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(71) Applicant: ABB SCHWEIZ AG [CH/CH]; Bruggerstrasse 66, 5400 Baden (CH).

(72) Inventors: GITZEL, Ralf; Rheinhäuserstr. 102, 68165 Mannheim (DE). SUBBIAH, Subanatarajan; Reilinger Strasse 5/1, 68809 Neußheim (DE). SCHMIDT, Benedikt; Obere Neckarstrasse 14, 69117 Heidelberg (DE).

(74) Agent: MAIWALD PATENTANWALTS- UND RECHTSANWALTSGESELLSCHAFT MBH; Elisenhof, Elisenstraße 3, 80335 München (DE).

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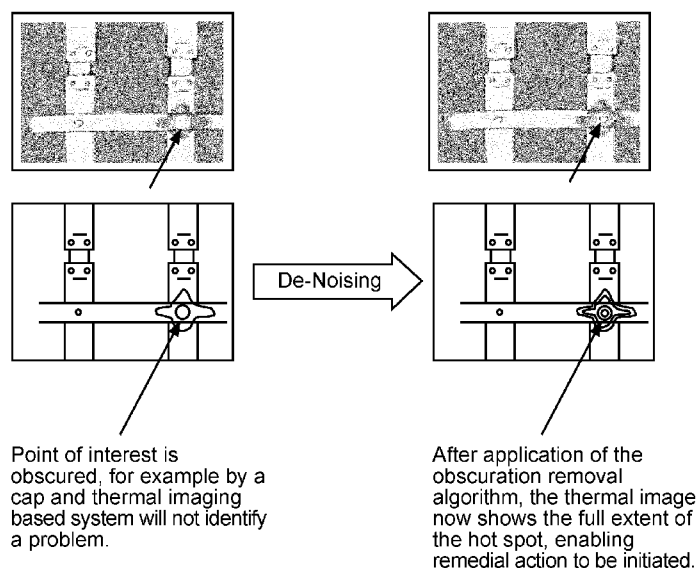


Fig. 1

(57) Abstract: The present invention relates to an apparatus for monitoring a switchgear. The apparatus comprises an input unit, a processing unit, and an output unit. The input unit is configured to provide the processing unit with a monitor infra-red image of a switchgear. The processing unit is configured to implement a machine learning classifier algorithm to analyse the monitor infra-red image and determine if there is one or more anomalous hot spots in the switchgear. The machine learning classifier algorithm has been trained on the basis of a plurality of different training infra-red images. The plurality of training infra-red images comprises a plurality of modified infrared images generated from a corresponding plurality of infra-red images. Each of the modified infra-red images has been modified to remove the effect of obscuration in the image. The output unit is configured to output information relating to the one or more anomalous hot spots.



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APPARATUS FOR MONITORING A SWITCHGEAR

10 FIELD OF THE INVENTION

The present invention relates to an apparatus and system for monitoring a switchgear.

BACKGROUND OF THE INVENTION

15

Switchgear failures due to high temperatures at hot spots can have dramatic consequences, for example electric arcs / flash overs that can act almost like explosions. A method for monitoring and early warning before such incidents is highly needed and currently not available, but this is not available in an affordable form, which

20 could be installed as a standard in every switchgear and give enough information on the switchgear health state. Or where images are acquired and transmitted for processing elsewhere. Currently in utilities the measurement of temperature variations is one of the most common measurement indicators of the structural health of equipment and components. Corroded connections, faulty contacts, damaged

25 components etc. can cause hotspots. Currently one common practice is to use infra-red cameras to capture thermal variation images and analyze them manually to find hotspots and then perform a maintenance action, where such manual inspection of the thermal images is carried out by domain experts from time to time to detect any damages in the components and additional data from current and voltage values are

30 used to fuse with the infra-red images to detect damages. A further problem related to the utilisation of infra-red sensors in this way, is that some elements in switchgear, for example elements in circuit breakers that are anomalously hot can be obscured by foreign objects such as caps that do not transmit the infrared radiation and if in contact with the underlying part of the switchgear are not raised to the same temperature as

35 that underlying element and/or have a lower emissivity. Thus, this obscuring element

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leads to a lower detection value in infra-red imagery required for damage detection. A common solution for all switchgear and all circuit breakers within such switchgear is not possible because of different types and geometry.

5 There is a need to address these issues.

SUMMARY OF THE INVENTION

10 Therefore, it would be advantageous to have an improved ability to monitor a switchgear.

The object of the present invention is solved with the subject matter of the independent claims, wherein further embodiments are incorporated in the dependent claims.

15 In an aspect, there is provided an apparatus for monitoring a switchgear, the apparatus comprising:

- an input unit;
- a processing unit; and
- an output unit.

20 The input unit is configured to provide the processing unit with a monitor infra-red image of a switchgear. The processing unit is configured to implement a machine learning classifier algorithm to analyse the monitor infra-red image and determine if there is one or more anomalous hot spots in the switchgear. The machine learning classifier algorithm has been trained on the basis of a plurality of different training infra-red images. The plurality of training infra-red images comprises a plurality of modified
25 infra-red images generated from a corresponding plurality of infra-red images. Each of the modified infra-red images has been modified to remove the effect of obscuration in the image. The output unit is configured to output information relating to the one or more anomalous hot spots.

30 In this manner, the apparatus can determine if there are hot spots in switchgear and other electrical components more accurately, because a large training set can be conveniently generated based on visible imagery and where some of that imagery can be manipulated in order to provide a training data set that exhibits a greater portion indicating problems, and in this way this improves the ability to determine if there are hot spots over a wider range of situations for different switchgears and without human
35 intervention.

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In an example, generation of the plurality of modified infra-red images comprises utilisation of a trained image processing algorithm.

5 In an example, the trained image processing algorithm is a trained de-noising algorithm.

10 In an example, training of the image processing algorithm comprises a manual indication of one or more obscuring features in at least one of the plurality of infra-red images prior to modification and/or a manual indication of one or more obscuring features in at least one visible image corresponding to at least one infra-red image of the plurality of infra-red images prior to modification.

15 In an example, analysis of the monitor infra-red image comprises modification of the monitor infra-red image to remove the effect of obscuration in the image.

In an example, modification of the monitor infra-red images comprise utilisation of a trained image processing algorithm.

20 In an example, the trained image processing algorithm is a trained de-noising algorithm.

25 In an example, training of the image processing algorithm comprises a manual indication of one or more obscuring features in at least one of the plurality of infra-red images prior to modification and/or a manual indication of one or more obscuring features in at least one visible image corresponding to at least one infra-red image of the plurality of infra-red images prior to modification.

30 In an example, the image processing algorithm utilised to generate the plurality of modified infra-red images is the same image processing algorithm used to modify the monitor infra-red image.

In an example, the plurality of training infra-red images comprises image data of a switchgear.

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In an example, the plurality of training infra-red images comprises image data of a switchgear.

5 In an example, the monitor infra-red image comprises image data of at least one circuit breaker.

In an example, the machine learning classifier algorithm is a neural network.

10 In an example, the neural network is a convolutional neural network.

In an example, the processing unit is configured to update the training of the machine learning classifier algorithm comprising utilisation of the monitor infra-red image.

15 In an example, the processing unit is configured to update the training of the machine learning classifier algorithm comprising utilisation of the modified monitor infra-red image

20 In an example, the training update comprises a manual indication that the monitor infra-red image comprises no anomalous hot spots or a manual indication that the monitor infra-red image comprises one or more anomalous hot spots.

25 In an example, the training update comprises a manual indication that the modified monitor infra-red image comprises no anomalous hot spots or a manual indication that the modified monitor infra-red image comprises one or more anomalous hot spots.

In an example, the manual indication that the monitor infra-red image comprises one or more anomalous hot spots comprises a manual indication of one or more locations in the monitor infra-red image of the one or more anomalous hot spots.

30 In an example, the manual indication that the modified monitor infra-red image comprises one or more anomalous hot spots comprises a manual indication of one or more locations in the modified monitor infra-red image of the one or more anomalous hot spots.

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In a second aspect, there is provided a system for monitoring a switchgear, the system comprising:

- an infra-red camera; and
 - an apparatus for monitoring a switchgear according
- 5 to the first aspect.

The infra-red camera is configured to acquire the monitor infra-red image of the switchgear.

10 The above aspects and examples will become apparent from and be elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Exemplary embodiments will be described in the following with reference to the following drawings:

Fig. 1 shows an example of the removal of an obscuring element in an infrared image through utilisation of a de-noising autoencoder.

DETAILED DESCRIPTION OF EMBODIMENTS

20

The apparatus and system enables hot spots in switchgear, for example in circuit breakers, and in other electrical equipment to be detected through identifying hot spots in infra-red imagery of this equipment, even when there are obscuring objects between surfaces that are being monitored, and that could be anomalously hot, and the infra-red sensor. To do this objects and elements that are "noise" data are automatically removed using machine learning approaches in infra-red images of hotspots on components or sub-systems of electrical assets. This de-noising effect uses relevant data and provides precise information on structural damages in a circuit breaker, switchgear or other electrical equipment components. This is achieved through

30 utilization of a machine learning algorithm that has been trained on imagery, at least some of which has used a de-nosing autoencoder to perform the removal of obscuring features from infra-red images. A module is used to enable an operator or expert to mark potential obscuring elements on the infra-red images and a learning module that learns features that are obscuring and performs the de-noising action. Thus, a labelling

35 mechanism is used to identify de-noising features, enabling thermal variation images

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with proper information to be retained, providing for reliable results in detecting hotspots using machine learning methods. The technical outcome of this solution allows maintenance and service engineers to get an indication of any abnormalities or hotspots in the circuit breakers by the detection mechanism based on machine learning
5 models. In this way imagery can be provided order that the training set can be used to take into the account obscuring elements in infra-red imagery enabling the machine learning algorithm to be able to identify hot spots in different equipment types, from different vantage points and in different situations.

10 Thus, this is achieved by apparatus that comprises an input unit, a processing unit, and an output unit. The input unit is configured to provide the processing unit with a monitor infra-red image of a switchgear. The processing unit is configured to implement a machine learning classifier algorithm to analyse the monitor infra-red image and determine if there is one or more anomalous hot spots in the switchgear. The machine
15 learning classifier algorithm has been trained on the basis of a plurality of different training infra-red images. The plurality of training infra-red images comprises a plurality of modified infra-red images generated from a corresponding plurality of infra-red images. Each of the modified infra-red images has been modified to remove the effect of obscuration in the image. The output unit is configured to output information relating
20 to the one or more anomalous hot spots.

According to an example, generation of the plurality of modified infra-red images comprises utilisation of a trained image processing algorithm.

25 According to an example, the trained image processing algorithm is a trained de-noising algorithm.

According to an example, training of the image processing algorithm comprises a manual indication of one or more obscuring features in at least one of the plurality of
30 infra-red images prior to modification and/or a manual indication of one or more obscuring features in at least one visible image corresponding to at least one infra-red image of the plurality of infra-red images prior to modification.

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According to an example, analysis of the monitor infra-red image comprises modification of the monitor infra-red image to remove the effect of obscuration in the image.

- 5 According to an example, modification of the monitor infra-red images comprise utilisation of a trained image processing algorithm.

According to an example, the trained image processing algorithm is a trained de-noising algorithm.

10

According to an example, training of the image processing algorithm comprises a manual indication of one or more obscuring features in at least one of the plurality of infra-red images prior to modification and/or a manual indication of one or more obscuring features in at least one visible image corresponding to at least one infra-red image of the plurality of infra-red images prior to modification.

15

According to an example, the image processing algorithm utilised to generate the plurality of modified infra-red images is the same image processing algorithm used to modify the monitor infra-red image.

20

According to an example, the plurality of training infra-red images comprises image data of a switchgear.

According to an example, the plurality of training infra-red images comprises image data of a switchgear.

25

According to an example, the monitor infra-red image comprises image data of at least one circuit breaker.

- 30 According to an example, the machine learning classifier algorithm is a neural network.

According to an example, the neural network is a convolutional neural network.

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According to an example, the processing unit is configured to update the training of the machine learning classifier algorithm comprising utilisation of the monitor infra-red image.

5 According to an example, the processing unit is configured to update the training of the machine learning classifier algorithm comprising utilisation of the modified monitor infra-red image

10 According to an example, the training update comprises a manual indication that the monitor infra-red image comprises no anomalous hot spots or a manual indication that the monitor infra-red image comprises one or more anomalous hot spots.

15 According to an example, the training update comprises a manual indication that the modified monitor infra-red image comprises no anomalous hot spots or a manual indication that the modified monitor infra-red image comprises one or more anomalous hot spots.

20 According to an example, the manual indication that the monitor infra-red image comprises one or more anomalous hot spots comprises a manual indication of one or more locations in the monitor infra-red image of the one or more anomalous hot spots.

25 According to an example, the manual indication that the modified monitor infra-red image comprises one or more anomalous hot spots comprises a manual indication of one or more locations in the modified monitor infra-red image of the one or more anomalous hot spots.

30 As discussed above, the apparatus can be part of a system that has a camera that acquires the monitor infra-red image and provides this to the processing unit, via the input unit.

The apparatus and system are explained in more detail with reference to a circuit breaker in a switchgear, but this is just one example and the apparatus and system find utility to other parts of switchgear and many other types of electrical equipment, where hot spots can occur and be problematic.

Thus, it is convenient to set the scene. There is currently a strong interest in using infra-red data to assess a circuit breaker's health state, where hot spots are indicative of a problem and these hotspots are easy for a human to identify and interpret.

Currently in utilities, the measurement of temperature variations is one of the most common measurement indicators of the structural health of equipment and components. Corroded connections, faulty contacts, damaged components etc. can cause hotspots. One common practice is to use infra-red cameras to capture thermal variation images and analyze them manually to find hotspots and then perform a maintenance action. However, additional elements covering the bus bars, for example, can obscure the capturing of original thermal variations through infra-red cameras to detect hotspots. However, using skilled technicians and engineers in this manner is very expensive. Machine learning algorithms are here utilised to achieve this without a human. However, machine learning algorithms require an extensive training dataset of relevant data, and this is difficult and expensive to provide, and when there are obscuring elements the training set data itself cannot be acquired. The apparatus and system described here addresses this situation.

Thus, the described apparatus and system provides a way to analyze an infra-red image as a whole and can take into account obscuring elements in the imagery that would otherwise lead to a reduced infra-red signal and to "noise" in the data that would otherwise lead a machine learning model to classify the situation incorrectly. For this purpose a machine learning algorithm (e.g. a convolutional neural network) is used. The network is trained with modified infra-red data, where a human has indicated where obscuring elements can be in imagery and the effects of those obscuring elements mitigated through use of a de-noising algorithm.

The de-noising algorithm used to remove the effects of obscuring elements in infra-red imagery of switchgear, circuit breakers, and other electrical system is shown in operation in Fig. 1. It operates in a similar manner to the de-noising autoencoder method that for example can remove watermarks such as "DRAFT" or other watermarks that overlay images. Fig. 1 shows image representations and below associated line drawings.

Thus, the structural health of the components in electrical systems, such as circuit breakers, can be detected through hotspots created in the component. Infra-red

cameras focusing on such components capture thermal variations to detect the hotspots. Using a neural network classifier algorithm to automate this process requires that it be trained with properly labelled images, and large numbers of such training images with and without problems are required to detect automatically such hotspots.

5 There are several variants of circuit breakers, and the internal structure are very different and using data-driven approaches such as machine learning will therefore be challenging, as the quantity of relevant images do not exist in large numbers and obtaining such imagery requires long waiting periods to obtain them for various circuit breakers, for example when hot spots occur. Current practice is that a manual
10 inspection of the thermal images is carried out by domain experts from time to time to detect any damages in the components and this might be detrimental if the elapsed monitoring period is large enough to have a damage happened in the meantime.

15 However, the above situation is further complicated in that obscuring elements can sit between the surface to be monitored, such as a joint, and the infra-red sensor. Such an obscuring element can for example be a cap over a joint, as shown in Fig. 1. To achieve there is provided the following elements:

20 **Labelling Module:** This element presents the infra-red images and normal images to experts and contains the functionality to mark elements that are potential obscuring parts, which can create noisy data in the infra-red image.

25 **De-noising Module:** This element extracts features based on the labels provided by the previous module and removes the “noise” to generate clean infra-red image data.

30 **Classification Model Generator:** This element gets the de-noised images generated by the previous module “De-noising Module” and is trained to generate a machine learning classification model for the circuit breaker (or other electrical equipment). This pre-trained model can then identify structural damages. The machine learning model that corresponds to a circuit breaker variant can detect and provide a technical result whether the breaker is undergoing any structural damage or not by classifying the infra-red image that is generated in the field.

Thus, in summary the apparatus and system enables:

1. Template for hotspot marking: The apparatus/system contains the feature that enables the domain expert to mark components that can potentially have hotspots and provides noise.

5 **2. De-noiser:** The apparatus/system extract features that represent obscuring elements and automatically generates clean infra-red images using de-noising autoencoders.

10 **3. Pre-trained model generation:** The apparatus/system generate respective pre-trained models based on the synthetically generated infra-red images for circuit breakers to automatically classify images given as input from a live system with infra-red cameras to detect hotspots. Here, synthetically generated refers to infra-red images that have been modified to remove the effect of obscuration in the image.

Claims

1. An apparatus for monitoring a switchgear, the apparatus comprising:
- 5 - an input unit;
- a processing unit; and
- an output unit;
- wherein, the input unit is configured to provide the processing unit with a monitor infra-red image of a switchgear;
- 10 wherein, the processing unit is configured to implement a machine learning classifier algorithm to analyse the monitor infra-red image and determine if there is one or more anomalous hot spots in the switchgear;
- wherein, the machine learning classifier algorithm has
- 15 been trained on the basis of a plurality of different training infra-red images, wherein the plurality of training infra-red images comprises a plurality of modified infra-red images generated from a corresponding plurality of infra-red images, wherein each of the modified infra-red images has been modified to remove the effect of obscuration in the image; and
- 20 wherein, the output unit is configured to output information relating to the one or more anomalous hot spots.
2. Apparatus according to claim 1, wherein generation of the plurality of modified infra-red images comprises utilisation of a trained
- 25 image processing algorithm.
3. Apparatus according to claim 2, wherein the trained image processing algorithm is a trained de-noising algorithm.
- 30 4. Apparatus according to any of claims 2-3, wherein training of the image processing algorithm comprises a manual indication of one or more obscuring features in at least one of the plurality of infra-red images prior to modification and/or a manual indication of one or more obscuring features in at least one visible image corresponding to at least one infra-red
- 35 image of the plurality of infra-red images prior to modification.

5. Apparatus according to any of claims 1-4, wherein analysis of the monitor infra-red image comprises modification of the monitor infra-red image to remove the effect of obscuration in the image.
- 5 6. Apparatus according to claim 5, wherein modification of the monitor infra-red images comprise utilisation of a trained image processing algorithm.
- 10 7. Apparatus according to claim 6, wherein the trained image processing algorithm is a trained de-noising algorithm.
8. Apparatus according to any of claims 6-7, wherein training of the image processing algorithm comprises a manual indication of one or more obscuring features in at least one of the plurality of infra-red images prior to modification and/or a manual indication of one or more obscuring features in at least one visible image corresponding to at least one infra-red image of the plurality of infra-red images prior to modification.
- 15 9. Apparatus according to any of claims 6-8 when dependent upon any of claims 2-4, wherein the image processing algorithm utilised to generate the plurality of modified infra-red images is the same image processing algorithm used to modify the monitor infra-red image.
- 20 10. Apparatus according to any of claims 1-9, wherein the plurality of training infra-red images comprises image data of a switchgear.
11. Apparatus according to any of claims 1-10, wherein the plurality of training infra-red images comprises image data of a switchgear.
- 25 12. Apparatus according to any of claims 1-11, wherein the monitor infra-red image comprises image data of at least one circuit breaker.
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13. Apparatus according to any of claims 1-12, wherein the machine learning classifier algorithm is a neural network.
14. Apparatus according to claim 13, wherein the neural network is a convolutional neural network.
15. Apparatus according to any of claims 1-14, wherein the processing unit is configured to update the training of the machine learning classifier algorithm comprising utilisation of the monitor infra-red image.
16. Apparatus according to claim 15 when dependent upon any of claims 5-9, wherein the processing unit is configured to update the training of the machine learning classifier algorithm comprising utilisation of the modified monitor infra-red image
17. Apparatus according to claim 15, wherein the training update comprises a manual indication that the monitor infra-red image comprises no anomalous hot spots or a manual indication that the monitor infra-red image comprises one or more anomalous hot spots.
18. Apparatus according to claim 16, wherein the training update comprises a manual indication that the modified monitor infra-red image comprises no anomalous hot spots or a manual indication that the modified monitor infra-red image comprises one or more anomalous hot spots.
19. Apparatus according to claim 17, wherein the manual indication that the monitor infra-red image comprises one or more anomalous hot spots comprises a manual indication of one or more locations in the monitor infra-red image of the one or more anomalous hot spots.
20. Apparatus according to claim 18, wherein the manual indication that the modified monitor infra-red image comprises one or more anomalous hot spots comprises a manual indication of one or more locations in the modified monitor infra-red image of the one or more anomalous hot spots.

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21. A system for monitoring a switchgear, the system comprising:
- an infra-red camera; and
 - an apparatus for monitoring a switchgear according to any of claims 1-20; and
- 5 wherein, the infra-red camera is configured to acquire the monitor infra-red image of the switchgear.

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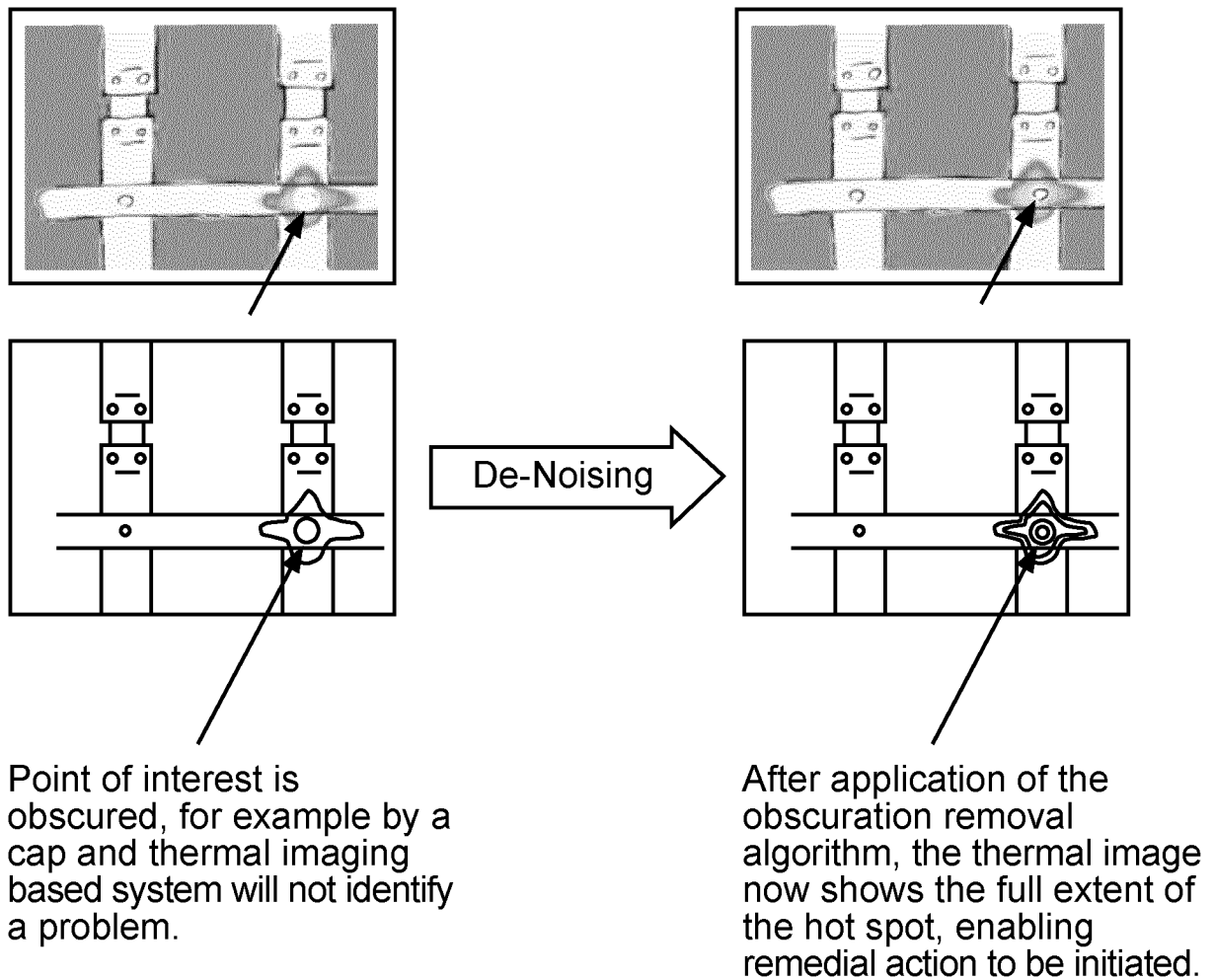


Fig. 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/055471

A. CLASSIFICATION OF SUBJECT MATTER

INV. H02B3/00 G06K9/62 G06K9/20 G06N3/02
ADD. G06N3/04

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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02B G06K G06N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	CN 107 680 195 A (EAST INNER MONGOLIA ELECTRIC POWER CO LTD ET AL.) 9 February 2018 (2018-02-09) paragraphs [0039] - [0043] ----- -/-	1-21



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

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Name and mailing address of the ISA/

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NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

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Overdijk, Jaco

INTERNATIONAL SEARCH REPORT

International application No
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