

PREDICTION MODEL GENERATION DEVICE, EXHAUST GAS CONCENTRATION CONTROL SYSTEM, PREDICTION MODEL GENERATION METHOD, AND EXHAUST GAS CONCENTRATION CONTROL METHOD

TECHNICAL FIELD

[0001] The present disclosure relates to a prediction model generation device and a prediction model generation method for generating an exhaust gas concentration prediction model which predicts the concentration of a gas component contained in exhaust gas discharged from a furnace, and to an exhaust gas concentration control system and an exhaust gas concentration control method for controlling the concentration of a gas component contained in exhaust gas discharged from the furnace using the exhaust gas concentration prediction model.

BACKGROUND

[0002] For example, Patent Document 1 discloses a technique for estimating CO concentration (process value of a furnace) from an image (feature) of the furnace interior, using an estimation model (exhaust gas concentration prediction model) generated by machine learning of training data in which image information obtained from an image of the furnace interior is associated with the quantity of state (e.g., CO concentration) after a predetermined time elapses from the time when the image was captured.

Citation List

Patent Literature

[0003] Patent Document 1: JP2019-074240A

SUMMARY

[0004] It is desirable that the feature is information that improves the prediction accuracy of the exhaust gas concentration prediction model, but a specific method for extracting the

feature from image data of a combustion region of a plant is not disclosed.

[0005] The present disclosure was made in view of the above problem, and an object thereof is to provide a prediction model generation device and a prediction model generation method whereby it is possible to improve the prediction accuracy of the exhaust gas concentration prediction model.

[0006] To achieve the above object, the present disclosure provides a prediction model generation device for generating an exhaust gas concentration prediction model which predicts a concentration of a gas component contained in an exhaust gas discharged from a furnace, comprising: an image acquisition unit configured to acquire an image of a combustion region of the furnace; an extraction unit configured to convert the image into color image data and extract a feature from the color image data; an exhaust gas concentration acquisition unit configured to acquire a concentration of the gas component contained in the exhaust gas, on a downstream side of the combustion region, after a preset time has elapsed from the time when the image has been captured; and a model generation unit configured to generate the exhaust gas concentration prediction model by machine-learning training data in which the feature extracted by the extraction unit and the concentration of the gas component acquired by the exhaust gas concentration acquisition unit are associated with each other.

[0007] To achieve the above object, the present disclosure provides a prediction model generation method for generating an exhaust gas concentration prediction model which predicts a concentration of a gas component contained in an exhaust gas discharged from a furnace, comprising: a step of acquiring an image of a combustion region of the furnace; a step of converting the image into color image data and extracting a feature from the color image data; a step of acquiring a concentration of the gas component contained in the exhaust gas, on a downstream side of the combustion region, after a preset time has elapsed from the time when the image has been captured; and a step of generating the exhaust gas concentration prediction model by machine-learning training data in which the feature and the concentration of the gas component contained in the exhaust gas after the preset time has elapsed from the time when the image has been captured are associated with each other.

[0008] According to the prediction model generation device and the prediction model generation method of the present disclosure, it is possible to improve the prediction accuracy of the exhaust gas concentration prediction model.

BRIEF DESCRIPTION OF DRAWINGS

[0009] FIG. 1 is a schematic configuration diagram of a furnace in which a prediction model generation device according to the first embodiment is installed.

FIG. 2 is a schematic functional block diagram of the prediction model generation device according to the first embodiment.

FIG. 3 is a diagram showing color image data.

FIG. 4 is a schematic configuration diagram of a furnace in which a prediction model generation device according to the second embodiment is installed.

FIG. 5 is a schematic functional block diagram of the prediction model generation device according to the second embodiment.

FIG. 6 is a schematic configuration diagram of an exhaust gas concentration control system according to the third embodiment.

FIG. 7 is a diagram for describing the effect of the exhaust gas concentration control system according to the third embodiment.

FIG. 8 is a schematic configuration diagram of an exhaust gas concentration control system according to a modified example of the third embodiment.

FIG. 9 is a flowchart of a prediction model generation method according to an embodiment.

FIG. 10 is a flowchart of an exhaust gas concentration control method according to an embodiment.

DETAILED DESCRIPTION

[0010] Hereinafter, a prediction model generation device, an exhaust gas concentration control system, a prediction model generation method, and an exhaust gas concentration

control method according to embodiments of the present disclosure will be described with reference to drawings. The following embodiments are illustrative and not intended to limit the present disclosure, and various modifications are possible within the scope of technical ideas of the present disclosure.

[0011] <First Embodiment>

(Configuration of furnace)

FIG. 1 is a schematic configuration diagram of a furnace 100 in which a prediction model generation device 1 according to the first embodiment is installed. In the embodiment illustrated in FIG. 1, the furnace 100 is a stoker-type waste incinerator which uses solid fuel Fs such as municipal waste, industrial waste, and biomass. However, the furnace 100 is not limited to a stoker-type waste incinerator. Hereinafter, the direction in which the solid fuel Fs moves in the furnace 100 is referred to as a moving direction W1.

[0012] As shown in FIG. 1, the furnace 100 includes a hopper 102, a feeder 104, a combustion chamber 106, an air supply device 108, and a gas duct 110.

[0013] The solid fuel Fs fed from the hopper 102 is accumulated in a passage 103 extending toward the combustion chamber 106. The feeder 104 is arranged in the passage 103, and is configured to move reciprocally along the extending direction (moving direction W1) of the passage 103. The feeder 104 pushes the solid fuel Fs accumulated in the passage 103 into the combustion chamber 106.

[0014] The combustion chamber 106 includes a grate 112 (stoker) which corresponds to the floor of the combustion chamber 106 and on which the solid fuel Fs pushed into the combustion chamber 106 falls. The grate 112 is configured to move the solid fuel Fs on the grate 112 in a direction away from a receiving port 114 of the combustion chamber 106 (from upstream to downstream in the moving direction W1). Such a combustion chamber 106 includes a drying region 128, a combustion region 130, and a post-combustion region 132, which are arranged in order from upstream to downstream in the moving direction W1. In the drying region 128, the solid fuel Fs is dried by heat in the combustion chamber 106. In the combustion region 130, the solid fuel Fs is combusted by generating a flame Fr. In the

post-combustion region 132, unburnt fuel that has not combusted in the combustion region 130 are completely combusted. The solid fuel Fs that has been dried, combusted, and post-combusted in the combustion chamber 106 becomes ash Fa and is discharged out of the furnace 100.

[0015] An image of the combustion region 130 is captured by an imaging device 116 such as a visible camera. In the embodiment illustrated in FIG. 1, an image of the combustion region 130 is captured by the imaging device 116 disposed at a furnace outlet 118 of the combustion chamber 106. However, the imaging device is not limited to a visible camera as long as it can take an image of the combustion region. For example, the imaging device 116 may be an infrared camera. Further, the installation position of the imaging device 116 is not limited to the furnace outlet 118 of the combustion chamber 106.

[0016] The air supply device 108 is configured to supply the combustion chamber 106 with primary air used for combusting the solid fuel Fs and secondary air used for further combusting the exhaust gas Eg produced by combustion of the solid fuel Fs. In the embodiment illustrated in FIG. 1, the air supply device 108 includes an air supply pipe 120 and a blower 122 disposed in the air supply pipe 120. Part of the air flowing through the air supply pipe 120 is supplied as the primary air from the grate 112 to a lower portion of the combustion chamber 106 via a first flow rate regulating valve 124, and the remainder is supplied as the secondary air from a side wall of the combustion chamber 106 to an upper portion of the combustion chamber 106 via a second flow rate regulating valve 126. In other words, the air supply device 108 functions as a primary air supply device for supplying the primary air to the lower portion of the combustion chamber 106, and also functions as a secondary air supply device for supplying the secondary air to the upper portion of the combustion chamber 106. In the embodiment illustrated in FIG. 1, the primary air is supplied to each of the drying region 128, the combustion region 130, and the post-combustion region 132 of the combustion chamber 106.

[0017] The gas duct 110 communicates with the upper portion of the combustion chamber 106 to pass the exhaust gas Eg produced by combustion of the solid fuel Fs. A gas analyzer

140 is provided at an outlet portion 111 of the gas duct 110. The gas analyzer 140 measures the concentration of a gas component such as oxygen and carbon monoxide contained in the exhaust gas Eg discharged from the furnace 100.

[0018] In the embodiment illustrated in FIG. 1, the furnace 100 is configured as a part of an incineration system 150. As shown in FIG. 1, the incineration system 150 is equipped with the furnace 100, a temperature reduction tower 152, a dust collection device 154, and a stack 156. The temperature reduction tower 152 is connected to the outlet portion 111 of the gas duct 110 of the furnace 100. The temperature reduction tower 152 decreases the temperature of the exhaust gas Eg discharged from the furnace 100 (the gas duct 110 of the furnace 100). The dust collection device 154 is connected to the temperature reduction tower 152. The dust collection device 154 collects fly ash contained in the exhaust gas Eg discharged from the temperature reduction tower 152. The stack 156 is connected to the dust collection device 154. Through the stack 156, the exhaust gas Eg from the dust collection device 154 is discharged to the outside of the incineration system 150, for example, to the atmosphere.

[0019] (Configuration of prediction model generation device)

The prediction model generation device 1 disposed in the furnace 100 acquires data (image and concentration of gas component) from each of the imaging device 116 and the gas analyzer 140 and generates an exhaust gas concentration prediction model which predicts the concentration of a gas component contained in the exhaust gas Eg discharged from the furnace 100, on the basis of the acquired data. The prediction model generation device 1 may be electrically connected to each of the imaging device 116 and the gas analyzer 140, and may be configured to acquire data in real time. Alternatively, data previously acquired from each of the imaging device 116 and the gas analyzer 140 may be stored in a database, and the prediction model generation device 1 may be configured to acquire the data from the database.

[0020] The prediction model generation device 1 is a computer such as an electronic control unit, and includes a processor such as CPU or GPU, a memory such as ROM or RAM, and an I/O interface (not shown). The prediction model generation device 1 operates the

processor (e.g. computation) in accordance with a program loaded to the memory, and thereby functional units of the prediction model generation device 1 are implemented. The functional units of the prediction model generation device 1 according to an embodiment will be described with reference to FIG. 2.

[0021] FIG. 2 is a schematic functional block diagram of the prediction model generation device 1 according to the first embodiment. As shown in FIG. 2, the prediction model generation device 1 includes an image acquisition unit 2, an extraction unit 4, an exhaust gas concentration acquisition unit 6, and a model generation unit 8.

[0022] The image acquisition unit 2 acquires an image of the combustion region 130 of the furnace 100 from the imaging device 116.

[0023] The extraction unit 4 converts the image acquired by the image acquisition unit 2 into color image data 160. Specifically, the extraction unit 4 converts the image acquired by the image acquisition unit 2 into color image data 160 divided into a plurality of color regions A according to color information by clustering process. Further, the extraction unit 4 extracts a feature from the color image data 160.

[0024] An example of “dividing into a plurality of color regions A according to color information by clustering process” will be described. The color information is RGB color components, and each of the color regions A is set by clustering process so that the RGB color components do not overlap with each other. The extraction unit 4 decomposes the image acquired by the image acquisition unit 2 into RGB color components for each pixel, and determines the color regions A including the pixels. However, the color information is not limited to RGB color components, but may be luminance or chroma.

[0025] The algorithm of the clustering process is not limited, and a known clustering algorithm can be used. For example, the clustering process may be performed using an algorithm such as k-means which can specify the number of clusters, or the clustering process may be performed using an algorithm such as flowsom which automatically determines the number of clusters.

[0026] FIG. 3 is a diagram showing the color image data 160. In the embodiment

illustrated in FIG. 3, the color image data 160 is divided into seven color regions A by clustering process, including a first color region A1 (A), a second color region A2 (A), a third color region A3 (A), a fourth color region A4 (A), a fifth color region A5 (A), a sixth color region A6 (A), and a seventh color region A7 (A) in descending order of luminance. Each of the first color region A1 to the seventh color region A7 is converted into a black-and-white (gray scale) shading value, and the color becomes darker from the first color region A1 to the seventh color region A7.

[0027] Next, an example of “extracting a feature from the color image data 160” will be described. The extraction unit 4 calculates the total number of pixels divided into the first color region A1 and extracts the total number of pixels as a feature. Further, the extraction unit 4 extracts the total number of pixels of the first color region A1 at predetermined time intervals (for example, every second). The extraction unit 4 also calculates the total number of pixels for each of the second color region A2 to the seventh color region A7 at predetermined time intervals and extracts the respective total numbers of pixels as features.

[0028] In the first embodiment, the feature includes the total numbers of pixels of all the color regions (first color region A1 to seventh color region A7) of the plurality of color regions A, but the present disclosure is not limited to this embodiment. The feature may include the total number of pixels of at least one of the plurality of color regions A. In some embodiments, the feature includes the total number of pixels of a color region A that has a high correlation with the concentration of the gas component among the plurality of color regions A. Here, the color region A that has a high correlation may be a color region A having a higher correlation than a predetermined correlation, or may be a color region A selected in descending order of correlation among the plurality of color regions A.

[0029] The exhaust gas concentration acquisition unit 6 acquires the concentration of the gas component contained in the exhaust gas Eg, on the downstream side of the combustion region 130, after a preset time t has elapsed from the time when the image has been captured. In other words, the exhaust gas concentration acquisition unit 6 acquires the concentration of the gas component measured by the gas analyzer 140 after a preset time t has elapsed from the

capture time of the image from which the total number of pixels is extracted. The preset time t is calculated on the basis of, for example, the length of the gas duct 110 or the distance from the combustion region 130 to the gas analyzer 140.

[0030] The model generation unit 8 generates the exhaust gas concentration prediction model by machine-learning training data in which the total number of pixels (feature) extracted by the extraction unit 4 and the concentration of the gas component acquired by the exhaust gas concentration acquisition unit 6 are associated with each other. Specifically, the model generation unit 8 executes regression analysis on a plurality of training data with different image capture times, and generates a regression equation for calculating the concentration of the gas component from the total number of pixels.

[0031] (Effect of prediction model generation device)

According to findings of the present inventors, the concentration of the gas component contained in the exhaust gas E_g discharged from the furnace 100 has a high correlation with the total number of pixels extracted from the color image data 160 divided into the plurality of color regions A according to color information among information obtained from the image of the combustion region 130 of the furnace 100.

[0032] According to the first embodiment, the exhaust gas concentration prediction model generated by the model generation unit 8 is generated by machine learning of training data in which the total number of pixels extracted from the color image data 160 is associated with the concentration of the gas component measured by the gas analyzer 140 after a preset time t has elapsed from the image capture time of the image from which the total number of pixels is extracted. Thereby, it is possible to improve the prediction accuracy of the exhaust gas concentration prediction model. Further, since the clustering process is applied to convert the image into the color image data 160, it is unnecessary to prepare labeled data. Further, the clustering process does not require manual adjustment such as preprocessing or threshold setting. This facilitates the automation of feature extraction.

[0033] The installation position of the gas analyzer 140 may be downstream of the generation point of the exhaust gas E_g . Accordingly, there may be a time lag between the

generation point of the exhaust gas Eg and the measurement point of the concentration of the gas component by the gas analyzer 140. In this regard, according to the first embodiment, the exhaust gas concentration acquisition unit 6 acquires the concentration of the gas component measured by the gas analyzer 140 after a preset time t has elapsed from the capture time of the image. Thus, since the training data is generated in consideration of the time lag, it is possible to improve the prediction accuracy of the exhaust gas concentration prediction model.

[0034] The total number of pixels is one of information that can be quickly extracted. According to the first embodiment, since the extraction unit 4 extracts the total number of pixels as the feature, the model generation unit 8 can quickly generate the exhaust gas concentration prediction model.

[0035] <Second Embodiment>

The prediction model generation device 1 according to the second embodiment of the present disclosure will be described. The second embodiment is different from the first embodiment in that a process data acquisition unit 10 is further provided, but the other configurations are the same as those described in the first embodiment. In the second embodiment, the same constituent elements as those in the first embodiment are associated with the same reference characters and thus not described again in detail.

[0036] (Configuration of furnace)

First, a furnace 100 in which the prediction model generation device 1 according to the second embodiment is installed will be described. FIG. 4 is a schematic configuration diagram of the furnace 100 in which the prediction model generation device 1 according to the second embodiment is installed. The furnace 100 according to the second embodiment further includes a pressure gauge 142, a temperature sensor 144, and a heat recovery steam generator 146 for measuring process data of the furnace 100.

[0037] The pressure gauge 142 is disposed in an upper portion of the combustion chamber 106, and measures the pressure in the combustion chamber 106 (in the furnace 100). The temperature sensor 144 is disposed in the gas duct 110, and measures the temperature of

the exhaust gas Eg flowing through the gas duct 110 as the temperature in the furnace 100. The heat recovery steam generator 146 is disposed in the gas duct 110, and generates steam from the thermal energy of the exhaust gas Eg flowing through the gas duct 110. In the present embodiment, the heat recovery steam generator 146 is configured to measure the amount of steam generated by the heat recovery steam generator 146. In the embodiment illustrated in FIG. 4, the gas duct 110 is provided with the temperature sensor 144, the heat recovery steam generator 146, and the gas analyzer 140 in this order from upstream to downstream in the flow direction of the exhaust gas Eg, but the present disclosure is not limited to this embodiment.

[0038] (Configuration of prediction model generation device)

FIG. 5 is a schematic functional block diagram of the prediction model generation device 1 according to the second embodiment. As illustrated in FIGs. 4 and 5, the prediction model generation device 1 acquires data (image, temperature, pressure, and steam amount in the furnace 100, and concentration of gas component) from each of the imaging device 116, the gas analyzer 140, the pressure gauge 142, the temperature sensor 144, and the heat recovery steam generator 146, and generates an exhaust gas concentration prediction model which predicts the concentration of a gas component contained in the exhaust gas Eg discharged from the furnace 100, on the basis of the acquired data.

[0039] As shown in FIG. 5, the prediction model generation device 1 further includes a process data acquisition unit 10 configured to acquire process data. In the embodiment illustrated in FIG. 5, the process data acquisition unit 10 acquires the pressure in the combustion chamber 106 (pressure in the furnace 100) measured by the pressure gauge 142, the temperature of the exhaust gas Eg flowing through the gas duct 110 (the temperature in the furnace 100) measured by the temperature sensor 144, and the amount of steam generated by the heat recovery steam generator 146. The process data acquisition unit 10 acquires process data measured at the same time as the image is captured. In the second embodiment, the process data includes the pressure in the furnace 100, the temperature in the furnace 100, and the amount of steam, but the present disclosure is not limited to this embodiment. The

process data may include at least one of the pressure in the furnace 100, the temperature in the furnace 100, or the amount of steam.

[0040] The model generation unit 8 generates the exhaust gas concentration prediction model by machine-learning training data in which the total number of pixels (feature) extracted by the extraction unit 4, the concentration of the gas component acquired by the exhaust gas concentration acquisition unit 6, and the process data acquired by the process data acquisition unit 10 are associated with each other. Specifically, the model generation unit 8 executes linear regression analysis on a plurality of training data with different image capture times, and generate a regression equation for calculating the concentration of the gas component from the total number of pixels and the process data. The basis function in the linear regression may be selected from polynomials and Gaussian functions, for example, so as to reduce an error of a predicted value of the regression analysis.

[0041] (Effect of prediction model generation device)

The concentration of the gas component contained in the exhaust gas Eg discharged from the furnace 100 has a high correlation with the process data. According to the second embodiment, since the exhaust gas concentration prediction model is generated in consideration of the process data, it is possible to further improve the prediction accuracy of the exhaust gas concentration prediction model.

[0042] In some embodiments, the exhaust gas concentration acquisition unit 6 further acquires an uncorrected concentration which is the concentration of the gas component contained in the exhaust gas Eg at the time when the image is captured. Further, the model generation unit 8 generates the exhaust gas concentration prediction model by machine-learning training data in which the total number of pixels (feature) extracted by the extraction unit 4, the uncorrected concentration and the concentration of the gas component acquired by the exhaust gas concentration acquisition unit 6, and the process data acquired by the process data acquisition unit 10 are associated with each other.

[0043] According to findings of the present inventors, the error (RMSE) of the exhaust gas concentration prediction model can be reduced by machine-learning training data that

includes the uncorrected concentration. With this configuration, since the exhaust gas concentration prediction model is generated in consideration of the uncorrected concentration, it is possible to further improve the prediction accuracy of the exhaust gas concentration prediction model.

[0044] <Third Embodiment>

An exhaust gas concentration control system 50 according to the third embodiment of the present disclosure will be described. The exhaust gas concentration control system 50 controls the concentration of the gas component contained in the exhaust gas Eg discharged from the furnace 100 by using the exhaust gas concentration prediction model generated by the prediction model generation device 1. In the third embodiment, the exhaust gas concentration control system 50 controls the concentration of oxygen by using the exhaust gas concentration prediction model generated by the prediction model generation device 1 according to the first embodiment. In other embodiments, the exhaust gas concentration control system 50 controls the concentration of oxygen by using the exhaust gas concentration prediction model generated by the prediction model generation device 1 according to the second embodiment. The concentration of the gas component controlled by the exhaust gas concentration control system 50 is not limited to the concentration of oxygen, but may be, for example, the concentration of carbon monoxide or the concentration of nitrogen oxides (NOx).

[0045] (Configuration of exhaust gas concentration control system)

FIG. 6 is a schematic configuration diagram of the exhaust gas concentration control system 50 according to the third embodiment. As shown in FIG. 6, the exhaust gas concentration control system 50 includes an imaging device 52 and an adjustment device 54.

[0046] The imaging device 52 captures an image of the combustion region 130 of the furnace 100. In the second embodiment, the imaging device 52 is the same device as the imaging device 116 and is disposed at the furnace outlet 118 of the combustion chamber 106. In other embodiments, the imaging device 52 may be a different device from the imaging device 116 which is configured to capture an image of the combustion region 130 of the furnace 100.

[0047] The adjustment device 54 is electrically connected to the imaging device 52, and acquires the image captured by the imaging device 52 in real time. The adjustment device 54 extracts the total number of pixels (feature) from the captured image with the above-described method, and inputs the extracted total number of pixels into the exhaust gas concentration prediction model generated by the prediction model generation device 1. The adjustment device 54 adjusts the amount of air supplied to the furnace 100 on the basis of the concentration of oxygen (hereinafter referred to as predicted value X1) output by inputting the total number of pixels into the exhaust gas concentration prediction model.

[0048] In the embodiment illustrated in FIG. 6, the adjustment device 54 is provided separately from the prediction model generation device 1, and the exhaust gas concentration prediction model is acquired from the prediction model generation device 1. In other embodiments, the adjustment device 54 is configured to function as the prediction model generation device 1, and inputs the total number of pixels extracted from the captured image into the exhaust gas concentration prediction model generated by the adjustment device 54 itself.

[0049] An example of the operation of the adjustment device 54 according to the third embodiment will be described. In the embodiment illustrated in FIG. 6, the adjustment device 54 is electrically connected to each of a blower 122, a first flow rate regulating valve 124, and a second flow rate regulating valve 126, and is configured to adjust the rotation speed of the fan of the blower 122, the opening degree of the first flow rate regulating valve 124, and the opening degree of the second flow rate regulating valve 126 by transmitting an electric signal (hereinafter, described as “instructing”) to each of the blower 122, the first flow rate regulating valve 124, and the second flow rate regulating valve 126. When the predicted value X1 is smaller than a reference value of the adjustment device 54, the adjustment device 54 instructs the blower 122 to increase the rotation speed of the fan, the first flow rate regulating valve 124 to increase the opening degree, and the second flow rate regulating valve 126 to increase the opening degree. In other words, when the predicted value X1 is smaller than the reference value of the adjustment device 54, the adjustment device 54 increases the

amount of air supplied to the furnace 100. The reference value of the adjustment device 54 is a preset value of the concentration of oxygen in the exhaust gas Eg discharged from the furnace 100 below which the combustion state of the furnace 100 is unstable. The reference value is set to, for example, 2 wet% or less. The oxygen concentration at the outlet of the furnace 100 (the outlet portion 111 of the gas duct 110) varies around 1 wet% when the combustion state is stable. Therefore, if the combustion state is not unstable, the reference value is rarely 2 wet% or less. Therefore, by setting the reference value to 2 wet% or less, the adjustment device 54 can increase the amount of air supplied to the furnace 100 at the timing of the transition to the unstable state (that is, at an appropriate timing) and thus can return the state to the stable state.

[0050] In some embodiments, the amount of air supplied to the furnace 100 is determined according to a difference between the predicted value X1 and a preset target value. The target value is set to be larger than the reference value of the adjustment device 54. This target value is a value that can be freely set. For example, the concentration of oxygen contained in the exhaust gas Eg is set to 3 wet% so that the air ratio is 1.2.

[0051] In the third embodiment, the adjustment device 54 adjusts each of the rotation speed of the fan of the blower 122, the opening degree of the first flow rate regulating valve 124, and the opening degree of the second flow rate regulating valve 126, but the present disclosure is not limited to this embodiment. The adjustment device 54 may adjust at least one of the rotation speed of the fan of the blower 122, the opening degree of the first flow rate regulating valve 124, or the opening degree of the second flow rate regulating valve 126.

[0052] When the predicted value X1 returns to the reference value by increasing the amount of air supplied to the furnace 100, the adjustment device 54 instructs the blower 122 to decrease the rotation speed of the fan, the first flow rate regulating valve 124 to decrease the opening degree, and the second flow rate regulating valve 126 to decrease the opening degree. In other words, when the predicted value X1 returns to the reference value, the adjustment device 54 decreases the amount of air supplied to the furnace 100. In some embodiments, when the predicted value X1 returns to the reference value, the adjustment

device 54 adjusts the rotation speed of the fan of the blower 122, the opening degree of the first flow rate regulating valve 124, and the opening degree of the second flow rate regulating valve 126 to values before they are adjusted (increased) by the adjustment device 54.

[0053] (Effect of exhaust gas concentration control system)

FIG. 7 is a diagram for describing the effect of the exhaust gas concentration control system 50 according to the third embodiment. FIG. 7 shows a graph with the vertical axis representing the oxygen concentration and the horizontal axis representing the time. The solid line indicates the concentration (predicted value X1) of oxygen output from the exhaust gas concentration prediction model. The dash-dotted line indicates the concentration (hereinafter, measured value X2) of oxygen acquired by the gas analyzer 140 in real time. The dotted line indicates the concentration (hereinafter, corrected value X3) of oxygen obtained by displacing the dash-dotted line by the preset time t .

[0054] As described above, there is a time lag between the generation point of the exhaust gas Eg and the measurement point of the concentration of oxygen by the gas analyzer 140. Therefore, it may not be appropriate to use the measured value X2 to adjust the amount of air supplied to the furnace 100. As shown in FIG. 7, there is a lag in acquiring the measured value X2 by the preset time t , and it is appropriate to use the corrected value X3 to adjust the amount of air supplied to the furnace 100.

[0055] According to the third embodiment, the concentration of oxygen contained in the exhaust gas Eg discharged from the furnace 100 is controlled on the basis of the concentration (predicted value X1) of oxygen predicted from the exhaust gas concentration prediction model generated in consideration of the time lag. Thus, as compared to the case where the concentration of oxygen is controlled on the basis of the measured value X2, the concentration of oxygen contained in the exhaust gas Eg discharged from the furnace 100 can be controlled at an early stage. In addition, according to the third embodiment, it is possible to automate the control of the concentration of oxygen contained in the exhaust gas Eg discharged from the furnace 100.

[0056] When the concentration of oxygen contained in the exhaust gas Eg is low, the

concentration of carbon monoxide contained in the exhaust gas Eg is high, and the combustion state of the furnace 100 is often unstable. According to the third embodiment, when the predicted value X1 (concentration of oxygen) is lower than the reference value, the amount of air supplied to the furnace 100 is increased. Thus, the combustion state of the furnace 100 is stabilized, so that it is possible to reduce the concentration of carbon monoxide contained in the exhaust gas Eg discharged from the furnace 100.

[0057] On the other hand, increasing the amount of air supplied to the furnace 100 may promote the generation of nitrogen oxides when combusting the solid fuel Fs in the combustion chamber 106. According to the third embodiment, when the predicted value X1 returns to the reference value by increasing the amount of air supplied to the furnace 100, the amount of air supplied to the furnace 100 is decreased. Thus, it is possible to reduce the concentration of nitrogen oxides contained in the exhaust gas Eg while reducing the concentration of carbon monoxide contained in the exhaust gas Eg discharged from the furnace 100.

[0058] <Modified example of third Embodiment>

In the third embodiment, the adjustment device 54 adjusts the amount of air supplied to the furnace 100. Alternatively or additionally, the adjustment device 54 may adjust the amount of the solid fuel Fs supplied to the furnace 100. FIG. 8 is a schematic configuration diagram of the exhaust gas concentration control system 50 according to a modified example of the third embodiment. As shown in FIG. 8, the adjustment device 54 is electrically connected to the feeder 104, and can adjust the reciprocating speed of the feeder 104 by transmitting an electric signal to the feeder 104.

[0059] An example of the operation of the adjustment device 54 according to the modified example of the third embodiment will be described. The adjustment device 54 instructs the feeder 104 to decrease the reciprocating speed when the predicted value X1 is smaller than the reference value of the adjustment device 54. In other words, when the predicted value X1 is lower than the reference value of the adjustment device 54, the adjustment device 54 decreases the amount of the solid fuel Fs supplied to the furnace 100.

[0060] With this configuration, when the predicted value X1 is smaller than the reference value, the amount of the solid fuel Fs supplied to the furnace 100 is decreased, so that the concentration of carbon monoxide contained in the exhaust gas Eg discharged from the furnace 100 can be reduced.

[0061] In some embodiments, the adjustment device 54 is configured to adjust the speed of the grate 112, and decreases the speed of the grate 112 when the predicted value X1 is smaller than the reference value of the adjustment device 54. With this configuration, when the predicted value X1 is smaller than the reference value, the stirring of the solid fuel Fs supplied to the combustion chamber 106 is suppressed, so that the concentration of carbon monoxide contained in the exhaust gas Eg discharged from the furnace 100 can be reduced.

[0062] <Prediction model generation method>

The prediction model generation method according to the present disclosure is a method for generating an exhaust gas concentration prediction model which predicts the concentration of a gas component contained in exhaust gas Eg discharged from the furnace 100. FIG. 9 is a flowchart of the prediction model generation method according to an embodiment. As shown in FIG. 9, the prediction model generation method includes an image acquisition step S2, a feature extraction step S4, a concentration acquisition step S6, and a model generation step S8.

[0063] In the image acquisition step S2, an image of the combustion region 130 of the furnace 100 is acquired. In the feature extraction step S4, the image acquired in the image acquisition step S2 is converted into color image data 160 divided into a plurality of color regions A according to color information by clustering process, and a feature is extracted from the color image data 160. In the concentration acquisition step S6, the concentration of a gas component contained in the exhaust gas Eg is acquired, on the downstream side of the combustion region 130, after a preset time t has elapsed from the time when the image has been captured. In the model generation step S8, an exhaust gas concentration prediction model is generated by machine-learning training data in which the feature extracted in the feature extraction step S4 and the concentration of the gas component acquired in the

concentration acquisition step S6 are associated with each other. The concentration acquisition step S6 is performed before the model generation step S8, but it is not limited to the embodiment illustrated in FIG. 9.

[0064] According to this prediction model generation method, the image of the combustion region 130 of the furnace 100 is converted into the color image data 160 divided into a plurality of color regions A according to color by clustering process, and the exhaust gas concentration prediction model is generated by machine learning of training data in which the feature extracted from the color image data 160 is associated with the concentration of the gas component contained in the exhaust gas Eg after a preset time has elapsed from the time when the image has been captured. Thereby, it is possible to improve the prediction accuracy of the exhaust gas concentration prediction model. Further, since the clustering process is applied to convert the image into the color image data 160, it is unnecessary to prepare labeled data, and it is possible to quickly generate the exhaust gas concentration prediction model.

[0065] (Exhaust gas concentration control method)

The exhaust gas concentration control method according to the present disclosure is a method for controlling the concentration of the gas component contained in the exhaust gas Eg discharged from the furnace 100 by using the exhaust gas concentration prediction model generated by the prediction model generation method. FIG. 10 is a flowchart of the exhaust gas concentration control method according to an embodiment. As shown in FIG. 10, the exhaust gas concentration control method includes an imaging step S52 and an adjustment step S54.

[0066] In the imaging step S52, an image of the combustion region 130 of the furnace 100 is captured. In the adjustment step S54, at least one of the amount of air supplied to the furnace 100 or the amount of solid fuel Fs supplied to the furnace is adjusted on the basis of the concentration of the gas component output by inputting the image captured in the imaging step S52 into the exhaust gas concentration prediction model.

[0067] With this exhaust gas concentration control method, since the concentration of the

gas component is controlled on the basis of the concentration of the gas component output (predicted) from the exhaust gas concentration prediction model, the concentration of the gas component can be controlled appropriately compared to the case where the concentration of the gas component is controlled on the basis of the concentration of the gas component acquired in real time.

[0068] The contents described in the above embodiments would be understood as follows, for instance.

[0069] [1] A prediction model generation device (1) according to the present disclosure is a prediction model generation device for generating an exhaust gas concentration prediction model which predicts a concentration of a gas component contained in an exhaust gas (Eg) discharged from a furnace (100), and comprises: an image acquisition unit (2) configured to acquire an image of a combustion region (130) of the furnace; an extraction unit (4) configured to convert the image into color image data (160) and extract a feature from the color image data; an exhaust gas concentration acquisition unit (6) configured to acquire a concentration of the gas component contained in the exhaust gas, on a downstream side of the combustion region, after a preset time has elapsed from the time when the image has been captured; and a model generation unit (8) configured to generate the exhaust gas concentration prediction model by machine-learning training data in which the feature extracted by the extraction unit and the concentration of the gas component acquired by the exhaust gas concentration acquisition unit are associated with each other.

[0070] According to findings of the present inventors, the concentration of the gas component contained in the exhaust gas has a high correlation with a feature (information) extracted from the color image data among information obtained from the image of the combustion region of the furnace. According to the above configuration [1], the exhaust gas concentration prediction model is generated by machine learning of training data in which the feature extracted from the color image data converted from the image of the combustion region of the furnace is associated with the concentration of the gas component contained in the exhaust gas after a preset time has elapsed from the time when the image has been

captured. Thereby, it is possible to improve the prediction accuracy of the exhaust gas concentration prediction model.

[0071] [2] In some embodiments, in the above configuration [1], the color image data includes dividing the image into a plurality of color regions (A) according to color information by clustering process.

[0072] According to the above configuration [2], since the clustering process is applied to convert the image into the color image data, it is unnecessary to prepare labeled data. Further, the clustering process does not require manual adjustment such as preprocessing or threshold setting. This facilitates the automation of feature extraction.

[0073] [3] In some embodiments, in the above configuration [1] or [2], the feature includes an area of at least one color region of the plurality of color regions.

[0074] The area of the color region is one of information that can be quickly extracted. According to the above configuration [3], since the feature includes the area of the color region, the training data can be quickly prepared.

[0075] [4] In some embodiments, in any one of the above configurations [1] to [3], the prediction model generation device further comprises a process data acquisition unit (10) configured to acquire process data including at least one of a temperature in the furnace, a pressure in the furnace, or an amount of steam generated by combustion of fuel in the furnace. The model generation unit is configured to generate the exhaust gas concentration prediction model by machine-learning training data in which the feature extracted by the extraction unit, the concentration of the gas component acquired by the exhaust gas concentration acquisition unit, and the process data acquired by the process data acquisition unit are associated with each other.

[0076] The concentration of the gas component contained in the exhaust gas discharged from the furnace has a high correlation with the process data. According to the above configuration [4], since the exhaust gas concentration prediction model is generated in consideration of the process data, it is possible to further improve the prediction accuracy of the exhaust gas concentration prediction model.

[0077] [5] In some embodiments, in the above configuration [4], the exhaust gas concentration acquisition unit is configured to further acquire an uncorrected concentration which is a concentration of the gas component contained in the exhaust gas at the time when the image is captured. The model generation unit is configured to generate the exhaust gas concentration prediction model by machine-learning training data in which the feature extracted by the extraction unit, the uncorrected concentration and the concentration of the gas component acquired by the exhaust gas concentration acquisition unit, and the process data acquired by the process data acquisition unit are associated with each other.

[0078] According to findings of the present inventors, the error (RMSE) of the exhaust gas concentration prediction model can be reduced by machine-learning training data that includes the uncorrected concentration. According to the above configuration [5], since the exhaust gas concentration prediction model is generated in consideration of the uncorrected concentration, it is possible to further improve the prediction accuracy of the exhaust gas concentration prediction model.

[0079] [6] An exhaust gas concentration control system (50) according to the present disclosure is an exhaust gas concentration control system for controlling a concentration of a gas component contained in the exhaust gas discharged from the furnace, using the exhaust gas concentration prediction model generated by the prediction model generation device described in any one of [1] to [5], and comprises: an imaging device (52) configured to capture an image of the combustion region of the furnace; and an adjustment device (54) configured to adjust at least one of an amount of air supplied to the furnace or an amount of fuel supplied to the furnace, on the basis of a concentration of the gas component output by inputting a feature extracted from the image captured by the imaging device into the exhaust gas concentration prediction model.

[0080] It may not be appropriate to use the concentration of the gas component acquired in real time to adjust the amount of air supplied to the furnace or the amount of fuel supplied to the furnace. According to the above configuration [6], since the concentration of the gas component is controlled on the basis of the concentration of the gas component output

(predicted) from the exhaust gas concentration prediction model, the concentration of the gas component can be controlled appropriately compared to the case where the concentration of the gas component is controlled on the basis of the concentration of the gas component acquired in real time. Further, according to the above configuration (6), it is possible to automate the control of the concentration of the gas component.

[0081] [7] In some embodiments, in the above configuration [6], the gas component includes oxygen, and the adjustment device is configured to increase the amount of air supplied to the furnace when the concentration of oxygen output from the exhaust gas concentration prediction model is lower than a reference value of the adjustment device.

[0082] When the concentration of oxygen contained in the exhaust gas is low, the concentration of carbon monoxide contained in the exhaust gas is high, and the combustion state of the furnace is often unstable. According to the above configuration [7], when the concentration of oxygen output from the exhaust gas concentration prediction model is lower than the reference value, the amount of air supplied to the furnace is increased. Thus, it is possible to reduce the concentration of carbon monoxide contained in the exhaust gas discharged from the furnace.

[0083] [8] In some embodiments, in the above configuration [7], the amount of air supplied to the furnace is determined according to a difference between the concentration of oxygen output from the exhaust gas concentration prediction model and a preset target value.

[0084] According to the above configuration [7], since the amount of air supplied to the furnace is determined according to a difference between the concentration of oxygen output from the exhaust gas concentration prediction model and the target value, the concentration of oxygen contained in the exhaust gas discharged from the furnace can be brought close to the target value.

[0085] [9] In some embodiments, in the above configuration [7] or [8], the adjustment device is configured to decrease the amount of air supplied to the furnace when the concentration of oxygen output from the exhaust gas concentration prediction model returns to the reference value of the adjustment device.

[0086] Increasing the amount of air supplied to the furnace may promote the generation of nitrogen oxides when combusting the fuel in the furnace. According to the above configuration [9], when the concentration of oxygen output from the exhaust gas concentration prediction model returns to the reference value by increasing the amount of air supplied to the furnace, the amount of air supplied to the furnace is decreased. Thus, it is possible to reduce the concentration of nitrogen oxides contained in the exhaust gas while reducing the concentration of carbon monoxide contained in the exhaust gas discharged from the furnace.

[0087] [10] In some embodiments, in any one of the above configurations [6] to [9], the gas component includes oxygen, and the adjustment device is configured to decrease the amount of fuel supplied to the furnace when the concentration of oxygen output from the exhaust gas concentration prediction model is lower than a reference value of the adjustment device.

[0088] According to the above configuration [10], when the concentration of oxygen output from the exhaust gas concentration prediction model is lower than the reference value, the amount of fuel supplied to the furnace is decreased. Thus, it is possible to reduce the concentration of carbon monoxide contained in the exhaust gas discharged from the furnace.

[0089] [11] A prediction model generation method according to the present disclosure is a prediction model generation method for generating an exhaust gas concentration prediction model which predicts a concentration of a gas component contained in an exhaust gas discharged from a furnace, and comprises: a step (S2) of acquiring an image of a combustion region of the furnace; a step (S4) of converting the image into color image data and extracting a feature from the color image data; a step (S6) of acquiring a concentration of the gas component contained in the exhaust gas, on a downstream side of the combustion region, after a preset time has elapsed from the time when the image has been captured; and a step (S8) of generating the exhaust gas concentration prediction model by machine-learning training data in which the feature and the concentration of the gas component contained in the exhaust gas after the preset time has elapsed from the time when the image has been captured are

associated with each other.

[0090] According to the above method [11], the exhaust gas concentration prediction model is generated by machine learning of training data in which the feature extracted from the color image data converted from the image of the combustion region of the furnace is associated with the concentration of the gas component contained in the exhaust gas after a preset time has elapsed from the time when the image has been captured. Thereby, it is possible to improve the prediction accuracy of the exhaust gas concentration prediction model.

[0091] [12] An exhaust gas concentration control method according to the present disclosure is an exhaust gas concentration control method for controlling a concentration of a gas component contained in the exhaust gas discharged from the furnace, using the exhaust gas concentration prediction model generated by the prediction model generation method described in [11], and comprises: an imaging step (S52) of capturing an image of the combustion region of the furnace; and an adjustment step (S54) of adjusting at least one of an amount of air supplied to the furnace or an amount of fuel supplied to the furnace, on the basis of a concentration of the gas component output by inputting a feature extracted from the image captured in the imaging step into the exhaust gas concentration prediction model.

[0092] According to the above method [12], since the concentration of the gas component is controlled on the basis of the concentration of the gas component output (predicted) from the exhaust gas concentration prediction model, the concentration of the gas component can be controlled appropriately compared to the case where the concentration of the gas component is controlled on the basis of the concentration of the gas component acquired in real time.

CLAIMS

1. A prediction model generation device for generating an exhaust gas concentration prediction model which predicts a concentration of a gas component contained in an exhaust gas discharged from a furnace, the prediction model generation device comprising:

an image acquisition unit configured to acquire an image of a combustion region of the furnace;

an extraction unit configured to convert the image into color image data divided the image into a plurality of color regions according to RGB values by clustering process and extract a total numbers of pixels of at least one color region of the plurality of color regions having a correlation of a predetermined value or more with the concentration of the gas component among the plurality of color regions as a feature from;

an exhaust gas concentration acquisition unit configured to acquire a concentration of the gas component contained in the exhaust gas, on a downstream side of the combustion region, after a preset time has elapsed from the time when the image has been captured; and

a model generation unit configured to generate the exhaust gas concentration prediction model by machine-learning training data in which the feature extracted by the extraction unit and the concentration of the gas component acquired by the exhaust gas concentration acquisition unit are associated with each other.

2. The prediction model generation device according to claim 1, further comprising a process data acquisition unit configured to acquire process data including at least one of a temperature in the furnace, a pressure in the furnace, or an amount of steam generated by combustion of fuel in the furnace,

wherein the model generation unit is configured to generate the exhaust gas concentration prediction model by machine-learning training data in which the feature extracted by the extraction unit, the concentration of the gas component acquired by the exhaust gas concentration acquisition unit, and the process data acquired by the process data acquisition

unit are associated with each other.

3. The prediction model generation device according to claim 2,

wherein the exhaust gas concentration acquisition unit is configured to further acquire an uncorrected concentration which is a concentration of the gas component contained in the exhaust gas at the time when the image is captured, and

wherein the model generation unit is configured to generate the exhaust gas concentration prediction model by machine-learning training data in which the feature extracted by the extraction unit, the uncorrected concentration and the concentration of the gas component acquired by the exhaust gas concentration acquisition unit, and the process data acquired by the process data acquisition unit are associated with each other.

4. An exhaust gas concentration control system for controlling a concentration of a gas component contained in the exhaust gas discharged from the furnace, using the exhaust gas concentration prediction model generated by the prediction model generation device according to any one of claims 1 to 3, the exhaust gas concentration control system comprising:

an imaging device configured to capture an image of the combustion region of the furnace;
and

an adjustment device configured to adjust at least one of an amount of air supplied to the furnace or an amount of fuel supplied to the furnace, on the basis of a concentration of the gas component output by inputting a feature extracted from the image captured by the imaging device into the exhaust gas concentration prediction model.

5. The exhaust gas concentration control system according to claim 4,

wherein the gas component includes oxygen, and

wherein the adjustment device is configured to increase the amount of air supplied to the furnace when the concentration of oxygen output from the exhaust gas concentration prediction model is lower than a reference value of the adjustment device.

6. The exhaust gas concentration control system according to claim 5,
wherein the amount of air supplied to the furnace is determined according to a difference
between the concentration of oxygen output from the exhaust gas concentration prediction
5 model and a preset target value.

7. The exhaust gas concentration control system according to claim 5 or 6,
wherein the adjustment device is configured to decrease the amount of air supplied to the
furnace when the concentration of oxygen output from the exhaust gas concentration prediction
10 model returns to the reference value of the adjustment device.

8. The exhaust gas concentration control system according to any one of claims 4 to 7,
wherein the gas component includes oxygen, and
wherein the adjustment device is configured to decrease the amount of fuel supplied to
15 the furnace when the concentration of oxygen output from the exhaust gas concentration
prediction model is lower than a reference value of the adjustment device.

9. A prediction model generation method for generating an exhaust gas concentration
prediction model which predicts a concentration of a gas component contained in an exhaust
20 gas discharged from a furnace, the prediction model generation method comprising:

a step of acquiring an image of a combustion region of the furnace;
a step of converting the image into color image data divided the image into a plurality of
color regions according to RGB values by clustering process and extracting a total numbers of
pixels of at least one color region of the plurality of color regions having a correlation of a
25 predetermined value or more with the concentration of the gas component among the plurality
of color regions as a feature from;

a step of acquiring a concentration of the gas component contained in the exhaust gas, on
a downstream side of the combustion region, after a preset time has elapsed from the time when

the image has been captured; and

a step of generating the exhaust gas concentration prediction model by machine-learning training data in which the feature and the concentration of the gas component contained in the exhaust gas after the preset time has elapsed from the time when the image has been captured are associated with each other.

10. An exhaust gas concentration control method for controlling a concentration of a gas component contained in the exhaust gas discharged from the furnace, using the exhaust gas concentration prediction model generated by the prediction model generation method according to claim 9, the exhaust gas concentration control method comprising:

an imaging step of capturing an image of the combustion region of the furnace; and

an adjustment step of adjusting at least one of an amount of air supplied to the furnace or an amount of fuel supplied to the furnace, on the basis of a concentration of the gas component output by inputting a feature extracted from the image captured in the imaging step into the exhaust gas concentration prediction model.