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(54) **Title:** AUTOMATIC SEAM DETECTION FOR A WELDING PROCESS

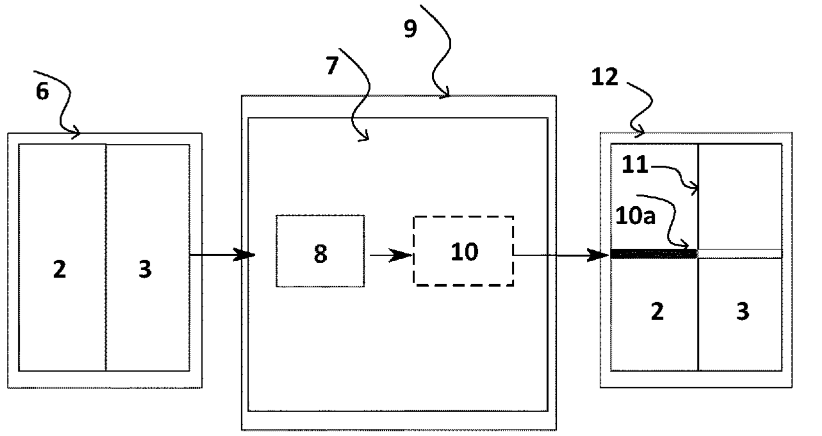

Fig. 2

(57) **Abstract:** The present invention relates to a computer-implemented method for detecting a welding seam position in a welding process, in particular a laser welding process, the method comprising the steps of: receiving visual input data (6) of a welding edge; providing the visual input data (6) as an input to a neural network (8) configured to determine the welding seam position based on the visual input data (6); and outputting the welding seam position. The present invention further relates to a data processing system (9), a welding apparatus, a computer program, and a computer-readable medium.

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Automatic Seam Detection for a Welding Process

The present invention relates to a computer-implemented method for detecting a welding seam position in a welding process, a data processing system comprising means for carrying out the method, a welding apparatus comprising such data processing system, a computer program and a computer-readable medium.

Welding is widely applied in various fields of technology, in particular for joining or repairing metal components. Frequently, welding processes are carried out in an at least partially automized manner, e.g. using welding robots or computer guided welding processes. The different welding technologies available, such as tungsten inert gas welding, metal inert gas welding or spot welding, are in principle known from various state of the art documents and will not be described in detail in this application. Another welding technology constantly gaining popularity is laser welding which is due to several advantages, e.g. a high precision, low heat-affected zones, a high energy density, a high welding speed, and low shape distortions.

The efficiency and accuracy of a weld highly depends on a precise detection of the welding seam position, in particular in a laser welding processes for which harsh precision requirements need to be fulfilled. The welding seam position is defined as an edge to be joint, e.g. between two components to be welded. Seam position detection and control is usually carried out either completely manually or by using various types of sensors, e.g. displacement or ultra-sonic sensors. However, most sensors are associated with specific problems. For instance, ultrasonic sensors necessitate a stable non-interference state which is difficult to achieve in an industrial environment.

In case of visual sensing systems used for the seam detection, in particular sensing systems with auxiliary light sources, the seam position is frequently detected by means of an applied algorithm based on visual input about the joint. Also these systems usually require human intervention on a regular basis to correct and verify detected seam positions, e.g. the Hough edge detector algorithm (Qian-Qian Wu et al., “A study on the modified hough algorithm for image processing in weld seam tracking”, Journal of Mechanical Science and Technology, 29, (11): 4859 – 4865, 2015) or the canny edge detection algorithm (Jin-Yun Lu et al., “The weld image edge-detection algorithm combined with canny operator and mathematical morphology, Proceedings of the 32nd Chinese Control Conference, pp. 4467-4470, 2013).

Involving human intervention in the seam detection process in welding systems is not only timely intensive, but also results in varying quality and results due to deteriorating human performance with increasing working hours and subjective considerations of different persons.

EP2792447B1 relates to a welding position detecting apparatus and method, for which an imaging device captures, at a predetermined time interval, images of an irradiated portion of a material to be welded and a surrounding area thereof, an image processing device that identifies a position of the irradiated portion by performing an image processing calculation from two or more images acquired by the imaging device, in which a direction and an amount of parallel movement of points in the images is calculated, and a display device that displays the position of the irradiated portion, wherein the position is identified by the image processing device.

Several further approaches to provide a high level of automation in seam detection processes using visual input data such as images rely on structured light methods based on optical triangulation, as e.g. described by Yanbiao Zou and Tao Chen in “laser vision seam tracking system based on image processing and continuous convolution operator tracker”, Optics and Lasers in Engineering, 105: 141-149, 2018. Similar methods were also described to detect and control the motion of a welding torch in real time (Xinde Li et al., “Automatic welding seam tracking and identification”, IEEE Transactions on industrial electronics, 64(9):7261-7271, 2017). However, such methods, which typically rely on hand-crafted algorithms using surface patterns, often become problematic in case of joints with relatively narrow gaps or in case of components and materials to be welded which feature relatively poor contrast with respect to each other or against a background. To be able to reduce the influence of background artefacts and to help to focus on the welding seam, it was suggested (Yanbiao Zou and Weilin Zhou in “Automatic seam detection and tracking system for robots based on laser vision”, Mechatronics, 63:102261, 2019; Mitchell Dinham et al. in “ Experiments on automatic seam detection for a mig welding robot", International Conference on Artificial Intelligence and Computational intelligence, pp. 390-397, Springer, 2011; Andres Ryberg et al. in "Stereo vision for path correction in off-line programmed robot welding", 2010 IEEE International Conference on Industrial Technology, pp. 170-1705, IEEE, 2010) to consider only certain regions of interest as input. However, the procedures suggested are still limited in terms of achievable resolution and precision.

Therefore, the objective technical problem underlying the present invention is to provide an improved possibility for edge detection in a welding process.

The object is achieved by the method according to claim 1, the data processing system according to claim 10, the welding apparatus according to claim 11, the computer program according to claim 12 and the computer-readable medium according to claim 13.

With respect to the method, the objective technical problem is solved by a computer-implemented method for detecting a welding seam position in a welding process, in particular a laser welding process, the method comprising the steps of:
receiving visual input data of a welding edge, providing the visual input data as an input to a neural network configured to determine the welding seam position based on the visual input data, and outputting the welding seam position.

Neural networks (NN), belonging to the field of machine learning, are based on a plurality of interconnected units called artificial neurons which are typically organized in various layers and are able to detect complex and nonlinear relationships. With respect to the present invention, the use of a neural network for automatically detecting a welding seam position in a welding process results in a very high robustness and high resolution. Achieving the required resolution, in particular down to a pixel-level or a millimeter, especially submillimeter, range, without need for any human intervention can be ensured. Such a high precision is not achievable in a fully automated manner in the state of the art.

Thus, the present invention provides superior precision and a full automation level of the welding seam detection. The high precision also ensures a correct and precise positioning of a welding zone mandatory for a high quality of the welding.

The visual input data can e.g. be an image, a series of images or a video. The input data can be collected by means of a visual sensing device, e.g. a camera. It is either possible to use the entire input data, e.g. an image, as input or to cut out a certain region of interest which isolates the welding seam area prior to processing the input data. The input data can also be subjected to any data processing means e.g. for cropping out shadow and glare background effects, prior to providing the visual input data as an input to the neural network.

The neural network preferably is trained before it is employed in the method according to the present invention. In this case, a trained neural network is employed for the method. The training is preferably performed by an individually created and/or labeled data set of input data of welding seams, in particular relating to the particular welding apparatus used for welding.

In one embodiment, the neural network is a convolutional neural network (CNN). CNNs have the advantage that less pre-processing of the input data is required compared to other classification algorithms. CNNs are capable of capturing spatial and temporal dependencies in an image and thus improve the precision of the method according to the present invention.

It is further of advantage, if the convolutional neural network is a, especially modified, U-net convolutional neural network. They have been proposed by Olaf Ronneberger et al., in “U-net: Convolutional networks for biomedical image segmentation”, CoRR, abs/1505.04597, 2015. Compared to other convolutional networks U-net convolutional networks can operate based on smaller training data sets still yielding in a highly precise segmentation. While U-Net convolutional networks were originally developed mainly for biomedical applications it is a finding of the present invention, that by modification of such architecture increased precision regarding the automatic seam position detection can be achieved.

In a preferred embodiment the method according to the present invention comprises the step of providing the visual input data to a preprocessing module including a binary classifier configured to classify the visual input data based on at least one predeterminable criterion relating to a quality parameter of the visual input data. In case the visual input data are provided as images, the quality parameter can e.g. be an image quality parameter.

It is of advantage, if the predeterminable criterion is related to a clarity of the visual input data, the presence of lighting artefacts, or the presence of a joint in the input data.

The classifier can be either based on any standard data processing algorithm, e.g. a filtering algorithm, e.g. regarding the brightness of the visual input data or also any other filtering or processing means. However, the classifier can also be embodied as a neural network, in particular a trained neural network, or as a part of a neural network architecture, the classifier being configured to classify the visual input data based on the predeterminable criterion. Only visual input data which fulfills the predeterminable criterion is forwarded as input towards the neural network configured to determine the welding seam position.

The preprocessing module serves for further improving the precision and accuracy of the welding seam position detection, because only visual input data of sufficient quality is forwarded towards the neural network configured to determine the position of the welding seam.

Furthermore, the security of the detection process of the welding seam position is increased, because in an unknown situation, e.g. where the joint cannot be clearly recognized in the visual input data, carrying out the welding process can be prevented.

The classifier in principle is trained to detect normal and abnormal input data by distinguishing visual input data falling under the at least one predeterminable criterion from such data which do not fulfill the criterion. Any input data that deviates from the, especially predeterminable, normal conditions defined by the criterion, will be flagged as abnormal and not forwarded as input towards the neural network configured to determine the position of the welding seam.

It is also of advantage, if the preprocessing module further includes an alert operator configured to output an alert in case that a visual input data does not fulfill the predeterminable criterion. In case the criterion is not fulfilled, e.g. assistance from an operator of the welding apparatus for which the method of the present invention is used can be sought, further increasing security of the welding process. In such cases, a warning, in particular a visual and/or sound signal may be output and/or the welding process can be stopped until the process is checked by the operator.

In another preferred embodiment of the present invention, the welding seam position is output in form of a mathematical function representing the welding seam, in particular by outputting at least one parameter characterizing the mathematical function. The mathematical function can be specified in advance and be adopted to the welding apparatus in use. For example, there are welding machines where the work pieces can be moved horizontally and/or vertically for producing the weld along the welding edge, but also machines where the welding system is moved while the work pieces remain in a fixed position, or where both the work pieces and the welding system are movably arranged. In each type different mathematical functions need to be chosen for defining or describing the welding seam position.

The mathematical function can e.g. be any, especially steady, function. However, it is of advantage, if the mathematical function is a line, in particular a vertical or horizontal line. This allows a characterization of the function by outputting one or two parameters and thus provides a straightforward output of the welding seam position.

Another preferred embodiment includes that the welding seam position is output in form of an edge mask. The edge mask defines the welding seam position and may be related to the mathematical function describing the welding seam position. For example, the welding seam position can be defined as a boundary between two different areas of the edge mask.

The objective technical problem is also achieved by means of a data processing system comprising means for carrying out the method according to the present invention.

Further, the objective technical problem underlying the present invention is achieved by means of a welding apparatus, in particular a laser welding apparatus comprising the data processing system according to the present invention.

The objective technical problem is also achieved by a computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the steps of the method according to the present invention and finally, by a computer-readable medium comprising instructions which, when executed by a computer, cause the computer to carry out the method according to the present invention.

It shall be noted that the embodiments described in connection with the method are mutatis mutandis applicable to the data processing system, the welding apparatus, the computer program and the computer-readable medium.

The invention will be explained in more detail with reference to the following figures.

Fig. 1 illustrates the advantages of a detection of the welding seam position with pixel-level accuracy,

Fig. 2 shows a block diagram of a first preferred embodiment of the method according to the present invention,

Fig. 3 shows a block diagram of a second preferred embodiment of the method according to the present invention including a pre-processing module, and

Fig. 4 shows a scheme of a welding apparatus according to the present invention.

In the figures, identical elements are each provided with the same reference signs.

Fig. 1 illustrates the importance of a highly accurate and precise welding seam detection. Two components 2 and 3, especially metal components, are to be welded along welding seam 5. If the welding seam position 1 is correctly and precisely detected (Fig. 1a) at the welding seam 5, the welding zone 4 is also precisely provided along the welding edge 5. The result is a high quality and stable weld. Already a very small offset (e.g. an offset of less than one millimeter) between the detected seam position 1 and the welding seam position 5 results in a highly reduced weld quality between the two components 2 and 3, as illustrated in Fig. 1b, because the welding zone 4, where the weld is produced, is not centered at the position of the welding edge anymore. A greater offset, even if still in the millimeter range, can also prevent to produce a joint of the two components 2 and 3 at all, as shown in Fig. 1c. Thus, it is of utmost importance to detect the welding seam position 1 accurately and precisely prior to joining the components 2 and 3 to be welded.

Such welding seam position detection can automatically and precisely be achieved by means of the method according to the present invention. In Fig. 2 a first embodiment of the method according to the present invention is shown. Visual input data 6 is exemplarily provided in the form of an image of the joint, i.e. here an image of the welding edge of the two metal components 2 and 3 to be welded. The visual input data 6 may be processed by any processing means [not shown] prior to using the input data 6 as input for the neural network 8 of the welding seam position detection block 7, which e.g. may be a computer program or be part of a data processing system 9 for carrying out the method. The processing means may include choosing a region of interest in the input data 6 or cropping out shadow and glare background effects.

In order to detect the welding seam position 5, the input data 6 is provided as input to neural network 8 which is configured to determine the welding seam position 5 based on the visual input data 6. There are different possibilities to output the welding seam position 5. Optionally, the welding seam position 5 may be output in the form of an edge mask 10a produced in the optional block 10, as illustrated in the output 12 image of the welding seam of the two components 2 and 3. But, the welding seam position 5 can also be output in the form of a mathematical function, preferably defined by at least one relevant parameter describing the mathematical function of the welding seam position 5. For the present case, the welding seam position 5 is a mathematical function in the form of a horizontal line 11 defined by a single parameter section as also illustrated in the output 12 image of the welding seam of the two components 2 and 3.

Preferably, neural network 8 is embodied in the form of a modified U-net convolutional network. Assuming that a binary edge mask 10 is provided as output as it is the case for the example shown in Figs 2 and 3, and providing an architecture that is converted to this one dimensional output, a pixel-wise binary cross-entropy loss L_{ED}, where ED refers to the edge detection, can be used to train the U-net architecture, which binary cross-entropy loss may be defined as

$$L_{ED} = -\frac{1}{W}\sum_{i=1}^{W} y_i \log(p(y_i)) + (1 - y_i)\log(p(1 - y_i));$$

wherein the loss is calculated for each pixel W, and where y_i is the class label, and $p(y_i)$ is the probability of the predicted class.

In another preferred embodiment the input data 6 is first provided to a preprocessing module 13 including a binary classifier 14 to classify the visual input data 6 based on at least one predeterminable criterion, e.g. dividing the input data 6 into normal and abnormal images based on at least one predeterminable criterion relating to a quality parameter of the visual input data 6. For the example shown in Fig. 3 the preprocessing module further includes an alert operator 15 configured to output an alert in case that a visual input data 6 does not fulfill the predeterminable criterion. The alert operator 15 can e.g. be embodied as to provide an alarm stopping the welding process. If, on the other hand, the predeterminable criterion is fulfilled the input data 6 is transferred to block 7 and provided as input to neural network 8.

The binary classifier 14 may be embodied in the form of any standard data processing algorithm, e.g. a filtering algorithm. However, it can also be embodied in the form of a neural network, which can be trained together with or separate from neural network 8. For the example of a binary classifier 14 in the form of a neural network, the visual input data 6 serves as input and the output can be a label specifying e.g. either a “1” (normal image) or a “0” (abnormal image). Abnormal may correspond to cases where the input data 6 lacks clarity of if a welding seam is already present in the input data 6. A binary cross-entropy loss L_{EC}, where EC refers to the edge classification, which is used to train the binary classifier based on N training images, may then be calculated as

$$L_{EC} = -\frac{1}{N}\sum_{i=1}^{N} y_i \log(p(y_i)) + (1 - y_i)\log(p(1 - y_i)),$$

where y_i is the class label (here: “1” or “0”), and $p(y_i)$ is the probability of the predicted class. The output of preprocessing module 13 is then given as

$$Label_i = EC(I_i),$$

EC being the edge classification module 14, I_i the i^{th} image and $Label_i$ the normal/abnormal label or corresponding i^{th} input image.

When using a preprocessing module 13, the welding seam position detection block 7 only operates if the preprocessing module 13 outputs a label “1” for the corresponding visual input data 1, e.g. a label corresponding to fulfillment of the predeterminable criterion. The output of block 7 and module 13 may be written as

$$Mask_i = \begin{cases} ED(I_i), if Label_i == 1 \\ 0, otherwise, \end{cases}$$

The additional use of preprocessing module 13 further increases the detection accuracy. The preprocessing module ensures that spurious input data 6 caused e.g. by misplacement of parts, blurring, machine errors or the like, are filtered out.

Fig. 4 finally shows a schematic drawing of a welding apparatus 16 which for the present example is a laser welding apparatus. The apparatus 16 includes a visual sensing system in the form of a camera for producing the visual input data 6 of the joint of the two components 2 and 3 located on a work piece platform which can be turned around a central axis. The apparatus 16 further includes a welding system, here in the form of a laser system 18, with a laser used to produce welds of the work pieces 2 and 3. The laser system is arranged such that it can be horizontally and vertically moved and turned around a central axis in order to follow any seam position to be welded. The welding apparatus 16 may further comprise a computer or any data processing system which is embodied to carry out an embodiment of the method according to the present invention.

Reference symbols

1	detected welding seam position
2	component to be welded
3	component to be welded
4	welding zone
5	welding seam position
6	visual input data
7	welding seam position detection block
8	neural network configured to determine the welding seam position
9	data processing system
10	block to produce edge mask 10a
11	mathematical function, esp. in the form of a line
12	output image
13	preprocessing module
14	binary classifier
15	alert operator
16	welding apparatus
17	camera
18	laser system
19	work piece platform

Patent Claims

1. A computer-implemented method for detecting a welding seam position (5) in a welding process, in particular a laser welding process, the method comprising the steps of:
receiving visual input data (6) of a welding edge;
providing the visual input data (6) as an input to a neural network (8) configured to determine the welding seam position (5) based on the visual input data (6); and
outputting the welding seam position (5).

2. The computer-implemented method according to claim 1,
wherein the neural network (8) is a convolutional neural network.

3. The computer-implemented method according to claim 2,
wherein the convolutional neural network is a, especially modified, U-net convolutional neural network.

4. The computer-implemented method according to any of the preceding claims, comprising the step of providing the visual input data to a preprocessing module (13) including a binary classifier (14) configured to classify the visual input data (6) based on at least one predeterminable criterion relating to a quality parameter of the visual input data (6).

5. The computer-implemented method according to claim 4,
wherein the predeterminable criterion is related to a clarity of the visual input data (6), the presence of lighting artefacts, or the presence of a joint in the input data (6).

6. The computer-implemented method according to claim 4 or 5,
wherein the preprocessing module (13) further includes an alert operator (15) configured to output an alert in case that a visual input data (6) does not fulfill the predeterminable criterion.

7. The computer-implemented method according to any of the preceding claims,

wherein the welding seam position (5) is output in form of a mathematical function representing the welding seam, in particular by outputting at least one parameter characterizing the mathematical function.

8. The computer-implemented method according to claim 7, wherein the mathematical function is a line (11), in particular a vertical or horizontal line.

9. The computer-implemented method according to any of the preceding claims, wherein the welding seam position (5) is output in form of an edge mask (10a).

10. A data processing system (9) comprising means for carrying out the method according to any of the proceeding claims.

11. A welding apparatus (16) comprising the data processing system (9) according to claim 10.

12. A computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the steps of the method according to any of the preceding claims.

13. Computer-readable medium comprising instructions which, when executed by a computer, cause the computer to carry out the method according to any of the preceding claims.

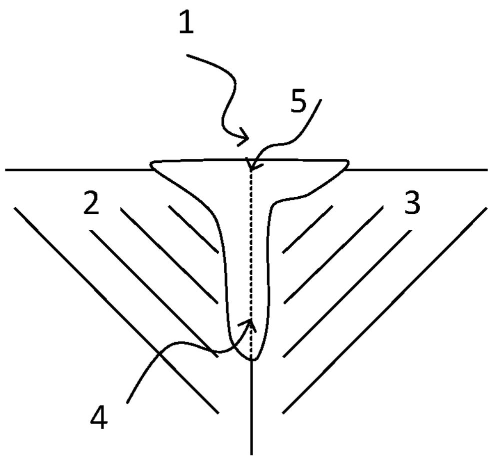

Fig. 1a

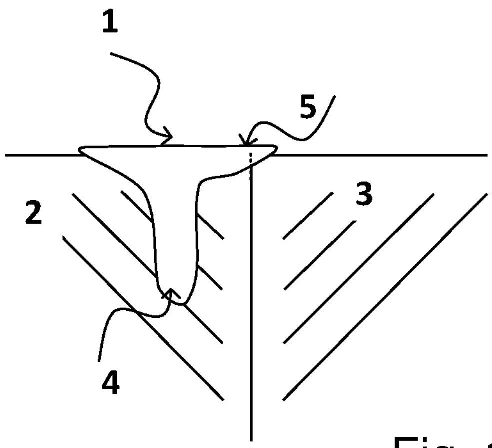

Fig. 1b

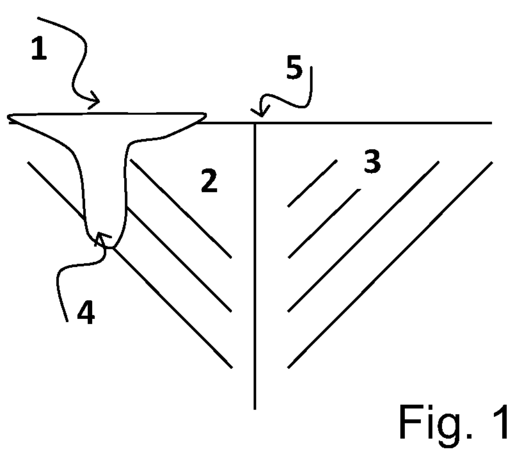

Fig. 1c

Fig. 1

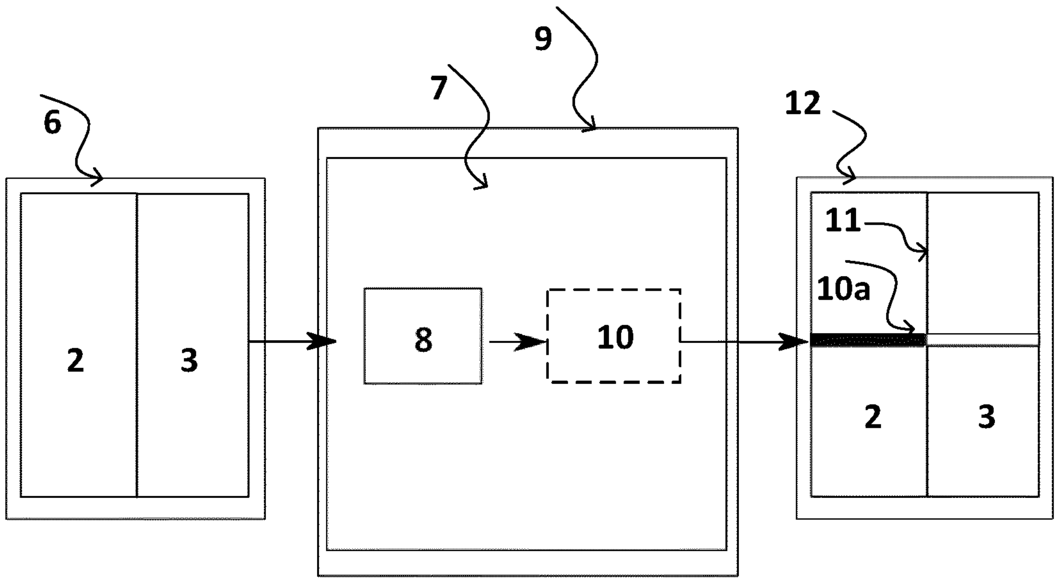

Fig. 2

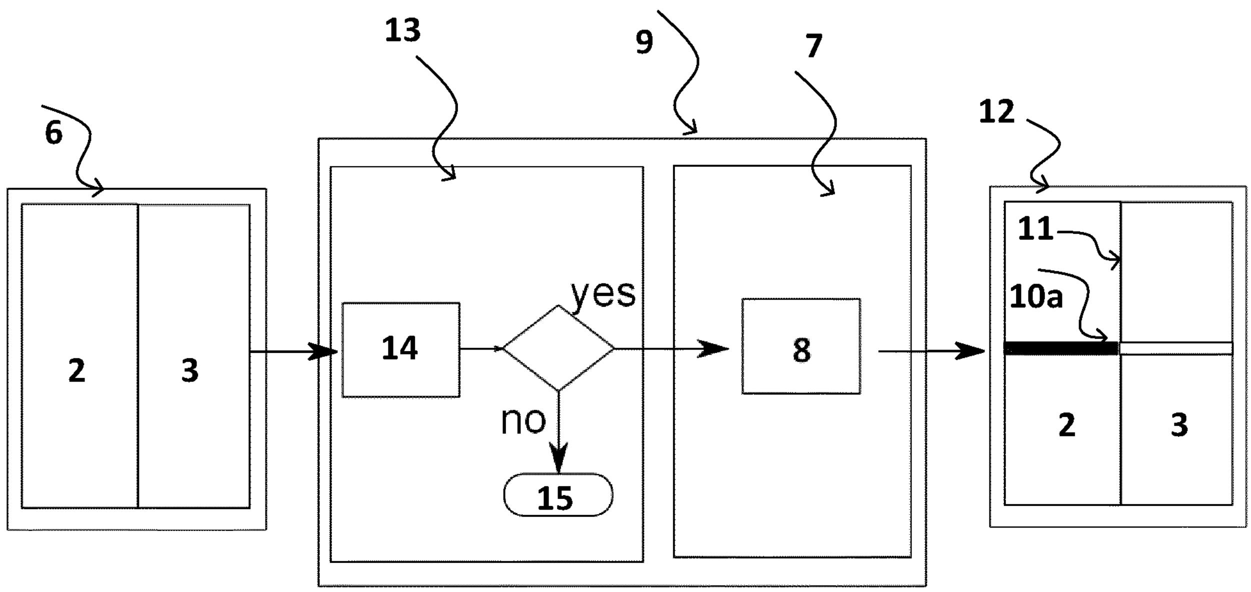

Fig. 3

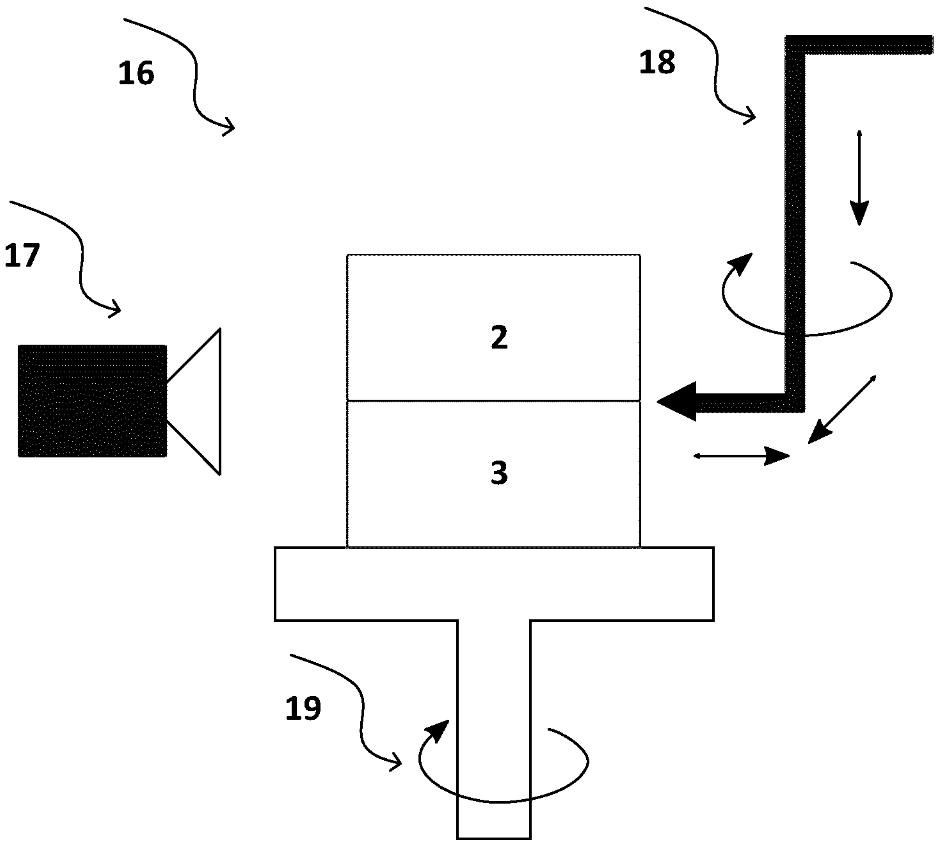

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/068122

A. CLASSIFICATION OF SUBJECT MATTER
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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)
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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)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Zhang Wenbin: "Semi-Supervised Training for Positioning of Welding Seams", , 7 June 2021 (2021-06-07), XP55971927, Retrieved from the Internet: URL:https://ruor.uottawa.ca/bitstream/10393/42257/1/Zhang_Wenbin_2021_thesis.pdf [retrieved on 2022-10-18] page ii, paragraph 2 title figure 4.3(a) figure 4.2 page 40, line 2 page 55, lines 4-5 page 36, last paragraph page 90, lines 7-9 -----	1-3, 10-13

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	HE FENG ET AL: "Research on Weld Recognition Method Based on Mask R-CNN", 2021 IEEE ASIA-PACIFIC CONFERENCE ON IMAGE PROCESSING, ELECTRONICS AND COMPUTERS (IPEC), IEEE, 14 April 2021 (2021-04-14), pages 545-551, XP033911792, DOI: 10.1109/IPEC51340.2021.9421157 [retrieved on 2021-04-30] page 548, left-hand column, Section "V. MODEL TRAINING AND RESULTS" page 546, left-hand column, lines 24-25 page 545, right-hand column, lines 6-8 figure 9(a) figure 3 abstract figure 9(e) -----	1,2,7-13
X	ZOU YANBIAO ET AL: "Robust seam tracking via a deep learning framework combining tracking and detection", APPLIED OPTICS, vol. 59, no. 14, 10 May 2020 (2020-05-10), page 4321, XP55972410, US ISSN: 1559-128X, DOI: 10.1364/AO.389730 Retrieved from the Internet: URL:https://opg.optica.org/DirectPDFAccess/2011CBB5-9619-4EDE-A93800A1A0CE8904_431503/ao-59-14-4321.pdf?da=1&id=431503&seq=0&mobile=no> [retrieved on 2022-10-18] abstract title figure 5 page 4323, left-hand column, lines 4-6 -----	1,4-6, 10-13
A	Zhang Wenbin: "Semi-Supervised Training for Positioning of Welding Seams", , 7 June 2021 (2021-06-07), pages 1-1, XP055972641, Retrieved from the Internet: URL:https://ruor.uottawa.ca/handle/10393/42257 [retrieved on 2022-10-18] the whole document -----	1-13

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