[0012]

According to an aspect of the present disclosure, there is provided a control device for an unmanned aircraft including a rotary-wing control signal generation circuit for generating a rotary-wing control signal for causing a driving device to drive a plurality of rotary wings for flying an unmanned aircraft, a measuring device for measuring a physical amount relating to an operation of at least one of the plurality of rotary wings, and a fault detection circuit for detecting a fault in an operation of at least one of the plurality of rotary wings by using the physical amount measured by the measuring device, and the rotary-wing control signal generation circuit is configured to generate the rotary-wing control signal depending on the fault detected by the fault detection circuit in an operation of at least one of the plurality of rotary wings, wherein the rotary-wing control signal generation circuit includes a control-amount distributor for distributing control amounts relating to flight of the unmanned aircraft correspondingly to the respective ones of the plurality of rotary wings; and the control amount distributor is configured to change distribution amounts of the control amounts corresponding to the respective ones of the plurality of rotary wings so that the unmanned aircraft performs an operation depending on the control amounts, depending on the fault detected by the fault detection circuit.

[0013]

In the aforementioned control device for an unmanned aircraft, the rotary-wing control signal generation circuit may include a control-amount distributor for distributing control amounts relating to a flight of the unmanned aircraft correspondingly to the respective ones of the plurality of rotary wings, and the control-amount distributor may be configured to change distribution amounts of the control amounts corresponding to the

respective ones of the plurality of rotary wings so that the unmanned aircraft performs the operation depending on the control amounts, depending on the fault detected by the fault detection circuit.

[0014]

In the aforementioned control device for an unmanned aircraft, the fault detection circuit may be configured to detect a fault in an operation of at least one of the plurality of rotary wings by comparing an output value of an identification model when a control signal indicating a control amount is input into the identification model of the unmanned aircraft with an output

system, and to determine a control command value at least for reducing the angular speed of a rotary wing, among the plurality of rotary wings, located on the side facing a rotary wing in which the fault in the operation is detected by the fault detection circuit by using the control command values relating to the throttle amount, the roll angle, and the pitch angle in the aircraft body coordinate system.

[0023]

Moreover, the present invention provides an unmanned aircraft including any of the above control devices.

[0024]

Moreover, the present invention provides a method for controlling an unmanned aircraft in which a physical amount relating to an operation of at least one of the plurality of rotary wings for flying the unmanned aircraft is measured, a fault in the operation of at least one of the plurality of rotary wings is detected by using the measured physical amount, and a rotary-wing control signal depending on the detected fault in the operation of at least one of the plurality of rotary wings is generated.

[0024a]

According to an aspect of the present disclosure, there is provided a method for controlling an unmanned aircraft comprising: measuring a physical amount relating to an operation in at least one of the plurality of rotary wings for flying the unmanned aircraft; detecting a fault in the operation of at least one of the plurality of rotary wings by using the measured physical amount; and generating a rotary-wing control signal depending on the detected fault in the operation of at least one of the plurality of rotary wings, wherein generation of the rotary-wing control signal includes changing of distribution amounts of control amounts corresponding to the respective ones of the plurality of rotary wings so that the unmanned aircraft performs an operation depending on the control amounts relating to a flight of the unmanned aircraft depending on the

detected fault.

[0025]

In the aforementioned method for controlling an unmanned aircraft, generation of the rotary-wing control signal may include changing of distribution amounts of control amounts corresponding to the respective ones of the plurality of rotary wings so that the unmanned aircraft performs the operation depending on the control amounts relating to the flight of the unmanned aircraft depending on the detected fault.

[0026]

The aforementioned method for controlling an unmanned aircraft may include generation of the rotary-wing control signal at least for reducing the rotation speed of a rotary wing, among the plurality of rotary wings, located on the side facing a rotary wing in which the fault in the operation is detected, depending on the detected fault in an operation of at least one of

Claims:

[Claim 1]

A control device for unmanned aircraft comprising:

a rotary-wing control signal generation circuit for generating a rotary wing control signal for causing a driving device to drive a plurality of rotary wings for flying the unmanned aircraft;

a measuring device for measuring a physical amount relating to an operation of at least one of the plurality of rotary wings; and

a fault detection circuit for detecting a fault in the operation of at least one of the plurality of rotary wings by using the physical amount measured by the measuring device, wherein

the rotary-wing control signal generation circuit is configured to generate a rotary wing control signal depending on the fault detected by the fault detection circuit in the operation of at least one of the plurality of rotary wings,

wherein

the rotary-wing control signal generation circuit includes a control-amount distributor for distributing control amounts relating to flight of the unmanned aircraft correspondingly to the respective ones of the plurality of rotary wings; and

the control-amount distributor is configured to change distribution amounts of the control amounts corresponding to the respective ones of the plurality of rotary wings so that the unmanned aircraft performs an operation depending on the control amounts, depending on the fault detected by the fault detection circuit.

[Claim 2]

The control device for unmanned aircraft according to claim 1, wherein

the fault detection circuit is configured to detect a fault in an operation of at least one of the plurality of rotary wings depending on the difference between (i) an estimated value of an identification model when a control signal indicating a control amount is input into the identification model of the unmanned aircraft and (ii) a comparison value related to the unmanned aircraft when a control signal indicating the control amount is input into the unmanned aircraft.

[Claim 3]

The control device for unmanned aircraft according to claim 2, wherein

the estimated value of the identification model when a control signal indicating the control amount is input into the identification model is an electric current model value for each motor determined using a PWM signal corresponding to the number of rotations of each motor rotating each rotary-wing and a signal indicating a measured value of each voltage applied to each motor, and

the comparison value related to the unmanned aircraft when a control signal indicating the control amount is input into the unmanned aircraft is a measured value of each electric current flowing through each motor.

[Claim 4]

The control device for unmanned aircraft according to claim 2, wherein

the estimated value of the identification model when a control signal indicating the control amount is input into the identification model is an estimated value of the number of rotations of each motor determined using a signal indicating a measured value of each electric current flowing through each motor rotating each rotary-wing and a signal indicating a measured

value of each voltage applied to each motor, and

the comparison value related to the unmanned aircraft when a control signal indicating the control amount is input into the unmanned aircraft is each the number of rotations indicated by a control command value for each motor.

[Claim 5]

The control device for unmanned aircraft according to claim 2, wherein

the estimated value (a multivariate vector or a univariation (univariate)) of a state of a rotary-wing depending on the voltage v applied to a motor in respective motors rotating respective rotary-wings, the electric current i flowing through the motor and the number of rotations ω (omega) of the motor, is defined by:

[Formula 1]

$$\hat{y}(v,i,\omega)$$,

the measured value (a multivariate vector or a univariation (univariate)) of the state of the rotary-wing is defined by:

[Formula 2]

$$y(v,i,\omega)$$,

a control input to the rotary-wing is defined by u (a multivariate vector or a univariation (univariate)),

with regard to the control input and the measured value of the state, a model is established as follows by using the estimated value the state:

[Formula 3]

$$\begin{cases} \boldsymbol{x}(k+1) = A_m \boldsymbol{x}(k) + B_m \boldsymbol{u}(k) \\ \hat{\boldsymbol{y}}(k) = C_m \boldsymbol{x}(k) \end{cases}$$

(x is a univariation (univariate) or a multivariate vector introduced for modeling. A_m, B_m, and C_m are coefficients with respect to the univariations (univariants) x and u, or coefficient matrices with respect to the multivariate vectors x and u. k is the number of times that the estimation is repeated, and m is an index specifying any one of the motors (A_m, B_m, and C_m may be different for each motor.),

a remainder r(k) of the measured value of the state:

[Formula 4]

$$y(k)$$

from the estimated value of the k-th time of the state:

[Formula 5]

$$\hat{y}(k)$$

is defined by:

[Formula 6]

$$r(k) = y(k) - \hat{y}(k)$$

(r is a multivariate vector or a univariation (univariate).),

a remainder evaluation value δ (delta) (k) at the k-th estimation is defined by:

[Formula 7]

$$\delta(k) = \int_t^{t+k\times T} \sqrt{\frac{r^2}{k}}\, dt$$

(t is time when the estimation is started, and T is a time interval between which the estimation is made. r^2 (square of r) is assumed to be an inner product of r and r when r is a multivariate vector),

the estimated value of the identification model when a control signal indicating the control amount is input into the identification model is

[Formula 8]

$$\hat{y}(k)$$

,

the comparison value related to the unmanned aircraft when a control signal indicating the control amount is input into the unmanned aircraft is

[Formula 9]

$$y(k)$$

,

and the control device is configured to detect a fault in an operation of at least one of the plurality of rotary wings by comparing the remainder evaluation value δ (delta) (k) with a predetermined threshold value.

[Claim 6]

The control device for unmanned aircraft according to claim 2, wherein

the estimated value of the identification model when a control signal indicating the control amount is input into the identification model is an electric current model value for each normal motor determined using signals indicating measured values of voltage applied to each motor rotating each rotary-wing and the number of rotations of each motor, and

the comparison value related to the unmanned aircraft when a control signal indicating the control amount is input into the unmanned aircraft is a measured value of each electric current flowing through each motor.

[Claim 7]

The control device for unmanned aircraft according to any one of claims 1 to 6, wherein

six rotary wings are provided as the plurality of rotary wings; and

the control-amount distributor is configured to distribute the control amounts by using the following control-amount distribution matrix M:

[Formula 10]

$$M = \overline{M}(\eta_i)^T (\overline{M}(\eta_i)\overline{M}(\eta_i)^T)^{-1} \begin{bmatrix} \sigma_T & 0 & 0 & 0 \\ 0 & \sigma_L & 0 & 0 \\ 0 & 0 & \sigma_M & 0 \\ 0 & 0 & 0 & \sigma_N \end{bmatrix}$$

where

[Formula 11]

$$\overline{\mathbf{M}} = \begin{bmatrix} \kappa_f\eta_1 & \kappa_f\eta_2 & \kappa_f\eta_3 & \kappa_f\eta_4 & \kappa_f\eta_5 & \kappa_f\eta_6 \\ \frac{\kappa_f l\eta_1}{2} & \kappa_f l\eta_2 & \frac{\kappa_f l\eta_3}{2} & \frac{-\kappa_f l\eta_4}{2} & -\kappa_f l\eta_5 & \frac{-\kappa_f l\eta_6}{2} \\ \frac{\sqrt{3}\kappa_f l\eta_1}{2} & 0 & \frac{-\sqrt{3}\kappa_f l\eta_3}{2} & \frac{-\sqrt{3}\kappa_f l\eta_4}{2} & 0 & \frac{\sqrt{3}\kappa_f l\eta_6}{2} \\ e_1\kappa_\tau\eta_1 & e_2\kappa_\tau\eta_2 & e_3\kappa_\tau\eta_3 & e_4\kappa_\tau\eta_4 & e_5\kappa_\tau\eta_5 & e_6\kappa_\tau\eta_6 \end{bmatrix}$$

[Formula 12]

$$\eta_i = \begin{cases} 1 & (when\ normal) \\ 0 & (when\ fault) \end{cases}$$

where i is a number of the rotary wing, σ_T ($sigma_T$) is a mixing (control amount distribution) matrix integer parameter relating to a throttle amount (Thr), σ_L ($sigma_L$) is a mixing (control amount distribution) matrix integer parameter relating to a roll (Roll) angle, σ_M ($sigma_M$) is a mixing (control amount distribution) matrix integer parameter relating to a pitch (Pitch) angle, σ_N ($sigma_N$) is a mixing (control amount distribution) matrix integer parameter relating to a yaw (Yaw) angle, κ_f ($kappa_f$) is a proportional constant of a thrust with respect to a square value of an angular speed ω (omega), κ_τ ($kappa_{tau}$) is a proportional coefficient ($\tau = \kappa_\tau \cdot \omega^2$) (tau = $kappa_{tau}$ multiplied by $omega^2$) of a square of a motor rotation angular speed and a torque (τ: tau), l (ell) is a distance (length) between a gravity center of an aircraft body and a motor rotation axis, and f is a thrust, e_i is +1 or -1 depending on the direction of rotation of the rotary-wing.

[Claim 8]

The control device for unmanned aircraft according to any one of claims 1 to 7, wherein

the rotary-wing control signal generation circuit is configured to generate a rotary-wing control signal at least for reducing a rotation speed of a rotary wing located on a side facing a rotary wing in which a fault in an operation is detected by the fault detection circuit in the plurality of rotary wings, depending on a fault detected by the fault detection circuit in an operation of at least one of the plurality of rotary wings .

[Claim 9]

The control device for unmanned aircraft according to claim 8, wherein

the rotary-wing control signal generation circuit is configured to generate a rotary-wing control signal for stopping a rotation of a rotary wing located on a side facing a rotary wing in which a fault in an operation is detected by the fault detection circuit in the plurality of rotary wings, depending on a fault detected by the fault detection circuit in an operation of at least one of the plurality of rotary wings.

[Claim 10]

The control device for unmanned aircraft according to any one of claims 1 to 9, wherein

the rotary-wing control signal generation circuit and the fault detection circuit are configured as the same hardware.

[Claim 11]

The control device for unmanned aircraft according to any one of claims 8 to 10, wherein

signals indicating measured values of the respective physical amounts relating to an operation of at least one of the plurality of rotary wings are transmitted to the fault detection circuit via a common signal transmission path.

[Claim 12]

The control device for unmanned aircraft according to any one of claims 8 to 11, wherein

the driving device includes motors of the same number as the number of the rotary wings, each of the motors applies power to each of the rotary wings;

the measuring device is configured to measure at least one of: each voltage applied to each motor; each electric current flowing through each motor; and the number of rotations of each motor; and

the fault detection circuit is configured to detect a fault in an operation of at least one of the plurality of rotary wings by using each estimated value relating to each motor determined by using at least one of the each voltage, the each electric current, and the each number of rotations, measured by the measuring device, and a comparison value to the each estimated value.

[Claim 13]

The control device for unmanned aircraft according to any one of claims 8 to 12, wherein

when no fault is detected by the fault detection circuit in any operation of the plurality of rotary wings, the rotary-wing control signal generation circuit is configured to determine control command values for controlling angular speeds of the plurality of rotary wings from control command values for controlling a throttle amount, a roll angle, a pitch angle, and a yaw angle; and

when a fault in an operation of at least one of the plurality of rotary wings is detected by the fault detection circuit, the rotary-wing control signal generation circuit is configured to determine a control command value at least for reducing the angular speed of a rotary wing, among the plurality of rotary wings, located on the side facing a rotary wing in which the fault in the operation is detected by the fault detection circuit, from control command values for controlling the throttle amount, the roll angle, and the pitch angle depending on the detected fault.

[Claim 14]

The control device for unmanned aircraft according to claim 13, further comprising:

a receiving device for receiving an external input signal indicating an external input command value in a reference coordinate system from an

external input device, wherein

when no fault is detected by the fault detection circuit in any operation of the plurality of rotary wings, the rotary-wing control signal generation circuit is configured to:

determine control command values relating to the throttle amount, the roll angle, the pitch angle, and the yaw angle in the reference coordinate system by using the external input command value;

determine control command values relating to the throttle amount, the roll angle, the pitch angle, and the yaw angle in an aircraft body coordinate system of the unmanned aircraft from the control command values relating to the throttle amount, the roll angle, the pitch angle, and the yaw angle in the reference coordinate system; and

determine control command values relating to the angular speeds of the plurality of rotary wings by using the control command values relating to the throttle amount, the roll angle, the pitch angle, and the yaw angle in the aircraft body coordinate system;

when a fault in an operation of at least one of the plurality of rotary wings is detected by the fault detection circuit, the rotary-wing control signal generation circuit is configured to, depending on the detected fault:

determine control command values relating to the throttle amount, the roll angle, and the pitch angle in the reference coordinate system by using the external input command value;

determine control command values relating to the throttle amount, the roll angle, and the pitch angle in the aircraft body coordinate system of the unmanned aircraft from the control command values relating to the throttle amount, the roll angle, and the pitch angle in the reference coordinate system; and

determine a control command value at least for reducing the angular speed of a rotary wing, among the plurality of rotary wings, located on the side facing a rotary wing in which the fault in the operation is detected by

the fault detection circuit by using the control command values relating to the throttle amount, the roll angle, and the pitch angle in the aircraft body coordinate system.

[Claim 15]

An unmanned aircraft comprising the control device according to any one of claims 1 to 14.

[Claim 16]

A method for controlling an unmanned aircraft comprising:

measuring a physical amount relating to an operation in at least one of the plurality of rotary wings for flying the unmanned aircraft;

detecting a fault in the operation of at least one of the plurality of rotary wings by using the measured physical amount; and

generating a rotary-wing control signal depending on the detected fault in the operation of at least one of the plurality of rotary wings,

wherein

generation of the rotary-wing control signal includes changing of distribution amounts of control amounts corresponding to the respective ones of the plurality of rotary wings so that the unmanned aircraft performs an operation depending on the control amounts relating to a flight of the unmanned aircraft depending on the detected fault.

[Claim 17]

The method for controlling unmanned aircraft according to claim 16, further comprising:

generating a rotary-wing control signal at least for reducing a rotation speed of a rotary wing, among the plurality of rotary wings, located on a side facing a rotary wing in which a fault in an operation is detected, depending on the detected fault in an operation of at least one of the

plurality of rotary wings.