be incorporated in an object worn on the arm by the user such as an arm band, a wrist watch, a bracelet, or a ring. FIG. **15** represents transition of a detection value of an acceleration sensor worn on the arm of the user during walking. The X axis represents a change in acceleration due to swing of the arm in the front-back direction (in other words, the traveling direction). The Y axis represents a change in acceleration due to swing of the arm in the up-down direction (in other words, the vertical direction). The Z axis represents a change in acceleration due to swing of the arm in the left-right direction (in other words, the horizontal direction). The accelerations on the X, Y, and Z axes due to the swings of the arm of the user during the walking cyclically change according to the elapse of time as shown in the figure.

[0118] The position estimating unit **142***a* repeatedly acquires acceleration detected by the acceleration sensor worn on the arm. In this case, the acceleration sensor worn on the arm functions as the "second motion detecting unit" that detects motion of the body of the user. The position estimating unit **142***a* detects, concerning any one of the acquired accelerations on the X, Y, and Z axes, a point having a feature (hereinafter also referred to as "feature point") in a cyclical change. For example, the position estimating unit **142***a* detects, as the feature point, a point FP where the acceleration on the Y axis is the highest. When the feature point is detected, the position estimating unit **142***a* can regard a movement amount of the outer camera **61** from the last feature point detection as the size of the step of the user. Note that the size of the step of the user may be stored in the storing unit **120** in advance or may be calculated on the basis of a change amount of acceleration. In the other example of the method a2, a movement amount of the outer camera **61** is estimated in this way.

[0119] As explained above, with the method a2, the position estimating unit **142***a* can estimate a movement amount of the outer-scene acquiring unit (the outer camera **61**) using motion of the body of the user and acquire the second outside scene information (the image **2**). The motion of the body of the user may be motion consciously performed by the user or may be motion unconsciously performed by the user. The position estimating unit **142***a* can estimate the position TOB (X, Y, Z) of the target object TOB using a difference (the parallax PA, FIG. **9**) of a feature (an edge) of an outside scene included in the first and second outside scene information (the images **1** and **2**) caused when the user moves the body.

[0120] (a3) In the method a3, the position estimating unit **142***a* estimates a movement amount of the outer camera **61** from present position information of the user. Specifically, the position estimating unit **142***a* repeatedly acquires from the GPS module **134** a change in the present position information involved in movement of the user of the HMD **100***a*. The position estimating unit **142***a* calculates a movement amount of the outer camera **61** from an acquired change amount of the present position information. In this case, the GPS module **134** functions as a "present-position acquiring unit" that acquires present position information of the user.

[0121] Note that a change in the present position information of the user may be acquired by a method other than the GPS module **134**. For example, the position estimating unit **142***a* may calculate the present position information of the user according to self-contained navigation or may receive the present position information of the user from a vehicle-mounted GPS module.

[0122] As explained above, with the method a3, the position estimating unit **142***a* can estimate a movement amount of the outer camera **61** using the present position information of the user and acquire the second outside scene information (the image **2**). The movement of the user (the change in the present position) may be movement consciously performed by the user or may be movement unconsciously performed by the user. In this way, even in the HMD **100***a* not including a component that detects motion of the user (motion of the head or motion of the body), the position estimating unit **142***a* can acquire the second outside scene information (the image **2**).

[0123] As explained above, if the condition "a" (the movement amount of the outer camera **61** is equal to or larger than the predetermined amount) is adopted as the acquisition condition in step S**204**, it is possible to improve accuracy of estimation of the position of the position TOB (X, Y, Z) of the target object TOB in the position estimating unit **142***a*. For example, as explained in the embodiment, when the movement amount of the outside-scene acquiring unit (the outer camera **61**) is equal to or larger than the predetermined amount (the first threshold of the movement amount threshold **124***a*), the position estimating unit **142***a* acquires the second outside scene information (the image **2**). Then, if the predetermined amount (the first threshold of the movement amount threshold **124***a*) is designed as appropriate, the position estimating unit **142***a* can estimate the position TOB(X, Y, Z) of the target object TOB using the first outside scene information (the image **1**) in which a difference (the parallax PA, FIG. **9**) of a feature (an edge) of an outside scene included in the outside scene information is large and the second outside scene information (the image **2**).

[0124] Note that, in the methods a1 to a3, the inducing unit **146** may cause the image display unit **20** to form a virtual image for inducing motion of the user (motion of the head, motion of the body, and movement of the present position).

[0125] FIG. **16** is a diagram showing an example of the virtual image VI for inducing motion of the user. For example, the inducing unit **146** moves the object VO**1** for attracting attention of the user from one end to the other end of the visual field VR. The object VO**1** may be an image or may be a character string. The object VO**1** is preferably an image or a character string, the hue, the brightness, the chroma, the size, and the like of which are adjusted, to make it easy to attract attention of the user. In the example in FIG. **16**, the image VO**1** imitating a human face is moved from the left end to the right end of the visual field VR. Consequently, the inducing unit **146** can induce motion of the head of the user by causing the user to track the object VO**1** with the eyes.

[0126] FIGS. **17** and **18** are diagrams showing another example of the virtual image VI for inducing motion of the user. FIG. **17** shows the virtual image VI at time t**1**. FIG. **18** shows the virtual image VI at time t**2** after the time t**1**. For example, as shown in FIG. **17**, the inducing unit **146** displays, in an incomplete form, a virtual object VO**2** to be added to a target object TO**2**. In the example in FIG. **17**, a character string "beech tree", which is a virtual object to be added to a tree, is displayed in a partially cut incomplete shape.

[0127] Consequently, the inducing unit **146** can induce motion of the head of the user by causing the user to trace the incomplete object VO**2** with the eyes. In the example in FIG. **18**, when the user rotates the head and shifts the visual field VR to the right, the character string of the virtual object "beech tree" to be added to the tree is displayed in a complete form.

[0128] The inducing unit **146** may cause the image display unit **20** to form virtual images representing images c1 to c4 explained below together with or instead of the virtual image explained above. Note that the images c1 to c4 may be still images or may be moving images.

[0129] (c1) An image for inducing motion of the head or motion of the body by frightening the user. For example, a horror image for stirring fear of the user and causing the user to turn the face (the head) or the body away and a flash image for stirring fright of the user and causing the user to turn the face (the head) or the body away.

[0130] (c2) An image for instructing motion of the user to induce motion of the head, motion of the body, and movement of the present position. For example, an image of a person performing radio calisthenics, an image of a person practicing yoga, an image of a person performing stretch, and an image of a person performing shadow boxing for causing the user to imitate motion. An image for instructing movement of the user such as "please go to XX".

[0131] (c3) An image for asking questions to induce motion of the head or motion of the body. For example, an image for asking present time and an image for asking questions concerning an environment in which the user is present.

[0132] (c4) An image for causing the user to perform a predetermined gesture or predetermined motion to induce motion of the head or motion of the body. For example, it is assumed that a function for reducing the luminance of the virtual image VI when the user looks up and increasing the luminance of the virtual image VI when the user looks down is mounted on the HMD **100***a* in advance. In such a case, the luminance of the virtual image VI is increased (reduced) in order to induce operation by the user.

[0133] As explained above, if the inducing unit **146** causes the image display unit **20** to form the virtual image VI for inducing motion of the user (motion of the head, motion of the body, or movement of the present position), the position estimating unit **142***a* can easily acquire the second outside scene information (the image **2**).

B-2-2. Condition "b" (a Difference Between Features of an Outside Scene Included in the Outside Scene Information is Equal to or Larger than the Predetermined Amount)

[0134] FIGS. **19** and **20** are diagrams for explaining step S**204** (the condition "b") of the augmented reality processing. The condition "b" is effective when the user of the HMD **100***a* does not move and a target object moves. FIG. **19** is an example of the image **1** acquired in step S**202** (the time t**1**) of the augmented reality processing (FIG. **13**) in the second embodiment. FIG. **20** is an example of an outside scene image IM picked up at the time t**2** after the time t**1** among external scene images repeatedly picked up by the outer camera **61**.

[0135] The position estimating unit **142***a* detects an edge EG (a feature) of a target object FO included in the image **1** acquired in step S**202** (at the time t**1**) and an edge EG of the target object FO included in the outside scene image IM picked up at the time t**2**. The position estimating unit **142***a* determines whether a difference between the edges is equal to or larger than the second threshold stored in the movement amount threshold **124***a*. Note that the position estimating unit **142***a* may determine a difference between edges of the target object using, for example, three or more images acquired at the times t**1**, t**2**, and t**3**.

[0136] As explained above, if the condition "b" (a difference between features of an outside scene included in the outside scene information is equal to or larger than the predetermined amount) is adopted as the acquisition condition in step S**204**, it is possible to improve accuracy of estimation of the position TOB(X, Y, Z) of the target object TOB in the position estimating unit **142***a*. For example, when a difference between features (edges) of an outside scene included in the outside scene information is equal to or larger than the predetermined amount (the second threshold of the movement amount threshold **124***a*), the position estimating unit **142***a* acquires the second outside scene information (the image **2**). Then, if the predetermined amount (the second threshold of the movement amount threshold **124***a*) is designed as appropriate, the position estimating unit **142***a* can estimate the position TOB(X, Y, Z) of the object TOB using the first outside scene information (the image **1**) in which a difference between features (edges) of an outside scene included in the outside scene information is large and the second scene information (the image **2**).

[0137] As explained above, with the augmented reality processing in the second embodiment, as in the first embodiment, it is possible to provide the head-mounted display device (the HMD **100***a*) capable of grasping the position of any target object TOB present in the real world using single outside scene information acquiring means (e.g., a monocular camera).

[0138] Note that the HMD **100***a* may change, on the basis of contents being reproduced in the HMD or setting by the user, whether the condition "a" is adopted or the condition "b" is adopted, when the condition "a" is adopted, which of the method a1 to a3 is used, presence or absence of display of a virtual image for inducing motion of the user when the condition "a" is adopted, and a type of the virtual image. Consequently, it is possible to optimize conditions and the like according to the contents being reproduced and preference of the user.

C. Modifications

[0139] In the embodiment, a part of components implemented by hardware may be replaced with software. Conversely, a part of components implemented by software may be replaced with hardware. Besides, modifications explained below are also possible.

Modification 1

[0140] In the embodiment, the configuration of the HMD is illustrated. However, the configuration of the HMD can be arbitrarily set in a range not departing from the spirit of the invention. For example, addition, deletion, conversion, and the like of the components can be performed.

[0141] The allocation of the constituent elements to the control unit and the image display unit is only an example. Various forms of the allocation can be adopted. For example, forms explained below may be adopted. (i) A form in which processing functions such as a CPU and a memory are mounted on the control unit and only a display function is

mounted on the image display unit, (ii) a form in which the processing functions such as the CPU and the memory are mounted on both of the control unit and the image display unit, (iii) a form in which the control unit and the image display unit are integrated (e.g., a form in which the control unit is included in the image display unit and functions as an eyeglass-type wearable computer), (iv) a form in which a smartphone or a portable game machine is used instead of the control unit, (v) a form in which the control unit and the image display unit are connected via a wireless signal transmission line such as a wireless LAN, infrared communication, or Bluetooth (registered trademark) and a connecting unit (a cord) is removed. Note that, in this case, power supply to the control unit or the image display unit may be carried out wirelessly.

[0142] For example, the configurations of the control unit and the image display unit illustrated in the embodiment can be arbitrarily changed. Specifically, for example, in the embodiment, the control unit includes the transmitting unit, and the image display unit includes the receiving unit. However, both of the transmitting unit and the receiving unit may include a function capable of performing bidirectional communication and may function as a transmitting and receiving unit. For example, a part of the interface for operation (the keys, the track pad, etc.) included in the control unit may be omitted. Another interface for operation such as a stick for operation may be included in the control unit. Devices such as a keyboard and a mouse may be connectable to the control unit such that the control unit receives inputs from the keyboard and the mouse. For example, the secondary cell is used as the power supply. However, the power supply is not limited to the secondary cell. Various cells can be used. For example, a primary cell, a fuel cell, a solar cell, or a thermal cell may be used.

[0143] FIGS. **21**A and **21**B are explanatory diagrams showing the configurations of the external appearances of HMDs in a modification. In an example in FIG. **21**A, an image display unit **20***x* includes a right optical-image display unit **26***x* instead of the right optical-image display unit **26** and includes a left optical-image display unit **28***x* instead of the left optical-image display unit **28**. The right optical-image display unit **26***x* and the left optical-image display unit **28***x* are formed smaller than the optical member in the embodiment and are respectively arranged obliquely above the right eye and the left eye of the user when the user wears the HMD. In an example in FIG. **21**B, an image display unit **20***y* includes a right optical-image display unit **26***y* instead of the right optical-image display unit **26** and includes a left optical-image display unit **28***y* instead of the left optical-image display unit **28**. The right optical-image display unit **26***y* and the left optical-image display unit **28***y* are formed smaller than the optical member in the embodiment and are respectively arranged obliquely below the right eye and the left eye of the user when the user wears the HMD. In this way, the optical-image display units only have to be arranged near the eyes of the user. The size of optical members forming the optical-image display units also may be any size. The optical-image display units can also be implemented as an HMD of a form in which the optical-image display units cover only a portion of the eyes of the user, in other words, a form in which the optical-image display unit do not completely cover the eyes of the user.

[0144] For example, the processing units (e.g., the image processing unit and the display control unit) included in the control unit are described as being implemented by the CPU expanding, on the RAM, the computer program stored in the ROM or the hard disk and executing the computer program. However, these functional units may be configured using an ASIC (Application Specific Integrated Circuit) designed for implementing the functions.

[0145] For example, the HMD is the transmissive HMD of a binocular type. However, the HMD may be a HMD of a monocular type. The HMD may be a nontransmissive HMD that blocks transmission of an outside scene in a state in which the user wears the HMD. For example, as the image display unit, instead of the image display unit worn like eyeglasses, a normal display device (a liquid crystal display device, a plasma display device, an organic EL display device, a beam scanning-type display, etc.) may be adopted. In this case, as in the embodiment, the control unit and the image display unit may be connected via a wired signal transmission line or may be connected via a wireless signal transmission line. Consequently, the control unit can also be used as a remote controller of the normal display device. For example, as the image display unit, an image display unit of another shape such as an image display unit worn like a cap may be adopted instead of the image display unit worn like eyeglasses. As the earphone, an ear hook type or a headband type may be adopted. The earphone may be omitted. For example, the image display unit may be configured as a head-up display (HUD) mounted on vehicles such as an automobile and an airplane. For example, the image display unit may be configured as an HMD incorporated in body protective equipment such as a helmet or a portable hand held display (HHD). The image display unit may be combined with a nontransmissive HMD, which blocks transmission of an outside scene, and an outer camera to be configured as a video see-through HMD.

[0146] For example, in the embodiment, the image-light generating unit is configured using the backlight, the backlight control unit, the LCD, and the LCD control unit. However, the form is only an example. The image-light generating unit may include components for implementing another system in addition to the components or instead of the components. For example, the image-light generating unit may include an organic EL (organic Electro-Luminescence) display and an organic EL control unit. For example, the image generating unit can include a digital micro mirror device or the like instead of the LCD. For example, the invention can also be applied to a head-mounted display device of a laser retina projection type.

[0147] For example, in the embodiment, the configuration in which the outside-scene acquiring unit (the outer camera) is incorporated in the image display unit is illustrated. However, the outside-scene acquiring unit may be configured to be detachably attachable to the image display unit. Specifically, for example, as the outside-scene acquiring unit, a WEB camera detachably attachable to the image display unit using a clip or an attachment may be adopted. In this way, as in the embodiment, it is possible to estimate the position of the target object with respect to the outside-scene acquiring unit on the basis of at least two kinds of outside scene information acquired by the outside-scene acquiring unit over time. Note that, when the position of the target object is estimated, relative positions of the image display unit and the outside-scene acquiring unit may be taken into account. The relative positions of the image display unit and the outside-scene acquiring unit can be

detected by providing displacement sensors respectively in the image acquiring unit and the outside-scene acquiring unit.

[0148] For example, in the embodiment, the example of the arrangement of the outside-scene acquiring unit (the outer camera) is explained. However, the arrangement of the outer camera can be arbitrarily changed. For example, the outer camera may be arranged in a position corresponding to the middle of the forehead of the user or may be arranged in a position corresponding to the left temple of the user. An angle of view of the outer camera can also be arbitrarily set. Note that, when the angle of view of the outer camera is set wide (e.g., 360 degrees), in the augmented reality processing, a step of extracting an outside scene image including the target object out of outside scene images obtained by the outer camera may be carried out.

Modification 2

[0149] In the embodiment, the example of the augmented reality processing is explained. However, the procedure of the processing explained in the embodiment is only an example. Various modifications are possible. For example, a part of the steps may be omitted. Other steps may be added. The order of the steps to be executed may be changed.

[0150] For example, in steps **S102** and **S202**, the position estimating unit estimates a movement amount of the outer camera from the motion of the head of the user. However, a motion sensor may be added near the outer camera. A movement amount of the outer camera may be directly acquired using a detection value of the motion sensor.

[0151] For example, in steps **S104** and **S204**, the position estimating unit determines, according to whether the movement amount of the outer camera is equal to or larger than the threshold stored in the movement amount threshold, whether the image **2** is acquired. However, the position estimating unit may determine, using another condition, whether the image **2** is acquired. For example, as a condition for the determination, the position estimating unit may determine whether the position of the outer camera is a position desirable in acquiring the image **2**. "The position of the outer camera is a position desirable in acquiring the image **2**" can be a condition that, for example, a movement amount of the outer camera is equal to or larger than a predetermined amount and the position (the height) on the y axis of the outer camera does not greatly change from the point in time when the image **1** is acquired. If the condition concerning the position (the height) on the y axis of the outer camera is added, it is possible to guarantee the premise (y1=y2) in Expressions 1 to 3.

[0152] For example, in steps **S104** and **S204**, the position estimating unit may change, according to the velocity of motion of the user (motion of the head or motion of the body), the threshold used in step **S104** or **S204**. In this case, a plurality of thresholds corresponding to velocities may be stored in the movement amount threshold in the storing unit to change a threshold to be used. The threshold to be used may be changed by multiplying a threshold stored in the movement amount threshold with a coefficient corresponding to velocity. Note that the velocity of the motion of the user can be detected on the basis of, for example, acceleration detected by the nine-axis sensor.

[0153] For example, in steps **S104** and **S204**, the position estimating unit may learn a tendency of the magnitude of motion of the user (motion of the head or motion of the body) to change the threshold used in step **S104** or **S204**.

[0154] For example, in step **S108**, the position estimating unit can estimate the position of the target object with respect to the outer camera from the parallax between the image **1** and the image **2** using a publicly known technique other than the stereo image processing.

[0155] For example, in step **S108**, the position estimating unit estimates the position of the target object with respect to the outer camera from a plurality of still images. However, the position estimating unit may estimate the position of the target object with respect to the outer camera using a moving image (a set of a plurality of still images acquired over time).

[0156] For example, in step **S108**, the position estimating unit detects edges included in the outside scene image as features of the outside scene. However, the features of the outside scene are not limited to the edges. For example, the position estimating unit may use a specific position (e.g., the center) of the target object or a color of the target object as a feature of the outside scene. In this case, the position estimating unit can detect, for example, with an image analysis, specific positions or colors of the target object included in the images **1** and **2**.

[0157] For example, in steps **S110** and **S120**, the position estimating unit estimates the positions of the right eye and the left eye of the user with respect to the outer camera. However, the positions of the right eye and the left eye of the user with respect to the outer camera may be stored in the storing unit. Steps **S110** and **S120** may be omitted. The position estimating unit may estimate the positions of the right eye and the left eye with respect to the outer camera using ultrasound or an infrared ray instead of acquiring images of the eyes with the inner camera.

[0158] For example, the processing explained as being executed by the position estimating unit in the embodiment may be executed by the augmented-reality processing unit. The processing explained as being executed by the augmented-reality processing unit in the embodiment may be executed by the position estimating unit.

[0159] For example, the augmented reality processing may be repeatedly executed. When the augmented reality processing in FIG. **4** is repeated, the HMD executes steps **S102** to **S114** (**S124**) in the first processing and executes steps **S104** to **S114** (**S124**) in the second and subsequent processing. When the augmented reality processing in FIG. **13** is repeated, the HMD executes steps **S202** to **S114** (**S124**) in the first processing and executes steps **S204** to **S114** (**S124**) in the second and subsequent processing. In these cases, the image **1** is replaced with an image n (n is an integer equal to or larger than 1) and the image **2** is replaced with an image n+1.

Modification 3

[0160] The invention is not limited to the embodiments, the examples, and the modifications explained above and can be implemented as various configurations without departing from the spirit of the invention. For example, the technical features in the embodiments, the examples, and the modifications corresponding to the technical features in the forms described in the summary can be replaced or combined as appropriate in order to solve a part or all of the problems or attain a part or all of the effects. Unless the

technical features are explained in this specification as essential technical features, the technical features can be deleted as appropriate.

[0161] The entire disclosure of Japanese Patent Application No.:2014-054395, filed Mar. 18, 2014 and 2014-224114, filed Nov. 4, 2014 are expressly incorporated by reference herein.

What is claimed is:

1. A head-mounted display device with which a user can visually recognize a virtual image and an outside scene,

the head-mounted display device comprising:

an image display unit configured to cause the user to visually recognize the virtual image;

an outside-scene acquiring unit configured to acquire outside scene information including at least a feature of the outside scene in a visual field direction of the user;

a position estimating unit configured to estimate, on the basis of at least two kinds of the outside scene information acquired by the outside-scene acquiring unit over time, a position of any target object present in a real world; and

an augmented-reality processing unit configured to cause the image display unit to form, on the basis of the estimated position of the target object, the virtual image representing a virtual object to be added to the target object.

2. The head-mounted display device according to claim **1**, wherein the position estimating unit estimates the position of the target object using first outside scene information and second outside scene information acquired according to a movement amount of the outside-scene acquiring unit after acquisition of the first outside scene information.

3. The head-mounted display device according to claim **2**, further comprising a first motion detecting unit configured to detect motion of the head of the user, wherein

the position estimating unit estimates the movement amount of the outside-scene acquiring unit from the motion of the head detected by the first motion detecting unit.

4. The head-mounted display device according to claim **2**, further comprising a second motion detecting unit configured to detect motion of the body of the user, wherein

the position estimating unit estimates the movement amount of the outside-scene acquiring unit from the motion of the body detected by the second motion detecting unit.

5. The head-mounted display device according to claim **2**, further comprising a present-position acquiring unit configured to acquire present position information of the user, wherein

the position estimating unit estimates the movement amount of the outside-scene acquiring unit from the present position information acquired by the present-position acquiring unit.

6. The head-mounted display device according to claim **3**, further comprising an inducing unit configured to cause the image display unit to form the virtual image for inducing motion of the user.

7. The head-mounted display device according to claim **1**, wherein the position estimating unit estimates the position of the target object using first outside scene information and second outside scene information acquired according to a difference between features of the outside scene included in the outside scene information after acquisition of the first outside scene.

8. The head-mounted display device according to claim **2**, wherein the position estimating unit calculates a parallax between the first outside scene information and the second outside scene information and estimates the position of the target object using the calculated parallax, the movement amount of the outside-scene acquiring unit, and a focal length of the outside-scene acquiring unit.

9. The head-mounted display device according to claim **8**, wherein the position estimating unit calculates the parallax with reference to an edge of the target object included in the first outside scene information and an edge of the target object included in the second outside scene information.

10. The head-mounted display device according to claim **1**, wherein

the image display unit includes an optical-image display unit configured to form the virtual image in front of the eye of the user,

the position estimating unit further calculates a position of the optical-image display unit corresponding to an extended line of the estimated position of the target object and the position of the eye of the user, and

the augmented-reality processing unit determines a position of the virtual object on the basis of the calculated position of the optical-image display unit.

11. The head-mounted display device according to claim **10**, further comprising an eye-image acquiring unit configured to acquire an image of the eye of the user, wherein

the position estimating unit analyzes the image of the eye acquired by the eye-image acquiring unit, acquires size of the eye of the user, and estimates a position of the eye of the user on the basis of the acquired size of the eye.

12. The head-mounted display device according to claim **11**, wherein the eye-image acquiring unit is arranged near the outside-scene acquiring unit.

13. A method of controlling a head-mounted display device, comprising:

causing a user of the head-mounted display device to visually recognize a virtual image;

acquiring outside scene information including at least a feature of the outside scene in a visual field direction of the user;

estimating, on the basis of at least two kinds of the outside scene information acquired over time, a position of any target object present in a real world; and

forming, on the basis of the estimated position of the target object, the virtual image representing a virtual object to be added to the target object.

14. A computer program for causing a computer to implement:

a forming function for causing a user of the head-mounted display device to visually recognize a virtual image;

an acquiring function for acquiring outside scene information including at least a feature of the outside scene in a visual field direction of the user;

an estimating function for estimating, on the basis of at least two kinds of the outside scene information acquired over time, a position of any target object present in a real world; and

an augmented reality function for causing the forming function to form, on the basis of the estimated position of the target object, the virtual image representing a virtual object to be added to the target object.

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