

DESCRIPTION

TITLE OF THE INVENTION: TROLLEY WIRE INSPECTION DEVICE AND TROLLEY WIRE INSPECTION METHOD

TECHNICAL FIELD

[0001] The present invention relates to a trolley wire (contact wire) inspection device and a trolley wire inspection method.

BACKGROUND

[0002] An electric railway vehicle is powered by being supplied with electricity from a contact wire provided above the railway track via a current collector, such as a pantograph, when traveling along the railway track. Each time an electric railway vehicle passes, the current collector slides against the lower surface of the contact wire. For this reason, when electric railway vehicles are continuously operated, the contact wire gradually wears and eventually breaks. Accordingly, a wear limit is set for the contact wire, and when the remaining diameter of the contact wire falls below a control value, the contact wire is replaced with a new one. On the other hand, because the contact portion of a current collector also wears, the contact wire is installed so as to be offset in a zigzag manner in a direction perpendicular to the rails in order to prevent the contact portion from being concentrated at a single location, and this offset amount is also controlled. A great deal of time and effort is required for workers to manually perform such inspection and measurement of the contact wire.

[0003] For example, Patent Document 1 discloses an automatic inspection device provided with a lighting unit that illuminates a wear region located on a lower side of a contact wire above an electric railway vehicle, and a line sensor that captures images of the wear region (a sliding surface with which a pantograph comes into contact) of the contact wire illuminated by the lighting unit. More specifically, a line sensor is provided facing upward such that a scanning line crosses the contact wire, and images captured by the line sensor are arranged in a time-series manner to generate a line sensor image. After image processing is applied to the line sensor image, the offset, remaining diameter, and the like of the contact wire are calculated by using, for example, known data related to specifications of the contact wire, such as the height and thickness thereof.

CITATION LIST

PATENT LITERATURE

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0005] However, in a device such as that described above, differences may arise in the luminance of the wear region of the contact wire in the line sensor image due to lighting, the state of the wear region of the contact wire, the imaging environment, and the like, resulting in a problem where the wear region cannot be accurately acquired.

[0006] Therefore, the present invention addresses a problem of providing a contact wire inspection device and a contact wire inspection method that make it possible to accurately detect a wear region of a contact wire.

SOLUTION TO PROBLEM

[0007] The present invention adopts the following means to solve the problem described above.

Specifically, a contact wire inspection device according to a first aspect is provided with a line sensor that captures images of a contact wire and which inspects the contact wire based on images captured by the line sensor, the images being used as input images, the contact wire inspection device being provided with: a line sensor image generation unit that arranges the input images in a time-series manner to generate a line sensor image; an image processing execution procedure storage unit in which a plurality of image processing execution procedures are registered, each image processing execution procedure defining an execution order in which a plurality of image processing functions are sequentially executed on the line sensor image; a wear region extraction image generation unit that, in accordance with each of the plurality of image processing execution procedures, executes the plurality of image processing functions with the line sensor image as an input to extract a wear region of the contact wire, scans outward from the extracted wear region of the contact wire and defines, as a boundary of the wear region, a position at which a luminance value becomes equal to or less than a preset luminance value, thereby correcting the wear region, and generates a plurality of wear region extraction images corresponding to each of the plurality of image processing execution procedures; a wear region extraction image evaluation unit that calculates an evaluation value for each of the plurality of wear region extraction images and selects the wear region extraction image having the highest evaluation value; and a contact wire inspection unit that computes one or both of a remaining diameter and an offset of the contact wire based on the selected wear region extraction image having the highest evaluation value.

[0008] In addition, in a contact wire inspection device according to a second aspect, in each of the plurality of image processing execution procedures, contrast adjustment processing, background and noise removal processing, binarization processing, and interpolation processing are registered to be executed zero or more times, zero or more times, one or more times, and zero or more times, respectively, in this order.

[0009] In addition, in a contact wire inspection device according to a third aspect, each of the plurality of image processing execution procedures is stored in association with a priority, and, when the same evaluation value is computed for wear region extraction images, the wear region extraction image evaluation unit selects, as the wear region extraction image having the highest evaluation value, a wear region extraction image corresponding to the image processing execution procedure having a higher priority.

[0010] In addition, in a contact wire inspection device according to a fourth aspect, the wear region extraction image evaluation unit calculates, for each of the plurality of wear region extraction images, a number of wear regions, and calculates the evaluation value such that the evaluation value becomes higher when the difference between the number of wear regions and the actual number of contact wires is small.

[0011] In addition, in a contact wire inspection device according to a fifth aspect, the wear region extraction image evaluation unit calculates, for each of the plurality of wear region extraction images, a contact wire likelihood, which is an index indicating that the wear region has an image characteristic close to an image characteristic of the contact wire, and calculates the evaluation value such that the evaluation value becomes higher when the contact wire likelihood is high.

[0012] In addition, in a contact wire inspection device according to a sixth aspect: in the image processing execution procedure storage unit, the image processing execution procedures are registered in correspondence with each of a plurality of different environments in which the images are captured by the line sensor; the contact wire inspection device is further provided with an environment determination unit that determines, based on the line sensor image, an environment in which the input images were captured; and the wear region extraction image generation unit generates the wear region extraction images in accordance with the image processing execution procedure corresponding to the determined environment.

[0013] In addition, a contact wire inspection method according to a seventh aspect is a contact wire inspection method for inspecting a contact wire based on images captured by a line sensor that captures images of the contact wire, the images being used as input images, the contact wire inspection method including: arranging the input images in a time-series manner to

generate a line sensor image; executing, on the line sensor image, a plurality of image processing functions with the line sensor image as an input, an execution order for sequentially executing the plurality of image processing functions being registered as a plurality of image processing execution procedures, the plurality of image processing functions being executed in accordance with each of the plurality of image processing execution procedures, thereby extracting a wear region of the contact wire; scanning outward from the extracted wear region of the contact wire and defining, as a boundary of the wear region, a position at which a luminance value becomes equal to or less than a preset luminance value, thereby correcting the wear region, and generating a plurality of wear region extraction images corresponding to each of the plurality of image processing execution procedures; calculating an evaluation value for each of the plurality of wear region extraction images and selecting the wear region extraction image having the highest evaluation value; and computing one or both of a remaining diameter and an offset of the contact wire based on the selected wear region extraction image having the highest evaluation value.

EFFECTS OF INVENTION

[0014] According to this invention, the wear region of a contact wire can be accurately detected even when luminance differences arise in the wear region.

BRIEF DESCRIPTION OF DRAWINGS

[0015] Fig. 1 is an explanatory diagram illustrating a traveling environment of an electric railway vehicle on which a contact wire inspection device is mounted in an embodiment of the present invention.

Fig. 2 is a block diagram illustrating a functional configuration of the contact wire inspection device according to the present embodiment.

Fig. 3 is a schematic diagram illustrating an example of a line sensor image generated based on images captured by a line sensor of the contact wire inspection device according to the present embodiment.

Fig. 4 is a schematic diagram illustrating an example of a wear region extraction image temporarily acquired by the contact wire inspection device according to the present embodiment.

Fig. 5 is a schematic diagram illustrating an example of a wear region extraction image finally acquired by the contact wire inspection device according to the present embodiment.

Fig. 6 is an explanatory diagram of an image processing execution procedure storage unit of the

contact wire inspection device according to the present embodiment.

Fig. 7(a) is an explanatory diagram of a contact wire offset computation unit of the contact wire inspection device described above, and Fig. 7(b) is an explanatory diagram of a contact wire remaining diameter computation unit of the contact wire inspection device described above.

Fig. 8 is a flow chart for explaining an operation of the contact wire inspection method described above by the contact wire inspection device according to the present embodiment.

DESCRIPTION OF EMBODIMENTS

[0016] Below, with reference to the accompanying drawings, embodiments for practicing the present invention are described.

Fig. 1 is an explanatory diagram illustrating a traveling environment of an inspection vehicle 1 which performs inspection of a contact wire and on which a contact wire inspection device 20 in the present embodiment is mounted. In Fig. 1, the inspection vehicle 1 travels along a pair of rails 2 laid on the ground. Along the rails 2, a plurality of poles 3 are erected at intervals. The poles 3 are provided with a beam 5 and a pull-off fitting 6. Above the beam 5, a feeder 4, which is a power line for supplying power to the inspection vehicle 1, is provided so as to extend along a direction R in which the rails 2 extend and to be supported by the beam 5. Below the beam 5 and the pull-off fitting 6, a messenger wire 7 suspending a contact wire 9 to be described next is provided so as to be supported by the beam 5 and the pull-off fitting 6 and to likewise extend along the direction R in which the rails 2 extend. A plurality of hangers 8 are provided so as to be suspended from the messenger wire 7 at substantially regular intervals in the direction R in which the rails 2 extend.

[0017] The contact wire 9 is provided so as to be suspended from the plurality of hangers 8 with a constant tension and to be below the messenger wire 7 so as to be substantially parallel thereto. Power is supplied to the contact wire 9 from the feeder 4 by a feeder branch line (not shown). A current collector 1b such as a pantograph is provided on an upper surface 1a of the inspection vehicle 1, and while the inspection vehicle 1 is traveling, the current collector 1b contacts the contact wire 9, thereby supplying power from the contact wire 9 to the inspection vehicle 1.

[0018] The contact wire 9 is provided with respect to the pair of rails 2 as, for example, one contact wire or two contact wires extending in parallel. To prevent the occurrence of a section where power is not supplied when, during travel of an electric railway vehicle such as the inspection vehicle 1, the contact wire 9 serving as a power supply source transitions to the next adjacent contact wire 9 in the direction R in which the rails 2 extend, the contact wire 9 is

provided such that the end thereof overlaps with another adjacent contact wire 9 along the direction R in which the rails 2 extend. For this reason, in the present embodiment, there may be sections in which, with respect to the pair of rails 2, up to four contact wires 9 are provided so as to overlap. In addition to the above, when a branch point of the contact wire 9 corresponding to a branching of the rails is captured, a larger number of contact wires 9 than in a normal section may be captured.

[0019] When the contact wire 9 is provided in parallel with the rails 2, the portion of the current collector 1b that comes into contact with the contact wire 9 is limited. Therefore, a limited portion of the current collector 1b may be subject to uneven wear and damage. To prevent this, the contact wire 9 is provided so as to gently meander in a zigzag manner along the direction R in which the rails 2 extend. For the contact wire 9, the offset caused by this meandering, which is a left-right shift of the contact wire 9 from a center between the pair of rails 2, is strictly controlled.

[0020] Each time an electric railway vehicle such as the inspection vehicle 1 passes, the current collector 1b slides against the lower surface of the contact wire 9. For this reason, when electric railway vehicles are continuously operated, the contact wire 9 gradually wears and eventually breaks. Accordingly, a wear limit is set for the contact wire 9, and when the remaining diameter of the contact wire 9 falls below a control value, the contact wire 9 is replaced with a new one.

[0021] The contact wire inspection device 20 in the present embodiment inspects the contact wire 9 by measuring the remaining diameter and the offset of the contact wire 9. The contact wire inspection device 20 is provided with a lighting unit 21, a line sensor 22, and a control device 23. The lighting unit 21 is provided on the upper surface 1a of the inspection vehicle 1 so as to emit light upward. When an image of the contact wire 9 is captured by the line sensor 22 to be described next, a wear region formed on a lower side of the contact wire 9 and worn into a planar shape due to sliding of the current collector 1b reflects light from the lighting unit 21, and is thereby captured so as to be displayed as a bright region.

[0022] Similar to the lighting unit 21, the line sensor 22 is provided on the upper surface 1a of the inspection vehicle 1. The line sensor 22 is a camera that captures an image composed of one pixel in a vertical direction and a plurality of pixels in a horizontal direction, such as 8192 pixels. In the present embodiment, because the line sensor 22 captures a grayscale image, each pixel has a single luminance value.

[0023] The line sensor 22 is provided so as to face upward in a vertical direction, and such that a direction 22b of a scanning line 22a is orthogonal to the direction R in which the rails 2 extend and is the same as a direction in which sleepers (not shown) extend. As a result, the

scanning line 22a of the line sensor 22 crosses the contact wire 9. The line sensor 22 continuously captures images of the contact wire 9 at short time intervals while the inspection vehicle 1 is traveling. Images captured by the line sensor 22 are transmitted to the control device 23 as input images. The control device 23 is, for example, an information processing device such as a personal computer. The control device 23 is mounted on the inspection vehicle 1.

[0024] Fig. 2 is a block diagram illustrating a functional configuration of the contact wire inspection device 20 according to the present embodiment. In Figure 2, the control device 23 is provided with a line sensor image generation unit 30, an environment determination unit 31, a wear region extraction image generation unit 32, an image processing execution procedure storage unit 33, a wear region extraction image evaluation unit 34, a contact wire offset computation unit (contact wire inspection unit) 35, and a contact wire remaining diameter computation unit (contact wire inspection unit) 36.

[0025] The line sensor image generation unit 30 receives input images from the line sensor 22, arranges the input images in a time-series manner in a vertical direction, for example, into 1000 lines, and generates a line sensor image.

[0026] Fig. 3 is a schematic diagram illustrating an example of a line sensor image generated based on images captured by the line sensor of the contact wire inspection device according to the present embodiment. In a line sensor image 50, a horizontal direction X is the direction 22b of the scanning line 22a of the line sensor 22, and a vertical direction Y is a time-series direction, that is, a direction in which input images are arranged.

[0027] In the line sensor image 50 illustrated in Fig. 3, the contact wire 9 is captured in the foreground. In a new condition, the contact wire 9 has a substantially circular cross-section, and a lower side thereof is shaved by sliding of the current collector 1b, thereby forming a planar wear region 9a. Because the wear region 9a is irradiated with light by the lighting unit 21, the wear region 9a is captured as a bright region. On both sides of the wear region 9a of the contact wire 9, surfaces 9b of the contact wire 9 that extend upward while curving outward from widthwise end portions of the wear region 9a are captured. In the line sensor image 50 of Fig. 3, a portion where the contact wire 9 is bent by the pull-off fitting 6 is captured. In addition, luminance differences may arise in the wear region 9a due to lighting, the state of the wear region of the contact wire, the imaging environment, and the like, and dark regions 9c and 9d with partially reduced luminance may be generated.

[0028] Behind the contact wire 9, the messenger wire 7 is captured. Further behind the messenger wire 7, the feeder 4, the beam 5 supporting those wires, and the pull-off fitting 6 are

captured. The beam 5 and the pull-off fitting 6 are captured so as to appear thinner than they actually are due to the image capture interval of the line sensor 22.

The sky 10 is captured as the background behind the contact wire 9, the messenger wire 7, the feeder 4, the beam 5, and the pull-off fitting 6. In the present line sensor image 50, because the image is captured during bright daylight, the sky 10 is displayed brightly with a high luminance value.

[0029] The line sensor image generation unit 30 generates such a line sensor image 50 and transmits the generated line sensor image 50 to the wear region extraction image generation unit 32.

[0030] Based on the line sensor image 50 generated by the line sensor image generation unit 30, the environment determination unit 31 determines an environment in which the input images were captured. The environment determination unit 31 determines five types of environments: nighttime or a tunnel, dark daytime, bright daylight, a moment when entering a tunnel during daytime, and other situations. To make this determination, the environment determination unit 31 calculates a histogram of the line sensor image 50 and computes an average value, a mode, a luminance value having the second highest frequency, and a luminance value having the third highest frequency. Thereafter, the environment is determined by comparing each of a nighttime determination threshold, a dark daytime determination threshold, and a bright daylight determination threshold, which are set in advance, with each of the computed values, as described below.

[0031] When all of the following determination formulas are simultaneously satisfied, the environment determination unit 31 determines that the environment corresponding to the line sensor image 50 is nighttime or a tunnel.

$$0 \leq \text{average value} \leq \text{nighttime determination threshold}$$
$$0 \leq \text{mode} \leq \text{nighttime determination threshold}$$
$$0 \leq \text{luminance value having second highest frequency} \leq \text{nighttime determination threshold}$$
$$0 \leq \text{luminance value having third highest frequency} \leq \text{nighttime determination threshold}$$

[0032] When all of the following determination formulas are simultaneously satisfied, the environment determination unit 31 determines that the environment corresponding to the line sensor image 50 is dark daytime.

$$\text{nighttime determination threshold} < \text{average value} \leq \text{dark daytime determination threshold}$$

nighttime determination threshold < mode ≤ dark daytime determination threshold

nighttime determination threshold < luminance value having second highest frequency ≤ dark daytime determination threshold

nighttime determination threshold < luminance value having third highest frequency ≤ dark daytime determination threshold

[0033] When all of the following determination formulas are simultaneously satisfied, the environment determination unit 31 determines that the environment corresponding to the line sensor image 50 is bright daylight.

bright daylight determination threshold < average value

bright daylight determination threshold < mode

bright daylight determination threshold < luminance value having second highest frequency

bright daylight determination threshold < luminance value having third highest frequency

[0034] When all of the following determination formulas are simultaneously satisfied, the environment determination unit 31 determines that the environment corresponding to the line sensor image 50 is a moment when entering a tunnel during daytime.

nighttime determination threshold < average value ≤ maximum luminance value (e.g., 255)

$0 \leq \text{mode} \leq \text{nighttime determination threshold}$

$0 \leq \text{luminance value having second highest frequency} \leq \text{nighttime determination threshold}$

$0 \leq \text{luminance value having third highest frequency} \leq \text{nighttime determination threshold}$

[0035] When none of the environments above apply, the environment determination unit 31 determines that the environment is another environment.

The environment determination unit 31 transmits the environment determined as a result to the wear region extraction image generation unit 32.

[0036] The wear region extraction image generation unit 32 receives the line sensor image 50 from the line sensor image generation unit 30 and the determination result (environment) from the environment determination unit 31, and extracts the wear region 9a of the contact wire 9 by executing various image processing functions on the line sensor image 50, thereby generating a wear region extraction image.

[0037] The wear region extraction image generation unit 32 is provided with an image processing unit 40 and a post-processing unit 41. The image processing unit 40 is configured such that various image processing functions can be selectively executed. The image processing unit 40 is provided with a contrast adjustment processing unit 40A, a background and noise removal processing unit 40B, a binarization processing unit 40C, an interpolation processing unit 40D, and a wear region correction unit 40E.

[0038] The contrast adjustment processing unit 40A is configured such that one or more image processing functions intended to adjust the gradation of an image can be selectively executed. As contrast adjustment processing, for example, it is possible to apply gamma correction processing that corrects the gradation of an image to an appropriate curve corresponding to a gamma value, or processing that adjusts the gradation by normalizing luminance values. Note that the contrast adjustment processing included in the contrast adjustment processing unit 40A is not limited to the above.

[0039] The background and noise removal processing unit 40B is configured such that one or more image processing functions intended to remove noise and objects different from the overhead contact line, such as structures captured in the background, can be selectively executed. As background and noise removal processing, for example, grayscale top-hat (GSTH) processing can be applied in which a grayscale image is subjected to erosion and dilation to execute an opening operation, and then the original image serving as the basis for the dilation and erosion is subtracted. Note that the background and noise removal processing included in the background and noise removal processing unit 40B is not limited to the above.

[0040] The binarization processing unit 40C is configured such that one or more image processing functions intended to extract only the wear region 9a by converting an image having a plurality of gradations into, for example, two gradations of white and black, can be selectively executed. As binarization processing, for example, discriminant analysis binarization processing can be applied in which a histogram of luminance values is generated for an image, and a binarization threshold is determined in accordance with the image so as to maximize a variance ratio of between-class variance to within-class variance for each of the background and the wear region 9a. Note that the binarization processing included in the binarization processing unit 40C is not limited to the above.

[0041] The interpolation processing unit 40D is configured such that, for an image in which a region assumed to be the wear region 9a has been extracted by binarization processing executed by the binarization processing unit 40C, one or more image processing functions intended to interpolate a shape of the wear region 9a by connecting regions can be selectively executed in a case where a region originally assumed to be a single wear region 9a is divided

into a plurality of regions.

[0042] As interpolation processing, for example, closing processing can be applied in which an image is dilated and eroded in the horizontal direction X to connect regions that are divided and represented adjacent to each other in the horizontal direction X, and undulating wear interpolation processing can be applied to connect regions that are divided and represented in a stripe-shaped or wave-shaped pattern in the vertical direction Y. Note that the interpolation processing included in the interpolation processing unit 40D is not limited to the above.

[0043] Fig. 4 is a schematic diagram illustrating an example of a wear region extraction image temporarily acquired by the contact wire inspection device according to the present embodiment, and is a wear region extraction image 50A processed, as discussed above, by the interpolation processing unit 40D. In the wear region extraction image 50A, due to lighting, the state of the wear region 9a of the contact wire 9, the imaging environment, and the like, luminance differences may arise in the wear region 9a, resulting in dark regions 9c and 9d with lower luminance than other regions, as illustrated in Fig. 3. That is, in the wear region extraction image 50A processed by the interpolation processing unit 40D, the dark regions 9c and 9d are not detected as the wear region 9a, making it impossible to detect an accurate wear region 9a.

[0044] As illustrated in Fig. 4, in the wear region extraction image 50A processed by the interpolation processing unit 40D, only a brightly appearing wear region 9a is extracted. Accordingly, in the present embodiment, the wear region extraction image 50A processed by the interpolation processing unit 40D is corrected such that the dark regions 9c and 9d are detected as the wear region 9a. The wear region correction unit 40E, for each line in the vertical direction of the image, searches outward by raster scanning from a position of the wear region extracted by the extraction processing of the wear region 9a, and sets a position at which the luminance value becomes equal to or less than a preset luminance value as a boundary between a sliding surface and a non-sliding surface, that is, a boundary of the wear region 9a.

[0045] Fig. 5 is a schematic diagram illustrating an example of a wear region extraction image finally acquired by the contact wire inspection device according to the present embodiment. As a result of the correction discussed above, the dark regions 9c and 9d illustrated in Fig. 4 are detected as the wear region 9a, and thus, as illustrated in Fig. 5, the wear region 9a is accurately detected. The wear region correction unit 40E transmits, to the post-processing unit 41, a wear region extraction image 50B after correction together with the number of wear regions 9a corresponding thereto, length information including starting point coordinates and ending point coordinates of each wear region 9a in the vertical direction Y, and information related to an image processing execution procedure (or processing pattern) M corresponding to the wear region extraction image.

[0046] In this way, the wear region extraction image generation unit 32 accurately extracts wear regions of the contact wire 9 by causing the image processing unit 40 and the post-processing unit 41 to execute image processing functions using the line sensor image 50 as an input in accordance with each of a plurality of image processing execution procedures M, and generates a plurality of wear region extraction images 50B corresponding respectively to the plurality of image processing execution procedures M.

[0047] The respective image processing functions included in the contrast adjustment processing unit 40A, the background and noise removal processing unit 40B, the binarization processing unit 40C, the interpolation processing unit 40D, and the wear region correction unit 40E are executed in accordance with processing patterns (image processing execution procedures) M, each processing pattern M being an execution order for executing the respective image processing functions and registered in the image processing execution procedure storage unit 33.

[0048] Fig. 6 is an explanatory diagram of the image processing execution procedure storage unit of the contact wire inspection device according to the present embodiment. In Fig. 6, the image processing execution procedure storage unit 33 is provided with a processing storage unit 33a, a parameter set storage unit 33b, and a processing pattern registration unit 33c.

[0049] In the processing storage unit 33a, the respective image processing functions executed in the already-described contrast adjustment processing unit 40A, the background and noise removal processing unit 40B, the binarization processing unit 40C, the interpolation processing unit 40D, and the wear region correction unit 40E are stored. In the processing storage unit 33a of Fig. 6, X image processing functions PR1 to PRX, each included in one of the above-described processing units 40A, 40B, 40C, 40D, and 40E, are stored.

[0050] In addition, the parameter set storage unit 33b stores parameter sets that can be used when actually executing each of the image processing functions PR1 to PRX stored in the processing storage unit 33a. In the parameter set storage unit 33b of Fig. 6, Y types of parameter sets PS1 to PSY are stored, the parameter sets being used in one or more of the X image processing functions PR1 to PRX stored in the processing storage unit 33a.

[0051] The processing pattern registration unit 33c stores a plurality of processing patterns M for executing the above-described image processing functions when processing a line sensor image 50. The processing pattern registration unit 33c of Fig. 6 stores L processing patterns M1 to ML.

[0052] In Fig. 6, attention is focused on the first processing pattern M1 among these L processing patterns M1 to ML. The processing pattern M1 is registered such that Z image

processing functions P1 to PZ are sequentially executed. Here, the image processing function P1 in the processing pattern M1 is configured to refer to the image processing function PR1 in the processing storage unit 33a and the parameter set PS2 in the parameter set storage unit 33b. This indicates that the image processing function P1 in the processing pattern M1 is actually executed by applying the parameter set PS2 to the image processing function PR1 stored in the processing storage unit 33a.

[0053] In addition, in the image processing function P2 executed second in the first processing pattern M1, only the image processing function PRX stored in the processing storage unit 33a is referred to, and parameter sets in the parameter set storage unit 33b are not referred to. In this way, when the image processing functions PR1 to PRX stored in the processing storage unit 33a are registered in a processing pattern M, the parameter sets in the parameter set storage unit 33b do not necessarily have to be associated with and referenced.

[0054] Although a detailed description is omitted, the processing patterns M2 to ML are also configured, similarly to the processing pattern M1, by expressing image processing functions to be executed with reference to the processing storage unit 33a and the parameter set storage unit 33b.

[0055] In each of the processing patterns M1 to ML stored in the processing pattern registration unit 33c, the number of image processing functions to be executed is not a fixed length but a variable length. That is, in principle, the number of image processing functions to be executed in each of the processing patterns M1 to ML differs from one another.

[0056] In this way, a processing pattern M is configured by registering, in an ordered manner, a plurality of image processing functions, or combinations of image processing functions and parameter sets used in the image processing functions. In this way, the processing pattern M can be regarded as an image processing execution procedure M in which, when processing a line sensor image 50, the execution order of the image processing functions is registered together with parameter sets indicating how the image processing functions are actually executed. Hereinafter, the processing pattern M will be referred to as an image processing execution procedure M.

[0057] As described above, each image processing function is classified into processing intended for contrast adjustment processing, background and noise removal processing, binarization processing, or interpolation processing. In each image processing execution procedure M, the image processing functions are registered so as to be executed in the order of this processing classification. For example, because executing contrast adjustment processing after binarization processing is in principle meaningless, an image processing execution

procedure M in which an image processing function included in the binarization processing unit 40C is executed and then an image processing function included in the contrast adjustment processing unit 40A is executed is in principle not registered.

[0058] In addition, in order to extract the wear region 9a, at a minimum, binarization processing needs to be executed. In other words, in the image processing execution procedure M, the order of image processing functions is registered such that an image processing function included in the binarization processing unit 40C is executed at least once, and image processing functions included in the other processing units 40A, 40B, 40D, and 40E are executed as necessary, that is, zero or more times. In this way, in each of the plurality of image processing execution procedures M, contrast adjustment processing, background and noise removal processing, binarization processing, and interpolation processing are registered to be executed zero or more times, zero or more times, one or more times, and zero or more times, respectively, in this order.

[0059] Furthermore, the order of the image processing functions may be registered such that each of the image processing functions included in the respective processing units 40A, 40B, 40C, 40D, and 40E is executed multiple times. For example, in the interpolation processing unit 40D, it is possible to construct an image processing execution procedure M such that, after regions that are divided in the horizontal direction X are connected by closing processing, regions that are divided in the vertical direction Y are connected by undulating wear interpolation processing.

[0060] Alternatively, the same image processing function may be registered in the image processing execution procedure M so as to be executed multiple times, with the same parameter set or with changed parameter sets, either continuously or with execution of another image processing function included in the same processing classification interposed therebetween.

[0061] A plurality of image processing execution procedures M are registered such that all combinations of processing procedures can be achieved among the image processing functions within the respective processing units 40A, 40B, 40C, 40D, and 40E.

In each of the plurality of image processing execution procedures M, the accuracy with which the wear region 9a is extracted and the suitability with respect to conditions such as the background of the line sensor image 50 differ to varying degrees. For this reason, each of the plurality of image processing execution procedures M is stored in association with a priority.

For example, a high priority may be set for an image processing execution procedure M that can consistently achieve extraction accuracy of a certain level or higher for the wear region 9a,

without being greatly affected by the background luminance values.

In this way, the priorities are set such that the higher the extraction accuracy is considered to be for the wear region 9a, the higher the priority.

[0062] As described above, the image processing unit 40 executes each of the image processing execution procedures M, generates processed images corresponding to the respective image processing execution procedures M, and transmits the processed images to the post-processing unit 41.

[0063] The post-processing unit 41 receives a processed image from the image processing unit 40, performs edge extraction to extract a wear region 9a, and when a plurality of wear regions 9a are extracted in the processed image, computes, for each wear region 9a, the length of the wear region 9a in the vertical direction Y. As described previously, in the present embodiment, up to four contact wires 9 may be provided so as to overlap. That is, up to four contact wires 9 may be captured in a single line sensor image 50. For this reason, when five or more wear regions 9a are extracted, the post-processing unit 41 treats the four regions, in descending order of length, as wear regions 9a, and regards the other regions having shorter lengths as not being wear regions 9a. The post-processing unit 41 uses the image after edge extraction as a wear region extraction image 50A and transmits, to the wear region extraction image evaluation unit 34, the wear region extraction image 50A together with the number of wear regions 9a corresponding thereto, length information including starting point coordinates and ending point coordinates of each wear region 9a in the vertical direction Y, and information related to the image processing execution procedure M corresponding to the wear region extraction image.

[0064] The wear region extraction image evaluation unit 34 receives corrected wear region extraction images 50B corresponding to the respective image processing execution procedures M and associated pieces of information, calculates evaluation values for each of the received plurality of wear region extraction images 50B, and selects the wear region extraction image having the highest evaluation value.

For each wear region extraction image, a determination as to how many wear regions 9a are captured in the wear region extraction image is associated, in the wear region extraction image generation unit 32, with the wear region extraction image and transmitted to the wear region extraction image evaluation unit 34. For each wear region extraction image, the wear region extraction image evaluation unit 34 compares the number of wear regions 9a in the wear region extraction image with the number of contact wires 9 at the actual site where the wear region extraction image was captured, and calculates an evaluation value of the wear region extraction

image.

[0065] As the evaluation value of each wear region extraction image, a cost evaluation is used in which, by utilizing the fact that the number of contact wires appearing in the image is known from pre-registered facility information, cost calculation is performed for each image time series (line), and a wear region extraction image of a processing pattern having the lowest cost is adopted (the lower the cost, the higher the evaluation), or a likelihood evaluation, which is an index indicating that wear regions 9a have image characteristics close to those of the contact wires 9, is used for each of a plurality of wear region extraction images (the higher the likelihood, the higher the evaluation). Regarding the details of the cost evaluation and the likelihood evaluation, see JP Patent No. 7196806.

[0066] On the basis of the cost evaluation or the likelihood evaluation, the wear region extraction image evaluation unit 34 calculates centroid coordinates and the wear surface width of each wear region 9a for the wear region extraction image having the highest evaluation value, and transmits the calculated results, together with the wear region extraction image having the highest evaluation value, to the contact wire offset computation unit 35 and the contact wire remaining diameter computation unit 36.

[0067] The contact wire offset computation unit 35 receives the wear region extraction image selected as the one having the highest evaluation value, and based thereon, calculates the offset of the contact wire 9. Fig. 7(a) is an explanatory diagram of a principle for computing the offset.

The offset D (unit: mm) is expressed by the following equation, using: the centroid coordinates d (unit: pixels) of the wear region 9a received from the wear region extraction image evaluation unit 34; a distance h_s (mm) from the rails 2 to a sensor surface 22c of the line sensor 22, a focal length f (mm) of a lens of the line sensor 22, a length s (mm) of the sensor surface 22c of the line sensor 22, and a number of pixels p (pixels) of the line sensor 22, which are parameters set in advance; and a distance h (mm) from the rails 2 to the contact wire 9 calculated by another measurement device other than the present contact wire inspection device 20.

[0068] [Equation 1]

$$D = \frac{(h - h_s - f) \times s}{p \times f} \times d$$

[0069] As described above, the contact wire offset computation unit 35 calculates the offset of

the contact wire 9, and determines whether the contact wire 9 is positioned within an allowable offset range at an actual location corresponding to the wear region extraction image.

If the contact wire 9 is not positioned within the allowable offset range, an abnormality is determined and recorded.

[0070] The contact wire remaining diameter computation unit 36 receives the wear region extraction image selected as the one having the highest evaluation value, and based thereon, computes the remaining diameter of the contact wire 9. Fig. 7(b) is an explanatory diagram of a principle for computing the remaining diameter.

In the present embodiment, the remaining diameter of the contact wire 9, that is, the height of the contact wire 9 after wear, is calculated as the remaining diameter.

Using the same principle as the contact wire offset computation unit 35, the contact wire remaining diameter computation unit 36 calculates the actual wear surface width W (mm) of the contact wire 9 based on centroid coordinates d (pixels) and the wear surface width w (pixels) of the wear region 9a received from the wear region extraction image evaluation unit 34. The remaining diameter D_r (mm) of the contact wire 9 is expressed by the following equation, using the wear surface width W (mm) and the radius of the contact wire 9.

[0071] [Equation 2]

$$D_r = r + \sqrt{r^2 - \left(\frac{W}{2}\right)^2}$$

[0072] As described above, the contact wire remaining diameter computation unit 36 calculates the remaining diameter of the contact wire 9, and determines whether the remaining diameter is below a control value.

If the remaining diameter is below the control value, an abnormality is determined, and this fact is recorded.

[0073] Next, Fig. 8 is a flow chart for explaining an operation of the contact wire inspection method described above by the contact wire inspection device 20 according to the present embodiment. When processing is started, the line sensor image generation unit 30 generates, by arranging input images from the line sensor 22 in a time-series manner in a vertical direction, for example into 1000 lines, a line sensor image 50 as shown in Fig. 3, and transmits the

generated line sensor image 50 to the wear region extraction image generation unit 32, and the environment determination unit 31 determines an environment in which the input images were captured based on the line sensor image 50 generated by the line sensor image generation unit 30 (step S10).

[0074] Next, in the wear region extraction image generation unit 32, the contrast adjustment processing unit 40A adjusts the gradation of the line sensor image 50 (step S12), the background and noise removal processing unit 40B removes noise and objects different from the overhead contact line, such as structures captured in the background (step S14), and the binarization processing unit 40C converts the image having a plurality of gradations into, for example, two gradations of white and black, to extract only the wear region 9a (step S16).

[0075] Next, the interpolation processing unit 40D interpolates a shape of the wear region 9a, for the image in which a region assumed to be the wear region 9a has been extracted by binarization processing executed by the binarization processing unit 40C, by connecting regions in a case where a region originally assumed to be a single wear region 9a is divided into a plurality of regions (step S18).

[0076] Next, the wear region correction unit 40E searches outward by raster scanning, for each line in the vertical direction of the image, for a boundary between a sliding surface and a non-sliding surface from a position extracted by the extraction processing of the wear region 9a, and sets a position at which the luminance value becomes equal to or less than a preset luminance value as a sliding surface boundary, thereby correcting the wear region extraction image 50A to detect an accurate wear region 9a (step S20).

[0077] Next, the post-processing unit 41 generates, for a wear region extraction image 50B after correction, the number of wear regions 9a corresponding thereto and length information including starting point coordinates and ending point coordinates of each wear region 9a in the vertical direction Y, and transmits the generated information to the wear region extraction image evaluation unit 34 together with information related to the image processing execution procedure M corresponding to the wear region extraction image (step S22).

[0078] Next, the wear region extraction image evaluation unit 34 calculates evaluation values (likelihood evaluation or cost evaluation) for each of a plurality of wear region extraction images received, with images after edge extraction received from the wear region extraction image generation unit 32 being used as the wear region extraction images, on the basis of the number of wear regions 9a corresponding thereto, length information including starting point coordinates and ending point coordinates of each wear region 9a in the vertical direction Y, and information related to the image processing execution procedure M corresponding to the wear region

extraction image (step S24). The generation and evaluation of the wear region extraction images described above are executed for all of the image processing execution procedures M stored in the image processing execution procedure storage unit 33.

[0079] Next, a determination is made as to whether the generation and evaluation of the wear region extraction images have been executed for all of the image processing execution procedures M (step S26). If any image processing execution procedures M remain unexecuted (NO in step S26), the process proceeds to step S10 and continues processing for the unexecuted image processing execution procedures M.

[0080] On the other hand, if there are no unexecuted image processing execution procedures M (YES in step S26), the wear region extraction image evaluation unit 34 determines, among all of the wear region extraction images, that the image having the highest evaluation value is the image in which the wear region 9a has been extracted most appropriately (step S28). The wear region extraction image evaluation unit 34 calculates centroid coordinates and the wear surface width of each wear region 9a for the wear region extraction image having the highest evaluation value, and transmits the calculated results, together with the wear region extraction image having the highest evaluation value, to the contact wire offset computation unit 35 and the contact wire remaining diameter computation unit 36.

[0081] Next, the contact wire offset computation unit 35 receives the wear region extraction image selected as the one having the highest evaluation value, and based thereon, calculates the offset of the contact wire 9 (step S30). In addition, the contact wire remaining diameter computation unit 36 receives the wear region extraction image selected as the one having the highest evaluation value, and based thereon, computes the remaining diameter of the contact wire 9 (step S32). Thereafter, the process is ended.

[0082] According to the embodiment discussed above, a contact wire inspection device 20 is provided with a line sensor 22 that captures images of a contact wire 9 and inspects the contact wire 9 based on images captured by the line sensor 22, the images being used as input images, the contact wire inspection device 20 being provided with: a line sensor image generation unit 30 that arranges the input images in a time-series manner to generate a line sensor image 50; an image processing execution procedure storage unit 33 in which a plurality of image processing execution procedures M are registered, each image processing execution procedure M defining an execution order in which a plurality of image processing functions are sequentially executed on the line sensor image 50; a wear region extraction image generation unit 32 that, in accordance with each of the plurality of image processing execution procedures M, executes the image processing functions with the line sensor image 50 as an input to extract a wear region 9a of the contact wire 9, scans outward from the extracted wear region of the contact wire and

defines, as a boundary of the wear region, a position at which a luminance value becomes equal to or less than a preset luminance value, thereby correcting the wear region, and generates a plurality of wear region extraction images corresponding to each of the plurality of image processing execution procedures M; a wear region extraction image evaluation unit 34 that calculates an evaluation value for each of the plurality of wear region extraction images and selects the wear region extraction image having the highest evaluation value; a contact wire offset computation unit 35 that computes the offset of the contact wire 9 based on the selected wear region extraction image; and a contact wire remaining diameter computation unit 36 that computes the remaining diameter of the contact wire 9.

[0083] In addition, a contact wire inspection method according to the present embodiment is a contact wire inspection method for inspecting a contact wire 9 based on images captured by a line sensor 22 that captures images of the contact wire 9, the images being used as input images, the contact wire inspection method including: arranging the input images in a time-series manner to generate a line sensor image 50; executing, on the line sensor image 50, a plurality of image processing functions with the line sensor image 50 as an input, an execution order for sequentially executing the plurality of image processing functions being registered as a plurality of image processing execution procedures M, the plurality of image processing functions being executed in accordance with each of the plurality of image processing execution procedures M, thereby extracting a wear region 9a of the contact wire 9; scanning outward from the extracted wear region 9a and defining, as a boundary of the wear region 9a, a position at which a luminance value becomes equal to or less than a preset luminance value, thereby correcting the wear region 9a, and generating a plurality of wear region extraction images corresponding to each of the plurality of image processing execution procedures M; calculating an evaluation value for each of the plurality of wear region extraction images and selecting the wear region extraction image having the highest evaluation value; and computing both the remaining diameter and the offset of the contact wire 9 based on the selected wear region extraction image.

[0084] According to the configuration described above, even when luminance differences arise in the wear region 9a due to lighting, the state of the wear region 9a of the contact wire 9, the imaging environment, and the like, the wear region 9a of the contact wire 9 can be accurately detected. As a result, the extraction accuracy of the wear region 9a of the contact wire 9 is improved, and the computation accuracy of the remaining diameter and the offset is also improved.

[0085] In addition, according to the present embodiment, a wear region extraction image is generated for each of the plurality of image processing execution procedures M, an evaluation value is calculated for each of the wear region extraction images, the wear region extraction

image having the highest evaluation value is selected, and both the remaining diameter and the offset of the contact wire 9 are computed based on the selected wear region extraction image. That is, a number of wear region extraction images corresponding to the number of image processing execution procedures M are generated, and from among these, a wear region extraction image most suitable for evaluating a remaining diameter and an offset is selected as an evaluation target for the remaining diameter and the offset. As a result, among the plurality of registered image processing execution procedures M, a processing result of an image processing execution procedure M suitable for processing the line sensor image 50 to be processed is selected as a wear region extraction image.

[0086] In this way, even without a worker selecting, through trial and error, combinations of image processing functions suitable for a line sensor image 50 to be processed, a wear region extraction image suited for computing the remaining diameter and the offset of the contact wire 9 can be generated, enabling measurement of the remaining diameter and the offset. Thus, it is possible to reduce the workload of a worker when sifting through different combinations of image processing functions suitable for an inputted image.

[0087] In addition, according to the present embodiment, each of the plurality of image processing execution procedures M is stored in association with a priority, and the wear region extraction image evaluation unit 34 is configured such that when the same evaluation value is computed for wear region extraction images, the wear region extraction image evaluation unit 34 selects, as the wear region extraction image having the highest evaluation value, a wear region extraction image corresponding to the image processing execution procedure M having a higher priority. Thus, when the same evaluation value is computed for wear region extraction images, the wear region extraction image corresponding to the image processing execution procedure M having a higher priority is selected as the wear region extraction image having the highest evaluation value. For this reason, even when there are a plurality of wear region extraction images having similar evaluation values, a wear region extraction image corresponding to an image processing execution procedure M having a higher priority is selected, which makes it easier to select a wear region extraction image suitable for evaluating the remaining diameter and the offset.

[0088] In addition, according to the present embodiment, the wear region extraction image evaluation unit 34 is configured to calculate, for each of the plurality of wear region extraction images, the number of wear regions 9a, and to calculate the evaluation value such that the evaluation value becomes higher when the difference between the number of wear regions 9a and the actual number of contact wires 9 is small. Thus, this makes it easier to select, as a wear region extraction image for computing the remaining diameter and the offset, a wear region extraction image in which the actual number of contact wires 9 matches the number of wear

regions 9a. For this reason, the extraction accuracy of the wear region 9a of the contact wire 9 is improved, and the computation accuracy of the remaining diameter and the offset is also improved.

[0089] In addition, according to the present embodiment, an appropriate image processing execution procedure is selected in accordance with the environment, and a wear region extraction image corresponding thereto is generated. Thus, the computation accuracy of the remaining diameter and the offset is improved, and it is possible to shorten the processing time or reduce the processing load. In addition, because image processing execution procedures M that do not correspond to the selected environment are not executed, it is possible to reduce the processing time and memory required for execution of the contact wire inspection device 20.

[0090] In addition, according to the present embodiment, the wear region extraction image having the highest evaluation value, that is, the highest contact wire likelihood, is selected. Accordingly, a wear region extraction image in which image characteristics of the wear region 9a are close to the appearance of an actual contact wire 9 is more likely to be selected as a wear region extraction image for computing the remaining diameter and the offset. Thus, the extraction accuracy of the wear region 9a of the contact wire 9 is improved, and the computation accuracy of the remaining diameter and the offset is also improved.

[0091] In the above-described embodiment, for example, the post-processing unit 41 has been described, for convenience of explanation, as being included in the wear region extraction image generation unit 32. However, the present disclosure is not limited to such a configuration. The post-processing unit 41 may be included in the wear region extraction image evaluation unit 34, or may be configured as a function independent of each of the wear region extraction image generation unit 32 and the wear region extraction image evaluation unit 34.

Further, it goes without saying that the configuration within the control device 23 may be modified without departing from the scope of the present invention.

In addition, in the above-described embodiment, the contact wire inspection device is configured to be provided with both a contact wire offset computation unit 35 and a contact wire remaining diameter computation unit 36, and to compute both the remaining diameter and the offset of the contact wire 9. However, the present disclosure is not limited to such a configuration. For example, the contact wire inspection device may be configured to compute only one of the remaining diameter or the offset of the contact wire.

[0092] In addition, the present disclosure is not limited to the above-discussed embodiments and modifications described with reference to the drawings. The configurations mentioned in the above-described embodiments and modifications may be selectively added or removed and

combined, or appropriately modified to other configurations, so long as such changes do not depart from the scope of the present invention.

REFERENCE SIGNS LIST

[0093]

1	Inspection vehicle
9	Contact wire
9a	Wear region
9c, 9d	Dark regions
20	Contact wire inspection device
21	Lighting unit
22	Line sensor
23	Control device
30	Line sensor image generation unit
31	Environment determination unit
32	Wear region extraction image generation unit
33	Image processing execution procedure storage unit
34	Wear region extraction image evaluation unit
35	Contact wire offset computation unit (contact wire inspection unit)
36	Contact wire remaining diameter computation unit (contact wire inspection unit)
40	Image processing unit
40A	Contrast adjustment processing unit
40B	Background and noise removal processing unit
40C	Binarization processing unit
40D	Interpolation processing unit
40E	Wear region correction unit
41	Post-processing unit
50	Line sensor image
50A, 50B	Wear region extraction images
M, M1, M2, M3	Image processing execution procedures

CLAIMS

1. A contact wire inspection device which comprises a line sensor that captures images of a contact wire and which inspects the contact wire based on images captured by the line sensor, the images being used as input images, the contact wire inspection device comprising:

a line sensor image generation unit that arranges the input images in a time-series manner to generate a line sensor image;

an image processing execution procedure storage unit in which a plurality of image processing execution procedures are registered, each image processing execution procedure defining an execution order in which a plurality of image processing functions are sequentially executed on the line sensor image;

a wear region extraction image generation unit that, in accordance with each of the plurality of image processing execution procedures, executes the plurality of image processing functions with the line sensor image as an input to extract a wear region of the contact wire, scans outward from the extracted wear region of the contact wire and defines, as a boundary of the wear region, a position at which a luminance value becomes equal to or less than a preset luminance value, thereby correcting the wear region, and generates a plurality of wear region extraction images corresponding to each of the plurality of image processing execution procedures;

a wear region extraction image evaluation unit that calculates an evaluation value for each of the plurality of wear region extraction images and selects the wear region extraction image having the highest evaluation value; and

a contact wire inspection unit that computes one or both of a remaining diameter and an offset of the contact wire based on the selected wear region extraction image having the highest evaluation value.

2. The contact wire inspection device according to claim 1, wherein, in each of the plurality of image processing execution procedures, contrast adjustment processing, background and noise removal processing, binarization processing, and interpolation processing are registered to be executed zero or more times, zero or more times, one or more times, and zero or more times, respectively, in this order.

3. The contact wire inspection device according to claim 1 or 2, wherein:

each of the plurality of image processing execution procedures is stored in association with a priority; and

when the same evaluation value is computed for wear region extraction images, the wear region extraction image evaluation unit selects, as the wear region extraction image having

the highest evaluation value, a wear region extraction image corresponding to the image processing execution procedure having a higher priority.

4. The contact wire inspection device according to claim 3, wherein the wear region extraction image evaluation unit calculates, for each of the plurality of wear region extraction images, a number of wear regions, and calculates the evaluation value such that the evaluation value becomes higher when the difference between the number of wear regions and an actual number of contact wires is small.

5. The contact wire inspection device according to claim 3, wherein the wear region extraction image evaluation unit calculates, for each of the plurality of wear region extraction images, a contact wire likelihood, which is an index indicating that the wear region has an image characteristic close to an image characteristic of the contact wire, and calculates the evaluation value such that the evaluation value becomes higher when the contact wire likelihood is high.

6. The contact wire inspection device according to claim 1, wherein:

in the image processing execution procedure storage unit, the image processing execution procedures are registered in correspondence with each of a plurality of different environments in which the images are captured by the line sensor;

the contact wire inspection device further comprises an environment determination unit that determines, based on the line sensor image, an environment in which the input images were captured; and

the wear region extraction image generation unit generates the wear region extraction images in accordance with the image processing execution procedure corresponding to the determined environment.

7. A contact wire inspection method for inspecting a contact wire based on images captured by a line sensor that captures images of the contact wire, the images being used as input images, the contact wire inspection method comprising:

arranging the input images in a time-series manner to generate a line sensor image;

executing, on the line sensor image, a plurality of image processing functions with the line sensor image as an input, an execution order for sequentially executing the plurality of image processing functions being registered as a plurality of image processing execution procedures, the plurality of image processing functions being executed in accordance with each of the plurality of image processing execution procedures, thereby extracting a wear region of the contact wire;

scanning outward from the extracted wear region of the contact wire and defining, as a boundary of the wear region, a position at which a luminance value becomes equal to or less than a preset luminance value, thereby correcting the wear region, and generating a plurality of

wear region extraction images corresponding to each of the plurality of image processing execution procedures;

calculating an evaluation value for each of the plurality of wear region extraction images and selecting the wear region extraction image having the highest evaluation value; and

computing one or both of a remaining diameter and an offset of the contact wire based on the selected wear region extraction image having the highest evaluation value.