



(51) International Patent Classification:

H02B 3/00 (2006.01) G06N 3/02 (2006.01)

G06K 9/62 (2006.01) G06N 3/04 (2006.01)

G06K 9/20 (2006.01)

(21) International Application Number:

PCT/EP2020/055473

(22) International Filing Date:

02 March 2020 (02.03.2020)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

19161435.3 07 March 2019 (07.03.2019) EP

(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 Neuulßheim (DE). SCHMIDT, Benedikt; Obere Neckarstrasse 14, 69117 Heidelberg (DE).

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

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: APPARATUS FOR MONITORING A SWITCHGEAR

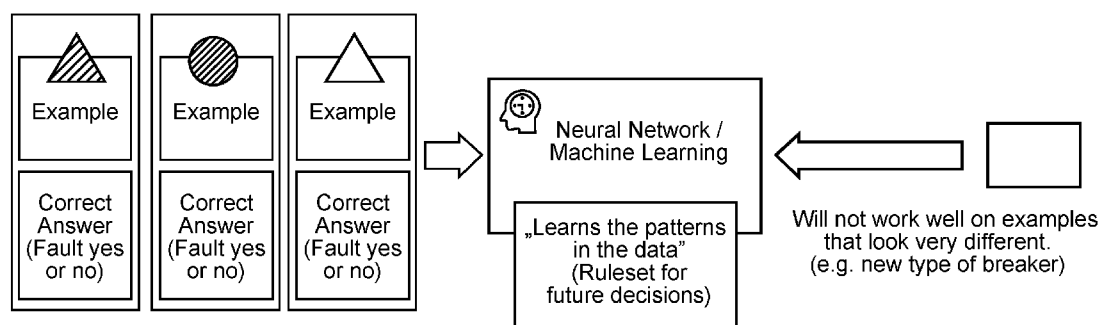


Fig. 1

(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 synthetic infra-red images generated from a corresponding plurality of visible images. The output unit is configured to output information relating to the one or more anomalous hot spots.

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

- *with international search report (Art. 21(3))*

5

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 hot spots of high temperatures can have dramatic consequences, for example electric arcs / flash overs that can act almost like explosions. A method and associated system for monitoring and early warning before such incidents develop is highly needed and currently not available in an affordable
20 form, which could be installed as a standard in every switchgear and give enough information on the switchgear health state. Also, no method or system is available where images of a switchgear are acquired and transmitted for processing elsewhere in order to provide such monitoring and early warning. At the moment, using IR sensors to detect hot spots in circuit breakers, switchgear, and other electrical equipment
25 requires a lot of very precise calibration to measure the temperature at exactly the right position. There is also an associated problem of identifying the right region in the IR image to monitor. A common solution for all switchgear and all circuit breakers within such switchgear is not possible because of different types and geometry.

30 There is a need to address these issues.

SUMMARY OF THE INVENTION

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

- 2 -

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.

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

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

10 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 synthetic
15 infra-red images generated from a corresponding plurality of visible images. The output unit is configured to output information relating to the one or more anomalous hot spots.

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
20 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 intervention.

25 In an example, generation of the plurality of synthetic images comprises utilisation of an image processing algorithm.

30 In an example, generation of the plurality of synthetic images comprises utilisation of a trained image processing algorithm.

In an example, the trained image processing algorithm is a trained style transfer algorithm.

- 3 -

In an example, generation of one or more synthetic infra-red images of the plurality of synthetic infra-red images comprises an addition of at least one hot spot to the one or more synthetic infra-red images.

5 In an example, generation of two or more synthetic infra-red images of the plurality of synthetic infra-red images comprises an addition of at least one hot spot to the two or more synthetic infra-red images.

10 In an example, addition of the at least one hot spot for at least one synthetic infra-red image is carried out manually.

In an example, addition of the at least one hot spot for at least one synthetic infra-red image is carried out automatically.

15 In an example, addition of the at least one hot spot comprises utilisation of an edge detection algorithm.

In an example, generation of plurality of synthetic infra-red images comprises utilization of a hue algorithm.

20 In an example, generation of plurality of synthetic infra-red images comprises utilization of a flood fill algorithm.

In an example, the plurality of visible images comprises image data of a switchgear.

25 In an example, the plurality of visible images comprises image data of at least one circuit breaker.

30 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.

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

- 4 -

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.

5 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.

10 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.

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

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

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

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

BRIEF DESCRIPTION OF THE DRAWINGS

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

Fig. 1 shows a schematic example relating to a machine learning training process; and Fig. 2 shows an example of transforming a visible image of the inside of a circuit breaker into a corresponding infra-red image.

30

DETAILED DESCRIPTION OF EMBODIMENTS

35 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. This is achieved through utilization of a machine

learning algorithm that has been trained on infra-red imagery, at least some of which is synthetically generated in order that the training set can be significant enough for the machine learning algorithm to be able to identify hot spots in different equipment types, from different vantage points and in different situations. The synthetically generated
5 infra-red imagery has been generated from visible imagery, and because there can be limited available real data relating to anomalous hot spots in equipment, hot spots have been added to the imagery as part of the process of transforming some of the visible imagery into corresponding infra-red imagery.

Thus this is achieved by apparatus that comprises an input unit, a processing unit, and
10 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
15 training infra-red images. The plurality of training infra-red images comprises a plurality of synthetic infra-red images generated from a corresponding plurality of visible images. The output unit is configured to output information relating to the one or more anomalous hot spots.

20 According to an example, generation of the plurality of synthetic images comprises utilisation of an image processing algorithm.

According to an example, generation of the plurality of synthetic images comprises utilisation of a trained image processing algorithm.

25 According to an example, the trained image processing algorithm is a trained style transfer algorithm.

30 According to an example, generation of one or more synthetic infra-red images of the plurality of synthetic infra-red images comprises an addition of at least one hot spot to the one or more synthetic infra-red images.

35 According to an example, generation of two or more synthetic infra-red images of the plurality of synthetic infra-red images comprises an addition of at least one hot spot to the two or more synthetic infra-red images.

- 6 -

According to an example, addition of the at least one hot spot for at least one synthetic infra-red image is carried out manually.

5 According to an example, addition of the at least one hot spot for at least one synthetic infra-red image is carried out automatically.

According to an example, addition of the at least one hot spot comprises utilisation of an edge detection algorithm.

10 According to an example, generation of plurality of synthetic infra-red images comprises utilization of a hue algorithm.

According to an example, generation of plurality of synthetic infra-red images comprises utilization of a flood fill algorithm.

15 According to an example, the plurality of visible images comprises image data of a switchgear.

20 According to an example, the plurality of visible images comprises image data of at least one circuit breaker.

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

25 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.

30 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.

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.

- 7 -

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.

- 5 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.

10 Thus, the described apparatus and system provides a way to analyze the an infra-red image as a whole without defining regions of interest. It specifically takes into account the fact that there are different circuit breaker geometries. For this purpose a machine learning algorithm (e.g. a convolutional neural network) is used. The network is trained with infra-red training imagery at least some of which has been produced from visible imagery, and some of that synthetic imagery has had one or more hot spots added to
15 it. As a result, the expensive human intervention of either calibration or region definition is eliminated from the process.

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
20 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
25 problem and these hotspots are easy for a human to identify and interpret. 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. The apparatus and system described here
30 addresses this situation.

Continuing with the situation prior to development of the day described apparatus and system, some existing solutions require a very precise calibration of the sensor to look at the right spot. This means that engineering cost is high. A solution that covers a
35 larger area still requires a human to identify the right regions to look at.

Regarding any generic solution that does not require identification of the right areas (e.g. based on a convolutional neural network), this needs to be robust against the differences in circuit breaker geometry and function to be useful. However, if the training network has never experienced certain situations, it is less likely to classify them correctly. This situation can be referred to as overfitting, and results from the process of training a classifier neural network as shown in Fig. 1. Basically, the classifier neural network learns to recognize patterns, which are anticipated to apply to example situations encountered later. However, if the example is very different from the original training examples, there is a risk that the neural network will not work, because certain unique properties of the original data have become part of the patterns.

Overfitting can be avoided by providing a wide range of training data. Ideally, the training data includes examples of every type of input, which will be encountered in the future. However, IR images of circuit breakers, especially in a faulty state, are not readily available and expensive to produce.

Thus, the surprising solution utilised in the apparatus and system described here involves turning visible-light photos into infra-red images using for example a technique known as style transfer. Style transfer has been used to transforming a photograph into a "painting", where a working principle is to provide a training set of photographs and corresponding paintings.

However, now for the described apparatus and system the target "style" is an image that shares many properties of an infra-red image, and again is a visible light image. Most areas are close to ambient temperature but show some contours simulating reflected infra-red radiation (see Fig. 2). During the transformation process or afterwards, a hot spot is added to some of the images to simulate damage occurring in the circuit breaker.

Thus, the trained style transfer model is used to turn photographs of circuit breaker interiors into synthetic or fake infra-red images. For a circuit breaker type which is to be added to the training set of the classifier neural network the following is done: photographs of the circuit breaker interior are taken, with slight variations in angle and position. The style transfer process, or a similar transformation process, is then used to generate both healthy (no hot spot) and faulty (hot spot) images. These are

- 9 -

5 automatically labeled and added to the training set. The hot spots can be added, based on a marker provided by an expert, or based on edge recognition. Hot spots can be added to the synthetic infra-red image with classical image processing algorithms (hue, flood fill etc.). Also, real infra-red images can be used for the initial training along with synthetic infra-red images.

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 synthetic infra-red images generated from a corresponding plurality of visible images; and
- wherein, the output unit is configured to output
- 20 information relating to the one or more anomalous hot spots.
2. Apparatus according to claim 1, wherein generation of the plurality of synthetic images comprises utilisation of an image processing algorithm.
- 25 3. Apparatus according to claim 2, wherein generation of the plurality of synthetic images comprises utilisation of a trained image processing algorithm.
4. Apparatus according to claim 3, wherein the trained
- 30 image processing algorithm is a trained style transfer algorithm.
5. Apparatus according to any of claims 1-4, wherein generation of one or more synthetic infra-red images of the plurality of synthetic infra-red images comprises an addition of at least one hot spot to the one or
- 35 more synthetic infra-red images.

6. Apparatus according to wherein to claim 5, wherein generation of two or more synthetic infra-red images of the plurality of synthetic infra-red images comprises an addition of at least one hot spot to the two or more synthetic infra-red images.
- 5
7. Apparatus according to any of claims 5-6, wherein addition of the at least one hot spot for at least one synthetic infra-red image is carried out manually.
- 10
8. Apparatus according to any of claims 5-7, wherein addition of the at least one hot spot for at least one synthetic infra-red image is carried out automatically.
- 15
9. Apparatus according to claim 8, wherein addition of the at least one hot spot comprises utilisation of an edge detection algorithm.
- 20
10. Apparatus according to any of claims 1-9, wherein generation of plurality of synthetic infra-red images comprises utilization of a hue algorithm.
- 25
11. Apparatus according to any of claims 1-10, wherein generation of plurality of synthetic infra-red images comprises utilization of a flood fill algorithm.
- 30
12. Apparatus according to any of claims 1-11, wherein the plurality of visible images comprises image data of a switchgear.
13. Apparatus according to any of claims 1-12, wherein the plurality of visible images comprises image data of at least one circuit breaker.
14. Apparatus according to any of claims 1-13, wherein the monitor infra-red image comprises image data of at least one circuit breaker.

15. Apparatus according to any of claims 1-14, wherein the machine learning classifier algorithm is a neural network.
16. Apparatus according to claim 15, wherein the neural network is a convolutional neural network.
17. Apparatus according to any of claims 1-16, wherein the processing unit is configured to update the training of the machine learning classifier algorithm comprising utilisation of the monitor infra-red image.
18. Apparatus according to claim 17, 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.
19. Apparatus according to claim 18, 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. 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 1-19; and
- wherein, the infra-red camera is configured to acquire the monitor infra-red image of the switchgear.

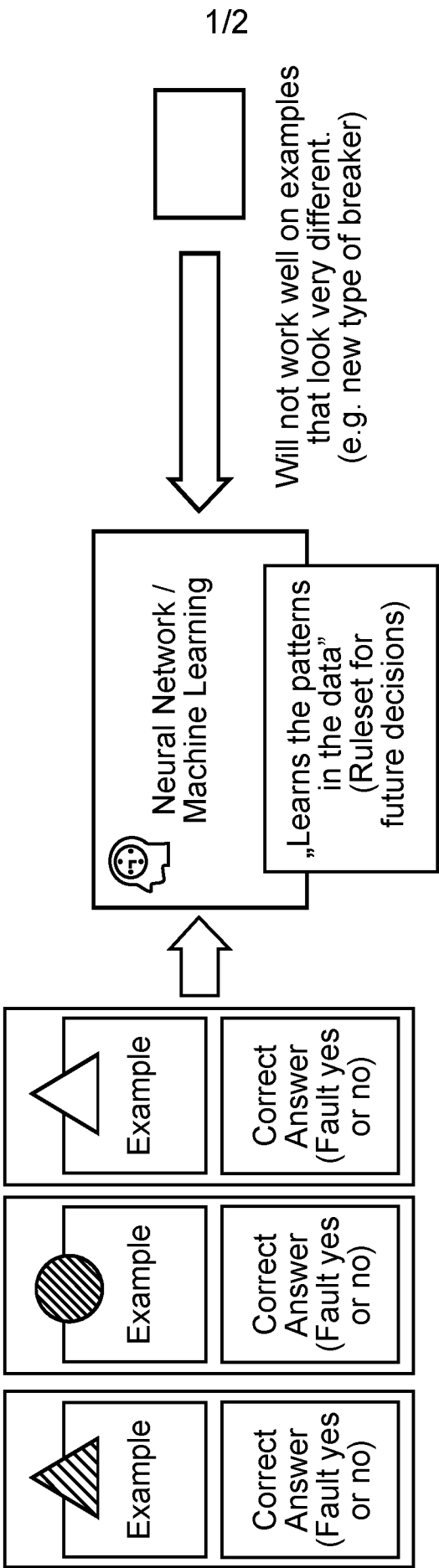


Fig. 1

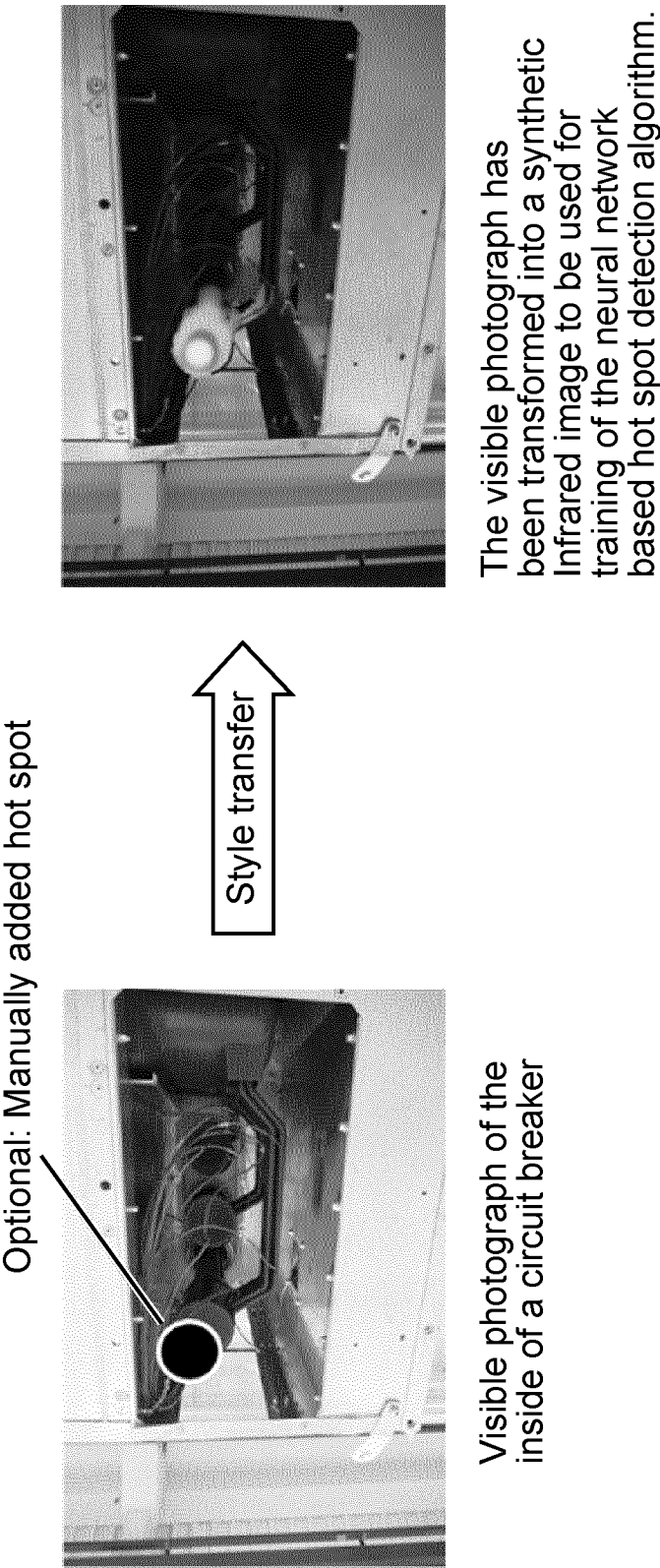


Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/055473

A. CLASSIFICATION OF SUBJECT MATTER

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

According to International Patent Classification (IPC) or to both national classification and IPC

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.
Y	WO 2019/002507 A1 (ABB SCHWEIZ AG [CH]) 3 January 2019 (2019-01-03) page 8, lines 4-18 -----	1-20
Y	US 2018/307947 A1 (CHOI WONGUN [US] ET AL) 25 October 2018 (2018-10-25) paragraphs [0036] - [0055], [0066] -----	1-20
A	CN 107 680 195 A (EAST INNER MONGOLIA ELECTRIC POWER CO LTD ET AL.) 9 February 2018 (2018-02-09) paragraphs [0039] - [0043] ----- -/-	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

13 March 2020

Date of mailing of the international search report

26/03/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Overdijk, Jaco

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/055473

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BINHAI WANG ET AL: "SmartGuard: An autonomous robotic system for inspecting substation equipment", JOURNAL OF FIELD ROBOTICS, vol. 29, no. 1, 16 November 2011 (2011-11-16), pages 123-137, XP055471462, US ISSN: 1556-4959, DOI: 10.1002/rob.20423 figures 3, 11, 14, 17 -----	1,20
A	EP 0 342 597 A2 (HITACHI LTD [JP]) 23 November 1989 (1989-11-23) page 6, lines 13-45; figure 2 page 16, line 29 - page 19, line 40; figures 30-33 -----	1,20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2020/055473

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2019002507 A1	03-01-2019	CN 110832720 A WO 2019002507 A1	21-02-2020 03-01-2019
US 2018307947 A1	25-10-2018	DE 112018002166 T5 US 2018307947 A1 WO 2018200072 A1	13-02-2020 25-10-2018 01-11-2018
CN 107680195 A	09-02-2018	NONE	
EP 0342597 A2	23-11-1989	AU 611800 B2 CN 1039659 A DE 68920198 D1 DE 68920198 T2 EP 0342597 A2 IN 173042 B JP 2751834 B2 JP 2885223 B2 JP H0738011 B2 JP H0749362 A JP H01287475 A JP H10185980 A KR 890017543 A US 5107447 A	20-06-1991 14-02-1990 09-02-1995 11-05-1995 23-11-1989 29-01-1994 18-05-1998 19-04-1999 26-04-1995 21-02-1995 20-11-1989 14-07-1998 16-12-1989 21-04-1992