

5 AIRCRAFT POSITION CONTROL SYSTEM, AIRCRAFT, AND AIRCRAFT
 POSITION CONTROL METHOD

 Technical Field

[0001]

10 The present invention relates to an aircraft position control system, an
 aircraft, and an aircraft position control method.

 Background Art

[0002]

15 In the related art, there are known techniques for guiding an aircraft to a
 target point. For example, Patent Literature 1 discloses a navigation system that
 performs image processing on image information of a target point acquired by a
 stereo camera to determine a distance to the target point, calculates a relative
 position of the aircraft with respect to the target point based on the distance and
20 the attitude angle of the aircraft, and generates navigation information using the
 relative position.

 Citation List

 Patent Literature

25 [0003]

 Patent Literature 1: JP 2005-115623 A

 Summary of Invention

 Technical Problem

30 [0004]

 The navigation system described in Patent Literature 1 described above
 causes the aircraft to descend while controlling the position, altitude, rate of
 descent or the like of the aircraft based on the navigation information generated
 using the relative position, so as to cause the aircraft to land on the landing
35 point. Here, the landing point may move in a case where the landing point is a
 movable body such as a marine vessel, for example. In this case, the navigation
 system described in Patent Literature 1 generates navigation information using
 the relative position, whereby it can grasp the relative position between the
 aircraft and the landing point, as well as grasping the relative velocity with
40 respect to a fixed landing point. However, Patent Literature 1 does not allow
 for appropriate control of the aircraft based on the navigation information in a
 case where the landing point is moving, and may fail to accurately and quickly

5 control the position of the aircraft such as, for example, the aircraft taking an excessive time to approach the target landing point, or passing over the target landing point.

[0005]

10 It is an object of the present invention, which has been made in consideration of the foregoing description, to move the aircraft more accurately and faster toward a target landing point moving relatively thereto.

Solution to Problem

[0006]

15 In order to solve the problems described above and achieve the object, an aircraft position control system according to the present invention includes: a relative position acquisition unit configured to acquire a relative position between an aircraft and a target landing point; a relative velocity acquisition unit configured to acquire relative velocity of the aircraft with respect to the target landing point; and a control unit configured to control the aircraft, wherein the control unit has: a feedback control unit configured to calculate a feedback manipulated variable of the aircraft by feedback control so that the aircraft heads toward the target landing point, based on at least the relative position and the relative velocity; a multi-value control unit configured to set, by referring to a switching line preliminarily provided in a manner passing through an origin of a coordinate plane whose orthogonal axes represent the relative position and the relative velocity and separating an acceleration region in which the relative velocity is increased and a deceleration region in which the relative velocity is decreased, an addition value that tends to increase the relative velocity when a coordinate point of the current relative position and the current relative velocity is located in the acceleration region, or set an addition value that tends to decrease the relative velocity when the coordinate point is located in the deceleration region with respect to the switching line; and an addition circuit configured to calculate a manipulated variable of the aircraft by adding the addition value to the feedback manipulated variable.

[0007]

40 In order to solve the problems described above and achieve the object, an aircraft position control system according to the present invention includes: a relative position acquisition unit configured to acquire a relative position between an aircraft and a target landing point; a relative velocity acquisition unit configured to acquire relative velocity between the aircraft and the target landing point; and a control unit configured to control the aircraft to head

5 toward the target landing point, based on at least the relative position and the
relative velocity, wherein the relative velocity acquisition unit calculates the
relative velocity by adding a value acquired by applying, to a differential value
of the relative position, a low-pass filter that attenuates frequencies equal to or
higher than a cutoff frequency being predetermined, and a value acquired by
10 applying, to the velocity of the aircraft, a high-pass filter that attenuates
frequencies below the cutoff frequency.
[0008]

In order to solve the problems described above and achieve the object,
an aircraft according to the present invention includes the aircraft position
15 control system.
[0009]

In order to solve the problems described above and achieve an object, an
aircraft position control method according to the present invention comprising:
acquiring a relative position between an aircraft and a target landing point;
20 acquiring relative velocity of the aircraft with respect to the target landing
point; calculating a feedback manipulated variable of the aircraft by feedback
control so that the aircraft heads toward the target landing point, based on at
least the relative position and the relative velocity; setting, by referring to a
switching line preliminarily provided in a manner passing through an origin of
25 a coordinate plane whose orthogonal axes represent the relative position and
the relative velocity and separating an acceleration region in which the relative
velocity is increased and a deceleration region in which the relative velocity is
decreased, an addition value that tends to increase the relative velocity when a
coordinate point of the current relative position and the current relative velocity
30 is located in the acceleration region, or setting an addition value that tends to
decrease the relative velocity when the coordinate point is located in the
deceleration region with respect to the switching line; and calculating a
manipulated variable of the aircraft by adding the addition value to the
feedback manipulated variable.

35

Advantageous Effects of Invention

[0010]

The aircraft position control system, the aircraft, and the aircraft
position control method according to the present invention exhibits an effect
40 that allows for moving the aircraft more accurately and faster toward a
relatively moving target landing point.

[0011]

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[0012]

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[0013]

[First Embodiment]

5 FIG. 1 is a schematic configuration diagram illustrating an example of
an aircraft position control system according to a first embodiment, and FIG. 2
is an explanatory diagram illustrating an aircraft according to the first
embodiment heading toward a target landing point. An aircraft 1 according to
the first embodiment is a flying object as a rotorcraft (e.g., helicopter, drone,
10 etc.). In the present embodiment, the aircraft 1 is an unmanned aerial vehicle.
Here, the aircraft 1 may be any flying object that can fly forward, fly backward,
turn, fly sideways, or hover, and may be a manned aerial vehicle. The aircraft 1
equipped with a position control system 100 is flight-controlled by the position
control system 100 so as to land on a target landing point 2 illustrated in FIG.

15 2.

[0014]

(Target Landing Point)

 In the present embodiment, the target landing point 2 is provided on a
marine vessel 5, as illustrated in FIG. 2. Accordingly, the aircraft 1 lands on
20 (touches down) the marine vessel 5, which is a movable body on the water.
Here, although not illustrated, the marine vessel 5 has an arresting gear
provided thereon for arresting the aircraft 1 when the aircraft 1 lands on the
target landing point 2. However, the target landing point 2 is not limited to the
marine vessel 5 and may be provided on a vehicle or the like, which is a
25 movable body on the ground, or may be provided on a fixed facility or the
ground.

[0015]

 The target landing point 2 has a marker 7 provided thereon that allows
the aircraft 1 to recognize the position of the target landing point 2. FIG. 3 is an
30 explanatory diagram illustrating an example of a marker provided on the target
landing point. As illustrated, the marker 7 is a square AR marker color-coded
with two colors, black and white, for example. Here, the marker 7 is not limited
to an AR marker and may be any marker that can recognize the position of the
target landing point 2 via image processing, such as, for example, an H mark or
35 an R mark indicating a landing point in a heliport. In addition, the marine
vessel 5 may have a plurality of markers of different shapes provided thereon
as the marker 7, and the aircraft 1 may be guided toward the target landing
point 2 corresponding to any one of the different markers 7.

[0016]

40 (Position Control System)

 An aircraft position control system 100 according to the first
embodiment is a system that controls the position of the aircraft 1 in order to

5 cause the aircraft 1 in flight to land on the target landing point 2. The position control system 100 is mounted on the aircraft 1. The position control system 100 includes, as illustrated in FIG. 1, a camera 10, a navigation system 20, and a control unit 30.

[0017]

10 (Imaging Device)

The camera 10 is an imaging device mounted on the aircraft 1 with a gimbal (not illustrated) interposed therebetween. The camera 10 may be a monocular camera, a compound-eye camera, an infrared camera or the like, provided that it can capture an image of the marker 7. The camera 10 is
 15 provided in order to capture, from the aircraft 1, an image of the marker 7 provided on the target landing point 2. It is assumed that the camera 10 can adjust the shooting direction via a gimbal (not illustrated). In the present embodiment, the camera 10 is controlled by the control unit 30 so that its shooting range B (see FIGS. 2 and 6) faces directly downward in the vertical
 20 direction, for example. Here, the camera 10 may be controlled by the control unit 30 so that its shooting range B faces diagonally forward with respect to the vertical direction. In addition, the camera 10 may be devoid of a gimbal and fixed directly below the body of the aircraft 1 so that the shooting direction faces downward in the vertical direction.

25 [0018]

(Navigation System)

The navigation system 20 is an inertial navigation system (INS), for example. Here, although the present embodiment is described applying an inertial navigation system as the navigation system 20, it is not particularly
 30 limited thereto and any type of navigation system may be used as the navigation system 20. In addition, the navigation system 20 serves as an inertial navigation system including the global positioning system (GPS) in order to improve the accuracy of position measurement. Although the present embodiment is described applying an inertial navigation system including the
 35 GPS, it is not particularly limited to the GPS and any position measurement unit that can accurately measure the position may be used, such as those using the Quasi-Zenith Satellite System, for example, and there may also be a configuration with the position measurement unit such as the GPS being omitted provided that the position can be accurately measured using only the
 40 navigation system 20. The navigation system 20 including the GPS acquires attitude angles of the aircraft 1 in the roll, yaw and pitch directions, and aircraft velocity V_h (see FIG. 4), aircraft acceleration a (see FIG. 4), an aircraft

5 heading ψ_h (see FIG. 6), and position coordinates of the aircraft 1. Here, the navigation system 20 may include an attitude angle sensor that detects the attitude angle of the aircraft 1, a velocity detection sensor that detects the aircraft velocity V_h of the aircraft 1, an acceleration detection sensor that detects the aircraft acceleration a of the aircraft 1, and a sensor that detects the aircraft heading ψ_h of the aircraft 1. The navigation system 20 outputs, to the control unit 30, the attitude angle, the aircraft velocity V_h , the aircraft acceleration a , and the position coordinates of the aircraft 1, all of which have been acquired.

[0019]

15 In addition, the position control system 100 includes, as illustrated in FIG. 1, an altitude sensor 25 that detects the altitude of the aircraft 1 from the ground level or the water surface. The altitude sensor 25 may use any of a laser altimeter, a radio altimeter, or a barometric altimeter, for example. In addition, these altimeters may also be applied in combination as appropriate, depending on the use environment, i.e., measurement of the altitude from the ground level or the altitude from the sea level. The altitude sensor 25 outputs a detected altitude of the aircraft 1 to the control unit 30. However, the position control system 100 is not limited to the altitude sensor 25, and may be one that calculates a relative altitude between the aircraft 1 and the marine vessel 5 by performing, in an image processing unit 32 described below, image processing on an image including the marker 7 captured by the camera 10.

[0020]

(Control Unit)

The control unit 30 includes the image processing unit 32, a guidance calculation unit 34, and a flight control unit 36. Here, the control unit 30 includes an imaging control unit (not illustrated) that controls the shooting direction of the camera 10 via a gimbal (not illustrated) provided on the aircraft 1. In the present embodiment, as described above, the camera 10 is adjusted so that the shooting range B faces directly downward in the vertical direction.

35 [0021]

(Image Processing Unit)

The image processing unit 32 performs image processing on an image captured by the camera 10 and calculates a center (C_x , C_y) of the marker 7, i.e., the target landing point 2 (see FIG. 3). Here, the center (C_x , C_y) is a coordinate point in a fixed camera coordinate system, with the center of the image captured by the camera 10 being an origin O_c (see FIG. 6), and can be calculated from the number of pixels from the center of the image. The

5 calculation method for the center (C_x , C_y) will be described below. The image processing unit 32 outputs the calculated center (C_x , C_y) of the marker 7 to the guidance calculation unit 34. Here, the target landing point 2 is not limited to the center (C_x , C_y) of the marker 7, and may be any of the four corners of the marker 7, or may be a position offset from the center of the marker 7.

10 [0022]

In addition, the image processing unit 32 determines the orientation of the marker 7 by performing image processing on the image including the marker 7 captured by the camera 10, and calculates a ship heading ψ_s (see FIG. 6) of the marine vessel 5 by associating the orientation of the marker 7 with the aircraft heading ψ_h of the aircraft 1 acquired by the navigation system 20. Here, as described above, the image processing unit 32 may calculate the relative altitude between the aircraft 1 and the marine vessel 5 by performing image processing on an image including the marker 7 captured by the camera 10.

[0023]

20 (Guidance Calculation Unit)

The guidance calculation unit 34 calculates a manipulated variable C' (see FIG. 4) of the aircraft 1 for guiding the aircraft 1 toward the target landing point 2. The manipulated variable C' is a manipulated variable for adjusting the aircraft velocity V_h , attitude angle, attitude rate, or the like, of the aircraft 1.

25 [0024]

Specifically, the guidance calculation unit 34 performs a relative position calculation process of calculating a relative position (X_{hg} , Y_{hg}) (see FIG. 4) between the aircraft 1 and the target landing point 2, based on the center (C_x , C_y) of the marker 7 calculated by the image processing unit 32, the aircraft heading ψ_h , and the altitude of the aircraft 1. Accordingly, the image processing unit 32 and the guidance calculation unit 34 function as a relative position acquisition unit that acquires the relative position (X_{hg} , Y_{hg}) between the aircraft 1 and the target landing point 2.

[0025]

35 In addition, the guidance calculation unit 34 performs a relative velocity calculation process that calculates relative velocity (ΔV_x , ΔV_y) (see FIG. 4) between the aircraft 1 and the target landing point 2 based on the relative position (X_{hg} , Y_{hg}) and aircraft velocity (V_x , V_y). Accordingly, the guidance calculation unit 34 functions as a relative velocity acquisition unit that acquires the relative velocity (ΔV_x , ΔV_y) between the aircraft 1 and the target landing point 2.

40 [0026]

5 In addition, as described above, the guidance calculation unit 34 calculates the relative altitude with respect to the target landing point 2, based on the altitude of the aircraft 1. Therefore, the altitude sensor 25 and the guidance calculation unit 34 function as a relative altitude acquisition unit that acquires the relative altitude between the aircraft 1 and the target landing point

10 2. Here, the image processing unit 32 serves as the relative altitude acquisition unit in a case where the relative altitude between the aircraft 1 and the marine vessel 5 is calculated in the image processing unit 32 by performing image processing on the image including the marker 7 captured by the camera 10.

[0027]

15 Subsequently, the guidance calculation unit 34, while calculating a feedback manipulated variable C by feedback control (PID control), based on the relative position (X_{hg} , Y_{hg}), the relative velocity (ΔV_x , ΔV_y), and aircraft acceleration (a_x , a_y), calculates the manipulated variable C' (see FIG. 4) by adding an addition value D to the feedback manipulated variable C via multi-

20 value control which will be described below. Here, feedback control is not limited to PID control and may be P control, PI control, PD control, or the like. Details of the calculation process in the aforementioned guidance calculation unit 34 will be described below. The guidance calculation unit 34 outputs the calculated manipulated variable C' to the flight control unit 36.

25 [0028]

(Flight Control Unit)

The flight control unit 36 controls respective components of the aircraft 1 in accordance with the manipulated variable C' calculated by the guidance calculation unit 34 described below, and assists the aircraft 1 in flight. The

30 flight control unit 36 controls the blade pitch angle, rotational speed or the like of respective rotary blades in accordance with the manipulated variable, and adjusts the aircraft velocity V_h , attitude angle, and attitude rate of the aircraft 1. Accordingly, the aircraft 1 is guided toward the target landing point 2. Note that, although the image processing unit 32 and the guidance calculation unit 34

35 are described as separate functional units from the flight control unit 36 in the present embodiment, the flight control unit 36, the image processing unit 32, and the guidance calculation unit 34 may be integrated as a single functional unit. In other words, the flight control unit 36 may substitutionally perform processes that have been supposed to be performed by the image processing

40 unit 32 and the guidance calculation unit 34.

[0029]

(Aircraft Position Control Method)

Next, a procedure of calculating the manipulated variable C' of the aircraft 1 by the control unit 30 will be described as an aircraft position control method according to embodiments. FIG. 4 is a block diagram illustrating an example of a configuration of calculating the manipulated variable of the aircraft by the guidance calculation unit. According to the block diagram illustrated in FIG. 4, the control unit 30 calculates the manipulated variable of the aircraft 1 for guiding the aircraft 1 toward the target landing point 2. Here, FIG. 4 illustrates both the component in the X direction that serves as the direction of the pitch axis, and the component in the Y direction that serves as the direction of the roll axis, with the manipulated variable of each component being calculated by the guidance calculation unit 34.

[0030]

(Relative Position Calculation Process)

The control unit 30 performs a relative position calculation process of calculating the relative position (X_{hg} , Y_{hg}) between the aircraft 1 and the target landing point 2. The relative position calculation process is performed by the image processing unit 32 and the guidance calculation unit 34 according to the procedure illustrated in FIG. 5. FIG. 5 is a flowchart illustrating an example of the relative position calculation process performed by the image processing unit and the guidance calculation unit. The flowchart illustrated in FIG. 5 is repeatedly performed by the image processing unit 32 and the guidance calculation unit 34 at a predetermined time interval. In addition, FIG. 6 is an explanatory diagram illustrating an aircraft being guided toward a target landing point. The following explanation describes calculation of the relative position between the aircraft 1 and the target landing point 2 in the horizontal direction, with the camera 10 having successfully captured the marker 7. The relative altitude of the aircraft 1 with respect to the target landing point 2 is calculated based on the altitude of the aircraft 1 detected by the altitude sensor 25, and is appropriately controlled in accordance with the relative position or the like between the aircraft 1 and the target landing point 2. Additionally, in a case where the aircraft 1 and the marine vessel 5 are separated to an extent that the camera 10 cannot capture the marker 7, the aircraft 1 is assisted to fly toward the marine vessel 5 using, for example, GPS-based position information of each other.

[0031]

The control unit 30 acquires, in the image processing unit 32, the image captured by the camera 10 (step S1). Next, the control unit 30 calculates, in the image processing unit 32, the center (C_x , C_y) of the marker 7 in the fixed

5 camera coordinate system (step S2). Specifically, as illustrated in FIG. 3, the image processing unit 32 determines, by image processing, two diagonal lines L_d extending between corners of the marker 7, and defines the intersection of the two determined diagonal lines L_d as the center (C_x, C_y) of the marker 7. Here, the image processing unit 32 may determine only one diagonal line L_d ,
 10 and may define the center position of the length of the determined diagonal line L_d as the center (C_x, C_y) of the marker 7. In addition, the image processing unit 32 may determine two or more diagonal lines L_d , and define a position that is the average of the center position of the determined diagonal lines L_d as the center (C_x, C_y) of the marker 7. Furthermore, the image processing unit 32
 15 may, when performing keystone correction of the marker 7 having a square shape using a projective transformation-based function, calculate the center (C_x, C_y) of the square based on the function. On this occasion, keystone correction may be performed using coordinate points of the four corners of the marker 7, or coordinate points of respective points along the black and white
 20 color-coded boundary of the marker 7, and other coordinate points may be calculated by interpolation.

[0032]

Next, the control unit 30 calculates, in the guidance calculation unit 34, the relative position (X_{hg}, Y_{hg}) between the aircraft 1 and the target landing
 25 point 2 based on the center (C_x, C_y) of the marker 7, orientation of the camera 10, i.e., aircraft heading ψ_h of the aircraft 1, and altitude of the aircraft 1 (relative altitude with respect to the target landing point 2) (step S3). The relative position (X_{hg}, Y_{hg}) serves as the distance between the aircraft 1 and the target landing point 2 in the horizontal direction. Note that the process at
 30 step S3 may be performed by the image processing unit 32. Specifically, the guidance calculation unit 34 first transforms the coordinates of the center (C_x, C_y) of the marker 7 calculated by the image processing unit 32 into a target coordinate point (X_{img}, Y_{img}) in the fixed camera coordinate system.

[0033]

35 Next, the guidance calculation unit 34 calculates a relative position (X_{sg}, Y_{sg}) (see FIG. 6) between the aircraft 1 and the target landing point 2 in a ship inertial reference frame S_G (see FIG. 6), based on the following Equations (1) and (2). The ship inertial reference frame S_G is a coordinate system with the target landing point 2 being an origin $O_{sg}(0, 0)$, the direction
 40 along the ship heading ψ_s of the marine vessel 5 being the X-axis, the direction orthogonal to the ship heading ψ_s in the horizontal direction being the Y axis, and the vertical direction being the Z-axis.

5 [0034]

[Math. 1]

$$\begin{bmatrix} X_{sg} \\ Y_{sg} \end{bmatrix} = R_s \begin{bmatrix} -X_{img} \\ -Y_{img} \end{bmatrix} \quad \dots (1)$$

[0035]

[Math. 2]

10
$$R_s = \begin{bmatrix} \cos(\psi_s) & \sin(\psi_s) \\ -\sin(\psi_s) & \cos(\psi_s) \end{bmatrix} \quad \dots (2)$$

[0036]

Next, the guidance calculation unit 34 calculates the relative position (Xhg, Yhg) (see FIG. 6) between the aircraft 1 and the target landing point 2 in an aircraft inertial reference frame H_G (see FIG. 6), based on the following

15 Equations (3) and (4). The aircraft inertial reference frame H_G is a coordinate system with the aircraft 1 being the origin Ohg (0, 0), the direction along the aircraft heading ψ_h of the aircraft 1 being the X-axis, the direction orthogonal to the aircraft heading ψ_h in the horizontal direction being the Y-axis, and the vertical direction being the Z-axis. Accordingly, the relative position (Xhg,

20 Yhg) between the aircraft 1 and the target landing point 2 in the aircraft inertial system is calculated in the horizontal direction. The relative position (Xhg, Yhg) is the distance from the aircraft 1 to the target landing point 2.

[0037]

[Math. 3]

25
$$\begin{bmatrix} X_{hg} \\ Y_{hg} \end{bmatrix} = R_{sh}^T \begin{bmatrix} -X_{sg} \\ -Y_{sg} \end{bmatrix} \quad \dots (3)$$

[0038]

[Math. 4]

$$R_{sh} = \begin{bmatrix} \cos(\psi_s - \psi_h) & \sin(\psi_s - \psi_h) \\ -\sin(\psi_s - \psi_h) & \cos(\psi_s - \psi_h) \end{bmatrix} \quad \dots (4)$$

[0039]

30 (Relative velocity Calculation Process)

In addition, the control unit 30 performs, in the guidance calculation unit 34, a relative velocity calculation process of calculating the relative velocity (ΔV_x , ΔV_y) of the aircraft 1 with respect to the target landing point 2, i.e., the marine vessel 5, in accordance with the block diagram illustrated in FIG. 7.

35 FIG. 7 is a block diagram illustrating an example of a relative velocity calculation process performed by the guidance calculation unit. Here, FIG. 7

5 also illustrates both the component in the X direction that serves as the
direction of the pitch axis, and the component in the Y direction that serves as
the direction of the roll axis. Specifically, the guidance calculation unit 34
calculates the relative velocity (ΔV_x , ΔV_y) based on the relative position (X_{hg} ,
 Y_{hg}) between the aircraft 1 and the target landing point 2, and the aircraft
10 velocity (V_x , V_y) of the aircraft 1 detected by the navigation system 20.
[0040]

The guidance calculation unit 34 first calculates, as illustrated in FIG. 7,
the relative velocity (ΔV_{1x} , ΔV_{1y}) between the aircraft 1 and the target landing
point 2, by differentiating the relative position (X_{hg} , Y_{hg}) between the aircraft
15 1 and the target landing point 2. In the present embodiment, the relative
position (X_{hg} , Y_{hg}) is subject to pseudo-differential operation using a pseudo-
differential filter 51. A transfer function $G1(s)$ of the pseudo-differential filter
is represented by the following Equation (5). In Equation (5), the symbol "s" is
an operator, and " τ_1 " is a time constant.

20 [0041]

$$G1(s) = s/(\tau_1 \cdot s + 1) \dots (5)$$
[0042]

Using the relative velocity (ΔV_{1x} , ΔV_{1y}) calculated by the pseudo-
differential filter 51, such as that of Equation (5), for subsequent control may
25 result in decreased controllability due to primary delay. Therefore, the guidance
calculation unit 34 uses a complementary filter 52 to calculate the relative
velocity (ΔV_x , ΔV_y), as illustrated in FIG. 7. The complementary filter 52
includes a low-pass filter 52L and a high-pass filter 52H.
[0043]

30 The guidance calculation unit 34 applies a low-pass filter 52L to the
relative velocity (ΔV_{1x} , ΔV_{1y}) calculated by the pseudo-differential filter 51,
and calculates relative velocity (ΔV_{2x} , ΔV_{2y}) having attenuated frequencies
equal to or higher than a predetermined cutoff frequency. A transfer function
 $G2(s)$ of the low-pass filter 52L is represented by Equation (6). In Equation (6),
35 the symbol "s" is an operator, and " τ_2 " is a time constant. The predetermined
cutoff frequency turns out to be " $1/\tau_2$ ". Accordingly, it is possible to acquire
the relative velocity (ΔV_{2x} , ΔV_{2y}) reflecting relatively reliable and moderate
variation of the relative velocity (ΔV_{1x} , ΔV_{1y}), i.e., having a value in a low-
frequency range, which is equal to or lower than the predetermined cutoff
40 frequency.

[0044]

$$G2(s) = 1/(\tau_2 \cdot s + 1) \dots (6)$$

5 [0045]

In addition, the guidance calculation unit 34 applies the high-pass filter 52H to the aircraft velocity (V_x , V_y) of the aircraft 1 detected by the navigation system 20, and calculates relative velocity (ΔV_{3x} , ΔV_{3y}) having attenuated frequencies below a predetermined cutoff frequency. A transfer function $G3(s)$ of the high-pass filter 52H is represented by Equation (7). In Equation (7), the symbol "s" is an operator, and " τ_2 " is a time constant in common with the low-pass filter 52L. Therefore, the predetermined cutoff frequency turns out to be " $1/\tau_2$ " also in the high-pass filter 52H. In other words, variation of the short-term relative velocity (ΔV_x , ΔV_y) is estimated to have been generated by variation of the aircraft velocity (V_x , V_y) itself of the aircraft 1, and the value acquired by applying the high-pass filter 52H to the aircraft velocity (V_x , V_y) is estimated to be the value of the relative velocity (ΔV_x , ΔV_y) in the high-frequency range. Subsequently, the guidance calculation unit 34 calculates the value acquired by adding the relative velocity (ΔV_{2x} , ΔV_{2y}) and the relative velocity (ΔV_{3x} , ΔV_{3y}) as the relative velocity (ΔV_x , ΔV_y). Accordingly, it becomes possible to accurately calculate the relative velocity (ΔV_x , ΔV_y) by adding, to the relative velocity (ΔV_{2x} , ΔV_{2y}) with values in a high-frequency range having been cut-off to achieve an increased reliability, the relative velocity (ΔV_{3x} , ΔV_{3y}) estimated to be a value in the high-frequency range.

25 [0046]

$$G3(s) = \tau_2 \cdot s / (\tau_2 \cdot s + 1) \dots (7)$$

[0047]

(PID Control)

Let us return to explanation of FIG. 4. The guidance calculation unit 34, having calculated the relative position (X_{hg} , Y_{hg}) and the relative velocity (ΔV_x , ΔV_y) in a manner described above, applies a Kalman filter 61 to the calculated relative position (X_{hg} , Y_{hg}) and the relative velocity (ΔV_x , ΔV_y), and calculates a relative position (X_{hgf} , Y_{hgf}) with noise removed and error reduced. Here, the Kalman filter 61 may be omitted. Subsequently, the guidance calculation unit 34 performs PID control by a PID control unit 62 (feedback control unit) using the relative position (X_{hgf} , Y_{hgf}), the relative velocity (ΔV_x , ΔV_y), and the aircraft acceleration (a_x , a_y) and calculates a feedback manipulated variable C. Specifically, the guidance calculation unit 34 calculates the feedback manipulated variable C of the aircraft 1 by PID control so that the relative position (X_{hgf} , Y_{hgf}) corresponding to the distance in the horizontal direction between the aircraft 1 and the target landing point 2 becomes 0. Accordingly, the feedback manipulated variable C can be

5 determined so that the aircraft 1 is guided toward the target landing point 2 and
the aircraft 1 becomes relatively stationary with respect to the marine vessel 5
directly above the target landing point 2. In addition, the guidance calculation
unit 34 calculates the feedback manipulated variable C of the aircraft 1 by PID
control so that values of the relative velocity (ΔV_x , ΔV_y) and the aircraft
10 acceleration (a_x , a_y) become 0. Accordingly, the accuracy with regard to
guidance of the aircraft 1 toward the target landing point 2 can be improved.
Note that, although it is assumed that the PID control uses the aircraft
acceleration (a_x , a_y) in the present embodiment, it suffices that the PID control
is performed based on at least the relative position and the relative velocity
15 between the aircraft 1 and the target landing point 2.
[0048]

In addition, the guidance calculation unit 34 may skip the integration
operation of PID control when the relative velocity (ΔV_x , ΔV_y) is equal to or
higher than a predetermined value. In the present embodiment, a relatively high
20 gain of the integration operation of PID control is set when the aircraft 1 is
relatively stationary with respect to the target landing point 2, in consideration
of canceling the force that the aircraft 1 receives from surrounding wind. Here,
when the force of wind being received by the aircraft 1 has weakened, the
aircraft 1 may temporarily transit from the relatively stationary state and, being
25 balanced with the force of wind at a certain position, return to the stationary
state again. On this occasion, the feedback manipulated variable C for causing
the aircraft 1 to return to the target landing point 2 is calculated by the
integration operation of PID control. Accordingly, although the integration
operation of PID control is a necessary component, a relatively high gain is set
30 as described above, and therefore the value calculated by the integration
operation may be too large when the relative velocity (ΔV_x , ΔV_y) is high,
which may result in occurrence of overshooting that causes the aircraft 1 to
pass through the target landing point 2. Therefore, skipping the integration
operation of PID control when the relative velocity (ΔV_x , ΔV_y) is equal to or
35 higher than a predetermined value allows for suppressing overshooting even
when the integration gain is set to be relatively large.
[0049]

(Multi-value Control)

Furthermore, the guidance calculation unit 34 performs, by a multi-value
40 control unit 63 in parallel with PID control, a multi-value control of setting the
addition value D to be added to the feedback manipulated variable C. The
multi-value control unit 63 receives the relative position (X_{hgf} , Y_{hgf}) and the

5 relative velocity (ΔV_x , ΔV_y) input thereto. The multi-value control unit 63 calculates the addition value D, based on the input relative position (X_{hgf} , Y_{hgf}) and the relative velocity (ΔV_x , ΔV_y).
[0050]

10 FIG. 8 is an explanatory diagram illustrating a coordinate plane with the relative position and the relative velocity being orthogonal axes. The horizontal axis represents the relative position (X_{hgf} , Y_{hgf}) and the vertical axis represents the relative velocity (ΔV_x , ΔV_y). Here, FIG. 8 also illustrates both the component in the X direction that serves as the direction of the pitch axis, and the component in the Y direction that serves as the direction of the roll
15 axis. The relative position (X_{hgf} , Y_{hgf}) here corresponds to the distance from the aircraft 1 to the target landing point 2, which is assumed to be positive (right direction) when the aircraft 1 is ahead of the target landing point 2 in the forward direction of the aircraft 1, or negative (left direction) when the aircraft 1 is behind the target landing point 2 in the forward direction of the aircraft 1.
20 In addition, the relative velocity (ΔV_x , ΔV_y) here is assumed to be positive (upward direction) when the aircraft velocity (V_x , V_y) of the aircraft 1 is higher than the velocity of the marine vessel 5, and negative (downward direction) when the aircraft velocity (V_x , V_y) of the aircraft 1 is lower than the velocity of the marine vessel 5. Accordingly, the origin of the coordinate plane indicates a
25 coordinate point at which the aircraft 1 is directly above the target landing point 2 and relatively stationary with respect to the target landing point 2. Note that the positive and negative signs may be reversed with respect to the relative position (X_{hgf} , Y_{hgf}) and the relative velocity (ΔV_x , ΔV_y). FIG. 8 illustrates an example of a coordinate point P of the current relative position (X_{hgf} , Y_{hgf}) and the current relative velocity (ΔV_x , ΔV_y).
30 [0051]

The coordinate plane has preliminarily set thereon a switching line L1 passing through the origin and separating the plane into an acceleration region A1 (the range indicated by diagonal lines in FIG. 8) in which the relative
35 velocity (ΔV_x , ΔV_y) is increased and a deceleration region A2 (the range without diagonal lines in FIG. 8) in which the relative velocity (ΔV_x , ΔV_y) is decreased. The switching line L1 is a straight line passing through the origin of the coordinate plane and extending between a quadrant in which the aircraft velocity (V_x , V_y) of the aircraft 1 is higher than the velocity of the marine
40 vessel 5 (velocity of target landing point 2) and also the aircraft 1 is behind the target landing point 2 in the forward direction, and a quadrant in which the aircraft velocity (V_x , V_y) of the aircraft 1 is lower than the velocity of the

5 marine vessel 5, and also the aircraft 1 is ahead of the target landing point 2 in the forward direction. Therefore, in this embodiment, the switching line L1 passes through the origin and extends between the second quadrant and the fourth quadrant, as illustrated in FIG. 8. The angle of the switching line L1 is not limited to that illustrated in FIG. 8, and may be set by the user as
 10 appropriate. For example, although increasing the angle of the switching line L1 (tilting toward the relative velocity side) increases the aircraft velocity (V_x , V_y) of the aircraft 1 returning to the target landing point 2, it also increases the likelihood of overshooting and therefore the angle is set to an appropriate inclination.

15 [0052]

FIG. 9 is an explanatory diagram illustrating an example of a map defining an addition value to be set in multi-value control. In FIG. 9, the horizontal axis represents the distance from the switching line L1 to the current coordinate point P on the coordinate plane of FIG. 8, and the vertical axis
 20 represents the addition value D to be set. The distance from the switching line L1 to the current coordinate point P is positive when the current coordinate point P is located in the acceleration region A1, and negative when the current coordinate point P is located in the deceleration region A2. In the present embodiment, the addition value D, when taking a positive value, is set to a
 25 trend that increases the relative velocity (ΔV_x , ΔV_y), i.e., a trend that increases the velocity of the aircraft 1 in the forward direction. Additionally, in the present embodiment, the addition value D, when taking a negative value, is set to a trend that reduces the relative velocity (ΔV_x , ΔV_y), i.e., a trend that reduces the velocity of the aircraft 1 in the forward direction or increases the
 30 same in the backward direction. In addition, as indicated by the solid line in the drawing, the addition value D is set in a stepwise manner so that its absolute value becomes larger for a further distance between the coordinate point P and the switching line L1, or smaller for a closer distance between the coordinate point P and the switching line L1.

35 [0053]

The multi-value control unit 63 sets the addition value D illustrated in FIG. 9 in accordance with the distance between the switching line L1 and the coordinate point P of the relative position (X_{hgf} , Y_{hgf}) and relative velocity (ΔV_x , ΔV_y), and adds, in an addition circuit 64, the addition value D to the
 40 feedback manipulated variable C calculated by the PID control unit 62, as illustrated in FIG. 4. Subsequently, the guidance calculation unit 34 outputs, to

5 the flight control unit 36, the manipulated variable C' to which the addition value D has been added.

[0054]

Accordingly, when the coordinate point P is located in the acceleration region A1, the flight of the aircraft 1 is controlled by the manipulated variable C' having added thereto the addition value D that tends to increase the relative velocity (ΔV_x , ΔV_y). Consequently, as illustrated by the solid line in FIG. 8, the relative velocity (ΔV_x , ΔV_y) becomes larger than the case where the aircraft 1 flies according to the feedback manipulated variable C without the addition value D illustrated by the dashed line in FIG. 8 added thereto. In other words, the aircraft velocity (V_x , V_y) of the aircraft 1 rapidly increases, reducing the time required to travel a same distance. When, on the other hand, the coordinate point P crosses the switching line L1 and reaches the deceleration region A2, the flight of the aircraft 1 is controlled by the manipulated variable C' having added thereto the addition value D that tends to decrease the relative velocity (ΔV_x , ΔV_y). Consequently, as illustrated by the solid line in FIG. 8, although the relative velocity (ΔV_x , ΔV_y) indicated by the solid line becomes higher than the relative velocity indicated by the dashed line immediately after the coordinate point P moved from the acceleration region A1 to the deceleration region A2 across the switching line L1, the relative velocity indicated by the solid line becomes lower than the relative velocity indicated by the dashed line as the aircraft 1 approaches the target landing point 2. In other words, the aircraft velocity (V_x , V_y) of the aircraft 1 rapidly decelerates, thereby suppressing overshooting that causes the aircraft 1 to pass through the origin of the coordinate plane.

30 [0055]

In addition, a plurality of addition values D may be set in accordance with the altitude of the aircraft 1 (relative altitude with respect to the target landing point 2). For example, when the aircraft 1 is located directly above the target landing point 2 at a predetermined altitude (e.g., in a range of 3 m or more and 8 m or less with respect to the target landing point 2) (e.g., in a low-altitude hovering mode described below), the absolute value of the addition value D may be set larger than the value in the normal time indicated by the solid line (e.g., in a high-altitude hovering mode described below), as illustrated by the dashed line in FIG. 9. On this occasion, setting of the addition value D may be gradually changed in accordance with the value of the altitude. Accordingly, the manipulated variable C' of the aircraft 1 can be more accurately calculated in the vicinity of the target landing point 2 where the

5 aircraft 1 lands on, thereby facilitating accurate landing on the target landing point 2.
[0056]

Similarly, a plurality of the addition values D may be set in accordance with the control mode of the aircraft 1. For example, let us consider a case
10 where there are set, as the control mode for the aircraft 1, a high-altitude hovering mode that maintains the relative altitude with respect to the target landing point 2 at a first relative altitude (e.g., 8 m) directly above the target landing point 2, and a low-altitude hovering mode that lowers the relative altitude with respect to the target landing point 2 from the high-altitude
15 hovering mode to a second relative altitude (e.g., 3 m) directly above the target landing point 2. Here, transition from the high-altitude hovering mode to the low-altitude hovering mode can be performed under a condition that the relative position (X_{hgf} , Y_{hgf}) is equal to or lower than a predetermined threshold value, and also the operator has instructed mode transition. In
20 addition, transition from the high-altitude hovering mode to the low-altitude hovering mode may be performed under a condition that, in place of instructing mode transition by the operator, the attitude rate, the attitude angle, the relative velocity (ΔV_x , ΔV_y) of the aircraft 1, the angle of the target landing point 2 in the horizontal direction, the altitude of the aircraft 1 with respect to the target
25 landing point 2, the relative altitude with respect to the target landing point 2, or the like are equal to or lower than a predetermined value.
[0057]

In a case where such a high-altitude hovering mode and a low-altitude hovering mode have been set, setting of the addition value D is switched after a
30 first predetermined time period (e.g., 5 seconds) has elapsed since transition from the high-altitude hovering mode to the low-altitude hovering mode started. In other words, the addition value D is switched from the value indicated by the solid line in FIG. 9 to the value indicated by the dashed line in FIG. 9. On this occasion, the addition value D may be set so as to gradually
35 change during a second predetermined time period (e.g., 3 seconds). Accordingly, the manipulated variable C' of the aircraft 1 can be more accurately calculated in the vicinity of the target landing point 2 where the aircraft 1 lands on, thereby facilitating accurate landing on the target landing point 2.
40 [0058]
(Effect and Advantage of First Embodiment)

5 As has been described above, the aircraft position control system 100 according to the first embodiment includes: the image processing unit 32 and the guidance calculation unit 34 (relative position acquisition unit) that acquires the relative position (X_{hgf} , Y_{hgf}) between the aircraft 1 and the target landing point 2; a guidance calculation unit 34 (relative velocity acquisition unit) that acquires the relative velocity (ΔV_x , ΔV_y) of the aircraft 1 with respect to the target landing point 2; and the control unit 30 that controls the aircraft 1. The control unit 30 includes, in the guidance calculation unit 34: the PID control unit 62 (feedback control unit) that calculates the feedback manipulated variable C of the aircraft 1 by feedback control so that the aircraft 15 1 is directed toward the target landing point 2 based on at least the relative position (X_{hgf} , Y_{hgf}) and the relative velocity (ΔV_x , ΔV_y); the multi-value control unit 63 that sets, by referring to a switching line L1 preliminarily provided in a manner passing through an origin (0.0) of a coordinate plane whose orthogonal axes represent the relative position (X_{hgf} , Y_{hgf}) and the relative velocity (ΔV_x , ΔV_y) and separating an acceleration region A1 in which the relative velocity (ΔV_x , ΔV_y) is increased and a deceleration region A2 in which the relative velocity is decreased (ΔV_x , ΔV_y), the addition value D that tends to increase at least the relative velocity (ΔV_x , ΔV_y) when the coordinate point P of the current relative position (X_{hgf} , Y_{hgf}) and the current relative velocity (ΔV_x , ΔV_y) is located in the acceleration region A1, or sets the addition value D that tends to decrease at least the relative velocity (ΔV_x , ΔV_y) when the coordinate point P is located in the deceleration region A2 with respect to the switching line L1; and the addition circuit 64 that calculates the manipulated variable C' of the aircraft 1 by adding the addition value D to the feedback manipulated variable C.

[0059]

According to the aforementioned configuration, the flight of the aircraft 1 is controlled by the manipulated variable C' having added thereto the addition value D that tends to increase the relative velocity (ΔV_x , ΔV_y), whereby the relative velocity ΔV increases, when the coordinate point P of the current relative position (X_{hgf} , Y_{hgf}) and the current relative velocity (ΔV_x , ΔV_y) is located in the acceleration region A1 separated by the switching line L1 on a coordinate plane whose orthogonal axes represent the relative position (X_{hgf} , Y_{hgf}) and the relative velocity (ΔV_x , ΔV_y). As a result, the aircraft 1 can be moved fast. When, on the other hand, the current coordinate point P is located in the deceleration region A2 separated by the switching line L1, the flight of the aircraft 1 is controlled by the manipulated variable C' having added thereto

5 the addition value D, which tends to decrease the relative velocity (ΔV_x , ΔV_y), whereby the relative velocity ΔV decreases. As a result, overshooting that causes the aircraft 1 to pass through the target landing point 2 can be suppressed. Therefore, according to the aircraft 1, the aircraft position control system 100, and the position control method according to the first embodiment,

10 the aircraft 1 can be moved more accurately and faster toward the target landing point 2. Accordingly, accurately controlling the position of the aircraft 1 with respect to the target landing point 2 allows for suppressing interference between the aircraft 1 and a device or a structure provided in the vicinity of the target landing point 2.

15 [0060]

In addition, the switching line L1 is a straight line extending over the coordinate plane between a quadrant in which the aircraft velocity (V_x , V_y) of the aircraft 1 is higher than the velocity of target landing point 2 (velocity of the marine vessel 5) and also the aircraft 1 is behind the target landing point 2

20 in the forward direction, and a quadrant in which the aircraft velocity (V_x , V_y) of the aircraft 1 is lower than the velocity of the target landing point 2, and also the aircraft 1 is ahead of the target landing point 2 in the forward direction. According to the aforementioned configuration, it is possible to appropriately set the acceleration region A1 and the deceleration region A2, and set the

25 addition value D to an appropriate value.

[0061]

In addition, the addition value D is set in a stepwise manner so that its absolute value becomes larger for a larger distance on the coordinate plane between the switching line L1 and the coordinate point P of the current relative

30 position (X_{hgf} , Y_{hgf}) and the current relative velocity (ΔV_x , ΔV_y), or smaller for a closer distance.

[0062]

According to the aforementioned configuration, the addition value D is set larger for a further distance between the switching line L1 and the

35 coordinate point P of the current relative position (X_{hgf} , Y_{hgf}) and the current relative velocity (ΔV_x , ΔV_y) so that the aircraft 1 moves fast, or smaller for a closer distance between the current coordinate point P and the switching line L1 so that the aircraft 1 can be finely manipulated. However, the manner of setting the addition value D is not limited to the foregoing. FIG. 10 is an

40 explanatory diagram illustrating another example of a map defining an addition value to be set in multi-value control. As illustrated, the addition value D may be a positive constant value in the acceleration region A1, or a negative

5 constant value in the deceleration region A2, regardless of the distance between the current coordinate point P and the switching line L1.

[0063]

In addition, the PID control unit 62 (feedback control unit), having calculated the feedback manipulated variable by PID control, skips the
 10 integration operation of PID control when the relative velocity (ΔV_x , ΔV_y) is equal to or higher than a predetermined value. According to the aforementioned configuration, in case where a relatively large integrated gain of PID control has been set, it is possible to suppress reduction of controllability of the PID control, or more specifically, occurrence of overshooting that causes the
 15 aircraft 1 to pass through the target landing point 2 due to the relative velocity (ΔV_x , ΔV_y) between the aircraft 1 and the target landing point 2 being large.

[0064]

In addition, a plurality of the addition values D may be set in accordance with the altitude or control mode of the aircraft 1. The aforementioned
 20 configuration allows for increasing the degree of freedom of setting the addition value D. Accordingly, for example, in a case where the aircraft 1 is located in the vicinity of the target landing point 2, the position of the aircraft 1 can be controlled more accurately by setting the addition value D to a large value. Here, a plurality of gains of the PID control may also be set in
 25 accordance with the altitude or control mode of the aircraft 1.

[0065]

In addition, in the first embodiment, the guidance calculation unit 34 (the relative velocity acquisition unit) calculates the relative velocity (ΔV_x , ΔV_y) by adding a value (relative velocity (ΔV_{2x} , ΔV_{2y})) acquired by applying,
 30 to a differential value (relative velocity (ΔV_{1x} , ΔV_{1y})) of the relative position (X_{hgf} , Y_{hgf}), a low-pass filter 52L that attenuates frequencies equal to or higher than a predetermined cutoff frequency, and a value (relative velocity (ΔV_{3x} , ΔV_{3y})) acquired by applying, to the aircraft velocity (V_x , V_y) of the aircraft 1, a high-pass filter 52H that attenuates frequencies below the cutoff
 35 frequency.

[0066]

According to the aforementioned configuration, acquisition of the relative position (X_{hgf} , Y_{hgf}) between the aircraft 1 and the target landing point 2 and the aircraft velocity (V_x , V_y) of the aircraft 1 allows for calculating
 40 the relative velocity (ΔV_x , ΔV_y) between the aircraft 1 and the target landing point 2 without having to acquire the velocity of the marine vessel 5 side on which the target landing point 2 is provided. Accordingly, it is not necessary to

5 perform communication between the aircraft 1 and the marine vessel 5 side on which the target landing point 2 is provided, thereby preventing reduction of control accuracy and response speed due to communication delay. Furthermore, the relative velocity (ΔV_x , ΔV_y) can be accurately calculated by applying the high-pass filter 52H to the aircraft velocity (V_x , V_y) of the aircraft 1 and
 10 adding thereto the relative velocity (ΔV_{3x} , ΔV_{3y}) in the high-frequency range due to variation of the aircraft velocity (V_x , V_y) of the aircraft 1, while using, as the relative velocity (ΔV_{2x} , ΔV_{2y}), a highly reliable value in a low-frequency range, which has been acquired by applying the low-pass filter 52L to the differential value of the relative position (X_{hgf} , Y_{hgf}). Accordingly, it
 15 becomes possible to move the aircraft 1 more accurately and faster toward the target landing point 2. In addition, data communication is not required, and therefore the system can be simplified.

[0067]

In addition, the position control system 100 further includes the camera
 20 10 (imaging device) mounted on the aircraft 1, and the image processing unit 32 and the guidance calculation unit 34 (relative position acquisition unit) calculate the relative position (X_{hgf} , Y_{hgf}) by image processing using images, captured by the camera 10, of the marker 7 provided at the target landing point 2. According to the aforementioned configuration, the relative position (X_{hgf} ,
 25 Y_{hgf}) between the aircraft 1 and the target landing point 2 can be acquired by image processing, whereby it becomes unnecessary to acquire position information from the marine vessel 5 side on which the target landing point 2 is provided. Accordingly, it is unnecessary to perform communication between the aircraft 1 and the marine vessel 5 side on which the target landing point 2 is
 30 provided, and therefore the system can be simplified.

[0068]

[Second Embodiment]

Next, there will be described an aircraft position control system 200 and a position control method according to a second embodiment. FIG. 11 is a
 35 schematic configuration diagram illustrating an example of a position control system according to the second embodiment. The position control system 200 according to the second embodiment includes, as illustrated in FIG. 11, a data transmission device 40 in addition to the configuration of the position control system 100 according to the first embodiment. In addition, the position control
 40 system 200 includes a guidance calculation unit 34A, in place of the guidance calculation unit 34 of the first embodiment. Other configuration of the position control system 200 is similar to that of the position control system 100 and

5 therefore description thereof is omitted, and like components are indicated by like reference signs.

[0069]

10 Additionally, in the second embodiment, the marine vessel 5 having the target attaching point 2 provided thereon includes a navigation system 70, as illustrated in FIG. 11. Similarly to the first embodiment, the navigation system 70 is an inertial navigation system, for example, and the marine vessel 5 acquires, via the inertial navigation system, a ship velocity (V_{sx} , V_{sy}), as well as the acceleration, the ship heading ψ_s (see FIG. 6), or the like of the marine vessel 5. The inertial navigation system may include the GPS or may include
15 sensors to acquire various data. In addition, the marine vessel 5 includes a data transmission device 80.

[0070]

The data transmission device 40 and the data transmission device 80 communicate with each other to exchange information between the aircraft 1
20 and the marine vessel 5. Specifically, in the second embodiment, the data transmission device 80 of the marine vessel 5 transmits the ship velocity (V_{sx} , V_{sy}) of the marine vessel 5 acquired by the navigation system 70 to the data transmission device 40 of the aircraft 1. The data transmission device 40 of the aircraft 1 transmits the received ship velocity (V_{sx} , V_{sy}) of the marine vessel 5
25 to the guidance calculation unit 34A.

[0071]

FIG. 12 is a block diagram illustrating an example of a configuration for calculating a manipulated variable of an aircraft by the guidance calculation unit of the second embodiment. In the second embodiment, the guidance
30 calculation unit 34A skips the relative velocity calculation process of the first embodiment. The guidance calculation unit 34A calculates, as illustrated in FIG. 12, a difference between the aircraft velocity (V_x , V_y) of the aircraft 1 acquired by the navigation system 20 and the ship velocity (V_{sx} , V_{sy}) of the marine vessel 5, and sets the calculated difference as the relative velocity
35 (ΔV_x , ΔV_y) of the aircraft 1 with respect to the target landing point 2. On this occasion, the ship velocity (V_{sx} , V_{sy}) of the marine vessel 5 is the coordinates of the ship inertial reference frame S_G , and therefore subjected to coordinate conversion into the aircraft inertial reference frame H_G when calculating the difference. Therefore, the guidance calculation unit 34A functions, also in the
40 second embodiment, as a relative velocity acquisition unit that acquires the relative velocity (ΔV_x , ΔV_y) between the aircraft 1 and the target landing point 2. The guidance calculation unit 34A calculates the manipulated variable C' by

5 feedback control and multi-value control similar to those in the first
embodiment, using the calculated relative velocity (ΔV_x , ΔV_y). Here, although
the Kalman filter 61 is omitted in FIG. 12, the relative position (X_{hg} , Y_{hg})
calculated by applying the Kalman filter 61 to the relative position (X_{hg} , Y_{hg})
and the relative velocity (ΔV_x , ΔV_y) may be used, similarly to the first
10 embodiment.

[0072]

(Effect and Advantage of Second Embodiment)

According to the aforementioned configuration, the aircraft 1, the
aircraft position control system 200, and the position control method of the
15 second embodiment eliminates the necessity of calculating the pseudo-
differential values of the relative position (X_{hg} , Y_{hg}), or performing a
calculation process using the low-pass filter 52L and the high-pass filter 52H,
as in the first embodiment, when calculating the relative velocity (ΔV_x , ΔV_y)
of the aircraft 1 with respect to the target landing point 2. Therefore, the
20 calculation required for calculating the relative velocity (ΔV_x , ΔV_y) can be
simplified. Here, a filter such as a low-pass filter and a high-pass filter may be
applied to the ship velocity (V_{sx} , V_{sy}) of the marine vessel 5 which have been
subjected to coordinate conversion.

[0073]

25 It is assumed in the first and the second embodiments that an image of
the marker 7 is captured by the camera 10 and image processing is performed
on the captured image, and that the relative position between the aircraft 1 and
the target landing point 2 is calculated by the relative position calculation
process described above. However, the method for acquiring the relative
30 position between the aircraft 1 and the target landing point 2 is not limited to
the foregoing. For example, a laser irradiation device may be mounted on the
aircraft 1 to acquire a relative position by irradiating a laser beam toward the
target landing point 2 on the marine vessel 5 and receiving reflected waves by
the aircraft 1.

35 [0074]

In the first and the second embodiments, the guidance calculation units
34 and 34A may measure or estimate the wind velocity around the aircraft 1 or
the airspeed, which is the relative velocity between the aircraft 1 and the
atmosphere. Subsequently, the guidance calculation units 34 and 34A may
40 adjust each gain of feedback control in accordance with the acquired wind
velocity or airspeed. Similarly, the guidance calculation units 34 and 34A may
change the setting of the addition value of multi-value control in accordance

5 with the acquired wind velocity or airspeed. Accordingly, it is possible to
output a manipulated variable in accordance with the strength of wind around
the aircraft 1, and guide the aircraft 1 toward the target landing point 2 more
accurately and faster.

[0075]

10 Additionally, it is assumed in the first and the second embodiments that
the addition value D is set so as to increase or decrease the relative velocity
(ΔV_x , ΔV_y) in multi-value control. However, the addition value D may be set to
be added also to the attitude angle of the aircraft 1 and 2, the attitude rate, or
the like, which are included in the feedback manipulated variable C.

15

Reference Signs List

[0076]

- 1 Aircraft
- 2 Target landing point
- 20 5 Marine vessel
- 7 Marker
- 10 Camera
- 20, 70 Navigation system
- 25 Altitude sensor
- 25 30 Control unit
- 32 Image processing unit
- 34, 34A Guidance calculation unit
- 36 Flight control unit
- 40, 80 Data transmission device
- 30 51 Pseudo-differential filter
- 52 Complementary filter
- 52H High-pass filter
- 52L Low-pass filter
- 100, 200 Position control system

5

Claims

[Claim 1]

An aircraft position control system comprising:

- 10 a relative position acquisition unit configured to acquire a relative position between an aircraft and a target landing point;
- a relative velocity acquisition unit configured to acquire relative velocity of the aircraft with respect to the target landing point; and
- a control unit configured to control the aircraft, wherein the control unit includes:
- 15 a feedback control unit configured to calculate a feedback manipulated variable of the aircraft by feedback control so that the aircraft heads toward the target landing point, based on at least the relative position and the relative velocity;
- a multi-value control unit configured to set, by referring to a switching
- 20 line preliminarily provided in a manner passing through an origin of a coordinate plane whose orthogonal axes represent the relative position and the relative velocity and separating an acceleration region in which the relative velocity is increased and a deceleration region in which the relative velocity is decreased, an addition value that tends to increase the relative velocity when a
- 25 coordinate point of the current relative position and the current relative velocity is located in the acceleration region, or set an addition value that tends to decrease the relative velocity when the coordinate point is located in the deceleration region with respect to the switching line; and
- an addition circuit configured to calculate a manipulated variable of the
- 30 aircraft by adding the addition value to the feedback manipulated variable.

[Claim 2]

- The aircraft position control system according to claim 1, wherein the switching line is a straight line extending on the coordinate plane between a
- 35 quadrant in which the velocity of the aircraft is higher than the velocity of the target landing point and the aircraft is behind the target landing point in a forward direction, and a quadrant in which the velocity of the aircraft is lower than the velocity of the target landing point, and the aircraft is ahead of the target landing point in the forward direction.

40

[Claim 3]

5 The aircraft position control system according to claim 1 or 2, wherein
the addition value is set in a stepwise manner so that its absolute value
becomes larger for a further distance on the coordinate plane between the
coordinate point and the switching line, or smaller for a closer distance
between the coordinate point and the switching line.

10

[Claim 4]

 The aircraft position control system according to any one of claims 1 to
3, wherein the feedback control unit calculates the feedback manipulated
variable by PID control, and skips an integration operation of the PID control
15 when the relative velocity is equal to or higher than a predetermined value.

[Claim 5]

 The aircraft position control system according to any one of claims 1 to
4, wherein a plurality of the addition values are set in accordance with an
20 altitude or control mode of the aircraft.

[Claim 6]

 The aircraft position control system according to any one of claims 1 to
5, wherein the relative velocity acquisition unit calculates the relative velocity
25 by adding a value acquired by applying, to a differential value of the relative
position, a low-pass filter that attenuates frequencies equal to or higher than a
cutoff frequency being predetermined, and a value acquired by applying, to the
velocity of the aircraft, a high-pass filter that attenuates frequencies below the
cutoff frequency.

30

[Claim 7]

 The aircraft position control system according to any one of claims 1 to
5, wherein the relative velocity acquisition unit acquires a velocity of the
aircraft and a velocity of the target landing point, and calculates the relative
35 velocity based on a difference between the velocity of the aircraft and the
velocity of the target landing point.

[Claim 8]

 The aircraft position control system according to any one of claims 1 to
40 7 further comprising an imaging device mounted on the aircraft, wherein the
relative position acquisition unit performs image processing on a captured

- 5 image of a marker provided at the target landing point taken by the imaging device, and calculates the relative position.

[Claim 9]

- An aircraft position control system comprising:
- 10 a relative position acquisition unit configured to acquire a relative position between an aircraft and a target landing point;
- a relative velocity acquisition unit configured to acquire relative velocity between the aircraft and the target landing point; and
- a control unit configured to control the aircraft to head toward the target
- 15 landing point, based on at least the relative position and the relative velocity, wherein
- the relative velocity acquisition unit calculates the relative velocity by adding a value acquired by applying, to a differential value of the relative position, a low-pass filter that attenuates frequencies equal to or higher than a
- 20 cutoff frequency being predetermined, and a value acquired by applying, to the velocity of the aircraft, a high-pass filter that attenuates frequencies below the cutoff frequency.

[Claim 10]

- 25 An aircraft comprising the aircraft position control system according to any one of claims 1 to 9.

[Claim 11]

- An aircraft position control method comprising:
- 30 acquiring a relative position between an aircraft and a target landing point;
- acquiring relative velocity of the aircraft with respect to the target landing point;
- calculating a feedback manipulated variable of the aircraft by feedback
- 35 control so that the aircraft heads toward the target landing point, based on at least the relative position and the relative velocity;
- setting, by referring to a switching line preliminarily provided in a manner passing through an origin of a coordinate plane whose orthogonal axes represent the relative position and the relative velocity and separating an
- 40 acceleration region in which the relative velocity is increased and a deceleration region in which the relative velocity is decreased, an addition value that tends to increase the relative velocity when a coordinate point of the

- 5 current relative position and the current relative velocity is located in the acceleration region, or setting an addition value that tends to decrease the relative velocity when the coordinate point is located in the deceleration region with respect to the switching line; and
calculating a manipulated variable of the aircraft by adding the addition
- 10 value to the feedback manipulated variable.